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Acute Exercise and Creativity: Embodied Cognition Approaches

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ACUTE EXERCISE AND CREATIVITY: EMBODIED COGNITION APPROACHES

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ABSTRACT

This dissertation manuscript is the culmination of three years of research examining several unique, exercise-induced mechanisms underlying creativity. This collection of work addresses historical and current empirical concepts of creativity in a narrative review, providing recommendations for future research. Several reviews follow this introduction, highlighting the proposed effects of exercise on creativity, putative mechanisms for creativity, and the effects of exercise and embodied manipulations on creative behavior. Multiple experiments utilizing moderate-intensity exercise as a theoretical stimulus for higher-order cognitions were conducted to investigate associations between exercise and creativity, which lead to the final dissertation experiment. The dissertation experiment was the first to provide statistically significant evidence for acute, moderate-intensity treadmill exercise coupled with anagram problem-solving to prime subsequent RAT completion compared to a non-exercise, priming only condition. We emphasize that the additive effects of exercise plus priming may be a viable strategy for enhancing verbal convergent creativity. Future research is warranted to explore a variety of priming effects on the relationship between exercise, embodied interventions, and creativity

DEDICATION

This dissertation is dedicated to Dr. Paul Loprinzi for his guidance and mentorship. Thank you for teaching me confidence, integrity, and the power of hard work. It has been an honor and a privilege to be your student. You shaped me into the person and scientist I have become. I will forever be grateful.

LIST OF SELECTED ABBREVIATIONS AND SYMBOLS

Amusement Park Theoretical (APT) Model of Creativity

Prefrontal cortex (PFC)

Default mode network (DMN)

Executive control network (ECN)

Anterior cingulate cortex (ACC)

The Alternative Uses Task (AUT)

The Remote Associates Test (RAT)

Instances Creativity Task (ICT)

Biological Inventory of Creative Behaviors (BICB)

Kaufman Domain Scale (K-DOCS)

Creativity Styles Questionnaire (CSQ-R)

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CHAPTER I

TOWARDS A BOXED PANOPLY MODEL OF CREATIVE COGNITION: PLAUSIBLE MECHANISMS AND FUTURE RESEARCH ISEAS

Abstract

The measurement and evaluation of creativity has been explored for nearly a century. Although great strides have been made in recent research, historically misleading attempts to operationalize creativity as a unitary construct does little to enhance scientific exploration of the mechanisms underlying creative ideation and production. To this end, the purpose of this narrative review is to describe efforts driving empirical and theoretical work in the convoluted field of creativity, as well as to provide suggestions for future research in these areas. Although not an exhaustive synthesis, this narrative review proposes the Boxed Panoply Model of Creative Cognition, which includes biosocial factors, implicit and explicit cognitions, psychological parameters, and behavioral characteristics, along with various underlying subcomponents suggested to correlate with creative thought.

Introduction

One of the greatest mysteries of creative individuals is their unique ability to find unity in disorder. When contemplating the value of physical suffering in sport, the late Steve Prefontaine once said, *"Some people create with words or with music or with a brush and paints. I like to make something beautiful when I run. I like to make people stop and say, 'I've never seen anyone run like that before.' It's more than just a race, it's a style. It's doing something better than anyone else. It's being creative."* The dynamic process of creativity cannot be qualified by a unifying definition, nor can it be appropriately relegated to a singular cognitive or physical phenomenon. The inherent complexities of human creativity have intrigued and perplexed scientists for decades. Thus, science is at a crossroads of investigative quality, wherein new creative approaches are warranted to substantiate empirical measurements of creativity. That is, creative research designs are necessary to maximize comprehension of the convoluted underpinnings of novel thoughts and behaviors. Although it is impossible to reduce creative measurement and evaluation to a simplistic method of inquiry, great strides will be made in research as academics have increasingly begun to abandon the arbitrary confines of classically operationalized creativity. Misleading conglomerations of dissimilar constructs do little to explain creative concepts in isolation. To this end, the purpose of this narrative review is to propose a Boxed Panoply Model of Creative Cognition, depicted in Figure 1, to describe and guide research efforts driving the existing field of creative science, as well as to provide suggestions for future empirical work on this topic. Although the Boxed Panoply Model does not encompass an exhaustive list of creativity mechanisms, this narrative review addresses a variety of critical elements associated with creativity. Creative thinking components discussed herein include gender, personality, cognition, psychological parameters, and behavioral-based characteristics.

Describing creativity as a finite collection of neural substrates and brain activation is inherently flawed, as there has been no confirmed localization hub housed within the brain, from which all creativity burgeons [1]. Lack of focalization in creativity research mirrors alternative models of complex cognition, including reasoning and planning, which fail to indicate a central locus of neural activation, but are understood as a convoluted network of complementary and hierarchical regulation mechanisms. Thus, creativity cannot be described as anything less than a system of higher-order mentation [2], or a means to a reasonable and newly conceived end. Creativity is now accepted as a parameter of complex cognition that is accessible to all individuals, not just the prolific few [3]. The adaptive utilization of new ideas and behaviors in solving problems can be as simple as using a safety pin to pick a lock, or as complex as making a scientific discovery. A crucial distinction of creative thought, is that it is highly personal. A creative contribution is always new to the individual thinker, but is rarely new to every thinker. Only the most eminent pioneers in highly specialized domains achieve such distinguished creative acclaim. The most widely researched tenets of traditional creativity research are divergent thinking and convergent problem solving. Divergent thinking involves mental production of as many novel and useful ideas as possible, while only one correct solution is attainable in convergent tasks [4,5]. The possibility for multi-region regulation to underlie creative thought is justifiable from an evolutionary standpoint, as shared neural networks are hypothesized to subserve efficiency in neurobiological outputs, as opposed to variegated activation patterns for every complex mental activity[2]. An important caveat to the interrelated system of creativity is the argument for domain specificity[3], as it has been posited that creative people do not often exhibit distinguished creative abilities across diversified fields. Thus, while brain mechanisms underlying creative capacity in one domain (e.g. various art forms) may be shared across dissociable brain regions, it is unlikely that creativity intersecting disciplines (e.g. music and mathematics) is stimulated by shared neural infrastructures.

The waters of creative explication are undeniably recondite. Although, classically established descriptions for this broad term provide investigators with a starting point, from which research may systematically highlight partitions of the creativity process. Nevertheless, clear paths delineating the fundamental mechanisms is lacking. The hierarchical Amusement Park Theoretical (APT) Model of Creativity [6] has been proposed to include four major tenets of creative thought processes. *Initial Requirements* must be possessed in some capacity by all those who develop creative ideas or products. These requirements are suggested to be composed of intelligence, motivation, and context-specificity (among other characteristics). *General Thematic Areas* encompass learned skills, personality traits, and relevant knowledge that foster creativity within select domains. *Domains* reflect expertise in certain fields. Lastly, *Micro-Domains*, couched within broader fields of knowledge emphasize mastery in valuable creative thoughts, behaviors, and innovations [7].

Most definitions of creativity integrate cognitive and behavioral components into one umbrella term. Appropriateness (usefulness/value) and novelty (originality) are arguably the two most important subcomponents of creativity [8]. Is one more important? Perhaps it is misguided to define creativity in terms of immediate utility. Novelty should take precedence over usefulness if true *creative thought* is the primary construct under consideration. Although an idea may not be valuable in the present moment, it may be someday [9]. Moreover, much of the creative process is a summation of internalized behaviors, as individuals constantly censor their thoughts and select the most appropriate decisions. Thus, many creative ideas may be partially formulated, but only the most relevant will be demarcated as unique and worth implementation to fit situational requirements. For this reason, it appears that the narrative should begin by asking why certain individuals may be predisposed to exhibit worthwhile novelty in their thoughts and behaviors.

There is a common misconception that a greater prevalence of left-handed individuals exists in scientific, mathematic, artistic, and architectural disciplines, and may be partially explained by enhanced spatial and divergent thinking abilities among these individuals [10]. Neuroimaging data provides some evidence for a larger corpus callosum within left-handers [11]. Increased mass of this region may promote communication between the two hemispheres of the brain, which would subserve enhanced cognition. However, evidence for this neural distinction is not definitively supported [12]. Research suggests sinistrality may also play an associative role relative to specific domains of creativity [10]. Furthermore, fetal neural development is influenced by hormonal variability in vivo. Testosterone is suggested to exert a positive influence on neural growth, with the size of the planum temporale, among other cortical brain regions, increasing before birth [13]. This developmental asymmetry paradoxically results in equal hemispheric mass at birth, as the left hemisphere is usually larger than the right in normal individuals. Albeit equivocal, previous research has indicated left-handed males perform better than right-handed males on object-synthesis of divergent thinking, which require a high degree of imagination. Although, females may outperform males on tests of verbal creative ability [10]. Thus, the enhancement effect, or potential for appreciable change from baseline, of handedness on spatial/visual creativity assessments may be relegated to males alone. Again, this outcome may emerge as a function of increased testosterone exposure to the male brain during fetal development [10]. These suggested mechanisms potentially feed a raft of neural information exchange, which may be available to creative individuals with increased diffuse cortical mass, or improved communication between regions of the brain underlying neural systems implicated in creative thought [10]. Taken together, it is important to interpret inferences of potential laterality-creativity relationships with caution, as recent research illuminates the need for improved scientific rigor along within this area of examination, in light of highly conflicting evidence to date [14].

Gender

Beyond the normative values and conditional expectations society utilizes to recognize the creative accomplishments of men and women, there have been attempts to explain this disparity mechanistically. Biological plausibility for a gender difference may be a function of testosterone levels during neural development and hemispheric activation. Perhaps specific cognitive skills are associated with targeted input from certain neural substrates. If testosterone levels subserve activation of specialized hemispheric mental processes, this could explain the potential for men to exhibit higher levels of certain types of creativity. For example, females have been shown to act less creatively during competition against others than males[15]. Males are also suggested to be at a higher risk for failures associated with inhibitory control and substance abuse, which may promote heightened creativity in select cases [16,17]. Alternatively, females have exhibited greater fronto-parietal gyrification, suggestive of higher neuronal density compensating for smaller intracranial brain volume [17]. So, again, the cognitive playing fields may be rendered equal in terms of creative performance. However, Pinker demonstrated that males display wider cognitive variance than women, meaning men tend to be represented along the spectrum of creative output [18]. Clearly stated, males are often overrepresented at the height of creative accomplishment, but also aggregate within the troughs of failure. Therefore, despite the evidence of more prodigious excellence among men, creative potential for men and women may not differ as starkly as expected. In fact, the average creativity for both genders appears equivalent when considering the countless exemplars of creative thought [7,18]. A 2008 review [7] of proposed gender differences in creativity research dating back to 1974, suggested that a clear understanding of the four aforementioned critical features of the APT model aid explanation for traditionally assumed gender differences in creative performance. Men and women may differ with respect to access to available resources promoting mastery in *Micro-domains* (e.g., the current wealth gap between genders). Further, males and females are expected to disproportionately pursue certain socially normative, *General Thematic Areas* (e.g., the comparatively high ratio of males to females employed in math and science professions). Certain *Domains* are also perceived as more feminine than masculine, and may influence external ratings of creative production, and self-appraisal of creative behavior (e.g., dance is more feminine than graphic design) [7].

Gender and Possible Trait Differences Underlying Creativity. Culture and society clearly influence recognition and appreciation of creativity. Men have been perceived as more creative than their female counterparts, as creative qualities such as agency, adventure, and independence are traditionally identified as male traits, while feminine characteristics, such as social connectedness and harmony are not as commonly associated with creativity [19]. Lombardo and Roddy surveyed 1,500 CEOs, who identified creativity as the most important professional skill for future success [20]. In an experiment conducted by Proudfoot and colleagues, participants rated characteristics of technology, entertainment, design, business, science, and global issues relative to the 100 most viewed TED Talks [19]. Male speakers were rated statistically significantly higher on ratings of ingenuity by all viewers, and in all categories except design (which the authors speculate could be a consequence of subjective judgments of design being defined in terms of refinement and elegance, stereotypically feminine qualities). These findings highlight the pervasive influence of gender across multiple creative domains. A subsequent experiment [19] examined the role of risky decision-making on perceived reward deservingness. Risk has been associated with both stereotypically masculine behavior, and high levels of creativity. Participants read a descriptive scenario of male or female managers making choices explicitly indicative of risky professional behavior ("[John/Katherine] is taking a big chance by adopting this plan, hoping that it will result in a high payoff."). Participants rated males as expressing more creativity than females in the risky-decision condition, compared to a neutral condition in which no reference to risky business planning was made. Another recent study showed men scoring high on the Dark Triad trait Machiavellianism (cynicism and manipulation) generated more harm-based alternative uses for innocuous household objects than females given the same objects (e.g. using a brick as a weapon) [21]. On average, it seems that men do not outperform women on creativity assessments [7], however the gender divide is certainly exigent in modern society, especially as innovative technology has become a forerunner for professional advancement, and a dearth of women have established a foothold in power positions within the technology sector [22], which is becoming exponentially ingrained in the proliferation of social capital and global relevance. To this end, a gender imbalance in sociocultural expectations and access to resources for individual advancement, lends a plausible imbalance in creative productivity (but not acute creative performance) between the sexes (e.g., women more easily access resources promoting professional success within communication than in technology) [7]. Simply stated, the number and type of opportunities available to males and females is historically disparate, influencing creative achievement over time.

It has long been assumed that creative function is predominantly right-brain dependent. However, few empirical studies substantiate this claim. The laterality hypothesis has been addressed by previous neuro-electrical research examining EEG alpha activation, which offers an index of integrated bottom-up stimulation and top-down control attributed to creative processes [23]. A comprehensive review of EEG and neuroimaging data measuring divergent thinking fails to support an interminable argument for laterality [24]. Additionally, changes in alpha band power and synchrony provide contradictory evidence for and against alpha effects across various brain regions [25,26]. Notably, conflicting outcomes are prevalent for frontal alpha activity (as well as the gamut of cortical band frequency data), which may be expected to be influenced during divergent assignments [24]. A potentially interesting finding is the observed consistency in the lack of statistically meaningful beta frequency variations across numerous reports [24]. fMRI, NIRS, and PET imaging highlight the involvement of the prefrontal cortex as instrumental in divergent processes. However, it is uncertain whether this activation is diffuse or localized to specific areas, or even hemispheres, as divergent findings cannot demarcate clear activation patterns. Dietrich and Kanso conclude that the pillar of divergent thinking is neurobiologically intractable, as noncreative cognitive processes mirror similar regional activation [24]. In fact, most studies relating to gender differences in creativity have focused on divergent thinking, and these have not produced clear or consistent gender differences [7]. Thus, new approaches to testing divergent thinking must be proposed and validated, to protect divergent thinking from being rejected as an insufficient proxy for the neuroanatomical measurement of creativity [24]. The most common outcome across studies evaluating acute creativity performance, is that arguments in support of legitimate gender differences cannot be substantiated by the exigent body of literature. There are numerous studies reporting contrary findings, compounding the uncertainty of true gender effects. It is plausible for creative lifetime achievements to differ between the sexes [7], however further work is needed to consider the risk for systematically indoctrinated social gender biases to color judgments of creative output across the sexes.

Creativity and Personality

The dichotomized "genaplore" model of creativity suggests two distinct phases of creativity: generation and exploration. The generative and exploratory phases of creative cognition involve first generating mental representations of patterns, combinations, or singular idea nodes, before exploring and instantiating potential uses and pragmatic applications for novel ideas [27]. Longstanding methodologies tend to preferentially focus on the evaluation of *ideation*, otherwise known as generative frequency of creative ideas, and the ability to connect them, or *production* of creative outcomes, which is assessed according to the quantity and quality of lifetime achievements [28]. The investigation of individual differences in such theoretical paradigms is warranted as specific personality traits have been both positively and negatively associated with creative ideation and production. Openness to experience (OE) is the trait most attributed to creative potential [29], and is closely associated with high levels of verbal intelligence and curiosity [28]. A strong, positive relationship was also delineated between OE and nine measures of creativity (particularly divergent thinking) [28]. However, the strength of the relationship between OE and creativity varies considerably depending on the selected creativity assessment. Interestingly, OE explained the variance in creative production to a much greater extent than the variance in creative ideation. Another critical finding was the degree of variance explained by OE when controlling for sample characteristics. Among psychology students, the correlation between creativity and OE was magnified in comparison to other academic disciplines. Extraversion is also suggested to confer creativity benefits, as extraverted individuals tend to prefer interactive social engagement in multiple activities [28]. Although speculative, this motivated search for an array of multidisciplinary stimulations may guide novel and flexible thinking among extraverted individuals. Further, conscientiousness, which is reflective of self-discipline, commitment, and motivation to achieve goals, was statistically significantly correlated with increased creative production, but not ideation. The authors claim this finding may be explained by a predisposition for conscientious individuals to exhibit a high degree of persistence and motivation to transform ideas into certifiable creations [28]. That is, while the number and scope of ideas may not be influenced by conscientiousness, the ability to create novel realities from creative thought processes may be pronounced in conscientious individuals.

Previous work has also shown conscientious personalities are positively related to scientific creativity, but negatively related to creativity in art[29].

Explicit Cognitions

Memory. Creativity may be especially useful for solving difficult hypothetical situations. The ability to effectively consider potential "what-if" scenarios facilitates drawing from past experiences to plan for the future and solve problems in the present moment. Thus, episodic memory function may play an integral and complementary role in creative thinking. Past work has shown hippocampal damage inhibits both episodic memory and creative performance [30]. In healthy individuals, increased brain activation in the hippocampus is apparent during creative expression, as well as assessments of episodic memory [31]. Beyond hippocampal involvement, the mechanisms by which creativity and episodic memory are linked remain opaque. Madore et al conducted an experiment in which participants' episodic retrieval orientations were biased with a cognitive task preceding divergent and convergent creativity evaluations [32]. Manipulations of retrieval orientations are suggested to confer beneficial effects on goal-directed memory and imagination. Participants were exposed to a specificity induction meant to promote episodically specific recall of content presentation. The specificity induction probed participants to employ verbalization and focused mental imagery to remember detailed places, people, and behaviors related to the experiment. Divergent thinking and imagination were enhanced following episodic specific memory induction. The authors proposed an interesting theory that specific retrieval orientation may prompt the combination of archival and novel cognitive processes that enrich solving complex hypothetical problems that require imagination or original conceptions. This idea should be explored in future research, as activating episodic memory may serve as a viable strategy to intensify the quantity and quality of creativity [32].

Accessing appropriate creativity involves both shared and distinct neural mechanisms suggested to contribute to task novelty. While novelty is necessary for the originality component of creativity, appropriateness embeds reasoning within unique ideas. The absence of appropriateness renders novel conceptions ridiculous rather than ingenious. Episodic memory may be particularly important for formulating appropriate congruence with goal-oriented behaviors and task demands. Appropriateness may be a product of neural communication between the lateral parietal cortex and temporal gyrus, hippocampus and amygdala, with the hippocampus serving recollection of past experiences, and the amygdala enabling the "aha moment", or epitome of perceptual insight [33].

Creative mentation may be profoundly influenced by neural structures modulating procedural memory systems as well. Chunk decomposition, or the systematic process of simplifying information to solve complex creative tasks involves focal activation of the caudate [33]. The caudate is implicated in novel ideation, planning and shifting between mental sets of information. A de-combination of the ordinary, followed by a recombination into originality requires visual-spatial restructuring, which is achieved via selective activation of the basal ganglia (caudate), parietal cortex, postcentral gyrus, bilateral prefrontal cortex, and substantia nigra. In contrast to decomposing or simplifying information, analogies, another creative construct, are established via an associative retrieval of previously unrelated cues from long-term memory, which tend to operate in line with the imperative frontoparietal process of recalling relevant information available in working memory [34]. Working memory further facilitates the consistent alignment of structural paths, connections between appropriate signals, and the mapping of new inferences [34]. Taken together, the evaluation and re-representation of creative analogies result in a continuously active processes, reliant on executive functioning [34].

The dorsolateral prefrontal cortex (DLPFC) is suggested to play a prominent role in the alignment phase of drawing parallel relationships between shared intellectual architecture, and is, perhaps, a key neural center for analogy formation. The prefrontal cortex (PFC) is also instantiated in evaluative problem solving via updating working memory in accordance with changing task demands or situational factors. Not only are analogies dependent upon functional working memory, but metaphorical meanings arise from variations in the categorization and expressive abstraction of working memory components[35]. Neuroimaging data has shown activation of the left DLPFC, signifying greater involvement of working memory during analogy and metaphor. Neural activation of the anterior cingulate gyrus and temporal pole with metaphor generation is a consequence of increased attentional requirements and semantic comprehension of non-literal associations qualified in working memory. The ventrolateral prefrontal cortex is especially prominent in analogy and metaphor formation, as inhibitory processes are necessary to retrieve associations and map paths between abstract concepts [36]. Other neural mechanisms specific to conscious associative processing may be influenced by connectivity in the parahippocampus, hippocampus and amygdala (part of the limbic system), as well as cross-activation of frontal structures and the anterior cingulate cortex, which may promote unique combinations of information to be subsequently applied during task completion [37].

Creativity requires cognitive restructuring, executive control, memory, and affectual input. The default mode network (DMN) may also be activated and deactivated in flux during creativity to account for the demands associated with restructuring tight mental constraints established through knowledge and experience; constraints useful for critical problem-solving, but perhaps too restrictive for creative extension of thought. Functional coupling between the DMN and the executive control network (ECN) are suggested to underlie certain aspects of the creative process, specifically divergent thinking. Recent work indicates increased activity of the inferior frontal gyrus, which is linked with ideation, inhibition of prepotent responses, and controlled memory retrieval may direct subsequent DMN processes, which involve episodic future thinking, mind-wandering, and spontaneous combination of random concepts [38]. Direction provided by the ECN is expected to favorably manipulate cognitive search strategies across complex categories, initiating flexible thinking. In addition to guiding neural search and idea generation, the ECN is intertwined in fluid intelligence, working memory, and verbal fluency. These components of executive functioning may induce top-down control of bottom-up connections. In other words, the DMN may exert top-down evaluative constraints on bottom-up, generative thought processes. When coupled with the ECN, goal-directed cognition is thought to produce a sustained internal train of thought[39] necessary for creative ideation [40,41]. Increased activation of the inferior frontal gyrus (IFG) corroborates this claim, as the IFG is known to facilitate top-down regulatory mechanisms [36]. Resting-state fMRI measurements of neural signals dependent on cerebral oxygenation have provided support for the hypothesis of functional connectivity between IFG and DVM regions in highly creative individuals [40,42]. Homogeneity in local neural structures at the micro-level is indicative of functional segregation, or the specialization of regional areas linked with creative processing. Reduced functional homogeneity in the right precuneus, as well as augmented volume and cortical thickness [42,43], have been linked with increased verbal creativity performance. The precuneus is a structure within the DMN, and is responsible for retrieving episodic memories, processing visuo-spatial cues, understanding metaphors, and employing mental imagery in problem-solving. The DMN is assumed to dictate automatic processing, wherein internally-focused attention is coupled with the capacity for successfully recalling memory salient to the creative task. This integrative concept of ECN guiding the deliberative, conscious component of creativity, in line with concomitant, bottom-up connectivity of DMN creative search and evaluative functions [43].

However, these findings failed to evaluate connectivity during the creative task itself, and instead assessed neural activity following creative processes. Although Beaty et al. collected resting-state fMRI on only 24 participants (matched for age, personality, intelligence, and gender) who were dichotomized into either high-creativity or low-creativity groups based on divergent task performance, other work has included a larger number of participants, using similar methodology, and have provided support for functional connectivity to inform the neural architecture of creativity [42,43]. Nevertheless, these studies are not without their limitations. It is unlikely resting neuroimaging data on a small sample of highly-creative (and low-creative) individuals provides a representative distinction of neural differences in creativity. These experiments were also conducted exclusively on right-handed, intelligent university students, and thus do not warrant definite causative inferences [40,42,43]. However, this research does offer a sound framework for continued measurement of biomarkers contributing to sustained mental activation following creative thinking, as well as the exploration of individual creative differences at rest. These are important avenues to consider in creativity research, as cognitive differences between individuals may be present not only during creativity, but in general. Further, as the DMN is suggested to engage imaginative thought and internally-directed attentional allocation, brain activation at rest may supply a wealth of knowledge concerning the nature of exceptionally creative people, and the ways in which they may be distinguished from those who adopt conventional or conformist strategies to solve complex problems.

fMRI data collected during written creative tasks has corroborated the functional role of the IFG in flexible and divergent brainstorming of verbal responses to creative assessments. The IFG was not only implicated in language processing, but was also associated with the retrieval of semantically relevant information from memory to compose original written narratives. The dorsolateral PFC was suggested to influence ideation, direct planning of creative stories via the efficient access to content in working memory, as well as top-down inhibition of interference from contextually related, yet inappropriate information. Bilateral parieto-temporal regions may also be involved in freely associative thinking, fantasy and imaginative processes, and insight which are critical components of proficient creative performance. Occipital and motor activations were suggested to be related to complex mental conceptions, or imagination of the formulated story [26]. These stirring results point to the possibility for verbal creativity to act in concert with mechanisms of premotor cognitive ideation prior to initiation of the writing task. Storytelling involves a complex preparatory phase, ingrained in vivid imagination and evaluation preceding task execution. Participants in this experiment were also less likely to report alignment of their final creative product (the written story) with the elements they conceived during the brainstorming period[26]. Notably, however, participants were given only 140 seconds to complete the creative writing tasks. Writing a novel extension of a previously presented excerpt of literature may not be an adequate length of time to accurately describe the neuroelectrical creative process. However, fMRI blocks are time-sensitive, meaning there are finite limitations on the precision and quality of data that can be obtained from bold-oxygen-level dependent (BOLD) contrast activations [26].

Memories have the potential to either benefit or constrain creativity. Prior experiences offer a breadth of accessible knowledge for appropriate and comprehensive ideation. However, recently encoded information may also negatively influence originality should thoughts begin to conform to learned experience. At times, examples and past experiences can spark cognitive processing, but if examples are over-utilized, they may interfere with problem solving ability, resulting in cognitive fixation and diminished task performance. A classic example of misapplication of prior knowledge was demonstrated by Luchins and Luchins, who presented participants with a series of problems which could be solved using a unifying strategy. When a target problem was presented, participants tended to apply the strategy used for the previous set, even when this strategy was inappropriate for solving the newly presented problem [44]. This fixation effect is particularly constraining on creativity performance when distracting examples are closely related to the target problem[45]. Participants have also been shown to exhibit implicit conformity to examples provided for drawing tasks, sketching similar visual features as those experienced by an example set [46]. Building on the plausible concept that past experiences inform the quality and quantity of future creative acts, examples given to participants preceding a creative assessment increased the number of shared attributes, or critical features, present in their subsequent creative drawings [46]. Specifically, when tasked to draw unique alien figures, examples of alien drawings provided early in the experiment, as well as repeated exposure to the same alien exemplars, increased the number of critical features participants drew in their own artistic creations. Moreover, participants created fewer drawings during the allotted experimental time period in all example conditions (early, repeated, and late in the experiment) [46]. However, despite reduced fluency (number of drawings), the quality of creative drawings was increased following exposure to examples, suggesting increased depth and goal-directed mental processes during creative production. These results suggest examples "set the stage" for creative production by guiding acceptable, yet novel, representations of previously encoded information [46].

Thus, information that is active in working memory may induce this fixation effect, and is expected to persist over time. The risk of "example-induced conformity" has practical significance for modern innovative techniques for brainstorming solutions to real-world problems. Novel solutions may be rendered impractical, inefficient, and less than ingenuous when examples disadvantageously illuminate conventional strategies for solving posed problems. Therefore, it seems that the interference of recent memories is a more proximal risk for subconscious fixation than the visual or semantic relatedness of the example used to solve the problem under consideration (although closely related examples may exert a larger fixation effect). Although prior experiences are extremely important to the ability to identify and adapt known paths leading to acceptable ideas and solutions, highly productive, generative creativity is dependent upon new explorations and self-generations of previously uncharted territory. To this end, conformity and fixation can be dangerous to the creative process [47].

Implicit Cognitions

Fixation. There is a growing body of fractioned literature suggesting that the ECN is either essential, or dispensable, to creative thought. Executive control involves the manipulation of relevant information, and heightened ability to limit interference from competing stimuli [48]. Inhibition may benefit creative response selection and evaluation, although counter-arguments lend credence to the potential pitfalls of inhibitory ECN constraints in creative ideation [49]. Dissociated, free-thinking limits inhibition of irrelevant processing, but reduced attentional control may also mitigate fixation on conventional responses, allowing individuals to "think outside of the box." However, the ECN may facilitate dissociation from fixation via inhibition. Successful creative performance demands an ability to ascend beyond the scope of preexisting knowledge within an experienced cognitive domain, and assimilate novel concepts that are unusual, yet productive and appropriate. Despite the necessity for utilizing known concepts when accomplishing skillful creative tasks, prior knowledge may cause mental fixation. A critical risk inherent in creative assimilation is fixation competition, wherein known information runs counter to novel task goals and impedes successful task completion. Fixation may pose a significant threat to solving creative tasks which require convergence on an appropriate response. When previously consolidated stimuli interfere with the ability to form precise and novel solutions, creative processes can become cognitively taxing for the fixated individual. Thus, cognitive overloading of nonviable informative cues may degrade performance. Interestingly, however, people may be unaware of the detrimental impact of fixation on problem solving [50]. Specifically, accessing non-salient mental cues during problem-solving may promote continued cognitive effort allocation shifting to task-relevant evaluation that may subserve appropriate creative convergence. Past work has evaluated the fixation effects of implicit and explicit priming on creativity. Various strategies for nullifying fixation via forgetting techniques have been utilized. Forgetting fixation confined to episodic tasks is expected to occur after a brief incubation period (15 minutes) that would allow participants to disengage from incorrect mental representations. Semantic forgetting may require a longer incubation period to achieve robust forgetting outcomes.

Retrieval-induced forgetting, defined as suppressing items in memory, which are specifically linked to a competing retrieval cue, may enhance creative ideation as a function of the strength of memory inhibition [51]. However, research demonstrates memory suppression and thought suppression are fundamentally distinct, meaning cognitive rebounding from thought suppression may undermine creative performance, as thought-suppression could be preserved transiently, while memories may be easier inhibited [51]. Failure to forget has been evidenced by a tendency for participant conformity following researcher descriptions of testing procedures containing examples. Participants have been shown to exhibit reduced ability to generate imaginative deviancies from previously heard encoded cues. Even when participants are told to avoid utilizing information from examples provided, and to generate unique responses, some individuals are constrained by earlier exposure, and reemerging thoughts [52]. Future research is warranted to examine learning strategies to encourage creative generation in despite the risk of subconsciously engendered mental fixations [53].

Retrieval-induced forgetting may be impaired as a function of disrupted inhibition, which may be mechanistically localized to reduced prefrontal cortex activation [54]. However, creative performance may be augmented when individuals are unable to exhibit adequate retrieval-induced forgetting. In fact, fixated individuals have been shown to suffer less from fixation constraints when unable to forget fixation-inducing associates. Notably, however, inhibition may be facilitative only in those situations which require an overcoming of fixation, but not when thinking about extraneous information that could impair creativity. In situations where novel and known stimuli compete for presentation, novel stimuli may be preferentially generated when forgetting old ideas creates more space for thinking of new ideas. Importantly, forgetting may be goal-directed, adaptive process of discarding less useful information, and updating memory to include salient knowledge for future success. This theory lies in contrast to the theory of spreading activation to a wider range of accessible retrieval routes for a broad scope of information retrieval, but is also a process of top-down recruitment of inhibitory techniques that highlight the ambiguous, and exclude fixating cues on a level outside of cognitive awareness [55].

Functional fixedness has been implicated as an inhibitory agent in creative problem solving as fixation effectively traps thinkers in a congested mire of repetitive thoughts, which centralize on a single common use or component of a target object. However, this definition may be extended to account for overlooking certain aspects of ordinary items, including object composition, shape, size, and various parts that make up the whole. Creative individuals exert cognitive energy on establishing awareness of the obscure, and transforming these obscure concepts into valuable solutions. McCaffrey thus proposed the *obscure-features hypothesis* of innovation, which adequately addresses incomplete theoretical concepts surrounding insight problem solving and functional fixedness [56]. Diverse mental representations and associations take place across the entire process of real-world innovation. One strategy to overcome fixation in innovative pursuits is to develop function free descriptions for an object's parts. Explicitly, the sail of a ship may be re-expressed as a vast, movable fabric, as opposed to the actuality of its exigent state relative to sailing. Utilization of the *generic-parts technique* enables the dissociation of subcomponents from their archetypal entity. The hierarchical, funneling effect of this technique prompts multiplicative focus on the mechanistic aspects of a well-known target, and dissuades fixation on the cue itself. Although there may be a multitude of components with dissociable functions, a critical determinant of innovative creativity is identifying the obscure feature that is most appropriate to connect an insight problem with a correct solution. McCaffrey's work highlights the importance of learning the generic-parts technique, showing participants who applied this strategy to various creativity tasks demonstrated an enhanced ability to both list salient obscure features, and solve problems known to induce functional fixedness. The application of this framework suggests that innovation may not be an exclusively spontaneous generation of novel ideas and solutions, but may also be achieved through a methodical search within a set of relevant features [56].

Heuristic creativity approaches learned through cognitive training may activate recall of previously learned information through representation change. Re-encoding problems has the potential to induce appropriate representation transfers, which has been found to increase the likelihood of producing fluent, unique inferences from enigmatic scenarios. The utility of functional fixedness avoidance training has been demonstrated to improve solution rate specific to trained verbal categories. These memory-based training methods can reduce the implicit inclination for connecting with traditionally appropriate solution possibilities, and augments the drive to explore novel avenues of thought [57].

Conflict in Creativity

Creativity requires the creator to break normative mental sets to form connections between previously distinct neural networks [58]. Gino performed five experiments testing priming effects of individual dishonesty on creative assessments [59]. In the first experiment, a measure of insight creativity, the Duncker candle problem, was administered, wherein each participant was presented with a visual illustration of a box of tacks and a candle. Participants were meant to discover an optimal method to attach the candle to the wall using the tools provided. The correct solution involves fashioning a candleholder by emptying the box of tacks, tacking the box to the wall, and using it to hold the candle. Next, participants were asked to perform a mathematical filler task solving ten matrices by finding two numbers which would equal ten when summed together. Participants self-reported their performance, which allowed them the opportunity to cheat. The Remote Associates Test (RAT) [60] of insight convergence was administered post manipulation. The RAT is one of the most commonly administered test of insight creativity, and solution convergence is thought to occur beneath the level of consciousness. An important caveat to address is that although the RAT is a well-established measure of insight, it may be a suboptimal tool for evaluating real-world use of insight in creative achievement [61]. Even so, cheaters performed better on RAT creative performance, even after controlling for insight creativity performance on the Duncker candle problem [59].

The aforementioned experiments included a variety of cheating manipulations, including picture-based temptations to cheat, breaking rules with ethical implications, participants' subjective feelings towards being constrained by rules, as well as degree of caring about the implications of rule-breaking [59]. Cheaters exceeded the performance of rule followers on all experiments, suggesting that deviation from the rules may induce an implicit enhancement effect on creativity.

Rule breaking, or the circumvention of a well-established mental set, is essential to originality. However, individuals are prone to shy away from the risk of uncertainty. Ambiguity is thought to heighten stimulus aversion and motivation to reduce the influence of uncertain variables [62]. Although the social utility of creative innovation is widely recognized, people may implicitly feel uncomfortable when confronted with ideas which may be creative, but also contain a high degree of uncertainty. Experimental manipulations evoking feelings of uncertainty have corroborated these hypotheses [62]. Participants confronted with imposed uncertainty may be implicitly biased against creativity in favor of practical solutions [62]. When the threat of failure, lost productivity, or ridicule is proximal to the creative context, ambiguous circumstances foster implicit bias that dictates the ability to effectively recognize and evaluate ideas creatively. The theory of micro-genesis states rationalized thought is a product of past experiences. Micro-genesis involves the transformation of subjectively biased thought into more objective interpretations. This memory-driven processing schema affords individuals with a multitude of sensory perceptions, which serve as a mecca of resources for the creative individual to reimagine reality. An important caveat of this cognitive hyperstimulation, is that less creative people may feel inclined to resolve cognitive conflict via conformation to traditional methods proven effective in the past [9]. Implicit bias manipulations provide additional support for subconscious primes to augment uncertainty tolerance and impair the ability to break from normative preconceptions, and recognize creative ideas [62]. Further, even personalities more open to experience may be vulnerable to the pervasive drive for acceptance and familiarity, which is fatal to the creative process, as customary ideas are simply not creative. Taken together, implicit biases may effectively separate those more inclined to conform to convention, from those motivated to risk exploring the unknown.

Creative deviation from generally acceptable behaviors may arise from a disconnect between the allure of satisfying self-gratifications, and the pressure to retain consistency in established mental sets and normative behavior. Creative people may be better able to reconstruct their moral landscape, using cognitive flexibility strategies to form loopholes, which allow additional space for the justification of ambiguous ethical decisions. The anterior cingulate cortex (ACC) is suggested to enable mental deviation from a fixed set of presuppositions, as well as resolve cognitive conflicts linked with ruminative impasses [24]. Contextual complexity, the number of available options, and the degree of temptation may interact to influence decisions to engage in deviant thoughts and behavior. Priming individuals to display creative behavior and subsequently perform self-assessments which offer an opportunity to lie for money has illuminated fascinating insight into the realm of creativity. Both dispositional, or trait, creativity, in addition to stimulating a creative mindset utilizing verbal priming has proven to enhance cheating likelihood as well as deviously overstating desirable performances on problem-solving tasks. Crucially, creative individuals may employ moral flexibility to achieve self-serving goals, as well as preserve moral innocence. Situations devoid of modifiable behavioral or cognitive "gray areas" may not directly benefit the creative individual because the ability to initiate such flexibility in constructing novel justifications for questionable actions is unnecessary [59]. Thus, despite being associated with social progress, innovation, and ingenuity, the theoretical dark side of the creative mind is an underexplored area of current research [59]. Promising evidence details the likelihood for creativity to predicate dishonesty, an association that does not appear to be mediated by intelligence [59]. Those able to form original associations from ordinary resources may be motivated by either honest or dishonest cues in their search for new meaning. It is, however, important to present a viable argument to assuage some of the negative connotations linked to deviancy. The thoughts and actions of a creative contrarian could serve a morally courageous outcome if the right decision is one that is rejected by many (e.g., Martin Luther King Jr. serving as a pioneer of the American civil rights movement).

Priming

Environmental disorder has been linked with an increased propensity to engage in behavior that breaks free of traditional constraints associated with conservativism or conventionalism. Clean, orderly spaces may prime moral actions, such as generosity, while the opposite is expected to yield deviant behavioral consequences. Vohs, Redden, & Rahinel explored the potential for disorderly environments to heighten creativity [63]. Their findings highlighted an enhancement effect of cluttered environments on participants' average number, and quality, of creative output on a test of divergent thinking. Perhaps priming mental separation from normalcy or expected behavior confers benefits to the creativity process. In fact, Einstein, arguably one of the most creative individuals in history, was a known proponent of messy work spaces offering an environment conducive to productivity [63,64].

Color may also be influential on creativity. Specifically, brief exposure to the color green (two seconds) has been shown to enhance performance on word and picture-based creativity tasks. As green is often analogized to perceptions of growth and development, it could be utilized as an implicit affective cue [65] that may theoretically increase mastery-approach motivation to engage in novel thought. Mastery-approach motivation is favorably associated with creative capacity, but has been shown to exert no influence on analytical ability [66]. Priming with color manipulations may break down aversive or exclusionary barriers to free thinking. Although future work is needed to tease out extraneous mediational factors, such as cultural variation and alternative meanings linked with green, such as "go," the potential for implicit color cues to precede creative ideation is encouraging. Offices and work spaces could easily adopt this potential creative primer by tailoring decorative color schemes to include visual images of nature, or provide employees with direct exposure to windows, or natural, green spaces [67].

Promotion motivation, or approach motivation may be characterized by goal-oriented drive to successfully complete a meaningful task. On the other hand, prevention motivation, or avoidance motivation correlates with precautionary behaviors, targeting the maintenance or restoration of non-threatening conditions [68]. In the context of creativity, both forms of motivation may be modulated by deviancy (novelty) priming, which appears to be conceptually related to creative ideation, in that it fosters unique deviation from typical responses to problems [69].

Imagery and Insight

Mental imagery is yet another important tool in the creative toolbox. Internal representations of individual, subjective experiences may afford creative actualization. Mental imagery in creativity may be best exemplified by Kekule's discovery of the structure of benzene following his epiphanic dream of a snake-like circle of atoms, and subsequent realization that the molecule must match the same cyclical configuration [70]. Research suggests that imagery serves as a greater instrument for creative success when coupled with perceptual assistance, namely drawing. Drawing may foster completion of mental conceptions, which is paramount for high-quality creative artwork. Recent work has shown that mental imagery is perhaps most important in the initial phase of creativity, when synthesizing and sifting through mental resources is necessary for creative thoughts to take shape. External representations (drawing) appear to facilitate the evaluation phase of creativity, in perfecting the product for practical applications, uncovering spontaneous insight, and reframing cognitive ideas to encompass a broader perceptual scope [71].

Imagery is also extensively employed in scientific thought experiments. Consider Einstein's elevator thought experiment. The scientist posited that a free-falling being inside a downward moving elevator would be unable to feel his own weight. This epiphany led Einstein to conclude that acceleration and gravity are governed by the same unifying force, and thus would portend equivalent effects [72]. This conceptual framework inspired Einstein's pivotal Theory of Relativity [72]. Creative thoughts emerge from a complex cognitive process of imagining original approaches to problems. The core theme of brainstorming is the activation of mental resources to guide the exploration of possible solutions or explanations for preexisting phenomena. This imaginative sequence can unfold as constructive (confirming an accepted theory or mechanism) or destructive (questioning a set of conventional ideas) [73]. One common method observed during creative thought experiments is the imagery enhancement technique. Exceptionally creative individuals have the ability to imagine extreme cases within a particular line of inquiry; cases that are often improbable, and previously unexperienced. Imagining such extremes promotes an extended application of what is known and accepted to that which is not yet confirmed, but could plausibly occur [73].

Insight problems also require sustained attention and deliberation prior to converging upon an "Aha! moment," or Eureka experience. Admittedly, the evaluation of insight-associated creativity is fraught with methodological inconsistency, as numerous attempts to assess this broad construct, have used variegated techniques. Adding to the current confusion, selective activation of prefrontal regions in lieu of an "Aha!" experience, may be apparent in "non-creative," complex tasks, which do not necessarily demand mental faculties associated with insight. That is, both demanding tasks and insight problems may promote analogous prefrontal activation [74]. However, existing research has provided additional evidence for the ACC to underlie insight creativity [24]. The superior temporal gyrus is also predicted to influence insight, when remote associations must be formed through verbal convergence in search of a fitting solution [24].

The sudden jolt of the "Aha! moment" may be a consequence of an organized internal search for consistency. When a correct association is achieved, likely after multiple subconscious attempts to conflate mnemonic clues, it must be tested against what is known. "Aha!" epiphanies emerge when the utility of creative discoveries is deemed consistent with previous knowledge and experience, yet capable of adding meaningful information. Until the thinker overcomes a perceived impasse, his or her repertoire of accessible information is unusable and meaningless. Thus, a viable experimental approach to assessing insight is via implicit learning manipulations. Explicit knowledge may develop during implicit tasks, as participants suddenly become cognizant of a pattern of underlying regularity that aids successful problem solving [75]. In implicit learning protocols, the moment of insight may be measured by a corresponding decay in response time to cues. In other words, participants respond faster on trials after they have become aware of cue consistency patterns [75]. Although it may be reaching to equate pattern recognition to insight generation, research supports the hypothesis for shared neural pathways between insight activation and onset of explicit knowledge during implicit assessments.

Dual-processing theory suggests that distinct types of thinking involve the autonomous/implicit "Type 1" processing system, and working memory (WM) dependent "Type 2" reasoning processes. Type 1 processing is likely implicated in all thought, and, therefore, all creative thought. However, frontopolar cortex dependent, Type 2 processing may be the operative catalyst that draws creative thoughts from the subconscious. As Type 1 processing can be associated with general, or global thinking, it can be argued that its relation to creative thinking is inconsequential. Intervention of the ECN potentiates novel connections between cues for remote and complicated signals, which may not arise spontaneously. Connecting remotely associated items (e.g. RAT task) in semantic space has been linked with Type 2, analytic reasoning [76]. Implicit learning and insight may rely on basal ganglia or ventral perirhinal cortex activation [75]. Although speculative thus far, the importance of investigating the temporal onset, and neural correlates of implicit and explicit learning in conjunction with insight creativity remains relevant to modern creativity research.

Psychological Parameters

Activation, Affect, and Emotion. Activating states, initiated by cognitive and physiological arousal, may engender creativity through enhanced originality and fluency, or through prolonged time-on-task. Deactivating moods do not hinder creative thinking, per se, although, activation seems to enhance the creative process, priming individuals to outperform those who are not appropriately aroused. Flexibility in both set-breaking, and avoiding redundancy in creative problem-solving, is critical for performance success. Cognitive perseverance is also a prerequisite for overcoming constraining effects imposed by difficult problems. Creative individuals often experience an “aha” moment of clarity following sustained rumination over details associated with the most important task at hand. Neurotransmitter release is suggested to influence the degree and duration of prefrontal cortex activation. Dopamine and moderate noradrenaline release regulate prefrontal cortex activity, which dictates working memory functions such as comprehension, planning, processing, and focused attention in positively activated mood states [77]. Midbrain activity associated with emotion and motivation is linked with substantia nigra involvement as well. Further, perception of rewards may be a dopaminergic feature critical to the derivation of personal value when engaged in salient creative activities [33]. In contrast, negative activation may lend to more analytical, narrowed, and deep systematic processing of stimuli. Individuals who are negatively activated tend to be less vulnerable to distractions, and are more motivated to remain on task for extended periods of time. Positive, activated states rely more on right hemispheric activation, while negative activation is contingent upon activation within the left hemisphere. Release of the neurotransmitter serotonin is also suggested to associate with negative activation, facilitating goal-oriented processes [77,78].

Despite much research describing the favorable effects of positive mood on creativity, transient and enduring negative moods have also demonstrated promise in driving creative behaviors [79,80]. The mood contingency theory [81] proposes that sad or upset individuals will modify their current emotional state by seeking opportunities to engage in novelty. Conversely, happy individuals interested in preserving their positive mood will be less inclined to explore or engage in abstract thoughts and behaviors that could disrupt their present satisfaction [82]. Therefore, negative valence may promote openness to ambiguity and new experiences.

Competition may enhance creative production when framed as motivated cognitive effort guiding goal achievement. An aversive creativity task that concurrently activates aversive states may motivate individuals to cope via accessing broad mental categories as a conflict resolution tactic. Alternatively, if the creative domain is unrelated to the sentient conflict, creativity may be diminished. This particular outcome is hypothesized to be regulated by top-down neural processing, which focuses attention, and reduces the negative influence of distracting stimuli. Such focused, persistent mentation may signify a critical component of conflict-associated creative productivity [83]. Regarding motivational states, approach-related motivation (motivation to achieve a desired outcome) associates with flexible cognitive processing, while avoidance motivation (motivation to avoid an unfavorable outcome) is associated with mental persistence. Generally, avoidance motivation is thought to hinge on working memory and top-down control, depleting cognitive resources to a greater extent than creativity accessed via approach motivation techniques [84]. Despite historically ambiguous definitions of inspiration, this crucial component of creativity also deserves rigorous exploration in research. It is well established that inspiration is a passive state of approach-motivation in response to externally or internally supplied ideas. Thus, memory of previous experiences is essential to fuel sustained inspiration. Further, inspiration is likely to serve as a pivotal statistical mediator in the mentation-creativity linkage, as inspiration may delineate a clear path from specific ideas to highly creative products. Dopamine projections released from the ventral tegmental area are also suggested to indicate important neurophysiological localization hubs of inspiration [85].

Self-evaluation may be detrimental to creativity [86] via a magnified comparison to untenable performance standards, and/or a hyper self-conscious psychological state. Defensiveness and narrowing of focus towards social comparisons, or indoctrinated standards of success, shifts motivation away from intrinsic sources, which have been shown to facilitate creative performance [86]. Self-awareness manipulation, including illusory videotaping, or placing mirrors in front of participants are common methods employed to measure self-evaluation dynamics, such that people become hyperaware of their performance. Silvia and Phillips discovered that high self-awareness was only detrimental to convergent creativity when people felt unable to improve themselves on subsequent tasks (e.g. researchers informed participants future improvement was unlikely should they exhibit poor performance on an initial task) [87].

Alternatively, participants who felt capable of improving were not limited by increased self-awareness. In a follow-up experiment, the researchers found that women receiving details regarding performance compared to objective creativity standards scored better on a divergent creativity assessment when self-evaluation was high, but they were able to maintain confidence in their ability to improve [87]. However, when improvement seemed unlikely, high self-evaluation did not protect participants' creativity scores from suffering. Although expansive attention and mental resources have been touted as a prerequisite for the creative process, attentional diffusion alone cannot explain creativity performance. The moderating effect of achievement expectations may play an integral role in determining the bidirectional impact of self-evaluation on creativity.

Perhaps optimistic expectations to improve may underlie degree of intrinsic motivation to engage in creative pursuits. Thus, if failure is perceived as a modifiable factor, and performance-associated rewards or standards of proficiency are available, self-evaluation may not be a substantive barrier to creativity. However, this line of inquiry is raft with complexity. Baseline level of task competency must be considered, as history of success or failure in similar domains may govern individuals' perceived expectancy for future self-improvement. Additionally, projections of failure on the self or others may exert an appreciable influence on tendencies to internalize poor performance. Future work is needed to explore the magnitude of the effects of self-evaluation during creative production, as problem-solving grounded in self-evaluative thought aid the refinement of novel ideas and planning to share them with others.

Resiliency, Self-Monitoring, and Cognitive Distraction

In addition to motivational drivers of creativity, resiliency in adapting to adverse situations may also predict creative capacity [88]. If creativity involves composing order from disorder, then resilient personalities may be better equipped to overcome impasses and search for unconventional solutions to complex issues. Resiliency may be linked with creativity in terms of flexible thinking intended to fortify self-efficacy, while adapting to disruptions within intrapersonal domains [88]. Metzl and Morrell [88] cite Csikszentmihalyi's thorough definition of creative flow states, wherein the derivation of individual pleasure in discovery represents the culminating purpose of creative pursuits [89]. Creativity may serve as a means to achieve an end, but this stipulation is not required for sustained motivation across related domains [88]. This definition extends the scope of creative importance beyond what is considered transformative and beneficial to society, to individual capacities for handling difficult circumstances in everyday life, solving professional and personal conflicts, as well as navigating the nuances of human interaction [89]. In fact, evaluating day-to-day creative behaviors among "non-expert" populations, whom have not been explicitly recognized for exceptional mathematical, scientific, or artistic contributions may allow researchers to evaluate "micro" creative behaviors and strategies, which could inform practical implications for creativity to influence relationships and well-being irrespective of lifetime creative achievement.

The biology underlying the neuroelectrical foundation of creativity remains predominantly obscure. Recent work evaluating spontaneous music composition of talented jazz musicians describes the prefrontal cortex as a critical region necessary for enabling creativity [90]. Self-monitoring may be transiently disabled as self-expression is prioritized. Focal activation in the frontal polar medial prefrontal cortex, and diffuse activation of sensorimotor areas may preclude activation of the dorsolateral prefrontal and lateral prefrontal areas, with integrated activation and deactivation within limbic structures including the amygdala, entorhinal cortex, temporal pole, posterior cingulate cortex, parahippocampal gyri, hippocampus and hypothalamus. Other work suggests conscious stimuli may catalyze top-down cognitive control. As Dietrich indicated, information processed by limbic systems (including parahippocampus, hippocampus and amygdala) arrives at the medial prefrontal cortex and cingulate cortex to further complete highly integrative computations, enabling combinations of old concepts and information to be recognized and then subsequently applied [37]. The medial prefrontal cortex is suggested to facilitate a consciously intentional pursuit of behavioral divergence that arises from pre-established mental-sets, which structure a personalized environment subserving creativity. Deactivation of lateral prefrontal regions may limit inhibition of contextually inappropriate thoughts and behaviors, sequential implementation of planning processes, goal-directed problem solving, and attentional allocation, which are also necessary for creative thinking. These results provide convincing support for creative processes to integrate both volitional and automatic thought [90].

The mental capacity to subconsciously switch off regulatory neural networks may promote sudden bursts of insight, or “Aha moments.” Perhaps inviting random sensations to permeate the mental landscape allow for improvisational freedom in achieving spontaneous creativity. Sleep, hypnotic states, meditation, and daydreaming have demonstrated analogous deactivation in lateral prefrontal regions to what Limb and Braun have described as plausible prerequisites for creative improvisation [90,91]. Less work has been conducted examining the reasons why deactivation during spontaneous productivity may be apparent in limbic structures. However, one theory suggests that intensely pleasurable emotional valence during such processes, may be influenced by deactivation of structures associated more proximally with negative emotions, such as the amygdala and hippocampus. Critically, decreased amygdular activation may be explained by anticipation of an outcome, rather than the outcome itself, meaning the motivated pursuit of creative accomplishment may suffice to diminish input from the amygdala [92]. Nevertheless, modulation of these structures is complex, with alternative research experiments indicating contradictory outcomes, thus warranting the need for continued research on this topic [90].

Another plausible utility for unconscious processing may be an incubating effect of distraction. Research has shown that cognitively taxing distractors, when presented after a cue to engage in creative problem-solving, provides adequate latency for unsatisfactory approaches to be shifted from the forefront of the mind in favor of distantly accessible alternatives [93]. However, empirical research must continue to question evidence claiming spontaneous unconscious thought is truly a driver for creativity. Although unconsciously mediated, the creative process must not be assumed to manifest through blind insights. The environment, personality, and motivation for achievement are central to creativity [94]. To this end, assigning credence to such an assumption is largely unsubstantiated, as it is difficult to draw explicit lines of distinction between unconscious and conscious thinking. Past findings have shown that, although subconscious Eureka experiences, or “Aha! moments,” are generally likened to a spontaneous burst or spark of insight, the underlying cognitive approach towards an optimal solution is probably more methodical. The methodical approach to insight suggests that, even when suppressed from conscious deliberation, the unconscious may continue to cogitate, progressively drawing individuals closer and closer to target solutions. As this phenomenon often occurs gradually, the risk of diminishing motivation may partially explain why some individuals give up after repeated failed solution attempts. Nevertheless, unconscious processing also occurs rapidly, producing seemingly sudden insights, which are likely preceded by an ordered activation of associations via high-quality mnemonic clues [95].

Mental Health and Neurological Pathology

Bipolar disorder has been linked with creativity. One plausible theory is that of heightened motivational drive among those at risk for manic episodes. Even among those with no evidence of psychological disorder, effort and ambition are closely related to success in a multitude of disciplines. Those with bipolar disorder have been found to exhibit dopaminergic mediated activation within the PFC during tasks which require sustained attention and engagement for successful task completion [96,97]. Future work should address the concept of flow, or sustained immersion and intense pleasure derived from continued effort on a task, among those with bipolar disorder, to evaluate if the duration and quality of flow-state are enhanced in bipolar individuals. Individuals with bipolar disorder also tend to aspire to achieve highly ambitious goals, and are especially vulnerable to extrinsic and intrinsic motivational influences, as well as social climate pressure to achieve dominance and success. Notably, the manic pursuit of goals may only manifest when the environment becomes conducive to such behaviors. In other words, environments which present the possibility of incentivization may entice those prone to manic episodes. Research should investigate the distinct impact of both intrinsic and extrinsic incentives on creativity in special populations, in an attempt to address differential relationships to creative thinking and achievement. Of note is the delusional tendency for manic individuals to favorably self-report creative achievement, while actual performance on skills assessing creativity may not be especially associated with high levels of creative performance. Thus, a desire to be creative, and belief in one's creative aptitude may be strengthened among individuals with bipolar disorder, but scores on evaluations of creativity may not reflect these motivations. One plausible explanation is that mania may compound the drive for social dominance and respect from peers, causing people to develop higher confidence in their creative abilities [98].

Adults with Parkinson's disease may compulsively engage in creative pursuits, as a function of enhanced pharmacologic dopaminergic stimulation of neural reward circuitry. In other words, medications upregulating dopamine production may evoke heightened creativity [99]. Frontotemporal lobar degeneration (semantic variant) has also been shown to induce compulsive artistic behavior among certain patients affected with this neurogenerative disorder. Temporal atrophy, coupled with the relative sparing of the non-dominant parietal lobe and frontal lobes may contribute to an obsessive increase in creative generation. These are important discoveries, as frontal lobe function is extremely important to the creative process, having been explicitly linked with divergent thinking. Additionally, the parietal cortex is associated with visuospatial orientation, and increased gray matter volume has been demonstrated in the right parietal lobe of creative individuals scoring well on visual creativity tasks [100,101].

Deterioration of the parietal cortex is also suggested to confer visually-associated creative deficits in those with Alzheimer's disease [102]. In addition, damage to the temporal lobe portends worsened language ability in Alzheimer's patients[103]. Hippocampal dysfunction may also partially account for characteristic obstructions in creative thought that are highlighted within this population [101-103].

An increase in creative behavior has been demonstrated among individuals addicted to psychoactive substances. For some, drug abuse may be mediated by a genetically-regulated limbic system deficiency of the reward neurotransmitter dopamine, driving both novelty seeking and risk behavior [104]. Cortical neuroimaging data have shown enhanced EEG α- and θ-band power within the right hemisphere, indicative of searching, creativity, and parietal-temporal-occipital activation [105].

Behavioral-Based Characteristics

Art, Music, Exercise & Creativity. An overwhelming majority of creative masterpieces are attributed to the professional disciplines of art and music. Research in these areas is worthwhile as the stereotypical "creative individual" may provide validity and critical insight into the experimentation and measurement of domain-specific creativity. Arguments for artistically mediated prefrontal changes have been posited in the existing literature [106]. Equivocal trends of both deactivation and activation have also been proposed [107], perhaps highlighting the integration of affect, language processing, and motor functioning underlying the neural correlates of various art and music styles [107]. A prefrontal hypofrontality hypothesis is asserted to facilitate an explanation for the heightened enjoyment and focus, or "flow," that has been self-reported by some artists and musicians [90]. Alternatively, increased prefrontal activation may underlie high-order cognitive resource allocation and working memory utilization during generation of creative artistry and musicality [24,106]. A recent study found jazz musicians with previous improvisation training demonstrated increased bi-hemispheric, frontal upper alpha synchronization during musical improvisation, compared to exact playback of a rehearsed melody. Higher quality of creative performance among improvisation-trained musicians with greater frontal alpha EEG power was reported by independent raters, who also assessed improvisation performance according to musical technique, innovation, and aesthetic appeal [108].

Functional connectivity within neural networks of professional artists and non-artist participants has been measured via (fMRI). Participants were given specific instructions to visualize a "landscape", which may have been interpreted either literally or metaphorically, for future artistic recreation in the laboratory [109]. Findings of the experiment indicated functional connectivity between nodes of the DMN and the ECN. Specifically, reduced activation of the right inferior prefrontal gyrus in the ECN may restrict cognitive inhibition [50], while dorsolateral prefrontal areas are alternatively activated during visual creativity. Neural activity in the ECN may stimulate concurrently heightened activation within areas of the DMN, allowing creative thought to occur independently of stimulus inference, and confer novelty and divergent thinking benefits as well. The premotor cortex region of the DMN is one region which is thought to support free-thinking and abstract planning of creative products [38], and was especially active in artists, compared to non-professional artists [109]. Concomitant interplay of top-down control organized in the ECN and the DMN may underlie creative ideation and evaluation of creative ideas for translation into original, high-quality products. As the ECN is a neural corollary of success in problem-solving tasks and goal-oriented actions [109], perhaps the DMN promotes the supplication of an untapped mental repository, from which the ECN may draw reasonable inferences and evaluations of the most necessary products for creation in concert with preeminent goals. Exercise may also influence creative productivity via shared neural pathways. An exhaustive description of all potential exercise-creativity links is beyond the scope of this manuscript; however, several plausible neurobiological mechanisms are discussed as follows.

Much like creative thought processes, physical exercise requires self-regulation of effort, and awareness of both simple and complex movements. Attentional control and cognitive executive functioning are diffusely activated during physical activity[110]. Event related potentials released from the ACC may facilitate concentration when a variety of stimuli (either external or internal) are competing for attention, especially when these stimuli are related to tasks involving sensory, motor, emotional and cognitive processing[111]. Increased firing efficiency of exercise-regulated action potentials is linked with concentration, as well as inhibitory regulation of multiple, competing cues. The precision of these regulatory mechanisms may be partially explained by dopaminergic receptor action in the basal ganglia and prefrontal cortex, which are demonstrated to correlate with aerobic capacity and contribute to cognitive control and response inhibition [112]. Physical activity is also shown to influence neurotransmitter release (e.g. serotonin, dopamine, epinephrine, and norepinephrine), which moderates affect and arousal[113]. In addition to driving valence and motivational response, moderate exercise is related to reasoning, memory, and goal-directed behavior, via enhanced physical and cognitive arousal, and concomitantly reduced psychological distress[113]. Further, exercise participation may alter hippocampal connectivity, promote neural and synaptic plasticity, and facilitate neurogenesis to enhance learning, memory, and interpretation of personal experiences [114-116]. Taken together, there is a wealth of reasonable scientific evidence to support future empirical investigations across a litany of proposed associations between exercise and creative actions and thoughts.

It is well established that creativity is influenced by a multitude of cognitive and behavioral complexities. Empirical measurement and evaluation of creative ideation and production is difficult, as there is a lack of agreement in defining a unifying term for creativity. Although, this does not imply that creativity is an intractable phenomenon. Rather, we echo previous assertions that research efforts should abandon a search for operationalization, and instead target underlying constructs of creative thought, which will best serve the development of practical methods for transferring laboratory-enhanced creative potential to real-world innovation. This narrative review provides a snapshot of several potent mechanisms of creativity, which may be experimentally manipulated to further understand and advance this area of research. The Boxed Panoply Model of Creative Cognition (Figure 1) underscores the importance of conceptualizing creativity as a diffuse adjective, denoting actions and thoughts accessible to all individuals, and not a reductive term for some commodity of eminence. It is our contention that examining gender, personality, cognition, psychological parameters, and behavioral-based characteristics will shift focus from what exactly creativity is, to how individuals may utilize creative thinking as a renewable resource.

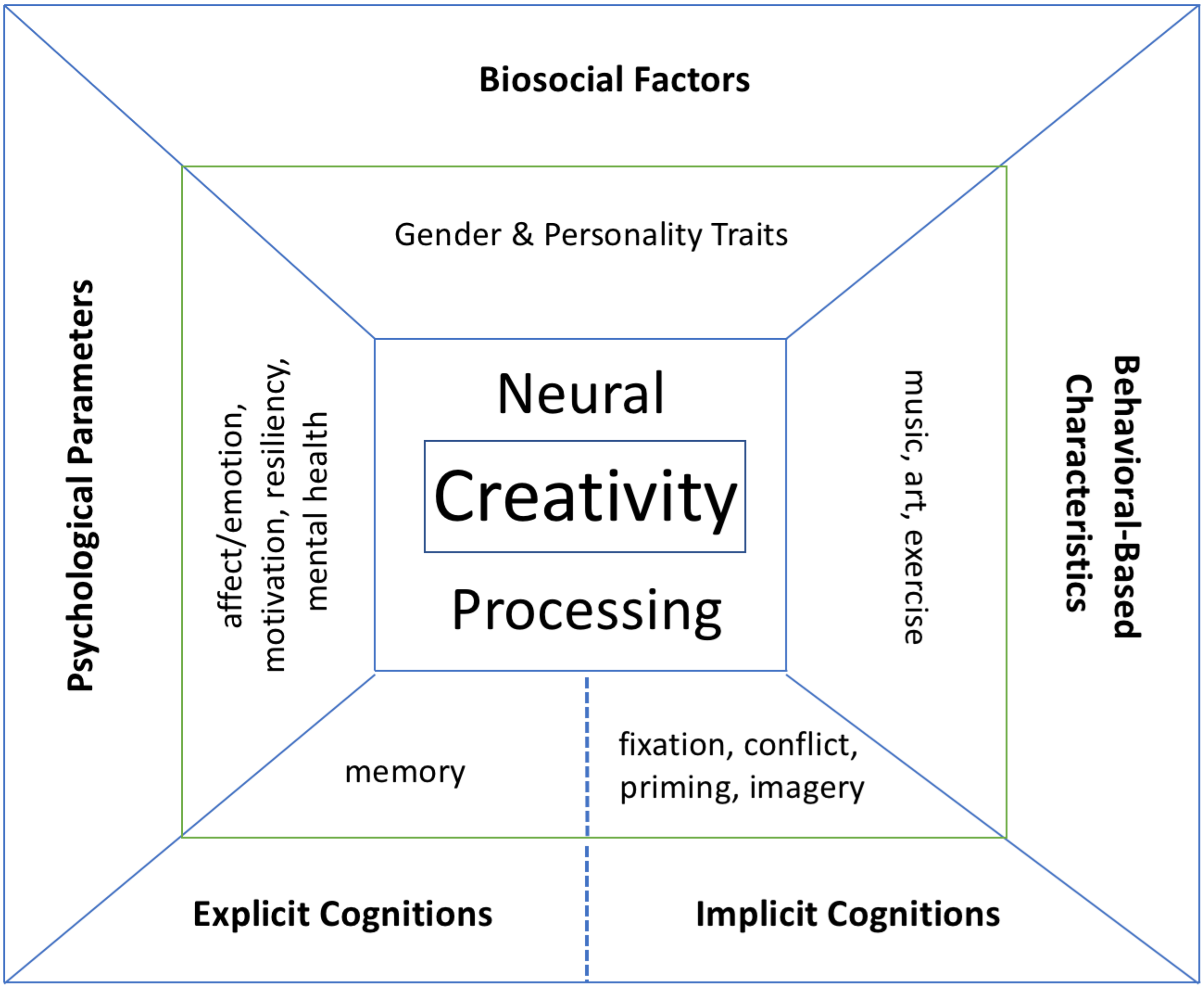

Figure 1.1. The Boxed Panoply Model of Creative Cognition

CHAPTER II

SYSTEMATIC REVIEW OF THE PROPOSED ASSOCIATIONS BETWEEN PHYSICAL EXERCISE AND CREATIVE THINKING

Abstract

A systematic review of experimental research was conducted to evaluate the association between physical exercise and creative thinking. Our primary objective was to delineate this potential relationship and highlight the importance of employing high-quality methodologies in exercise and creativity research programs, with a secondary aim to disseminate useful recommendations to facilitate the selection and assessment of relevant questions worth answering in this discipline. A systematic review approach was employed by searching PubMed, Google Scholar and PsychInfo databases. Among the evaluated 13 studies, 92% indicated a beneficial relationship. However, 77% were vulnerable to moderate-high risk for methodological bias, suggesting adherence to standardized and controlled research initiatives should be promoted. There appears to be weak to modest support for acute, moderate-intensity exercise to benefit creativity. Regarding the secondary aim, exercise timing relative to creativity assessment protocols should be addressed and further detailed. Creativity scoring procedures must be explicit and refined, and an increased focus on the motivational components of exercise may help guide researchers in measuring creative thoughts and behavior. Broader concluding claims that creativity, *in general*, is improved or impaired by exercise, is as problematic as sweeping statements that exercise improves or impairs a measure as dynamic as intelligence. This review identifies several fallible linkages between physical activity and creativity. Too few studies were conducted on strong methodological foundations, perpetuating the risk for undermining or inaccurately inflating the potential association between exercise and creative thinking behavior.

Introduction

Scientific inquiry in any field is difficult when the parameter beneath the lens of empirical scrutiny is difficult to both operationalize and localize. Researchers have attempted to define creativity as a broad construct that encompasses "the degree of novelty of which the person is capable, or which he [or she] habitually exhibits"[117]. More recently, the intricate processes of creativity have been posited to correspond with "our ability to change existing patterns, break with the present, and build something new"[118]. The variegated outcomes of such creative processes have also been described as products which "can be tested in terms of the frequency of uncommon, yet acceptable, responses to items" [117]. Further, a theme of societal relevance, or value, is proposed as a crucial standard for creative production, as "the creative work is a novel work that is accepted as tenable or useful or satisfying by a group in some point in time"[119].

Despite the volume and remarkable adaptability of creative exposition, 1950 revolutionized empirical creativity assessment with a push to evaluate creative divergent thinking [117]. The examination of divergent thinking, or the creative act of generating multiple solutions from a single stimulus [120], continued to serve as a pervasive staple for the best measurement practices in creativity studies for decades, and is still widely investigated in modern research. Indeed, it is well established that divergent thinking is a tool for predicting creative potential [121,122]. However, it is certainly not the only tool that should be wielded by scientists searching for causal relationships. For example, convergent thinking, or solving a task with one correct solution, is also suggested to play a large role in explaining the nature of creative thought [120]. By the late 1990's, creativity research diverted from a narrowed focus on the evaluation of divergent thinking, and began to encompass a broader range of scientific analysis, including neuroscientific correlates, personality, insight, and other systems-based approaches exposing important creativity measurement outcomes [123,124].

Unfortunately, as creativity research efforts in psychological and neurobiological disciplines appear to be making headway towards the practical conceptualization of such an untenable construct, creativity research in exercise science and health promotion is stunted. The lack of experimental work on this topic is staggering, with only 13 research studies investigating the associations between physical exercise and quantifiable creative products [125-137]. Over half of this body of literature was published prior to the millennium, and, as demonstrated herein, the vast majority lack sound rationale and methodological quality.

Following the systematic review framework detailed elsewhere [138], this systematic review will provide a detailed synthesis of the exercise and creativity work accomplished thus far. The dearth of unbiased research on exercise and creativity is a critical issue, which must be prevented for future development in this area to continue unencumbered by obstruction, or even absence, of meaningful evidence to answer the pervasive question, "*Does exercise influence creative potential?"* Therefore, a secondary aim of this review is to direct future experimentation towards more informed, and applicable, methods of inquiry, and provide direction for identifying prudent questions worth answering in the field.

Methods

Inclusionary Criteria

Research studies were included if they utilized an experimental study design, were published in English, indexed in PubMed, Google Scholar and PsycInfo, and specifically evaluated the influence of acute or habitual physical exercise on creativity in children or adults, of either gender and with no known psychological or physical limitations or preexisting pathology that would prevent them from being classified as healthy at baseline. Any exercise intervention (acute or chronic laboratory or free-living physical activities) coupled with either an active or traditional control group (no exercise) was considered.

Exclusionary criteria

Research studies were excluded if no exercise intervention was employed, self-report questionnaires of creative strengths and abilities were not accompanied by an observable laboratory measure of creative potential [139], or if creativity was not the outcome variable [140]. Additionally, articles were excluded if the study population was comprised of nonhuman subjects.

Outcome measure. Cognitive creativity (analogy, convergent thinking, divergent thinking, insight, metaphors, and problem-solving)

Search Strategy

The following databases were searched between 1 January 2018 and 10th January 2018: PubMed, PsychInfo, and Google Scholar. MeSH keyword terms included exercise, physical exercise, physical activity and creativity.

See Figure 1 for a flow diagram of the extracted studies from the computerized search. In total, 13 articles met the study criteria (Figure 1).

Quality Evaluation

Risk of bias/study quality was evaluated for each article using a checklist developed specifically for this study. The following checklist includes seven items with a yes (1) or no (0) response option and was constructed in accordance with the Cochrane Risk of Bias Tool [141]. This risk of bias checklist, as well as this entire systematic review, also adhered to the PRISMA checklist for reporting systematic reviews (except for item #5, prospective registration of the systematic review). Two of the authors independently scored each study based on this checklist. Discrepancies were discussed until agreement was made. In situations when consensus did not occur, the two remaining authors were consulted, which facilitated consensus for all risk of bias items. The risk of bias items are as follows:

Item 1: Was the physical activity manipulation controlled (e.g. completed in a laboratory setting, standardized by duration and intensity, and for interaction with other participants if administered in a group context)?

Item 2: Was there evidence of reliability for the creativity measure(s) utilized?

Item 3: Was there evidence of validity for the creativity measure(s) utilized?

Item 4: Were creativity scoring and evaluation procedures robust to bias (e.g. blinded scoring completed by multiple researchers, provision of strong interrater reliability, and/or using scoring manuals, or previously utilized scoring guidelines) and detailed or referenced?

Item 5: Were random group assignment and/or counterbalancing procedures appropriate (e.g. were participants assigned to groups based on course enrollment, rather than random selection and were the order of creativity assessments randomized to ensure resistance to temporal artifacts or learning effects?) for the study design?

Item 6: Did the intervention use a non-exercise control group or condition?

Item 7: Were statistically appropriate/acceptable methods of data analysis used?

Item 8: Were point estimates, standard deviations, confidence intervals, and/or effect sizes reported?

Items 2 and 3 required each manuscript to include an explicit description of evidence for reliability and validity of the creativity outcome assessments employed. The manuscript earned a ‘no’ (0) score for missing details regarding reliable/valid measures, which may have been utilized in some experiments, but were not adequately detailed per our quality evaluation criteria. A ‘no’ score for Item 7 was awarded to manuscripts that failed to use reasonable statistical methods for post-hoc analysis of outcomes. Statistically inappropriate decisions included reporting Pearson correlation coefficients for interrater reliability, failure to use the appropriate statistical tests and computing unpaired analyses of treatment effects on individual differences as a result of chronic training studies. Item 8 identified articles that neglected to report point estimates, confidence intervals, standard deviations, and/or effect sizes. The authors may have computed these values, but if all statistical results were not included in the publication, a ‘no’ score was given for Item 8.

The 13 included research studies were classified into categories based on cut points reflecting the degree of methodological bias considered for each individual study. Studies with a score of 6-8 (three studies) were classified as having low risk of bias. Studies with a score of 3–5 (eight studies) were classified as having moderate risk of bias. Studies with a score of 0–2 (two studies) were classified as having a high risk of bias (Table 1).

Data extraction

A data extraction table for the included research studies was created to provide a brief description of author names and publication date, sample characteristics, research design, creativity measures used and length of creativity assessment period, relevant creativity parameters assessed, exercise modality, intensity and duration, methods used for scoring creative products, as well as study outcomes and conclusions (Table 2).

Results

Creativity Assessments

There are many different creativity assessments which may be utilized to experimentally assess acute creative potential in the laboratory. Four studies employed the Torrance Tests of Creative Thinking (TTCT) Figural Tests A and B [142], with one utilizing both the Figural and Verbal forms. Eight studies assessed divergent thinking, and two studies employed both divergent and convergent thinking assessments. Two studies evaluated analogy generation or production of metaphors. Assuming that these measures all demonstrate comparable quality in assessing certain aspects of creativity, caution should be observed when interpreting these results for practical generalizability.

Study Description

Among the 13 manuscripts selected for this systematic review, all evaluated a hypothesized relationship between exercise manipulation and creativity performance. Of the 13 articles, three were published after 2013, two were published from 2002-2005, and eight were published from 1985-1998. Nine studies evaluated exercise and creativity within college-aged individuals, three studies assessed elementary and/or middle school children, and one study utilized a sample of adults at least 18 years of age. Nearly one-third of the included studies failed to report sample sizes per experimental or control group assignment. To this end, due to the substantial heterogeneity across study quality and methodology, a meta-analytic approach was not appropriate to include, and a qualitative review of research studies was chosen to avoid further convolution of conclusions suggested in the existing research on exercise and creativity [143]. Three studies utilized a traditional within-subject design, four used a between-subjects protocol, one used a two-visit between-subjects design [131], and four mixed-method studies implemented aerobic running sessions lasting 6-12 weeks, consisting of both between-and within-subject comparisons. One study was initially designed to employ a between-subjects design, but then collapsed the two experimental groups at the conclusion of the study to accrue a more robust sample size for analysis of treatment effects [135].

Risk of Bias

Among the 13 experimental studies, 23% (n= 3/13) were determined to contain low risk of bias, 62% (n= 8/13) of the included studies were considered to be of moderate risk of bias, and 15% (n= 2/13) were considered to have been conducted with high risk of bias.

Main Outcome Results Across Exercise Intensities

Among the 13 evaluated studies in this systematic review, 12 demonstrated some evidence of a beneficial effect of exercise on creativity. Further details on select studies, along with their limitations, are noted in the Discussion section. Among the 13 studies, eight evaluated moderate intensity and eight evaluated vigorous intensity exercise (two studies evaluated both moderate and vigorous intensity exercise). Regarding the eight studies focused on moderate intensity exercise, three demonstrated a significant effect of exercise on divergent thinking, specifically immediate and delayed improvements in figural creativity [125], increased fluency and novelty (defined as original and contextually appropriate) during and following exercise compared to rest, increases in high-quality analogies during exercise, an increase in novelty when walking outdoors [133], as well as when roaming (free ambulation), or walking unconstrained. Notably, constrained walking was also shown to increase novelty compared to rest, but novel responses while walking along a predetermined path were statistically significantly lower than roaming unconstrained. A moderate intensity cycling protocol was shown to have no statistically significant influence on figural creativity measured by fluency, originality, and elaboration (although Curnow & Turner [127] suggested weak support for a fluency effect at "the .05 level"). Among the seven studies employing vigorous exercise protocols, six demonstrated a significant effect. Convergent and divergent thinking was elevated among female dancers (although no scoring information was provided; Gondola, 1987 [131]). Alternatively, convergent thinking performance was reduced among inactive participants during intense cycling exercise, compared to both moderate intensity and rest conditions. Rest and moderate intensity cycling did not produce statistically significant outcomes in convergent thinking. Additionally, divergent thinking was higher during rest than intense exercise for inactive and active participants, with no statistically significant difference found between moderate cycling and rest (Colzato et al., 2013). Ramocki [134] demonstrated statistical significance for divergent thinking fluency improvements following vigorous intensity exercise. This study was vulnerable to substantial bias, receiving a score of "0" on our quality assessment, so these findings should be cautiously interpreted. Steinberg et al. (Steinberg et al., 1997) indicated divergent thinking flexibility was increased among participants; however, individuals completed either "low-impact, rhythmic stretching", or "high-impact" aerobic dance, and were analyzed as a homogenous experimental group following the conclusion of the study. Therefore, those findings cannot be considered meaningful.

High intensity, chronic training studies (aerobic running durations of 20-30 minutes with 2-5 sessions per week) were shown to enhance divergent thinking performance [128-130,132,136], with studies evaluating children demonstrating marginal gender-specific differences, specifically positing that girls may be more responsive to training-induced improvements in figural elaboration [132] and verbal flexibility and originality, with boys perhaps more likely to outperform girls on general divergent thinking measures [136].

Discussion

Results on Exercise and Creativity

Steinberg et al. [135] evaluated aerobic dance and stretching lasting approximately 17-20 minutes in duration. The exercise protocol consisted of six minutes warm-up, six minutes of an aerobics class and six minutes of cool-down exercises. The aerobic exercise procedure was classified as “high impact,” while the rhythmic dancing was considered low-impact and consisted of a four-to-five-minute warm-up, a 14-minute dance period, and three-to-four minutes of cooling down. Despite the decision to administer two distinct exercise protocols, the aerobics group and dancing group were combined into an aggregate sample following experimentation. This post-hoc deviation from the initial study design is problematic, as diverse modalities and intensities may uniquely influence the influence of physical exercise on creative cognitions. Creativity was also only measured post-exercise for this experiment, as further counterbalancing of creativity tasks would have rendered the procedure “too complicated and time-consuming.”

Other exercise protocols permitted participants to engage in weight lifting, as well as any accessible form of aerobic indoor or outdoor exercise (e.g. swimming, running, brisk walking, cycling, or stair climbing), continuous or intermittent, with a troubling dismissal of experimental control. Even among studies with adequate experimental control, the exercise regimen remained flawed, as one study asked participants to engage in both moderate and intense exercise within the same bout, failing to indicate that measurements of creative potential may be distorted by residual fatigue, particularly for inactive individuals randomized to complete the intense condition prior to the moderate intensity condition.

A crucial point must be considered as researchers aim to extend the field creativity and exercise. Specifically, the time-point at which creativity is assessed relative to the exercise bout warrants scrupulous empirical attention. If exercise is expected to exert evaluable effects on creative potential, then experiments must be designed to illuminate how, why, when, and for whom these effects may occur. Researchers often assess creativity before and after a single exercise bout [127,131,134] or multi-visit training program [128-130,132]. Although, some authors report testing creativity following the exercise bout, with no baseline assessment [125,135], while others administer a concurrent task protocol [133,137], to identify the relationship between creative cognitions activated during the transient stimulation of exercise. Research has also investigated timing differences between creativity assessed before and after, or during and immediately following acute exercise of moderate versus high-intensity [126]. There is utility in assessing potential temporal relationships across numerous research projects, or perhaps in a single research endeavor. To that end, it is troubling that no study, to date, has attempted to assess creativity before, during, immediately after, and many hours following exercise to test individual responses in a multi-visit study, in addition to isolating between-group differences contingent upon the timing of exercise.

Informed Methods of Inquiry. All articles included reported that creativity was either augmented or decreased as a function of exercise manipulation, failing to underscore the reservations inherent in creativity tasks designed to evaluate specific creative correlates (i.e. divergent thinking, convergent thinking, insight, imagination, analogy, metaphor, etc.). Therefore, stating that creativity, *in general*, is improved or impaired by exercise, is as problematic as concluding that exercise improves or impairs a measure as intricate as intelligence, for science must always aim to specify precisely which outcome characteristics are changing in line with research interventions.

Three studies matched the duration of the creativity task with the duration of exercise. These studies employed between-subject designs, but the practice of time-matching creativity assessments to exercise stimulus in between-subject designs is a compelling direction for researchers to consider, especially when evaluating exercise-induced cognitive resource depletion, and/or residual effects of exercise persisting for a shorter creativity assessment, with a creativity measure requiring sustained mental resource allocation equivalent in length to the exercise bout.

Scoring of creativity tasks was inadequate for the majority of included manuscripts. Perhaps authors adhered to best research practices, such as use of a validated scoring manual, blinded rating, utilization of more than one rater, or using more objective statistical measures to denote the originality facet of creativity, such as identifying cut-point percentages, using the *top-three method*, or calculating a *creativity quotient* [144-147]. It is crucial that participants be prohibited from scoring sample responses, even if these individuals are not scoring their own responses, and are blinded to the identities of the other participants. One research study utilized this approach, following a creativity assessment protocol, administered in a group format, making rendering exclusive anonymity impossible. Other studies neglected to describe the scoring protocol, or the selection criteria and verification procedures used to identify *expert* scorers, which effectively obscures paths for subsequent research to follow in replication and refinement of methodological decisions.

Recommendations for Future Research. Limitations of this review include the collaborative efforts of only two researchers to search databases and access relevant manuscripts. Searching three databases is another potential weakness, as it is possible research experiments fitting our inclusionary criteria may have been overlooked. However, we feel confident the search strategies employed were sufficiently comprehensive. Moreover, the full text of the exercise and creativity experiments extracted were read in full, and reference lists were crossed-checked by each of the primary researchers to ensure a parsimonious, yet extensive review of the literature was satisfied. Although quality assessment methods were developed in alignment with the PRISMA checklist for reporting systematic reviews, it is possible some items were overlooked which may have increased or reduced the bias scores for these studies. Further, the items developed to indicate risk of bias were formulated by the two researchers involved in this review. Additional researchers may have provided supplementary insight to refine the items to reflect higher quality evaluation methods than those achieved herein. Nevertheless, we feel the present evaluations are contextually appropriate, fair, and may engender continued discussion and more informed experimental practices.

Research has yet to definitively uncover *why* and *how* exercise may influence the global construct of cognitive creativity. However, the plausibility for exercise to exert measurable effects is encouraging, as facilitative mind-body connections have been extensively proposed as mechanisms for improvements in memory [148,149] and cognition [150-152]. Moreover, the underpinnings of movement and mental resource allocation are suggested to activate shared neural pathways, which further highlights the dynamic complexity of human physiology and cognition. In addition, much anecdotal evidence alludes to an influential relationship between physical exercise and cognitive creativity. Despite considerable efforts to illuminate this association, the results remain inconclusive.

There appears to be weak to modest support for acute, moderate-intensity exercise to benefit creativity. High-intensity exercise appears to induce a detrimental effect on convergent creativity when the creativity task and vigorous exercise are administered concurrently in unfit individuals. Interestingly, rest, or the absence of exercise may have a similar deleterious influence on convergent creativity among regular exercisers, however subsequent research should attempt to further question these speculations by examining valence-related effects of exercising on creativity scores. Specifically, when habituated, and perhaps enjoyable behaviors (e.g. exercise) are withheld, is substitution of a less enjoyable activity (e.g. forced inactivity) in an environment conducive to exercise, capable of inducing negative affect or amotivation, which may act synergistically to reduce creative performance? Conversely, moderate-intensity exercise has also been shown to impair convergent thinking performance, suggesting that, perhaps, convergent tests of creativity are susceptible to exercise-driven, cognitive-depletion of mental resources necessary to complete the task, or reductions in attention, motivation, or affectual responses. Although, it is possible these speculations are entirely misguided, as one study found exercise may be capable of enhancing creativity, independently of changes in mood state. Nevertheless, results from the studies included herein tend to suggest a potential immediate and residual effect of exercise participation on creative performance, specifically divergent fluency and flexibility assessed in the laboratory, with improvements in divergent flexibility more equivocal. Oppezzo & Schwartz [133] provided a practical interpretation of their findings, proposing that although walking may make people more talkative, fluency alone cannot equate to creativity. Therefore, the authors computed an additional analysis suggesting that appropriate novelty was elevated within individuals who walked, not only because these individuals were more fluent, but because their total ideation volume contained more divergent responses. To this end, it is prudent to consider the totality of the existing exercise and creativity research, fraught with shortcomings, but also promising trajectories for continued, careful investigation.

Aerobic training studies lasting at least six weeks in duration, and with at least two exercise session per week may have some utility on influencing adult and childhood creativity, however, these findings should be interpreted with caution, as many studies failed to employ a non-exercise control arm, or even standardize the exercise protocol within the experimental group. Additionally, one eight-week study showed no statistically significant improvements in 800-meter run performance, suggesting figural fluency was marginally augmented in the absence of fitness improvements.

To date, it is unclear whether exercise benefits, undermines, or has no bearing on creative functioning. Therefore, research studies should focus on first identifying relationships in controlled laboratory environments, more robust to confounding factors unaccounted for in outdoor environments. Further, while it was unclear if creativity assessments were always administered in either an individualized or group setting. For all training studies, the exercise portion was completed in a group format, which may exert unintended effects on motivation, affect, and effort. All training studies included in this review failed to report one or all of the following statistical indices of practically meaningful results, including effect sizes, confidence intervals, or point estimates. Reliance on p-values is insufficient, incomplete, and misleading for any research agenda [153]. Moreover, none of the four training studies reviewed were conducted in a laboratory setting, which would be less of a limitation if compliance to the training protocol was detailed, or perhaps, if evidence for habitual exercise to benefit creative thinking was well established in the literature. Again, the vast majority of conclusions presented within exercise and creativity research deteriorate in plausibility as fragile study designs and analytic decisions are applied, perhaps for the purposes serving feasibility, but undeniably at the cost of scientific progress.

Conclusions

Weak evidence exists, to date, in support of the proposed relationships between exercise and creative thinking processes. Inferences of causality are difficult to accept, given the paucity of well-designed experiments in this domain of scientific investigation. Exercise and creativity researchers should first align their methodologies with unbiased measurement and evaluation practices, carefully designed to answer prudent explanatory questions. Restructuring the current framework requires a swift dismissal of ideological barriers to discovery, namely the conflation of creativity with divergent thinking, as well as unmitigated advancement into the dense tangle of speculative discourse aiming to contrive tenuous links between creativity and exercise. Experiments continue to employ *minimal* standardization, laboratory control, resistance to confounding, and rigorous, detailed scoring procedures, leaving the same questions unanswered and limiting valid conclusions. The prospects for growth and development in research examining creativity and exercise associations are astronomical, but only if the field commits to consistency and quality when assessing the potential for such relationships.

Table 1. Risk of bias assessment.

Study	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Blanchett		x	x	x	x	x			5
Colzato et	x	x	x	x	x	x		x	7
Curnow &	x	x	x	x		x	x		6
Gondola		x	x	x		x			4
Gondola		x	x						2
Gondola		x	x			x	x		4
Herman-		x	x	x				x	4
Hinkle,		x	x	x	x	x	x		5
Oppezzo	x	x	x	x	x	x	x	x	8
Ramocki									0
Steinberg		x	x			x	x		4
Tuckman		x	x				x		3
Zhou et	x				x	x	x	x	5

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Item 4: Were creativity scoring and evaluation procedures robust to bias (e.g. blinded scoring completed by multiple researchers, provision of strong interrater reliability, and/or using scoring manuals, or previously utilized scoring guidelines) and detailed or referenced?

Item 5: Were random group assignment and/or counterbalancing procedures appropriate (e.g. were participants assigned to groups based on course enrollment, rather than random selection and were the order of creativity assessments randomized to ensure resistance to temporal artifacts or learning effects?) for the study design?

Item 6: Did the intervention use a non-exercise control group or condition?

Item 7: Were statistically appropriate/acceptable methods of data analysis used?

Item 8: Were point estimates, standard deviations, confidence intervals, and/or effect sizes reported?

Table 2. Extraction table of the extractted studies.

Study	Sample Characteristics	Research Design	Creativity Measures (duration)	Creativity Parameters Assessed	Exercise Modality (intensity and duration)	Scoring	Outcomes and Conclusions
Blanchette et al. 2005	N=60 30 males; 30 females; age range 18-27 ($\bar{X}$ = 20)	within-subject	1. TTCT Figural Tests A and B (10 min each form) 2. Creative Strengths Questionnaire	Abstractness of titles, fluency, originality, elaboration, resistance to premature closure per TTCT scoring guide	Acute exercise protocol; primarily aerobic; self-selected (moderate: 30-min)	four independent authors	Creative potential was elevated immediately post-exercise, relative to control (p<.001) Creative potential was elevated 2-hrs post-exercise, relative to control (p<.001) No statistically significant temporal differences were determined Between the two exercise conditions (p=.251)
Colzato et al. (2013)	N=96 Experimental Group: 48 habitual exercisers Control Group: 48 inactive individuals ($\overline{X}$ age = 21)	between-subjects cross-over design	30 RAT triads RAT (10 triads per condition) 3 AUT items (1 item per condition)	Flexibility, fluency, originality, elaboration	Cycle ergometer ((rest (6-min), (moderate (6-min), (and intense (6-min)) exercise (12-min total cycling time) Creativity was assessed during exercise for half of the participants in each group (24-min total	RAT scored numerically via an index of total correct responses AUT scoring was completed by two independent raters for the divergent thinking measure-no indication if participant responses were blinded to raters	Intense exercise was associated with reductions in convergent thinking performance on the RAT among inactive participants engaging in moderate exercise (p=0.002) and rest (p=0.029). Creative flexibility on the AUT was higher at rest, than for

Study	Sample Characteristics	Research Design	Creativity Measures (duration)	Creativity Parameters Assessed	Exercise Modality (intensity and duration)	Scoring	Outcomes and Conclusions
					protocol), and immediately after for the remaining half (36-min total protocol)	Cronbach's alpha scores for fluency, flexibility, originality and elaboration ranged from 0.74-1.00.	intense exercise (p=0.011) for both groups. There was no difference in AUT flexibility performance during rest or moderate-intensity exercise for both groups (p=0.150).
Curnow & Turner (1992)	N=46; age 18-24 (19) 35 females A) Music and Exercise B) Exercise Only C) Music Only D) Control Group (no exercise-no music) (no sample size reported for each separate group)	between-subjects	TTCT Figural tests A (pre) and B (3-min post condition)	Fluency, originality and elaboration	Cycle ergometer (20-min submaximal workload of 150 kpm at a rate of 55 rpm	The Scholastic Testing Service, Earth City, MO scored the assessments	There were no statistically significant differences between groups for any creativity measure assessed.
Gondola & Tuckman (1985)	n=23 control (no PA) n=26 experimental group	Mixed model	AUT, Match Sticks and Consequences	Pre-study and post-study chronic creativity (before exercising) Match Sticks, Obvious Consequences, Remote Consequen	8-week chronic training study (20-min run for 16 sessions-2x per week)	Followed scoring guides for convergent and divergent thinking measures Did not detail how the scoring was completed by internal	The experimental group outperformed the control group on the AUT (p<.01) No additional differences were determined for the included

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				ces and AUT		or external raters	creativity assessments
Gondola (1986)	Group 1: n=23 Experimental Group 2: Experimental n=19 Co-ed undergraduates (no other demographics reported) Control: no sample size reported	Mixed model	AUT, Match Sticks and Consequences	Group 1 and 2: Pre-study and post-study chronic creativity (before exercising) Match Sticks, Obvious Consequences, Remote Consequences Group 2: Acute Creativity (Match Sticks, Obvious Consequences, Remote Consequences and AUT) measured pre-and post-exercise for session 1	Group 1: 8-week chronic training study: 20-min run for 16 sessions (2x per week) Group 2: 6-week chronic training study: 20-min run for 12 sessions (2x per week)	Scoring was completed by the author and one assistant	Both experimental groups performed better on the AUT relative to controls ($p<.001$). Group 2 scored higher on Remote Consequences than the other two groups ($p<.01$). Pre and post-acute creativity scores for Remote Consequences and the AUT were statistically significantly different for Group 2 ($p<.001$).
Gondola (1987)	N=37 females; age 19-35 ($\bar{X}$ age= 23) Experimental Group: n=21 Control Group (no PA): n=16	Mixed-model	AUT and Consequences	Acute creativity assessed at baseline and 5-min post-exercise 1 week later (two visits)	20-min moderate-to-vigorous aerobic dance	No description of scoring methods was provided for replication	The experimental group scored higher on the AUT than the control group ($p<.0001$) The experimental group scored higher on the Remote Consequences than the

Study	Sample Characteristics	Research Design	Creativity Measures (duration)	Creativity Parameters Assessed	Exercise Modality (intensity and duration)	Scoring	Outcomes and Conclusions
							control group (p<.01)
Herman-Tofler & Tuckman (1998)	N=52 third graders randomized into an Experimental (aerobic exercise physical education) or Control Group (traditional physical education) No sample size per group was reported.	Mixed-Model	TTCT Figural Test-Forms A (vertical parallel lines) and B (circles) Time to complete the creativity assessments was not reported	Picture construction-original and detailed stories; multiple associations and divergent thinking	3 aerobic exercise sessions per week for 8 weeks	Scoring per the TTCT manual TTCT test-retest reliability coefficients were reported for the figural test forms (0.71-0.85)	The aerobic exercise group achieved increased figural fluency scores pre-to-post-intervention, compared to the control group (p=.04) Aerobic power (measured via an 800-m run) was not statistically significantly different from pre-intervention to post-intervention (p=0.266)
Hinkle, Tuckman, & Sampson (1993)	N=85 Experimental Group: n=42; 20 males; 22 females Control Group: n=43; 24 males; 19 females ($\bar{X}$ age = 13)	Mixed-Model	Figural and Verbal versions of the TTCT tested in a group setting	Verbal: divergent thinking, fantasy, unique thinking Figural: elaboration, fluency, originality, and breaking set	Five outdoor running sessions per week for 8 weeks (no duration provided)	No description of scoring methods was provided for replication All creativity assessments were scored by one independent rater	Pre-to-post scores for fluency, flexibility, and originality were marginally higher in the treatment group compared to controls (p<.05) Females, irrespective of condition assignment, achieved marginally higher increases in

Study	Sample Characteristics	Research Design	Creativity Measures (duration)	Creativity Parameters Assessed	Exercise Modality (intensity and duration)	Scoring	Outcomes and Conclusions
							verbal flexibility, verbal originality, and figural elaboration (p<.05).
Oppezzo & Schwartz (2014)	Experiment 1: N=48 undergraduate psychology students Experiment 2: N=48; sit-sit; sit-tread; tread-sit conditions Experiment 3: N=40; sit-sit; sit-walk; walk-sit; and walk-walk Experiment 4: N= 40; sit inside; walk inside; sit outside; walk outside	1) within-subject 2) between-subjects 3) between-subjects 4) between-subjects (2x2 design)	1) AUT (4-min x2 tasks consisting of 6 items total) and RAT (4-min for 16 triads) 2) AUT (4-min x2 tasks consisting of 6 items total) x2 3) AUT (same as above) 4) BSE (5-min x 3 tasks-16-min total session)	Ideation, novelty, appropriate uses, appropriate novelty, and non-repetitive uses 3 only) alfresco code (“outdoor” ideas) 4 only) analogy production coded for appropriateness, novelty, and high-quality responses, further determined by degree of detail and semantic distance	1) 12-min seated followed by 12-min treadmill walking 2) 8-min of condition; 8-min of complementary condition (i.e. 8-min sit followed by 8-min tread) 3) 16-min seated indoors; 8-minutes seated indoors and 8-min walking outdoors or 8-min walking outdoors and 8-min seated indoors; 16-min walking outdoors	All divergent thinking parameters were subject to a-priori defined, researcher operationalizations of creativity Analogies were further scored using Amabile’s (1996) consensual assessment technique	1) RAT performance decreased when walking (p=.03), while AUT performance increased when walking (p<.001). 2) The order of walking (before or after sitting) did not yield statistically significant differences (p=.975) at the end of the bout. Decreased ideation on the AUT was determined from time-point 1 to time-point 2 in the tread-sit condition (p=.016). Walking was associated with higher creativity performance on the AUT than sitting (p<.001). 3) Walking once was not

Study	Sample Characteristics	Research Design	Creativity Measures (duration)	Creativity Parameters Assessed	Exercise Modality (intensity and duration)	Scoring	Outcomes and Conclusions
							statistically different than walking at both time-points on the AUT (p=.253) Walking at both time-points resulted in a similar level of maintained creativity performance on the AUT across time (p=.507) Sitting after walking mirrored the findings of experiment 2. Sitting after walking was associated with comparable creativity performance on the AUT as that achieved during walking (p=.335). 4) Walking was associated with higher-quality, novel analogies relative to individuals who sat. Being outdoors was independently related to

Study	Sample Characteristics	Research Design	Creativity Measures (duration)	Creativity Parameters Assessed	Exercise Modality (intensity and duration)	Scoring	Outcomes and Conclusions
							novelty, albeit perhaps of lower-quality responses
Ramocki (2002)	N=31 Experimental Group: n=15 Control Group (no PA): n=16; age range 20-40	between-subjects	Baseline: AUT (20-min), game development, (40-min) Post: metaphors (20-min), planning a party (40-min)	Creative fluency, flexibility, novelty (categorical), and global creativity (rank-ordered)	One-hour of self-selected vigorous-intensity physical activity for experimental group	Double-blinded scoring completed by three faculty and three student-raters (also participants in the study)	Only the mean change in pre- to post-fluency was statistically significant for the experimental group (p<.01).
Steinberg et al. (1997)	N=63 Aerobic Exercise Group: 15 males; 16 females; age range 19-54; median age range 25-29 Aerobic Dance Group: 4 males; 28 females; age range 19-59; median age range 20-24 Four students were lost to attrition.	Mixed Model	Unusual Uses Test of Creative Thinking (Tin Cans and Cardboard Boxes-5-min per item)	Fluency, flexibility, and originality	17 minutes of aerobic exercise defined as high-impact 21.7 minutes of aerobic dance defined as low-impact A control condition was completed (counterbalanced order), consisting of a neutral video matched to exercise duration	Scoring of unusual uses was based on ratings summed across a four-point scale	Flexibility was marginally higher in the exercise condition, compared to the video condition (p<.05) Although favorable improvements in mood occurred with exercise (p<.001), mood failed to contribute to effects on creativity (P>.05)
Tuckman & Hinkle (1986)	N=154 n=48 4th graders ($\bar{X}$ age= 9)	Mixed Model	AUT (10 items-no duration provided)	No mention of specific creativity parameters was provided	Three outdoor running sessions per week (30-min each	No procedures for scoring methods were reported.	The experimental group outperformed the control group on the

Study	Sample Characteristics	Research Design	Creativity Measures (duration)	Creativity Parameters Assessed	Exercise Modality (intensity and duration)	Scoring	Outcomes and Conclusions
	n= 53 5th graders ($\overline{X}$ age= 10) n= 53 6th graders ($\bar{X}$ age= 11) Number of participants in Experimental and control groups was not specified				session) for 12 weeks Active control group participated in regular physical education class activities		AUT (p<.001) Boys in the experimental group achieved marginally higher AUT scores than girls following posttest analyses (p<.05)
Zhou et al. (2017) (Study 2a and 2b were excluded, as these did not evaluate exercise	Study 1a. N=63 21 males and 42 females, $\bar{X}$ age= 21.25 years) [1b. Same participants]	within-subject	1a) DIT divergent thinking task 1b) CIT divergent thinking task (10 trails; 1-min allocated to each trial)	1a) Scored task completion and task novelty 1b) Scored fluency, flexibility, and novelty	Study 1 and 1b) standing, constrained walking-Figure-of-8 Walk Test (F8W), and unconstrained walking (roaming) conditions (no exercise duration provided-likely about 10-min)	1a) Creative novelty was rated by six experts on a scale of 1 (not original) to 5 (very original) for both experiments. The interrater reliability achieved was 0.79, and 0.70, respectively. 1b) Fluency and flexibility was scored by the primary investigator	1a) Novelty was highest in the roaming condition, compared to constrained walking and standing (p<.001). 1b) Fluency, flexibility, and novelty were highest in the roaming condition, compared to constrained walking and standing (p<.001). Constrained walking was also associated with higher fluency, flexibility, and novelty than standing (p<.001)

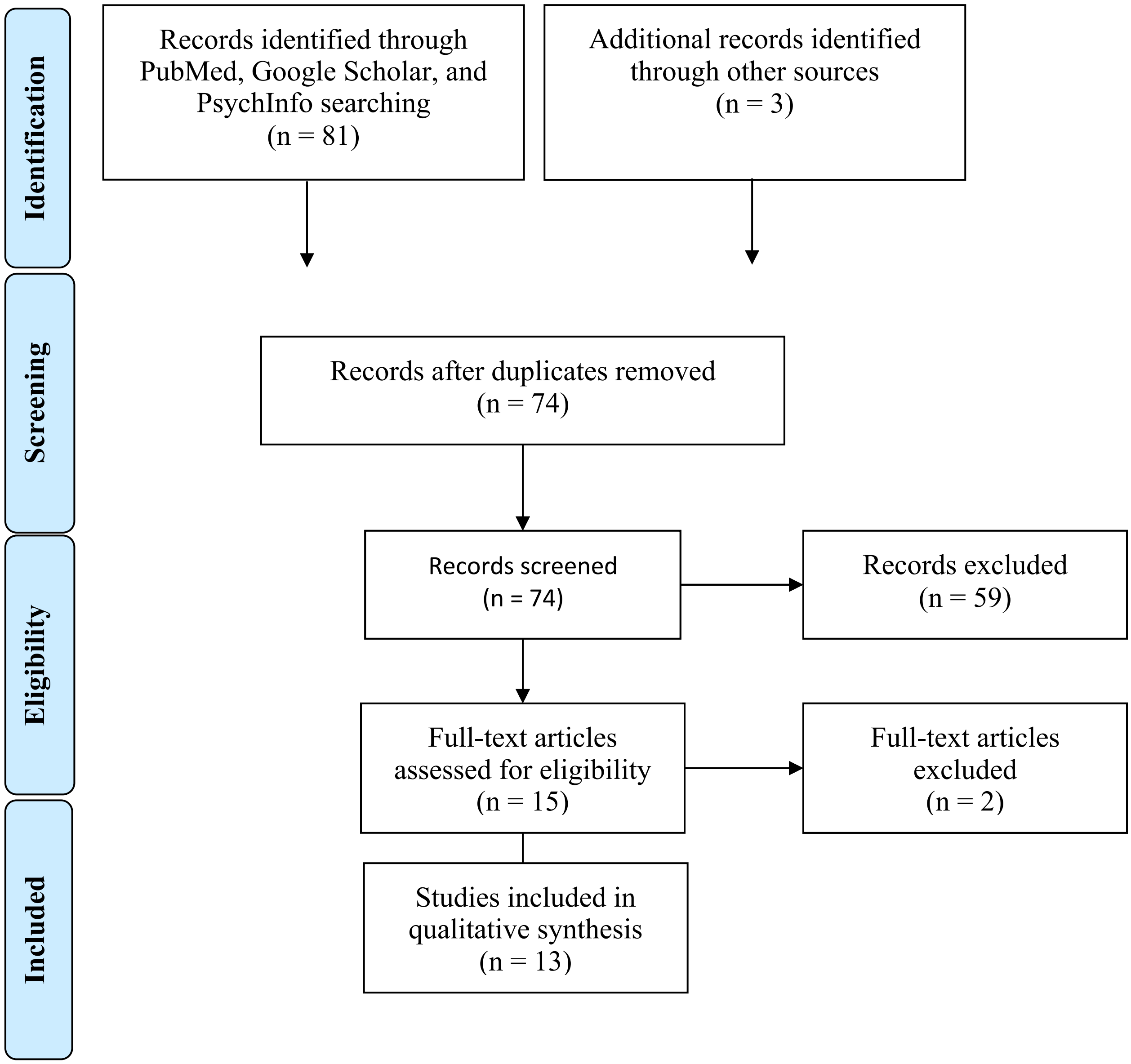


Figure 2.1. Flow diagram of the extracted studies.

CHAPTER III

THE KINESTHETICS OF CREATIVITY:

POTENTIAL PATHWAYS INFLUENCED BY EXERCISE

Abstract

Critical correlates of human creative abilities include antecedent creative skill, enduring creative drive, and observable creative performance. Although not all-encompassing, it is evident these parameters interact to actuate diversified creative contributions to social enlightenment. Emerging research demonstrates that exercise is uniquely associated with creative performance, but no study, to date, has provided a compendium of suggested psychological and physiological mechanisms to systematically link exercise and creativity. In fact, a mechanistic understanding of the exercise-creativity relationship is lacking. The rationale for exercise to promote mesocorticolimbic self-regulation, release of various neurotransmitters, protein expression within hippocampal structures, stress and arousal mediation, and reciprocal regulation of default-mode and executive network cognitions is presented, among other selected mind-body correlates. A comprehensive discussion of these unique exercise-related neural underpinnings may enrich scientific discourse with the provision of an impetus for future research to falsify or support our claims. Although speculative thus far, the positions asserted herein are supported by extensive research exploring the multifaceted correlates of creativity in both neuroscience, behavioral and cognitive psychology. This narrative review highlights compelling neural connections, facilitated by acute and chronic exercise participation, which have been shown to associate with creative conations and complex cognition, emotion, and memory.

Introduction

Description of Creativity

The paradox of everyday creativity is the most common psychological process investigated in modern creativity research laboratories. To some extent, creativity is assumed to be accessible to all individuals[154], as everyday creativity occurs with more ease and prevalence, albeit less fanfare, than historically revolutionizing creative achievements. Everyday creative behaviors occupy the empirical spotlight as the potential for explanatory utility may lead to an illumination of the dense mechanisms underlying the transcendent creativity known to inspire meaningful civic progress and global flourishing. Creativity has engendered both controversy and reverie in the psychological sciences, with research endorsing the potential for robust relationships to exist between creativity and mood[155], psychological disorders[156], evolutionary correlates[157], intelligence[157], cognitive or behavioral priming[158], and a seemingly endless range of probable associations which have both enriched the field and undermined its coherence. Every purposed addition to the incomplete picture of creativity is a reminder for researchers that humans are inherently complex, behave unpredictably, and cannot be encapsulated by a single, unifying theoretical framework. Such reminders underscore the importance of high quality research agendas to seek authenticity and transparency in justification and evaluation of questions worth answering, to better serve the comprehension of a construct as polarizing and elusive as it is fundamental for continued social advancement.

Creativity is traditionally described as a sophisticated aspect of human cognition and behavior that is contingent upon novelty, value, and appropriateness within a specific sociocultural context[159]. Creativity is a widely celebrated, psychological construct capable of crossing cultural divides, spanning multiple domains, and revising common conceptions of reality[160]. Although quite difficult to measure acutely, creativity researchers have traditionally focused on strategies to enhance fundamental creative processes, hypothesizing that execution of these strategies over time could exert a more enduring influence on everyday creativity. Elevation of creativity over time would, theoretically, promote sustained ability for individuals to develop creative skills, nurture a drive to sustain creative pursuits, and subsequently facilitate creative performance on goal-relevant tasks, which, under the lens of exercise, are the primary topics of this review (See Figures 1-3 for schematic and pictorial details). Selection of these topics allows for an inclusion of research encompassing critical neurobiological aspects of creative ability, motivation, and creative production (i.e., idea genesis→product generation) couched within the creative process, while retaining a parsimoniously motivated objective to adequately detail significant pathways linking exercise engagement to creativity.

Little empirical work has been conducted that explicitly examines the influence of physical exercise participation on creative thoughts and behaviors[161-173]. To date, thirteen experimental studies have evaluated this relationship, with twelve of these investigations demonstrating a beneficial association. Although, despite this evidence, we still know very little about the underlying mechanisms explaining the heterogeneous postulations for physical activity to meaningfully facilitate creativity, as these studies 1) did not examine mechanisms, and 2) did not comprehensively detail plausible, testable hypotheses for these candidate mechanisms. No paper, to our knowledge, has explored a comprehensive, biologically integrated justification for this specific relationship to occur. Thus, the purpose of this narrative review is to detail numerous justifications for shared neural correlates that link creative skill, drive, and performance with exercise participation. Creative skill, creative drive, and creative performance are instrumental elements of creativity, salient from the conceptualization of a creative pursuit to its ultimate completion. Exercise participation may uniquely influence each of these constituents, promoting enhanced creativity via numerous neural and cognitive-behavioral mechanisms, which have been widely studied in previous work focusing exclusively on the underpinnings of human creativity. Bassett and Gazzaniga (2011) assert "…mental properties do not exist or change unless physical properties exist or change,[174]" but unfortunately, little attention has been directed towards elucidating the extent to which the physical properties of exercise participation may magnify changes within proposed neural pathways and mental states serving creativity. In fact, one problematic trend in exercise and health promotion research on creativity is an enduring dismissal of the pivotal implications for anatomical connectivity, and the functionality of a brain-mind-body trifecta, to be essential criteria in the design of robust explanatory models for creativity. Thus, the purpose of this conceptual narrative review is to draft a compelling argument for exercise to appreciably influence selected neuro-behavioral aspects of creativity (i.e., skill, drive, performance). Further, the novelty of this work is to provide an impetus for future research to falsify or support our claims, which although speculative thus far, are supported by extensive research exploring the multifaceted correlates of creativity in both neuroscience, behavioral and cognitive psychology.

Influence of Aerobic Exercise on Creativity

Acute, moderate-intensity exercise participation appears to marginally facilitate creativity. However, the current research is lacking in high-quality, experimental controls for environmental and social influences, selection of exercise intensity and modality, and assessment and scoring of creativity assessments. Thus, the evidence for exercise-induced creativity benefits may be artificially inflated. On the other hand, perhaps strong associative outcomes are obscured by inappropriate research designs. Despite several noted indeterminacies, aerobic exercise has been frequently selected for experimental evaluation in multiple investigations[161-169,171,172], with the majority of studies providing evidence for an observable relationship to exist between aerobic exercise participation and select measures of creative performance[161,164-169,171,172]. Specifically, the frontal executive control network (ECN), involving planning and task-coordination, goal-setting, mental flexibility, updating and monitoring, inhibition, and self-control are expected to be particularly modifiable with habitual physical activity[175,176]. Over time, physical activity has been shown to augment cellular proteins, such as brain-derived neurotropic factor (BDNF), which increases synaptic plasticity and neurogenesis, especially within the dentate gyrus of the hippocampus[177-180]. Exercise may increase BDNF both directly and indirectly. The direct pathway, termed the Afferentation Theory of Cerebral Arousal[181], is suggested to be initiated during exercise via stimulation of muscle stretch receptors, which transmit afferent signals to cortical regions. Eventually these afferent potentials reach the spinal cord and are fed back to the cerebral cortex, with repetitive or habitual exercise stimulations expected to permit long-lasting neural potentiations (for a review, see Loprinzi, Edwards, & Frith, 2017). Conversely, the indirect, epigenetic, pathway that governs increased BDNF expression operates post-exercise and is precipitated by movement-induced synthesis of the ketone body D-B-hydroxybutyrate (DBHB) inside the hippocampus, effectively inhibiting class 1 histone deacetylases (HDACs), which counter BDNF gene expression within the hippocampus[182]. Hippocampal, relational memory has been shown to be preferentially enhanced following aerobic exercise training in animal models. Relational memory involves complex thought processes, cultivated by associative recall and the synthesis of salient environmental and contextual cues[183-185]. Voss et al. evaluated the cognitive effects of aerobic exercise in older adults, demonstrating that increased functional connectivity within the default mode network (DMN), which is thought to play a role during internally-directed cognition, mind-wandering, executive function, and episodic memory[186,187], may implicate exercise as a potential facilitator for optimized resting state neural transmission[185,188].

The DMN includes neural connections between hippocampal, entorhinal, and cortical areas, particularly the posterior cingulate and medial temporal and hippocampal/parahippocampal cortices[186], which also synapse with the medial prefrontal cortex and structures within the limbic system[186,189]. The contributory role of the limbic system to creative drive and affinity for novelty is suggested to be initiated when dopamine is released from areas in the mesolimbic system[190]. Emerging work also shows that dopamine is released from the locus coeruleus, a region known to produce norepinephrine[191]. Norepinephrine production in the locus coeruleus is additionally suggested to play a prominent role in the modulation of memory, emotional processing and creativity, particularly spatially oriented creativity via input to hippocampal structures[192]. Acute exercise may also influence positive affect and emotional perception of reward via intensified catecholamine reactivity in the limbic system[193,194]. More explanatory value may be assigned to catecholamine responses in acute exercise protocols[195], while BDNF effects may be evident at multiple time-points, meaning both acute and chronic exercise training is capable of upregulating BDNF[196]. Specifically, the neurotransmitters dopamine and norepinephrine have been shown to be upregulated following acute exercise in animal models[197]. Peripheral epinephrine, or adrenaline, binds to B-adrenoreceptors on the vagus nerve[198], which runs from the periphery to the nucleus tractus solitarii (NTS) located in the blood-brain barrier[199]. The NTS projects (indirectly via the nucleus paragigantocellularis) to the locus coeruleus[200,201], initiating norepinephrine release and subsequently increasing brain concentrations of noradrenaline[199]. Notably, electrical activation of the rat locus coeruleus augments dopamine transport from the periphery to the brain[202], suggesting the regulation of norepinephrine and dopamine is achieved via shared neural pathways. Noradrenaline release from the locus coeruleus (involved in the optimization of decision-making)[203] is propagated by exercise-mediated sympathetic nervous system activation. Noradrenaline projects to the ventral tegmental area and has been shown to regulate dopamine release and reinforce neural connections implicated in affective reward processing[195,204]. Further, context-dependent learning may be enhanced following acute exercise and may be partially explained by functional connectivity between the hippocampus and medial prefrontal cortex, which are thought to subserve episodic memory integration and self-referential coordination of behavior, respectively[195,205]. Tulving (2002) proposed the idea that episodic memory evokes "mental time travel"[206], allowing individuals to reflect on their past experiences, appraise the present context, and predict probable outcomes[207], given the strength of episodic, autobiographical detail assigned to an episode. The neuroscientific correlates of episodic thinking are thought to be heavily reliant on hippocampal function, a brain region also associated with creative divergent thinking, and everyday problem-solving of open-ended questions[208-210].

Underlying Mechanisms of Creative Skill

If everyday creativity is a psychological construct accessible to all individuals, then strategies to capitalize upon this skill set must be understood under the lens of functional neural synchrony. The collaborative dynamics of the creative mind may be empirically manipulated within various experimental conditions hypothesized to activate neural centers integral to the execution of these skills. To this end, a brief overview of select mechanisms thought to associate with creative skill will be presented, followed by a discussion of the similar mechanisms by which exercise may be incorporated to benefit creative skill.

Several antecedent skills such as visual-spatial or verbal/analytic reasoning are postulated as fundamental components of creativity. An interaction between visual, spatial, and verbal processing may serve additional creative skills, such as mathematical logic. There are a multitude of peripheral cognitive skills which may integrate to nurture individual creativity, but these are beyond the scope of this review, and thus will not be discussed herein. A discussion of three specific factors important for successful realization of everyday creativity have been selected for exposition, as these parameters are apparent from childhood through older age and have been extensively studied in creativity research programs examining outcomes as varied as convergent thinking, divergent thinking, insight and imagination[211-215]. Although these attributes do not wholly explain creative skill capacity or development, the selection of visuospatial, verbal/analytic, and mathematical creativity is sufficient to broadly address the topic of creative skill.

Visuospatial creativity is particularly important for artistic developments, architecture, technology and design, cooking, engineering, etc. Activities which require manipulation of common tools and resources into new forms require visuospatial skills, which may be refined through physical exercise behaviors. Visuospatial activations of the right parietal lobe, dorsolateral prefrontal cortex (DLPFC) and medial prefrontal cortex (mPFC) suggest an interplay between planning, attention, working memory, counterfactual thinking[216], and higher-order executive functions. Visuospatial creativity may be dependent on right hemispheric activity, although synchronous activation of the left hemisphere may promote effortful task-processing and top-down regulation via DLPFC and mPFC control[217].

Verbal/analytic creativity is often assessed with brainstorming and creative writing tasks, and is posited to strongly associate with language centers in the bilateral inferior frontal gyrus (IFG) and left temporal areas. Prefrontal activation is suggested to influence cognitive flexibility and fluency in verbal composition of stories and novel ideas. The DLPFC is also associated with verbal planning, working memory, flexibility, and executive functions governing task initiation[218-220]. The DLPFC and dorsal anterior cingulate cortex (dACC) may subserve coherence in crafting a logical storyline. Finally, left parieto-temporal regions are suggested to dictate language comprehension via auditory processes and have been shown to abet divergent and associative thinking[221], as well as insight and flexible, imaginative cognition[222]. To this end, frontal, parietal, and temporal activity seem to play a prominent role in both brainstorming and creative storytelling. Thus, the mental processes and ultimate product arise from a complex integration of dissociated brain regions[220].

Mathematical creativity is suggested to be invoked by fronto-parietal activation, with task-specific recruitment of parietal networks, and task demand characteristics modulated by executive control networks localized to the frontal cortex[223]. Creative computational abilities have also been linked with visuospatial processing as fronto-parietal regions are involved in language perception as well as the updating and manipulation of complex numerical sequences during calculation[224]. The bilateral intraparietal sulcus is perhaps one of the prime language-independent centers for quantification processing and computing[225,226]. Moreover, the basal ganglia, hippocampus, and areas governing working memory may be more involved in cognitively taxing arithmetic problems, while parietal influence directs mathematical efficiency towards developing procedural memory stores in support of computational task automaticity[227].

Memory provides a solid foundation for the generative process underlying creative thought. A method for identifying original and novel ideas is organized by pre-existing knowledge of conventional models. Although, despite the paramount importance of retrieving previously learned and experienced stimuli, memories can effectively interfere with the execution of creative skills[228]. For example, cued memories may activate prepotent responses which are governed by neural connectivity within the DMN[229]. Executive and salience networks mediate selection of responses which may satisfy task demands, but are contextually inappropriate, via cognitive control and flexible switching to alternative, novel responses. Notably, however, these mechanisms operate in dynamic synergism, illustrating the complexity of functional connections across neural systems ascribed to creative thought. Generating alternative uses for a paperweight might be initially constrained by previous memories activated during consideration of common, and appropriate ways to use a paperweight, which provide the aforementioned foundation for truly creative skill execution. As executive control and salience networks integrate to shift attention away from conventional uses, which, again, are prerequisites for envisioning alternative uses, attenuation of DMN activity is thought to occur, facilitating the effectuation of synaptic communication between the DMN, executive control, and salience networks[230].

Role Through Which Exercise May Influence Creative Skill Development

Ambulatory aerobic exercise training has demonstrated beneficial effects on higher cognitive functions, including visuospatial speed and executive control, suggesting that the impact of exercise may be especially instrumental for tasks reliant on frontal brain regions[231]. However, the DMN is known to reinforce optimal executive functioning, especially among older populations[232], offering additional support for the instrumental role of functional connectivity in creative cognitions. Further, documentation of superior bilateral hippocampal volume is associated with physical exercise in elderly individuals, and may influence spatial memory as well[233], which provides a compelling argument for the DMN to potentially influence creative skill development[234]. Beyond mind-wandering and self-directed evaluation, the DMN is also expected to supervise aspects of memory consolidation, working memory and episodic memory, with improvements in working and episodic memory performance extensively linked to aerobic exercise[235-238]. Exercise has also been shown to enhance functional connectivity between frontal and temporal cortices associated with DMN activity, providing plausibility for a "tripartite bidirectional" relationship to exist between DMN connections, memory, and exercise.

Exercise may be able to induce both task-specific and task-independent alterations in neural circuitry, which would support extended network coherence, and thus, increased ability to develop creative skill sets reliant on higher-order cognitions. Modulation of DMN and executive control cross-talk is important for completion of difficult tasks. Successful task performance may be influenced by the degree of separability achieved between networks. Exercise is likely to catalyze a separation of resource-allocation to favor the executive control network *during* task-execution, with concomitant suppression of the DMN. Furthermore, increased learning and memory are associated with favorable reductions in DMN input at encoding[239].

At this point, it is worth speculating that exercise prior to encoding may prevent residual DMN processes from impeding the magnitude of task-relevant frontal activation. Simply stated, exercise may be an efficacious strategy for preferentially engaging executive control networks, in light of difficult creativity tasks that are expected to cause fixation. A fascinating caveat has been introduced by recent work showcasing the beneficial effects of isolated motor imagery (even in the absence of physical exercise) on behavioral working memory performance, which is speculated to translate to performance in related cognitive-behavioral domains as well[240]. Unusual and novel responses are challenging at the outset due to prior, rote experiences with similar cognitive or behavioral stimuli, with prepotent responses compounding the threat of cognitive barriers to creative solutions. Particularly when solving convergent thinking or insight creativity tasks, which require a singular, accurate creative solution, exercise may even be utilized as a compensatory tool. Perceived task difficulty, or perhaps inadequate skill in verbal, spatial, mathematical, or alternative assessments of creativity may be overcome via increased frontal activations proliferated through acute or chronic exercise participation. In the absence of exercise, older adults, as well as sleep-deprived individuals[241], have been shown to experience increased frontal activation during demanding cognitive tasks, a mechanism explained in part by age-associated cognitive decline, but also by a neurocognitive susceptibility to dorsal and ventral attentional failure in light of increased demand for executive control[242]. Again, as exercise activates frontoparietal regions known to subserve executive control and memory, it is reasonable to postulate that increased neurogenesis, plasticity, and connectivity within these distinct networks may be upregulated to mechanistically remodel the creative process. Specifically, neurons in the hippocampus synapse with frontotemporal regions, as well as govern cingulate connections to parietal and lateral occipital cortices, suggesting hippocampal plasticity plays an overt role in the biological underpinnings of creative skill[243].

Underlying Mechanisms of Creative Drive

The temporal lobes may play an influential role in the activation of creative drive. Historically, neurological pathologies, such as bipolar disorder, were linked with not only structural brain abnormalities, but also higher propensities to seek novelty and create new products[244,245]. Amygdalar enlargement[246] is postulated to intensify evaluative valence connected to emotional experiences that may govern engagement and effort directed towards creative pursuits[190]. Creative drive is perhaps more putative to benefit creative performance than intelligence, with historically seminal research suggesting intelligence may not be as influential past a certain threshold[247]. Notably, however, alternative research suggests the intelligence threshold hypothesis is vulnerable to statistical artifact, and must be interpreted with an acknowledgement of the intricate caveats inherent in evaluating individual differences in creative ability[248,249]. Nevertheless, high motivation does seem to be a crucial and non-ignorable constituent of creative drive.

One plausible biological mechanism underpinning creative motivation may be the role of the neurotransmitter dopamine. The synthesis and release of dopamine from the ventral tegmental area (VTA), projecting to the nucleus accumbens may be a critical reward pathway to consider when interpreting creative drive. Secretion of dopamine into the extracellular space of the nucleus accumbens is augmented during rewarding behaviors, such as food consumption and sexual activity[250]. Pleasure associated with creative flow states, or recollection of past rewards associated with creative achievements may be sufficient to activate dopamine. Moreover, dopamine is a suggested mediator of neuronal growth[251], working memory[252], arousal, and attentional allocation[253,254]. In addition, supraphysiological stressors have been shown to diminish original thinking, with arousal receiving much attention as a heavily contested psychological and physiological response known to drive performance, with early studies proposing that arousal, even positive arousal activated by reward pathways may limit creative task execution[255,256].

Role Through Which Exercise May Influence the Drive to Create

The neural pathways driving creative motivation have yet to be definitively outlined. However, dopamine is well established as a principal "motivation molecule," with compelling evidence showing the biological effects of dopamine on motivation and reward responses. Although equivocal, the purposed importance of dopamine's role in sophisticated exercise-cognition interactions is further reinforced by research linking motor functionality with dopaminergic transmission, as dopamine release from the dorsolateral striatum has been shown to increase with treadmill exercise[257,258], coupled with the potential for prolonged exercise to exhaustion to reduce striatal dopamine in line with neuromuscular fatigue[259,260]. The augmentation of exercise-induced BDNF[261], as well as glial cell line-derived neurotrophic factor

(GDNF) expression[262] may also increase dopamine concentration, sustain survival of dopamine neurons, counteract inflammation-induced dopamine loss, and increase synaptic propensity and neurotransmitter potentiations enhancing motor skill execution[263,264]. Thus, exercise seems to be capable of activating the dopaminergic pathway, resulting in "activity-dependent neuroplasticity[265]." Activity-dependent neuroplasticity is a hypothesis describing central nervous system (CNS) modulations thought to be promulgated by habituated physical activity. Learning new movement-related skills is suggested to promote this process as a cohesive function of movement intensity, complexity, ease of execution, and specific, targeted practice[266-268].

Research on exercise-induced dopamine release is often conducted on mice models, as dopamine cannot cross the blood-brain barrier, and thus, is difficult to centrally measure in humans. However, considerable evidence suggests that peripheral dopamine concentrations correspond with central concentrations. Interestingly, regular, moderate endurance exercise is suggested to elicit a neuroprotective effect on dopamine neurons within the aforementioned VTA, a neural correlate of motor performance and divergent creativity[269,270]. There also appears to be support for a bidirectional relationship to manifest between dopamine production and exercise participation, as decreased stimulation and loss of dopaminergic receptors is associated with inactivity and reduced motivational drive to engage in activities requiring high energy expenditure[177,271-273]. To this end, there may be support for a physical activity (PA) participation threshold[274,275]. Specifically, repeated exercise exposures appear to exert protective effects against late-life cognitive decline, relative to unhabituated exercise engagement and sedentary behavior. There may be a dose-response relationship between level of PA participation and cognitive performance[276,277] over time[275]. However, such a relationship is difficult to pinpoint across a variety of activities and is likely contingent upon individual differences in physiological response to exercise, as well as exercise modality, intensity, and daily energy expenditure in leisure time PA, exceeding time spent in bouted exercise.

Exercise-related affectual responses may also be precipitated by dopamine release from the VTA, which has functional connections to the limbic system and prefrontal cortex. To this end, the mesocorticolimbic system is a primary network of interest, which regulates dopamine transmission from the VTA, and substantiates the rationale for exercise to precipitate an emotional drive to engage in creative thoughts and behaviors. Importantly, the mesocorticolimbic system is susceptible to exercise-mediated improvements in executive functioning[278], via the previously discussed neural coherence between limbic and prefrontal sites. The bolstering effects of habitual exercise on executive functioning may reinforce positive cognitive appraisals of mental and physical challenges, such as heightened self-efficacy despite task-demands present during acute exercise, or cognitive demands associated creativity assessment procedures.

As highlighted previously, increased executive functioning is corroborated by much experimental work underscoring the favorable effects of exercise participation on the maintenance and adaptability of higher-order cognitions[276]. Exercise supports neurogenesis and synaptic plasticity, which may be further substantiated by accelerated growth factor expression of genes such as BDNF, which continually establishes new neuronal connections and strengthens existing ones[279], with reductions in BDNF demonstrating concomitant deficits in spatial learning and memory[280]. However, treadmill exercise has not only been shown to counteract age-associated hippocampal dysfunction[280], but is also expected to enrich brain functionality and health independently of age[281]. Additional animal work has shown that tyrosine hydroxylase, the rate-limiting enzyme directing BDNF and dopamine synthesis, is increased in the striatum and substantia nigra, with BDNF similarly increased in the hippocampus following 28 days of treadmill exercise lasting 30-minutes in duration, providing further support for an exercise-motivation-cognition relationship[282].

A more forthright position defends physical fitness as a correlate of enhanced mood[283] state, as well as a deterrent against acute and chronic disease occurrence and advancement[283]. Motivation and self-efficacy are key antecedents to initial engagement and successful completion of creative tasks[284]. While creative drive may be attained via optimization of set-shifting, inhibition of prepotent responses, planning, self-control, and contextual monitoring for changes in environmental stimuli, persistence and time-on-task may be equally as essential to the assimilation of creative skill with creative drive. The multi-talented filmmaker, scholar, and author, Phil Coustineau wrote, “Inspiration comes and goes, creativity is the result of practice.” Interestingly, many of the most eminent exemplars of creative achievement have been showcased in early scientific literature as highly motivated individuals. In 1926 Cox[285] proposed a seminal compilation of 300 “geniuses,” including Newton, Galileo, and Darwin, which illuminated not only the precocity, but the perseverance and commonality of eminently creative personality characteristics. Flexibility, responsibility, tenacity, and positive self-image may be prerequisites for the most influential creative minds and behaviors[286]. However, individual factors essential to the development of motivation and self-image may be amplified with exercise engagement[287-289], suggesting exercise participation could be an integral supplement for not only “genius” creations, but everyday creative endeavors as well.

Prefrontal, amygdalar, cingulate, and hippocampal structures, as well as regions within the VTA-nucleus accumbens pathway govern physiological reward perception and cognitive appraisal[290]. Restating the importance of the dopamine system is useful for gaining a conceptual understanding of the intricacies and shared neural tracts that elicit puissant motivational effects. The mesocorticolimbic system synapses with the ventral tegmental area and contributes to motivational drive via dopamine release and the activation of additional CNS reward pathways incorporating neurotransmitter and hormonal signaling, which leads to stimulation of natural reward responses (e.g., food and sex). However, the strongest biologically regulated motivational activations may occur when these neural connections are stimulated by self-regulative behaviors[291], such as exercise[291]. Much evidence posits that the dysregulation of midbrain dopamine concentrations may contribute to hyperactivity seen in Attention-Deficit Hyperactivity Disorder, as well as memory impairment[292]. Encouragingly, exercise has been shown to augment dopamine levels in the brain and combat dopamine associated pathogenesis[282,293,294].

Underlying Mechanisms of Creative Performance

The subject of everyday creative performance is arguably the most important for research to evaluate and measure. As creative performances are directly observable human productions capable of social advancement, paradigm shifts, and a more complete understanding of individual differences in cognition, the neural basis underlying desirable performance in the context of creative activities is paramount. An extensive consideration of all variables appending explanatory power to the actualization of creative performance is beyond the scope of this manuscript. Therefore, the focus herein will instead be on practical *constraints* to acute, laboratory-based creative performance, given the assumption that participants in experimental investigations are capable of everyday creativity. Creative constraints will be described under the lens of behavioral psychology, followed by the potential utility of exercise participation to overcome such constraints in lieu of maximizing creative skill, drive, and successfully transporting creative pursuits to completion.

Volitional constraints. Often, participants are not given the opportunity to self-select creativity tasks, and must complete a series of assessments in line with the aims of the study protocol. As such, barriers to authentic creativity performance may emerge. This is a pervasive issue for many research programs, as standardization of methods is imperative, but creative domain-specificity[295] may also influence participants' degree of intrinsic motivation to engage in effortful task-performance[296]. Simply stated, if a participant feels confident in his or her ability to successfully execute a visuospatial task, but not mathematical tasks, successful (or unsuccessful) performance may not be a consequence of experimental manipulation, but may be an artifact driven by participant aversion to the imposed task domains. Moreover, the absence of free-choice may deter contextual autonomy, and result in negative affect. Affect is extremely important for sustained attentional allocation of cognitive resources towards challenging tasks, and may be especially salient during tasks that entail repeated trial-and-error attempts[297].

Complexity. Creative task complexity may also limit performance for some individuals. Specifically, if tasks require multi-step solutions, advanced skill sets, are excessively long or time-constrained, or involve a coordination of competing stimuli (e.g. instructions designed to induce fixation), peak performance is challenging. Of note, while divergent thinking and insight tasks are typically considered more difficult to than divergent thinking creativity tasks[298], as they involve mentally *converging* on a single correct solution, individual differences may predispose certain participants to consider the ambiguity of open-ended stimuli (e.g. figural and pattern completion or writing a story) more troublesome to navigate[299]. Open-ended evaluations may be particularly problematic by nature, as there is no unifying, correct response. Thus, some participants may be unsure of their acute creative performance, despite intentional effort[299]. Should this uncertainty elicit rumination and deflation of self-efficacy, subsequent task-performance could potentially be impaired. Although counterbalancing of creativity assessments is often observed in current research, our present speculation runs counter to the rationale for assessing divergent, open-ended creative thinking first, followed by more fixating convergent tasks, but should, nevertheless, be considered as a factor of influence in future research.

Test Environment. Beyond a lack of personal agency and demands associated with various creativity tasks, the laboratory setting may actually pose a problem to the genuine accessibility of participant creativity. In 1987, Amabile proposed competition, observation, awareness of subsequent evaluation, and inadequate time allowed for task completion is likely to obscure meaningful outcomes[255,300]. Although results have been equivocal, collaborative social contexts may be more beneficial to group creativity, as opposed to solidarity in fierce competition. The rationale behind active collaboration is that ideas are reciprocally attended to, and processed, prior to inclusion or exclusion into a final product, which theoretically, promotes broader associative combinations, and thus, engenders increased opportunities for creativity[301]. Nevertheless, individual differences in intrinsic motivation may moderate the competition-creativity relationship and should be further explored. Critically, the degree of demand relative to control present in the laboratory setting may exert a profound influence on the saliency of competition, surveillance, evaluation, and time-constraints. Practically, this resembles real-world negative influences of high career stress, coupled with minimal personal control, which unite to drain job satisfaction via the expression of chronic stress[302].

Role Through Which Exercise May Influence Creative Performance

Theoretical explanations for the health promoting utility of exercise are abundant in exercise psychology and public health literature. Two theories which may help bridge the gap between cognitive and physiological correlates of physical exercise and creativity are the Yerkes-Dodson law[303] and dual-process model of creativity. The Yerkes-Dodson law demonstrates the importance of inducing optimal physiological arousal to maximize psychological performance. Given that both aerobic fitness and moderate-intensity exercise have been shown to elicit improvements across various cognitive parameters, including executive functioning and working memory[304,305], with lower-intensity and higher-intensity exercise prompting less advantageous, curvilinear effects on cognition[306], there may be some utility for carefully designed exercise protocols to confer similar results for creativity task performance. These consequences may be partially attributed to increased neural activation within frontal brain regions, as well as the proliferation of excitatory catecholamines in the central nervous system[307]. The prospect for moderate-intensity exercise to associate with improvements in creativity may be better served when completion of creativity tasks (namely difficult or complex tasks) occur after exercise, as the influences of exercise on cognitive function during exercise continue to produce heterogeneous conclusions[308]. Nevertheless, the necessity for tailored exercise protocols is paramount, as much like cognitive test batteries, distinct creativity assessments, such as divergent or convergent thinking tests, imagery, or insight tasks, are likely to require specialized exercise prescriptions to observe reliable enhancement effects.

The dual-processing model of creativity subsumes behavioral antecedents to creative behavior with global and flexible cognitive processing styles, which are suggested to associate with personality traits, but are also susceptible to training modifications[309]. Positive activation, which can be simply conceptualized as the intersection between positive arousal and positive affect, are proposed to engender creativity, particularly flexible cognitive abilities, which involve the capacity to set-shift, avoid the snares of cognitive fixation, as well as stimulate global cognitive processing. A global processing style is thought to oppose fixation, as this method operates in tandem with cognitive flexibility to preferentially attend to diffuse, or general, information cues, rather than adopting a hyper-focused processing strategy[310]. The theoretical significance of this model is couched within the pervading hypothesis that inclusive, associative thinking is typically associated with higher ideation and insight performance than the limitations of narrowed attention. Interestingly, studies have indicated that exercise is capable of enhancing cognitive flexibility (e.g. attentional set shifting), via increased dendritic spine density and synaptic proteins, thought to mediate medial prefrontal cortex and hippocampal activity[311], hippocampal fibroblast proliferation[312], enhanced neural plasticity and BDNF[313], and preservation of neural and structural integrity in the aging brain[314]. Further, a dose-response relationship may be responsible for the magnitude of cognitive flexibility improvements across time[315]. In other words, increased frequency of exercise participation appears to strengthen frontal executive connections, and thus, support the optimization of higher-order cognitions.

Embodied Creativity: Closing the Distance Between the Mind-Body Gap

The cerebellum is known to participate in the coordination of movement and thought, eventually producing automaticity and refinement of behavior[316,317]. The "older" cerebellum is highly specialized to uphold motor skill acquisition and movement control, whereas the more recently evolved cerebellum is additionally involved in the refinement of working memory and higher cognitions[317]. It has been speculated that the cerebellum may have evolved in size and complexity in order to work synchronously with the association cortex, allowing for rapid information processing, as well as language comprehension and cognitive energetic efficiency[317]. There is encouraging support for the role of cerebellar input to function as a critical learning source for executive function and memory, serving to augment the capacity for problem-solving[318,319]. The processes of thought, from origin to action, can be conceptualized as analogous to movement processes, which are modulated by direct neural collaboration between cortical-cerebellar structures that control both internal and external control[320]. The cerebellum in isolation contains more neurons than the whole brain[321], and is a structure evidenced to control spatial, temporal, and verbal integration and interpretation of stimuli[320]. Therefore, it is reasonable to speculate that the cerebellum may be intimately involved in the development and execution of creative skills (spatial, verbal, mathematical, etc.)

A thought-provoking function of cerebellar movement coordination is that, rather than encoding and consolidating the precise sequences of mental and motor processes, the cerebellum essentially collects summaries of previously experienced psychological and physical contextual cues for ongoing manipulation and mastery[322]. The purpose underlying this diffuse amalgamation of pertinent stimuli, is that the cerebellum enables the reintegration of these cues to enable adaptation to comparable physical or psychologically activating situations. Is the essence of creativity not the utilization of everyday skill, abstracted to meet the variety and complexity of novel task demands? To this point, the mental and physical mastery responses elicited via cerebellar and working memory operations have been hypothesized to contribute to a crucial nexus between appropriate responses and novelty[322]. This hypothesis also reinforces previous neuroimaging data which indicates novelty of creative ideation is enhanced in the later stages of creativity assessment[323]. Earlier ideation seems to be dominated by memory of common experiences, which may be important to receive prior to creative abstraction[324]. Although inferior parietal and frontal cortices have been shown to be activated as common responses are inhibited in lieu of remote associations[228], these executive functioning structures are likely to involve direction from the cerebellum as well. Thus, continued exercise and creativity research should further explore the significance of these functional connections.

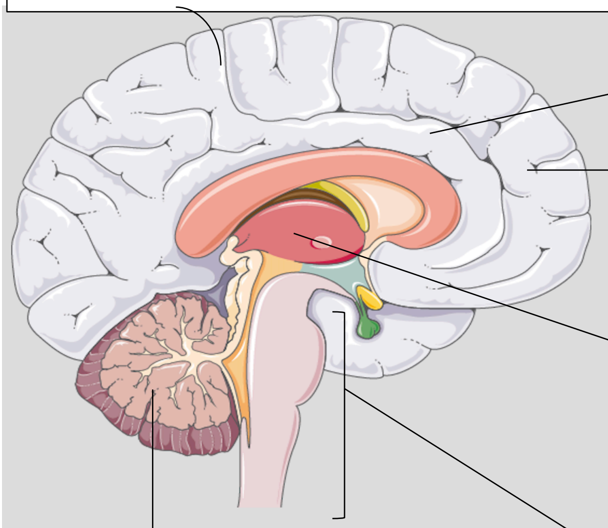
Exercise and Embodied Creativity

Exercise participation is an essential investigative parameter necessary to lend a more mechanistically comprehensive understanding of the psychology of creative individuals. Much like mental imagery is suggested to foster creative ideas, kinesthetic imagery and bodily movement may be equally as beneficial. Research has demonstrated that motor imagery activates frontal, parietal, and cerebellar areas in preparation[325] of movement execution. Creative visual imagery is similarly pronounced in frontal and parietal regions, with considerable overlap within cerebellar, thalamic, and insular (involvement in motor control and self-awareness) regions[326]. Further, Koziol and Budding (2012) proposed that the evolution of the brain has been primarily contingent upon adaptive mechanisms for survival, especially as the cerebellum developed prior to frontal cortex advancement, claiming that, “Evolutionary processes favored the development of predictive or “anticipatory,” and simulative or “imaginative” mechanisms for the purpose of action control and not for cognition per se[327]. Sensorimotor control, dictated by the cerebellum is perhaps not only a bridge to improved rate of survival, but also to creativity.

Brief Summary

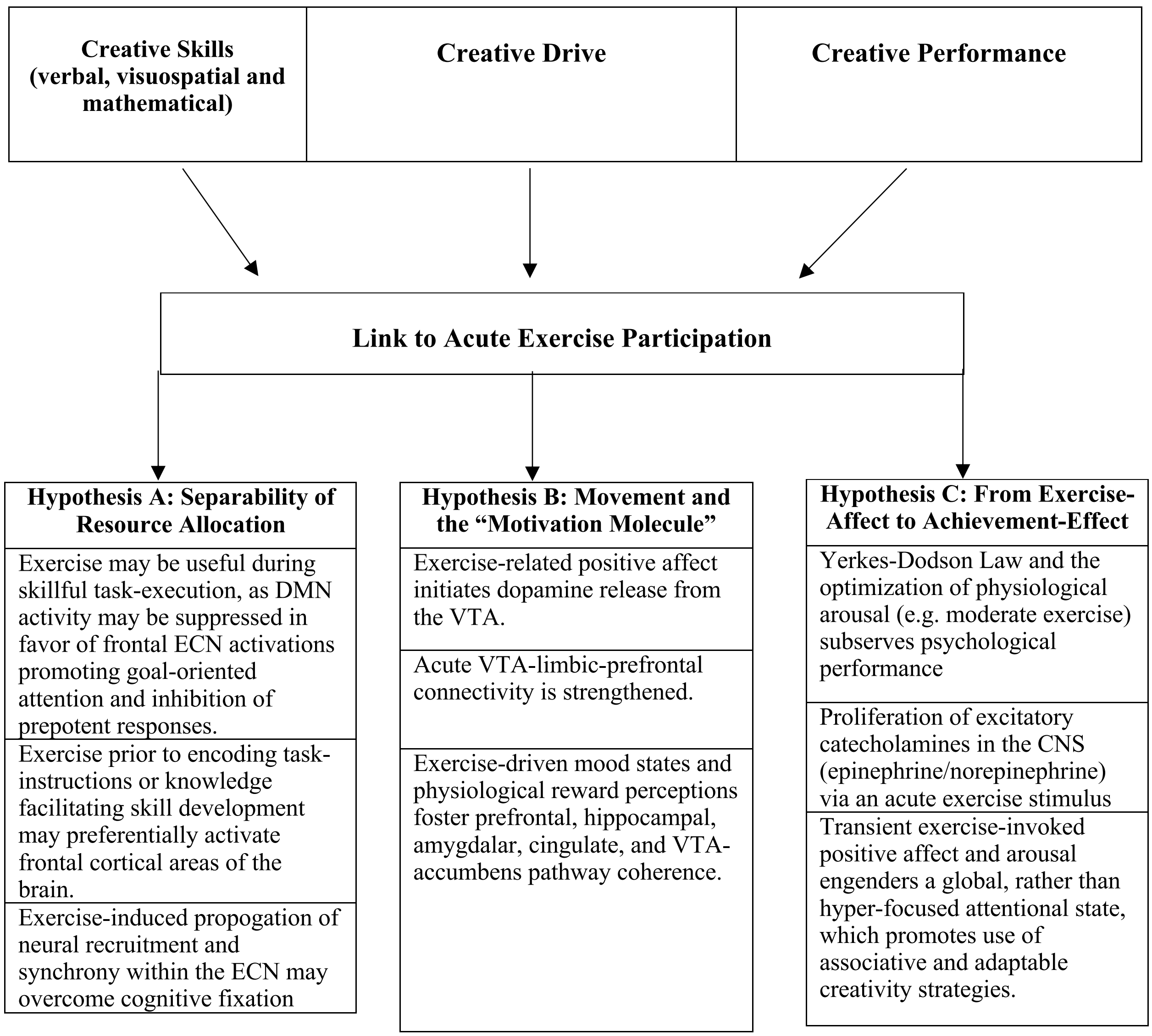
Creativity is by nature, an action-oriented endeavor, consisting of both spontaneous bursts of inspiration as well as the enduring devotion to building, exploration and discovery. As thinking is necessary for self-actualization and the survival and progress of social systems, so is bodily movement. A neural perspective of creativity is incomplete without a supplementary exploration of the mechanisms contributing to the undeniable mind-body connection. There is a magnificent relationship between kinesthetic imagery and perception, coordinated movements, and creative self-expression. The sparse field of exercise and creativity is littered with an ambiguous fusion of scientific recommendations to enhance creativity; speculations which have been adapted and refined from decades of creativity research. Still, explicit and reliable exercise prescriptions for creativity enhancement have yet to come to fruition, and research as a whole remains uncertain of how best to empirically capture the mystery of creativity. Clearly, extended research is needed in this area, and may require decades more of focused, empirical work to advance the explanatory process closer to meaningful breakthroughs. The purpose of this narrative review was to direct attention to the profound interplay between psychological and physical processes vital to creativity.

Methods of analysis may, of course, influence the validity of findings that suggest exercise is a sufficient stimulus to induce morphological and functional changes in neural connectivity, capable of directly enhancing cognition. Although, to date, encouraging research efforts have laid a preliminary foundation for facilitative, bidirectional relationships to exist between exercise and cognitive performance[175]. No reviews have described the neurobiological potential for a discernible association to exist between functional neural correlates of both physical exercise and creative cognitions, which was the motivation for the present review. However, as abridged in this narrative review, a wealth of convincing theoretical and evidential support for a dynamic brain-body connection should spearhead future empirical investigations of exercise-related creativity outcomes.



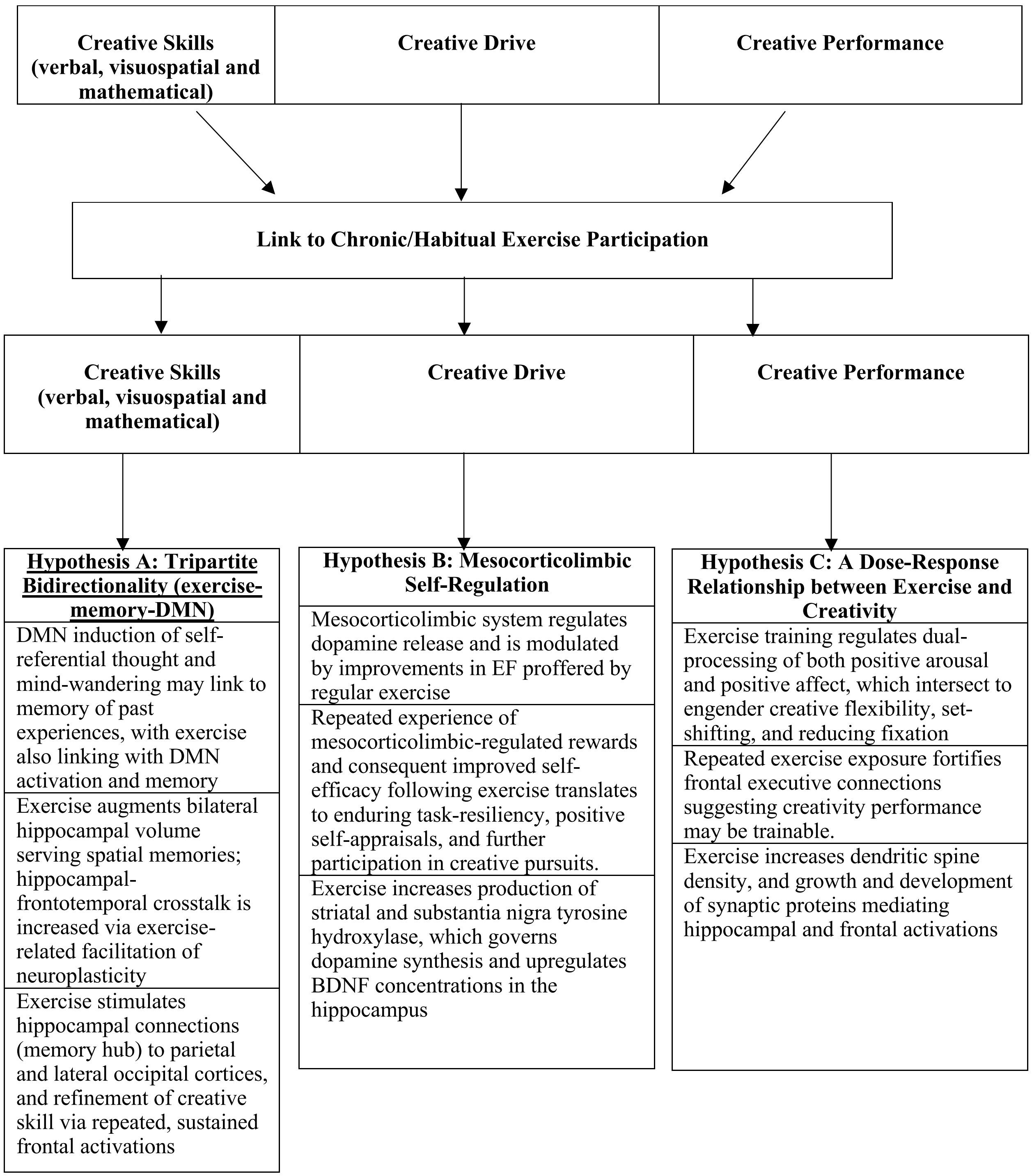
- **Mathematical Skill:** The bilateral intraparietal sulcus is perhaps one of the prime language-independent centers for computation. basal ganglia, hippocampus, and areas controlling working memory may be more involved in arithmetic problems with high task-demand
- **Verbal Skill:** integrates language centers in the bilateral inferior frontal gyrus (IFG) and left temporal areas. Prefrontal activation is suggested to influence cognitive flexibility and fluency in verbal composition of stories and novel ideas.
- **Visuospatial Skill:** involves the right parietal lobe, dorsolateral prefrontal cortex (DLPFC) and medial prefrontal cortex (mPFC) in the manipulation of attention, memory, counterfactual thinking, etc. Visual and spatial skills are assumed to rely on right hemispheric activity, although left hemisphere coherence may promote effortful task-processing and top-down regulation via DLPFC and mPFC control.

Figure 3.1. Functional Synchrony of Creative Skill



ECN: Executive Control Network
CNS: Central Nervous System
VTA: Ventral Tegmental Area

Figure 3.2. Schematic detailing three distinct hypotheses for acute exercise to facilitate three essential creativity correlates: creative skill, drive and performance.



BDNF: Brain-Derived Neurotropic Factor
DMN: Default Mode Network
EF: Executive Functioning

Figure 3.3. Schematic detailing three hypotheses for chronic/habitual exercise to facilitate three essential creativity correlates: creative skill, drive and performance

CHAPTER IV

A REVIEW OF EXPERIMENTAL RESEARCH ON EMBODIED CREATIVITY: REVISITING THE MIND-BODY CONNECTION

Abstract

Bodily movement may liberate thought processes essential to other higher-order cognitions, including creativity. A growing body of experimental work highlights the potential value of unstructured, interactive, or spontaneous motions, including gestures, dance, shifting body postures, physical object-manipulation, drawing, etc. to favorably impact creative performance. However, despite these favorable findings, to our knowledge, no systematic review has been conducted to explore the totality of evidence for embodied activities in this arena. Thus, the object of this paper was to systematically evaluate the potential effects of embodied experimental manipulations on traditionally assessed creativity outcomes. A systematic review was conducted utilizing PubMed, PsychInfo, Sports Discus and Google Scholar databases. The 20 studies evaluated employed a variety of methodological approaches regarding study design, embodied manipulation, and selection of specific creativity outcomes. Despite these variations, embodied movement robustly enhanced creativity across nearly all studies (90%), with no studies showing a detrimental effect. Based on the evaluation of the studies reviewed, several common themes emerged. These included the relevance of symbolic metaphors and distributed embodied cognitions, selection of embodied modality, specific measurement considerations, as well as the importance for implementing true, inactive control conditions in embodied creativity research. This review expands on these findings and places them in the context of improving future embodied creativity research.

Introduction

Systematic processes within the human mind and body are interconnected through complementary mental and physical motion. Motor activity has been linked to cognition, with experimental evidence supporting the functional importance of embodiment supplementing arithmetic and language performance[328,329]. People often use their fingers as aids to counting or to illustrate symbolic comparisons (e.g. differences in magnitude), a practice which may be mediated by shared neural pathways within the parietal cortex[330,331]. As fine-motor skills may correspond with optimal cognitive processing, so may gross, or complex, motor movements. Whole body movements introduce various potential configurations of personal space, which extend opportunities for unexpected perceptions, shifting perspectives, and the projection of ideas from an exclusively internal personal space to an externalization of prior inner cognitions. Specifically, peri-personal space has been defined as movement that is confined to the area "*within an arm's reach*," whereas the division of extra-personal movements exist "*beyond an arm's reach*[332]." Deeper neural processing may also occur through kinesthetic representation. Specifically, off-line, or imaginative, cognition may be embodied in situations where problem-solving is directed towards planned, anticipatory outcomes.[333] Potential candidates for a behavioral response may be coordinated via communication between basal ganglia and cortical regions, with predicted outcomes of action processed within the cerebellar system prior to implementation. Interestingly, the human cerebellum is functionally and bidirectionally connected to numerous regions of the cerebral cortex.[334] Connectivity between the prefrontal cortex and cerebellum is singularly apparent in human species[335], lending credence to the gravity of cerebellar input for the regulation of human executive functioning, knowledge acquisition and memory, and action-associated, symbolic cognitions[336-339].

Physical actions are conveyed through metaphoric articulations, such as "*We have this situation under control,*" or "*Your resolve is unshakeable*[329]." The action-sentence compatibility effect (ACE) additionally highlights intimate connections between language and movement[340]. Glenberg and Kaschak (2002) asked participants to distinguish between nonsense and sensible sentences, and to subsequently press buttons moving either away from, or towards, their immediate personal space. The sentences are also descriptive of directional motion, such as "*Put your finger under your nose*," and "*Put your finger under the faucet*," which imply movement toward, and away from, the physical self, respectively. Results indicated longer response times when the required (button-pressing) and described (sentence content) actions were oppositional, meaning that pressing a button away from the body after exposure to the sentence "*Open the drawer*," may portend a longer latency interval than if the sentence read "*Close the drawer*." The authors conclude that, as language emerged largely from evolutionary progress towards the coordination of movement, the comprehension of language may also be enhanced via sensorimotor experience[340]. However, it should be noted that, when oppositional instructions are presented in sequence, perhaps participants must engage higher-order cognitions involving the left inferior frontal cortex, which may initiate executive cognitive control when processing competing stimuli[341]. Effortful cognitive control would likely portend delayed responses to action-oriented commands.

Anderson's (2010) neural reuse theory proposes that neural circuitry, initially devoted to primitive cognitive functions, may undergo a series of evolutionary adaptations which deploy diverse functional connections without any detriment to the original cognitive domain[342]. Per the neural exploitation hypothesis, shared neural architecture across cognitive domains may have developed as sensory and motor systems integrate to rationally comprehend motion-oriented language relative to an agent and the object of interest via perceptual reactivations of isolated experiences[342,343]. For example, "*She dropped the ball*," is perhaps best understood by utilizing established semantic mental schemas and evaluating these against imagined contextual standards. That is, the concept of metaphorically *dropping the ball* may arise from an imagination-induced stimulation of functional clusters of sensorimotor neural frameworks that cooperate to subserve higher-order, abstract mental processing[343].

The simple act of bodily movement may liberate thought processes essential to other higher-order cognitions, including creativity. In their pivotal series of experiments examining the effects of forced walking on creativity, Oppezzo & Schwartz (2014) speculated that comfortable, mind-freeing movements (such as knitting) may be sufficient to activate the creative mind[344]. This suggests that structured physical activity, while shown in several studies to be sufficient to enhance creative output[161,162,164,344,345], may not be necessary to do so. In fact, a growing body of extant experimental work highlights the potential value of less-organized, unplanned or spontaneous motion, including gestures, dance, shifting body postures, physical object-manipulation, drawing, etc. for conferring benefits to creative performance[346-363]. Theoretical models have been proposed addressing the expectation that bodily action may concurrently and/or subsequently engender embodied cognitions underlying successful creative performances[332,333,341,342]. Specifically, embodied behaviors may stimulate executive functions, such as inhibition, updating, and mental set-shifting, as well as the development of inclusive, abstract thought schemas, the reconfiguration of challenging problem spaces, and the formation of novel associations, which perhaps interact to ultimately facilitate the expression of creativity[364]. Thus, the purpose of this review was to provide the first systematic evaluation of previous experimental work exploring the effects of embodied activities on creativity. An associated objective of this review was to evaluate the included studies for experimental rigor across both embodied manipulations and creativity outcome assessments to provide recommendations to further refine the measurement quality of these critical parameters as future empirical investigations are conducted in this area.

Methods

The experiments included in this review were identified via electronic search of several databases, including Embase, PubMed, PsychInfo, Sports Discus and Google Scholar[365]. Search terms utilized included: embodied creativity, sensorimotor creativity, movement creativity, and bodily expression. This process was completed until all combinations of these terms were performed. All searches were conducted on May 22, 2018 and all studies selected were published prior to this date (see Prisma flowchart; Figure 1).

Inclusionary criteria required that manuscripts be published in English, employ an experimental design, and evaluate the influence of embodied physical motion (independent variable) which holds that cognitions are influenced by sensorimotor experiences integrating mental perceptions and actions of the physical body on select creativity outcomes (dependent variable), including divergent thinking, convergent thinking, and insight problem-solving. Examples of embodied creativity experiments that were excluded from this review, but are related to this topic include the exclusive administration of an embodied *cognition* paradigm (such as metaphoric mental imagery[366]), rather than an independent variable requiring embodied *movement*. Studies assessing implicit embodied perceptions, including holding either a warm or cold beverage (to elicit warm or cold emotional valence) prior to completing creativity tasks were also excluded, as tactile manipulations of the objects were not included[367]. Additionally, studies assessing movement-based creative *dependent variables* were not included in this review (such as creative dance[368], tactical sports skills[369], or divergent movement[370]) as the focus of this manuscript was to explore whether transfer effects of physical motion emerge to impact traditional verbal and spatial or numerical creativity assessments, including divergent thinking, convergent thinking, and insight problem-solving.

Risk of bias/quality assessment for each article was evaluated in accordance with a seven-item checklist developed specifically for this study (Table 2). A yes (1 point) or no (0 points) response option was selected per the Cochrane Risk of Bias Tool. Higher total points indicate lower risk of bias for each manuscript. The risk of bias checklist, as well as this entire systematic review, adhered to the PRISMA checklist for reporting systematic reviews (except for item #5, prospective registration of the systematic review)[371]. The risk of bias items are listed as follows:

Item 1: Was the embodied manipulation controlled (e.g. completed in a laboratory setting, and/or for interaction with other participants if administered in a group context)?

Item 2: Was there evidence of reliability and validity for the creativity measure(s) utilized?

Item 3: Did the intervention use a non-embodied/true control group or condition?

Item 4: Did the researchers inform participants that they were involved in a creativity study (note: no point is awarded if participants were told a deceptive cover story)?

Item 5: Were statistically appropriate/acceptable methods of data analysis used?

Item 6: Were point estimates, standard deviations, confidence intervals, and/or effect sizes reported?

Item 7: Was the same dependent creativity measure(s) assessed at baseline and during or post-embodiment induction?

Item 6 identified articles that failed to report point estimates, confidence intervals, standard deviations, and/or effect sizes. The authors may have computed these values, but if all statistical results were not included in the publication, a ‘no’ (0 points) score was given for Item 6.

Relatedly, a 'no' (0 points) score was given for Item 7 if articles neglected to assess creativity at multiple time-points, which is crucial for acute research studies to establish a baseline measure of creativity, and subsequently evaluate meaningful change from baseline (either during or post-embodiment) respective to each experimental condition.

To provide a greater understanding of the totality of work on this topic, we included quasi-experimental research, as well as experiments conducted on both adult and child participants. Excluded studies from childhood research examined the influences of unrestricted imaginative play, as these experiments encompass a body of work beyond the interest of the present review and are typically not administered using robust experimental controls (e.g., social interaction, environmental distractions, etc.).

Results

Study Design and Participant Characteristics

In total, 20 experiments met our criteria and are detailed in the supplementary extraction table (Table 1). Seventeen studies employed a between-subjects experimental design[346-349,351-355,357-362,372,373], while one study employed a within-subjects protocol[363]. Three studies utilized a mixed-methods approach[350,356,374]. Leung et al. (2011) employed a mixed methods approach for study 1 (of 4) only[354]. Of the 20 studies, 17 assessed college-aged participants between the ages of 18-35[346,348,349,351-363,372,373]. Two studies assessed children, ages 4-6[350] and 8-11[374], respectively. Sample sizes ranged from 24-150 participants.

Embodiment Manipulations Selected

True implementations of non-embodied control conditions require physically-motionless activity, as drawing, grasping objects, writing responses to presented problems, etc. all involve bodily movement, and thus, are risks to the internal validity of the experiment. Fifteen experiments did not utilize a true, non-movement, or non-embodied, control group[347-351,353-361,363,373], while six experiments implemented a true, non-embodied control condition into their research protocol(s)[346,352,362,372,374] (Note: Friedman & Förster (2000) employed a true control group in study 6, but not studies 1-5[359]). Friedman & Förster (2002 employed a true control group in studies 3 and 4, but not studies 1 and 2[351]. Leung et al. included a true control group in study 2, but not studies 1 and 4[354]).

Four studies employed ambulatory-based physical manipulations[348,353,356,363]. Two of these employed walking or roaming experimental protocols[353,363], while Wang et al. (2018) utilized a simulated virtual reality walking protocol, rather than authentic physical movement[356]. Hutton and Sundar (2010) employed low, moderate, and high-intensity dance protocols[348]. Sixteen experimental manipulations utilized seated, standing or lying embodied experimental conditions[346,347,349-352,354,355,357-363,372-374]. Of those, 14 focused exclusively on upper extremity motion[346,347,349-352,355,358-362,373,374].

Risk of Bias Assessment Results

The 20 included articles were classified into categories based on cut points reflecting the degree of methodological bias considered for each individual study. Studies with a score of 5-7 (nine studies) were classified as having low risk of bias. Studies with a score of 3–4 (ten studies) were classified as having moderate risk of bias. Studies with a score of 0–2 (one study) were classified as having a high risk of bias (Table 2).

Creativity Outcome Results

Among the 20 studies, 18 (90%) demonstrated some evidence for embodied movement to favorably influence creative performance[346-363,373]. Further, one of the two studies among children demonstrated favorable effects for embodied movement (50%)[350]. Similarly, among the 18 embodiment studies among adults, 17 (94%) showed beneficial effects of acute creativity assessment. Two embodied creativity studies did not observe any statistically significant outcomes in favor of embodiment[372,374]; although, no studies reported detrimental effects of embodiment on creativity. Specific research findings for divergent thinking (i.e., the ability to generate many ideas from a single stimulus[375]), convergent thinking (i.e., the ability to associate task elements to discover one unifying solution to a specific problem[376]) and insight problem-solving (i.e., the ability to suddenly overcome initial task constraints to conceive a correct solution to a challenging problem via restructuring multiple problem elements[377]) are detailed below.

Divergent Thinking. Of the 20 experiments, fourteen (70%) evaluated creative originality, with twelve (86%) of these studies demonstrating a statistically significant, beneficial effect of embodied movement on creative originality[346,347,349,351-357,363,373]. Fourteen of 16 studies evaluating fluency (88%) demonstrated a statistically significant effect of embodied movement on creative fluency[346-357,363,373]. Seven of ten studies evaluating flexibility (70%) demonstrated a statistically significant effect of embodied movement on creative flexibility[346,348,353,355,356,363,373]. Kim (2015) demonstrated no statistically significant differences between conditions on flexibility outcomes[349]. Although there were no statistically significant differences in Study 1 on creativity outcomes, Kirk & Lewis (2017) reported statistical significance for embodiment on AUT fluency (but not originality or flexibility) in Study 2[374]. Leung et al. (2011) reported no statistically significant differences in Lego object identification fluency and flexibility scores between embodied conditions comparing free walking to constrained, rectangular walking and a seated control group. Originality performances were also not statistically different between constrained walking or seated task completion (study 2a). Lego Task scores also did not reach statistical significance across embodied recombination conditions, wherein participants were asked to either combine paper from a left-positioned stack with paper from a right stack and place the new stack combination in the center of both initial stacks for 2-min prior to creativity task completion, or participate in an active control condition, requiring the placement of paper from either the right or the left (counterbalanced) stack to the middle[354].

Convergent Thinking. Seven experiments assessed convergent thinking, and all seven indicated favorable effects for embodied interventions (100%) [349,352,354-356,360,361].

Insight Problem Solving. Five of five studies demonstrated a facilitative effect of movement on the solution rate and accuracy of insight creativity tasks (100%) [351,358-361]. Vallée-Tourangeau et al. (2016) suggest that building model solutions following task-instructions may be favorable to drawing potential answers to a challenging insight problem[360]. Friedman and Förster (2000) conducted a series of six experiments, demonstrating an advantage for arm flexion on time to completion, total solutions completed, on a variety of hidden image identification tasks, as well as an analogy completion task, and classification of best-fit exemplars in the Categorization Task[359]. Friedman and Förster (2002) extended their research investigating the potential impact of embodiment on creativity, highlighting the favorable role of arm flexion, compared to arm extension, on higher insight solution rates[351]. Similarly, Thomas and Lleras (2009) found that upper extremity swinging of the limbs across a series of planned "movement breaks" from problem-solving resulted in higher solution rates on an Maier's (1931) two-string insight task[378] than a stretching only group[361].

Discussion

The present review is the first systematic evaluation of extant experimental work designed to explore the effects of physically embodied activities on creative cognitions. Given the burgeoning scientific interest in exploring various mind-body connections, this synthesis of work aims to provide suggestions to enhance the empirical quality of assessment when investigating embodied creativity, as well as offer theoretical considerations to motivate continued research in this arena. As 90% of the 20 studies included in this review demonstrated evidence for embodied movement to benefit acute creative output,[346-363,373] it appears that embodied actions may exert a profound influence on divergent and convergent thinking and insight problem-solving performance. Based on the evaluation of the studies reviewed herein, common themes emerged. These included the relevance of symbolic metaphors and distributed embodied cognitions, selection of embodied modality, specific measurement considerations, as well as the importance for implementing true, inactive control conditions in embodied creativity experiments. The narrative that follows will expand on these findings and place them in the context of improving and guiding future creativity research.

Metaphoric and Distributed Embodied Cognitions. Gesture and upper-limb movement may favor subcomponents of creativity such as divergent thinking, associative flexibility, and convergent thinking when bodily movements are more fluid, rather than rigid or confined. Fluid movement, in this context, may be viewed as a metaphor for fluid cognition expected to benefit creativity. Fluid hand gestures have been shown to promote verbosity or fluency of generated ideas[355]; although, an important caveat to consider is that while physical stimulation may impact the totality of rational ideas produced, merely articulating more ideas does not always guarantee these ideas will be flexible or highly original. Relatedly, Leung et al. (2011) highlighted the potential importance of embodying creative metaphors, which may stimulate creative output on measures of both convergent and divergent thinking[354]. Individuals are expected to draw on previous experiences as they engage in metaphoric movements likely capable of stimulating sensorimotor systems conducive to original thinking, similar to "*thinking outside of the box*," flexible thinking, or thoughtful consideration of ideas, metaphoric movements such as "*on one* *hand, and then on the other hand*," and associative fluency, or "*putting two and two together*." To this point, associative embodiment, or recombination, may be especially useful for convergent creativity, which demands effortful awareness of an explicit association between different stimuli[354]. In addition, physically encoding information may facilitate insight problem-solving performance via the distribution of effort across both cognitive and mental search spaces. Physical movements dedicated to searching for potentially correct answers, such as manipulation of matchsticks to solve a classic matchstick algebra task[379], rather than using pencil and paper alone, may offer support for "distributed cognition[362]."

Ambulation and Modality Selection of Physical Embodiment. Divergent thinking fluency, flexibility, and originality may be subserved by roaming[353,363] (i.e., free-walking/unconstrained walking), when compared to constrained walking along a prescribed rectangular path or walking along a randomly-generated path drawn with a laser pointer (i.e. random-experienced condition). Comparatively, among older adults, roaming was associated with superior scores on all creativity measures (i.e., fluency, originality, and flexibility), and while younger adults outscored elderly participants on originality, fluency, and flexibility measures, performance discrepancies were not statistically significant[353], which suggests a potentially facilitative effect of the modality of embodiment, namely autonomously-directed embodiment on divergent thinking for both younger and older individuals. Importantly, although roaming was related to higher flexibility of divergent ideas than constrained walking and walking along a random, participant-drawn path, differences between the roaming and simply generating a random path with a laser pointer (non-ambulatory) did not reach statistical significance[353], suggesting that random, unconstrained motion may be more important for consideration than selections of ambulatory versus seated, gesture-based modalities. Another critical potential moderator is that different ambulatory protocols, such as standing, pattern/figure-8 walking, and roaming may be inclusive of bodily states requiring increased cognitive load, either simultaneously or subsequently increasing relaxation of cognitive control, may benefit certain types of creativity, but may be detrimental for other cognitive tasks requiring a high degree of focused attention, such as challenging insight problems or convergent thinking assessments. To our knowledge, of the embodiment research focused on lower extremity movement, only two studies have assessed walking-based ambulation[353,363], and one study employed different intensities of dancing[348], and one study simulated ambulation using virtual reality gaming technology[356]. Of these four studies, all four (100%) evaluated divergent thinking alone[348,353,356,363]. Interestingly, all research experiments included in the present review that were conducted to evaluate convergent thinking found favorable effects of embodiment on convergent creativity[349,352,354-356,360,361]. Thus, ambulatory-based interventions assessing convergent thinking are warranted to discern whether these findings may extend across movement modalities.

Measurement Considerations. Wang et al. (2018) highlighted the potential temporal effects of embodiment stimuli, as the authors noted that participants spent longer generating divergent ideas during simulated walking than after walking, despite the unlimited time allocated to idea generation post-walking. Notably, however, while participants spent longer generating ideas during walking, this expanded ideation time interval did not appreciably influence the quality or quantity of divergent thinking responses. Participants also spent more time reporting ideas (i.e. were more persistent) in the "break-" versus "no-break" condition[356]. Divergent thinking scores were higher among participants whom were instructed to break past a wall presented via a virtual reality medium, compared to no walls obstructing virtual ambulation along the prescribed simulation route. Perhaps the physical embodiment of "*breaking the rules*" influences divergent thinking performance in some situations, as this specific embodied metaphor strategy promoted both cognitive flexibility, as well as task persistence, or sustained time-on-task[356]. Taken together, a multitude of embodied states may influence divergent thinking and physical embodiment may activate metaphorical thought processes, which as aforementioned, is a recurring theoretical claim ascribed to embodied creativity interactions.

Congruence Effects and the Necessity of True Control Conditions. Despite the suggestion that low motor-demand (e.g., copying text using one's dominant hand) favorably influences creativity outcomes when compared to high motor-demand (e.g., copying text using one's non-dominant hand), a non-movement induction control group achieved statistically comparable divergent thinking fluency scores as the low-demand condition. The control group also achieved higher originality scores than all conditions[346]. Perhaps evidence exists in support of a unifying concept connecting the transferrable symbolism of physical movement to observable creativity, but, none of the included studies perceptively evaluated expectations of the control and experimental groups[380], and only six of 20 studies (30%) utilized a robust, non-movement control group in their research[346,352,362,372,374].

For example, squeezing a malleable, gel ball was observed to be superior than squeezing a rigid ball on both fluency and originality of divergent thinking, whereas squeezing a hard ball was facilitative convergent thinking problems when compared to the soft ball condition[349]. Perhaps restricted, or inflexible movement scenarios may be ideal for creativity assessments requiring convergence on a solution to a problem with unyielding preliminary instructions, whereas distributed, divergent cognitions may be stimulated by flexible and adaptive motions. However, a non-embodied control was not juxtaposed against these conditions to isolate meaningful experimental evidence for this protocol. Deformation of the gel ball did not appear to influence creative flexibility to a greater extent than squeezing a hard ball, which may suggest that the theoretical benefits of physically and cognitively "*molding ideas*" may be confined to the quality and quantity of creative output, rather than an enhanced ability to form remote associations spanning a variety of distinct categories. Although, to reiterate the necessity of immobile controls, creative flexibility may simply be congruently influenced/not influenced by the physical act of squeezing objects. Future research should attempt to parse out true effects with the inclusion of a static control conditions.

Control groups are also needed to identify whether interactive manipulation of task-related physical stimuli may confer benefits to solution response correctness, as shown by Fioratou & Cowley (2009)[358]. In their experiment, participants were asked to either derive solutions to an insight task using a pen and paper (group 1), or were given the opportunity to freely interact with necklace chain-links, which were related to the problem instructions for solving the *cheap necklace* insight problem[358,381]. Vallée-Tourangeau and colleagues (2016) also administered an insight creativity task to participants, highlighting the plausibility for cognitive representations of movement-related problem presentations to be facilitated by tactile and sensorimotor interactions, versus solving insight problems using pen and paper[360]. In the pen and paper conditions for both experiments, participants were allowed to draw pictures of potential solutions, and as art is a form of embodiment[382], we cannot be sure whether benefits of embodied manipulations would exceed problem-solving if responses were required to be submitted using verbal or mental imagery (non-movement) strategies for task completion. When an environment is enriched with tools suitable to develop problem-solving strategies, enhanced performance may ensue. It may be that some modalities of embodiment outperform others, but at this juncture, the field remains entrenched in speculation.

Conclusion

The manifestation of numerous, conflicting conclusions draws a shade over the relevance of embodied creativity to society and does little, except engender confusion. One example of equivocal recommendations surrounding embodied cognition processes is highlighted by the disputed role of affect and embodiment in shaping optimal psychological function. Affect may promote divergent thinking[347] relative to exploring alternative opportunities and utilizing "unconstrained" problem-solving strategies, with positive affect specifically expected to markedly increase one's likelihood to rationalize and practice a global (inclusive) processing style[351]. Importantly, physical cues may also provide individuals with useful contextual information about their personal experiences (e.g. perceptions of threat, safety, happiness, etc.), and have been shown to exert a powerful influence on judgment and behavior[383]. Research suggests that when affect and physical states are *congruent*, creative cognition may be supported. Specifically, posture-compatible conditions seemed to benefit creativity[357]. Conversely, other research suggests that an *incongruence* between motor action and affect appears to favorably influence fluency, flexibility, and originality, of divergent cognitions[373]. Both of the referenced manuscripts did not implement true control groups; thus, these postulations contribute to the uncertainty that limits sound recommendations for continued empirical work. Despite considerable evidence for embodied movement to acutely enhance creative performance, much research is needed to resolve the current state of ambiguity that undermines the potential weight of these interventions. In addition to administration of appropriate controls, research should also focus on discerning an optimal embodied modality for diverse creativity parameters, and may also consider employing a chronic training study to address the position that creativity is perhaps a stable trait requiring a training intervention of longer duration to discern a true impact of different embodied movements on creativity.[372] This is the first systematic review of experiments designed to investigate the import of embodied creativity in the context of mind-body interactions, which underscores the obligation of high-quality research programs to continue exploring these concepts to inform theoretical and mechanistic frameworks, practical recommendations for school-based education, professional growth and development, and maintenance of self-actualizing cognitions in later life.

PRISMA 2009 Flow Diagram

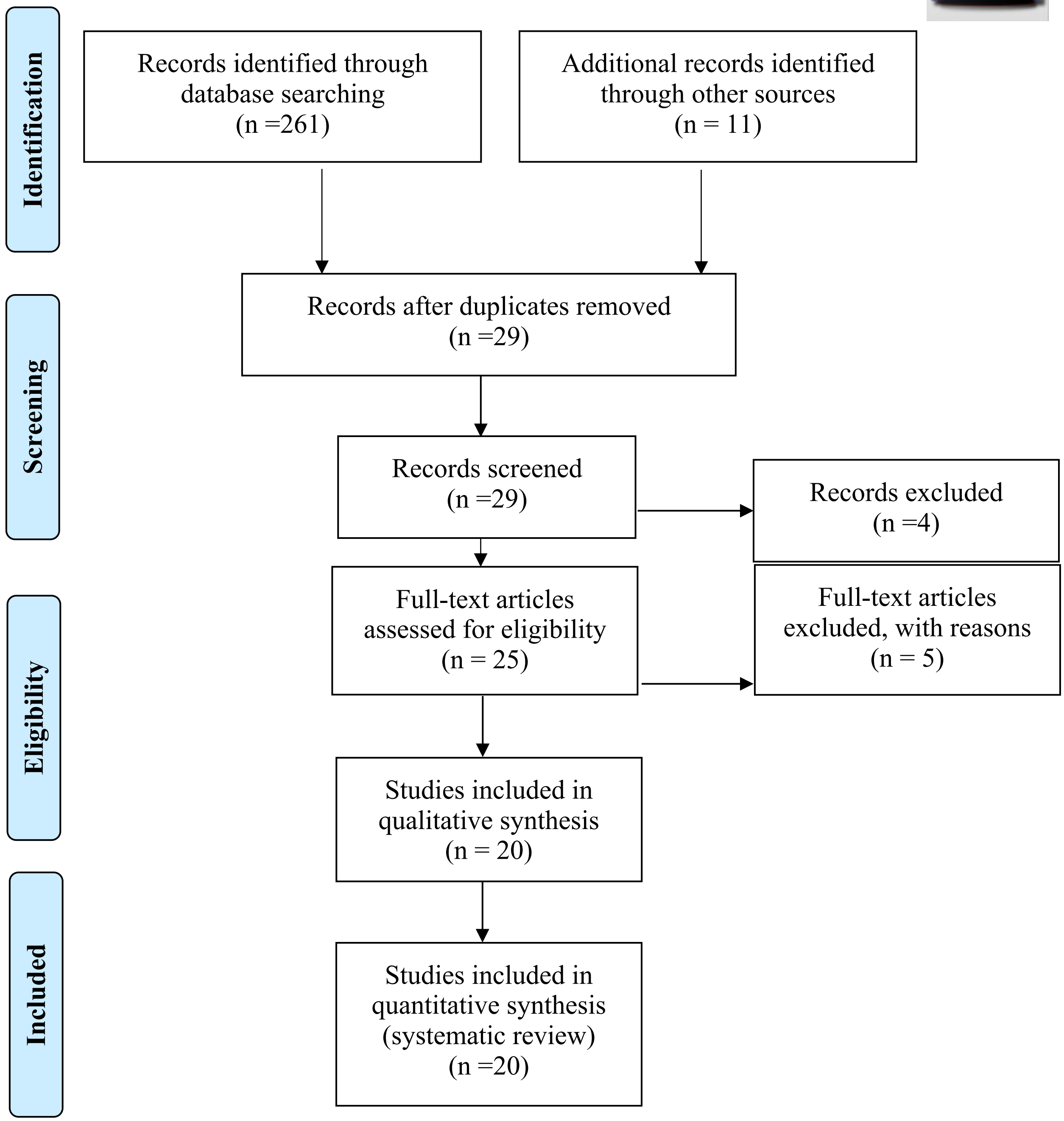


Figure 4.1. Prisma flow diagram detailing article retrieval.

Table 4.2. Risk of bias assessment.

Study	1	2	3	4	5	6	7	Total
Abraham et al (2018)		x	x	x	x	x		5
Dansky & Silverman (1973)	x	x			x			3
Fioratou & Cowley (2009)	x	x		x	x	x		4
Friedman & Förster (2000)	x	x			x	x		4
Friedman & Förster (2002)	x	x			x	x		4
Goldstein, Revivo, Kreitler, & Metuki (2010)	x	x	x		x	x		5
Hao et al. (2014)	x	x			x	x		4
Hao et al. (2017)	x	x		x	x	x		5
Hutton & Sundar (2010)	x	x			x	x		4
Khasky & Smith (1999)		x	x	x	x	x		5
Kim (2015)		x			x	x		3
Kirk & Lewis (2017)	x	x	x	x	x	x	x	7
Kuo & Yeh (2016)		x			x	x		3
Leung et al. (2011)	x	x			x	x		
Slepian & Ambady (2012)		x		x	x	x		4
Thomas & Lleras (2009)	x	x						2
Vallée-Tourangeau, Steffensen, Vallée-Tourangeau, & Sirota (2016)	x	x		x	x	x		5
Wang, Lu, Runco, & Hao (2018)	x	x		x	x	x		5
Weller, Villejoubert, & Vallée-Tourangeau (2011)	x	x	x	x	x	x		6
Yuan, Lu, & Hao (2018)	x	x			x	x		4
Zhou et al. (2017)	x	x		x	x	x		5

Item 1: Was the embodied manipulation controlled (e.g. completed in a laboratory setting, and/or for interaction with other participants if administered in a group context)?
Item 2: Was there evidence of reliability and validity for the creativity measure(s) utilized?
Item 3: Did the intervention use a non-embodied/true control group or condition?
Item 4: Did the researchers inform participants that they were involved in a creativity study (note: no point is awarded if participants were told a deceptive cover story)?
Item 5: Were statistically appropriate/acceptable methods of data analysis used?
Item 6: Were point estimates, standard deviations, confidence intervals, and/or effect sizes reported?
Item 7: Was the same dependent creativity measure(s) assessed at baseline and during or post-embodiment induction?

Authors	Sample Size (N) and Participant Characteristics	Study Design	Independent Variables (IV)	Description of Embodied IV	Creativity Outcome	Main Findings
Abraham, Asquith, Ahmed, & Bourisly (2018)	N = 150 (30 m; 120 f) $\bar{X}$age: 20.4 years old	Experimental: Between-subjects	Edinburgh Handedness Inventory Creative Personality Scale (Gough, 1979) Raven's Standard Progressive Matrices (SPM; Raven, 2000) Abbreviated Torrance Test for Adults (ATTA) scored across fluency, originality, elaboration, and flexibility Motor and Cognitive Induction Tasks Motor-low demand (n=29) Motor-high demand (n=31) Cognitive-low demand (n=34) Cognitive-high demand (n=37) Control (n=19)	Participants were presented with 244 sentences with the last word missing (e.g., The captain stayed with the sinking ___.) Participants completed as many as possible within 10-min, and were assigned to either complete the sentence with a semantically unconnected word (cognitive-high demand) or to provide the correct word (cognitive-low demand). A neutral document was given to participants whom were instructed to copy the lines of the document for 10-min using wither their non-dominant hand, left hand (motor-high demand) or	AUT (newspaper, brick, paperclip, knife, shoe, light bulb) scored across fluency, originality, and peak originality)	ANOVA results indicated a statistically significant effect of condition on originality ($F_{1127} = 8.707$, $p = 0.004$, $\eta^2 = 0.064$) and peak originality ($F_{1127} = 7.262$, $p = 0.008$, $\eta^2 = 0.054$) on the first AUT trial, demonstrating that both low-demand cognitive and motor inductions were related to higher originality. Notably, however, the no-induction control group indicated no statistically significant difference between no-induction and induction groups on fluency, originality, and peak originality (all $F_{4145} < 2.3$, all $p > .05$). Overall, low motor and cognitive demands were associated with higher fluency in comparison to both high demand inductions. ($F_{1127} = 4.35$, $p = 0.039$, $\eta^2 = 0.03$), but, again, when compared to the no-induction control group, differences in fluency were not statistically significant ($F_{4145} = 1.665$, $p = .161$). The no-induction group was also associated with higher originality ($F_{4145} = 4.118$, $p = .003$, $\eta^2 = 0.102$) than the cognitive and motor induction assignments (all $t > 3.11$, $p < .05$). An interaction effect was also observed, indicating that the no-induction group demonstrated higher originality across AUT trials ($F_{16,564} = 1.989$, $p = .012$, $\eta^2 = 0.048$). Further, peak originality decreased initially, but then increased and subsequently flattened across the AUT trials (main effect: $F_{4564} = 8.308$, $p < 0.001$, $\eta^2 = 0.055$) (quadratic trend: $t = 4.065$, $p < 0.001$).

				dominant, right hand (motor-low demand)		
Dansky & Silverman (1973)	N= 90 (45 m; 45 f) Age Range: 4.0-6.1, $\bar{X}$= 5.0	Experimental (block-design); within-subjects (objects); between-subjects (groups 1 and 2)	Presentation of the following materials to the play and imitation groups: Ten paper towels, a screwdriver, a wooden board, with five screws set in it, 30 paper clips, 15 blank cards, 10 empty matchboxes, and six, wet plastic cups Control group participants were given were given four pages from a coloring book, and a box of crayons.	1. Play group- played with the materials presented in random order 2. Imitation group- mimicked the researcher playing with the materials in random order 3. Control group- coloring (baseline visit)	AUT- Scored for fluency of responses, as well as environmentally-cued responses (orally reported)	Standard Responses: No statistically significant group x object interaction effect (F(3,261)= 1.44, *p*>.05) Unusual responses: A statistically significant group x object interaction was demonstrated (F(6,261)= 2.46, *p*<05). Children in the play group generated more non-standard responses (p<.01), as well as utilized more environmental clues to inform their responses (p<.01) than those in the other two groups, with no statistically significant differences observed between imitation and control conditions. When cued-responses were discarded from the analysis, participants whom played still generated more non-standard uses (*F*(2,87)= 28.16, *p*<.01).
Fioratou & Cowley (2009)	Study 1: N = 72 Study 2: Excluded as this experiment focused on extraneous characteristics of the insight task, allowing both groups to manipulate the	Experimental: between-subjects Group 1. n= 39 Group 2. n= 33	Static or interactive insight manipulation	Group 1. Paper and pen were given to participants to draw solutions Group 2. Participants were permitted to interact with necklace chain-links to generate solutions	Cheap Necklace Insight Problem (10-minutes) scored for correct solution	There was a statistically significant difference in solution rates between the pen and paper condition and interactive condition $\chi2(1,N=72)= 10.626$, p<.001), with 10/33 participants correctly solving the task in the interactive group, versus 1/39 in the pen and paper group.

	necklace chains Undergraduate and postgraduate					
Friedman & Förster (2000)	Study 1: N= 24 Study 2: N= 32 Study 3: N=30 Study 4: N=42 Study 5: N=30 Study 6: N=45 Study 7: Excluded as researchers evaluated embodiment and GRE analytical reasoning (although analytical reasoning may be associated with creativity, creativity was not an outcome variable) Undergraduates	Experimental: between-subjects Study 1: n=11 arm flexion; n=13 arm extension (n not reported for the other included studies)	Right arm flexion or extension while thinking about the solution to creativity tasks Also assessed post-experiment affect, effort during motor action, and enjoyment of insight task Study 4: Assessed pre-embodiment affect and anticipated task-enjoyment	Approach motor action (seated arm flexion) Avoidance motor action (seated arm extension) Study 6: Rest arm on chair with no tension (control)	**Study 1:** Embedded Figures Task (EFT; 12 designs; 3-min each). Participants provided verbal solutions assessed for time to completion **Study 2:** Snowy Pictures Task SPT (2 sets of 12 figures; 10s each). Participants provided verbal solutions assessed for correctly identifying embedded images **Study 3 &4:** Gestalt Closure Task (GCT; 10 pictures; 2-min total). Participants provided verbal solutions assessed for correctly identifying the hidden gestalt objects **Study 5:** Intelligence Structure Test (verbal analogy problem-solving	**Study 1:** Participants engaging in arm flexion solved EFT problems faster (M=255.45, SD=128.24) than arm extension participants (M=416.08, SD=206.12 *t* (22)= 2.24, p <.04). **Study 2:** Participants engaging in arm flexion solved more SPT problems (M=13.0, SD =2.56) than arm extension participants (M=9.5, SD=3.16 *t*(30)= 3.44, p <.002). **Study 3 &4:** Participants engaging in arm flexion solved more GCT problems (M=9.33, SD =0.72) than arm extension participants (M=6.6, SD=0.72 *t*(28)= 4.02, p <.0001); *Study 4:* Same design as Study 3 with pre-and post-embodiment measures of affect and enjoyment. Participants engaging in arm flexion solved more GCT problems (M=9.76, SD =0.44) than arm extension participants (M=7.29, SD=1.82 *t*(40)= 6.06, p <.0001); **Study 5:** Participants engaging in arm flexion solved more IST analogies (M=11.87, SD =2.75) than arm extension participants (M=8.60, SD=2.99 *t*(28)= 3.11, p <.004); **Study 6:** ANOVA results demonstrated a main effect for condition (F(2, 42) = 164.76, p < .0001. Arm flexion participants rated atypical exemplars as better fits to categories (M=4.70, SD=0.29), compared to the arm extension group (M=2.33; SD=0.42; t(42)=17.74, p<.0001. Arm flexion ratings were statistically significantly different from the control group (M=3.07; SD=0.38; t(42)=13.44,

					task; 20 analogies; 7-min total). Participants provided verbal solutions assessed for correctness. **Study 6:** Categorization Task (four problem categories: furniture, vehicle, vegetable, and clothing categories, followed by three "good," three "moderately good," and three "poor" exemplars. Participants provided verbal solutions assessed for cognitive flexibility (goodness-of fit ratings).	p<.0001). Arm extension ratings were also statistically significantly different from the control group (t(42)=17.28, p<.0001)
Friedman & Förster (2002)	Study 1: N= 30 Study 2: N= 25 Study 3: N=63 Study 4: 30 Undergraduates	Experimental: between-subjects	Right arm flexion or extension while thinking about the solution to creativity tasks (Experiments 3&4 employed left arm flexion or extension) Also assessed post-experiment affect, effort during	Approach motor action (seated arm flexion) Avoidance motor action (seated arm extension) Study 3 & 4: Rest arm on chair with no tension (control)	**Study 1:** Three insight problems (6-min per problem); participants provided oral solutions assessed for correctness and time to completion **Study 2:** AUT (brick; 1-min) scored for fluency and originality	**Study 1:** Participants engaging in arm flexion solved more insight problems than arm extension participants (*b*=-42.67, F(1, 27)=6.48, p<.02). **Study 2:** Participants engaging in arm flexion achieved higher originality scores (M=5.10) than arm extension participants (M=4.41; *t*(23)= 3.74, p <.002). Additionally, participants engaging in arm flexion achieved higher fluency scores (M=4.08) than arm extension participants (M=2.38; *t*(23)= 2.58, p <.02). **Study 3:** Word puzzle performance was statistically significantly different between

			motor action, and enjoyment of insight task Pre-task affect and anticipation of task-enjoyment were assessed in Study 2, 3, 4. Pre- and post-task motivation and arousal were also assessed in Study 4.		(oral responses) **Study 3:** Word puzzle task (15 letter strings, printed twice, and in two columns; *each letter string contained missing letters*. Participants solved for the missing letters to form a German word) 1-min (for each column) was allocated to solve as many word puzzles as possible. **Study 4:** Word puzzle task (15 letter strings, printed twice, and in two columns; *only the second string contained missing letters*. Participants solved for the missing letters to form a German word) 1-min (for each column) was allocated to solve as many word puzzles as possible.	conditions for the second column, as predicted ($M_{Extension}$=6.60, $M_{Control}$ =5.67, $M_{Flexion}$ =8.19; $F(2, 56)=3.47$, $P<.04$). Arm flexion, versus control appeared to facilitate higher scores on the second column ($t(56)=2.58$, $p=.01$). There was no statistically significant difference between arm extension and control ($t<1$), however arm flexion participants achieved higher scores than extension and control combined ($t(56)=2.46$, $p=.02$). Study 4: ANOVA results indicated that the arm flexion group outperformed the extension and control groups ($M_{Flexion}$ =9.2, $M_{Control}$ =7.5, $M_{Extension}$ = 5.6; $F(2, 27)=11.45$, $p<.0003$). Arm flexion, versus control appeared to facilitate higher scores on the second column ($t(27)=2.26$, $p=.04$). Arm extension also appeared to facilitate higher second-column performance than the control groups ($t(27)=2.52$, $p<.02$).

Goldstein, Revivo, Kreitler, & Metuki (2010)	N=40 Age range: 21-35	Experimental: between-subjects	Ball-squeezing manipulations Line-bisection manipulation check to assess hemispheric activation PANAS (affect)	1: control: participants rested both palms, face-down on the table or their legs (n=10) 2: squeeze (left-hand, n=15) 3: squeeze (right-hand, n=15) Ball was squeezed four times for 45 seconds, with 15 seconds rest	RAT (25-items): Participants were given 15-min to solve the RAT using pen-and-paper	ANOVA results demonstrated a statistically significant main effect of condition ($F(2,37)=7.35$, $p<.005$, $\eta p2=.28$). Left-handed muscular contractions appeared to facilitate convergent thinking to a greater extent than right-handed ($p<.01$, Cohen's *d*=0.59) and control manipulations ($p<.05$, Cohen's *d*=0.32). Results are depicted in Figure 1 of the manuscript.
Hao et al. (2014)	N= 96 (28 males (m); 68 females (f) 17-26; $\bar{X}$=20.76, SD=2.34	Experimental; between-subjects	Self-reported enjoyment, mood, and effort GRE problems were presented to assess (oral) organization of information and analytical reasoning performance	1: seated posture-arm extension 2: seated posture-arm flexion 3: lying posture-arm extension 4. lying posture-arm flexion	Divergent thinking performance on the AUT (3 tasks x 3-min; counterbalanced; assessed fluency and originality (orally reported)	No statistically significant main effect for body posture or arm position on divergent thinking, with evidence of a statistically significant interaction effect for fluency ($F(1, 92)=13.52$, $p<.001$, $\eta p2=.13$) and originality ($F(1, 92)=14.75$, $p<.001$, $\eta p2=.14$). For the seated posture-flexion group, AUT fluency scores (M=8.81, SD=2.94) were statistically significantly greater than the seated posture-extension group (M=6.81, SD=1.96; $t(48)=2.83$, $p<.01$, Cohen's d=.80). For the seated posture-flexion group, AUT originality scores (M= 3.29, SD=1.85) were statistically significantly greater than the seated posture-extension group (M=1.92, SD=.99); $t(48)=3.28$, $p<.01$, Cohen's d=.92). For the lying posture-extension group, AUT fluency scores (M=8.25, SD=1.93) were statistically significantly greater than the lying posture-flexion group (M=6.78, SD=2.21; ($t(44)=2.39$, $p<.05$, Cohen's d=.71). For the lying posture-extension group, AUT originality scores (M=2.71, SD= .45) were statistically significantly greater than the lying posture-flexion group

						(M=1.84, SD=1.29; (*t*(44)=2.15, p<.05, Cohen's d=.63). AUT fluency was highest in seated-flexion than lying-flexion (*t*(46)=2.72, p<.01, Cohen's d=.78). Fluency during lying-extension was higher compared to seated-extension (*t*(46)=2.55, p<.05, Cohen's d=.74). AUT originality was highest in seated-flexion than lying-flexion (*t*(46)=3.18, p<.01, Cohen's d=.91). Fluency during lying-extension was higher compared to seated-extension (*t*(46)=2.19, p<.05, Cohen's d=.64).
Hao et al., 2017	Study 1: N= 149 (89 m; 69 f) Study 2: N=130 (45 m; 85 f) Study 1: 18-23; $\bar{X}$= 20.34, SD= 2.13 Study 2: 19-26; $\bar{X}$=22.06, SD= 1.68	Experimental; between-subjects	Study 1 and Study 2: Emotional Induction video clip (2-min) Valence and Arousal (Self-Assessment Maniken Scale), self-reported enjoyment, power, and effort Posture manipulation: Standing open posture or standing closed posture	Study 1 and Study 2: Four between-subjects conditions 1: open posture-positive emotional induction 2: open-negative 3: closed posture-positive emotional induction 4: closed-negative	**Study 1:** Oral divergent thinking performance on the AUT (2 tasks x 3-min; assessed fluency and originality **Study 2:** oral divergent thinking performance on the AUT (1 task x 5-min; assessed fluency and originality, and RPP (1 task x 5-minutes) Oral Association-Chain Task (ACT; 5 tasks x 1-min) to assess associative flexibility	Study 1 and Study 2: No statistically significant main effect for posture or emotional induction on divergent thinking, with evidence of a statistically significant interaction effect on AUT fluency and originality (Study 1: F(2, 144)=8.87, p<0.001, η2p=0.11; Study 2: F(2, 125)=5.74, p<0.01, η2p=0.08). For the open posture-positive emotion group, AUT fluency scores (Study 1: M=8.72, SD=5.31; Study 2: (M=17.97, SD=7.28) were statistically significantly greater than the open posture-negative emotion group (Study 1: M=6.17, SD=3.37; post hoc LSD test, p<0.01; Study 2: (M=13, SD=6.11; LSD test, p<0.01). The same was observed for originality scores (open-positive emotion: Study 1: M=2.85, SD=2.51; Study 2: M =5.28, SD=3.21) open-negative: Study 1: M=1.33, SD=1.33, p<0.001; Study 2: M=3.64, SD=2.70, p<0.05). For the closed posture condition, no differences in fluency were observed between positive or negative emotional induction in either study. However, originality scores were lower for the closed-positive emotion (M=1.43, SD=1.18) compared

						to the closed-negative emotion group (M=2.32, SD=1.87) (p<0.05) in Study 1. There were no statistically significant differences in originality scores for study 2. No statistically significant main effect for posture or emotional induction on divergent thinking on RPP performance in Study 2, with a statistically significant interaction effect observed (F(1, 126)=7.00, p<0.01, η2=0.05). Fluency scores were higher in the open-positive condition (M=10.3, SD=3.93), than the open-negative condition (M=7.58, SD=3.78, p<0.05), with no difference observed between positive and negative emotion induction in the closed posture condition. RPP originality scores were also higher in the open-positive (M=7.6, SD=8.05), compared to open-negative condition (M=3.98, SD=4.48) (p<0.05). In the closed posture-negative condition (M=8.74, SD=8.69), participants outperformed the closed-positive condition (M=5.47, SD=4.46, p<0.05). For Study 2, ACT performance was highest in the open positive condition, compared to all other conditions (p<.05).
Hutton & Sundar (2010)	N = 90 (male/ female ratio = 2:3) Undergraduate and graduate students (no age range or mean age reported)	Experimental: between-subjects Six experimental conditions	Arousal Induction: *Dance Dance Revolution* video game Valence Induction: Emotion Recognition Test PANAS Self-reported energy level (1-10 scale)	Random assignment to one of three levels of dance exertion: low, medium, and high. Available levels of the game may be preselected to beginner, light, or standard, which were confirmed to correspond	Abbreviated Torrance Test for Adults: Verbal and Figural Forms assessed across fluency, originality, elaboration, and flexibility assed post-dance only.	Results from a 2x2 factorial ANOVA indicated no statistically significant main effects for level of arousal on flexibility. Although, a statistically significant quadratic trend demonstrated that both low and high levels of arousal, but not moderate arousal may facilitate flexibility (β= 3.1, p<.05). An interaction effect was also apparent between valence and arousal on overall creativity (summative score; F(2,84).3.43, p<.05, n^2 = .05) as well as on creative fluency. Low arousal was associated with

				to low, moderate, and high levels of arousal (measured via galvanic skin response). Group 1. Low exertion, positive mood induction Group 2. Low exertion, negative mood induction Group 3. Moderate exertion, positive mood induction Group 4. Moderate exertion, negative mood induction Group 5. High exertion, positive mood induction Group 6. High exertion, negative mood induction		higher creativity scores among participants in a negatively induced mood, while high arousal was associated with creativity scores among participants in a positively induced mood. resulted in higher creative scores.
Khasky & Smith (1999)	N = 114 (42 m; 72 f) $\bar{X}$= 24.5, SD = 7.0	Experimental: between-subjects Treatment groups 1-3: N= 20, 19, 19 = 58 Control: N = 56	Guided embodied relaxation exercises	Group 1. Progressive muscle relaxation (squeeze and release) guided through audiotaped instructions Group 2. Yoga stretching of the same target body	Torrance Tests of Creative Thinking: Verbal and Figural Forms assessed across fluency, flexibility, originality, and elaboration. Creativity	Analyses of variance results showed no statistically significant mean differences on Figural or Verbal Creativity ($F(3,119)=.31$, $p>.05$).

				parts as the progressive muscle relaxation group Group 3. Guided imagery instructions encouraged participants to imagine a "relaxing scene or setting, making the scene become as vivid and real as possible, [via] using all of the senses." Group 4. Magazine reading	was assessed post-embodied manipulation only.	
Kim (2015)	**Study 1:** N=50 (14 m; 36 f) **Study 2:** N=32 (5 m; 27 f) **Study 1:** $\bar{X}$= 20.86, Range= 18-37, SD= 2.81 **Study 2**: $\bar{X}$= 21.69, Range = 18-52, SD = 6.23	**Study 1 & 2:** Experimental: Between-subjects	**Study 1 & 2:** Affect (PANAS) Personality (Creative Personality Scale) Squeezing a Ball	**Study 1:** Group 1. Soft Ball (gel stress ball) Group 2. Hard Ball (lacrosse ball) Participants squeezed the ball using their non-dominant hand for three minutes while solving each TTCT tasks (9-min total)	**Study 1:** Three verbal TTCT tasks scored across fluency, flexibility, and originality **Study 2:** RAT 10-items (7-minutes)	**Study 1:** Participants whom squeezed the soft, gel ball achieved higher standardized summed (fluency + flexibility + originality) scores (M=0.96, SD=2.68) than participants in the hard ball condition (M.=-0.96, SD=1.83), t(48)=2.97, p=.005). The soft ball group scored higher for fluency (M=29.36, SD=8.73) than the hard ball group (M=25.04, SD=6.03), t(48)=2.04, p< .05). The soft ball group achieved higher originality (M=9.08, SD=5.36) than the hard ball group than those in the hard ball condition (M=4.56, SD=3.00), t(48)=3.68, p< .01). There was no statistically significant difference between groups on flexibility scores (t(48)= 1.57, p=0.12. Study 2: Participants achieved higher successful completion rates in the hard ball condition

						(M=6.12, SD=0.58), compared to the soft ball group (M=4.33, SD=1.72), t(30)=3.06, p=.005).
Kirk & Lewis (2017)	**Study 1:** N=78 (31 m; 47 f) **Study 2:** N= 54 (27 m; 27 f) **Study 1:** $\bar{X}$= 10.10, Range= 9-11, SD= 0.56 **Study 2**: $\bar{X}$= 8-11 9.45, SD = 0.75	**Study 1:** Experimental: between-subjects and within-subjects **Study 2:** Experimental (non-randomized): between-subjects	**Study 1:** Gesture manipulations coded as iconic gestures (gesture meaning is equivalent to linguistic meaning), with five categories; two-handed gestures were also coded for dominant function, as well as coded separately when each hand executed a separate function AUT item manipulability survey: Adults were asked to rate the perceived ease of miming, form manipulation, and graspability of each AUT item **Study 2:** Number of gestures, not coded for type British Picture Vocabulary Scale used to assess	**Study 1** 1: gesture-allowed condition (Study 1: n = 26) 2: gesture-restricted and gesture-allowed (Study1: n = 52) **Study 2** 1: gesture-allowed condition (Study 2: n = 27) 2: gesture-encouraged condition (Study2 :n = 27)	**Study 1:** Oral divergent thinking performance on the AUT (6 tasks x no time-limit; counterbalance sets A & B; assessed fluency, flexibility, and originality **Study 2:** Oral divergent thinking performance on the AUT (12 tasks x no time-limit; assessed fluency, flexibility, and originality	**Study 1:** Children whom gestured in the gesture-allowed condition generated more uses (fluency) than those whom did not. However these differences were not statistically significant (*t*(72)=−1.92, *p*=.059). Similarly, there were no statistically significant differences in originality (*t*(28.22)=−1.45, *p*=.159) and flexibility scores (*t*(30.52)=−0.68, *p*=.503) between gesturers and non-gesturers in the gesture allowed condition. Differences in fluency, (*t*(29)=1.17, *p*=.251), originality (*t*(29)=1.41, *p*=.170), and flexibility performance (*t*(29)=1.11, *p*=.277) also did not reach statistical significance when comparing the gesture-allowed and gesture-restricted conditions. **Study 2:** Differences in Fluency, (*t*(43.35) =3.59, *p*=.001, Cohen's *d* = 0.98) were statistically significant between the gesture-allowed and gesture-encouraged conditions. Originality (*t*(52) =0.85, *p*=.401) and flexibility performance (*t*(52) =−1.09, *p*=.280) did not reach statistical significance when comparing the gesture-allowed and gesture-encouraged conditions.

			verbal ability			
Kuo & Yeh (2016)	**Study 1:** N = 64 (24 m; 40 f) n= 16 participants per four groups **Study 2:** N = 32 n= 16 participants per four groups **Study 1:** $\bar{X}$ age = 23.95, SD = 2.72 **Study 2:** $\bar{X}$ age = 74.06, SD = 6.22	Experimental: Between-subjects	**Study 1 & 2:** Creativity Assessment Packet (CAP) Processing Speed Cognitive Flexibility	**Study 1 & 2:** Group 1. Rectangular-walking path (2-min walk) Group 2. Free-walking path (2-min walk) **Study 1 only:** Groups 3 and 4 were paired. Group 3. Free-generation of a path using a laser pointer. Group 4. Random-experienced generation (followed the path created by the free-generation participant	**Study 1 & 2**: AUT (chopsticks) (10-min) scored across fluency, flexibility, and originality **Study 1:** Written AUT **Study 2**: Oral AUT	**Study 1:** MANOVA results demonstrated statistically significant effects for fluency ($F(3,60) = 8.44$, $p < 0.001$, $n^2_p = 0.30$), flexibility ($F(3,60) = 4.30$, $p = 0.008$, $n^2_p = 0.18$), and originality $F(3,60) = 12.35$, $p < 0.001$, $n^2_p = 0.38$). Participants in the free-walking condition achieved higher AUT fluency than rectangular-walking (p = 0.001), free-generation (p = 0.003) and random-experienced (p = 0.002). Participants in the free-walking condition achieved higher AUT flexibility than rectangular-walking (p = 0.019), and random-experienced (p = 0.049). There were no statistically significant differences between free-walking and free-generation flexibility scores (p = 0.16). Participants in the free-walking condition achieved higher AUT originality than rectangular-walking (p < 0.001), free-generation (p < 0.001) and random-experienced (p < 0.001). **Study 2**: MANOVA results demonstrated statistically significant effects for fluency ($F(1,30) = 16.77$, $p < 0.001$, $n^2_p = 0.36$), flexibility ($F(1,30) = 15.74$, $p = 0.001$, $n^2_p = 0.30$), and originality $F(1,30) = 15.74$, $p < 0.001$, $n^2_p = 0.34$). Free-walking participants achieved statistically significantly higher scores on AUT fluency, flexibility, and originality than all other groups (results shown in table) MANOVA results also indicated that younger adults scored higher than older individuals on AUT fluency ($F(1,60) = 17.08$, $p < 0.001$, $n^2_p = 0.22$), flexibility ($F(1,60) = 27.04$, $p < 0.001$, $n^2_p = 0.31$), and originality ($F(1,60) = 10.56$, $p = 0.002$, $n^2_p = 0.15$). However, there was no

						statistically significant fluency, flexibility, and originality interaction effect present between free-walking older and younger participants, suggesting free-walking was supported favorable AUT performance within both study populations (*p*s > 0.30),
Leung et al. (2011)	**Study 1:** N= 40 (28 m; 12 f) **Study 2a:** N= 102 (50 m; 52 f) **Study 2b:** N= 104 (38 m; 66 f) **Study 3:** (mental imagery-excluded from review) **Study 4:** N= 64 (25 m; 39 f) Undergraduates participated in all studies.	Experimental: **Study 1:** Between and within-subjects **Study 2a:** Between-subjects **Study 2b:** Between-subjects **Study 4:** Between-subjects	**Study 1:** Two-hand gestures (*"On the other hand"*) **Study 2a:** Sitting inside or outside a box **Study 2b:** Rectangular-walking, free-walking, sitting **Study 4:** Recombination (*"putting two and two together"*)	**Study 1:** Trial 1. Participants generated ideas holding their right hand toward the wall with palm facing upward and left hand behind their backs. Trial 2. Control participants were asked to perform the same hand action when generating additional ideas, while Experimental participants raised their left hand toward the wall and right hand behind the back. **Study 2a:** Group 1. Participants completed the RAT sitting inside a 5x5 cardboard box Group 2. Completed the RAT	**Study 1:** AUT (Novel uses for a building complex); no time constraint; scored across fluency, flexibility, and originality **Study 2a:** RAT (10-item task) **Study 2b:** Divergent thinking tasks: Droodle Task (caption-making) scored for deviation from example captions and originality. Lego Task (writing up to eight potential objects represented by Lego blocks scored across deviation from examples, fluency,	**Study 1:** There was no statistically significant main effect for condition. However, on Trial 2, participants whom switched hand actions achieved higher fluency scores (M=8.17, SD=4.00) than the control condition (M=5.75, SD=3.15), t(38)=2.02, p=.05, n^2_p =.10). Similarly, flexibility (F(1,38)=4.28, p=.045, n^2_p =.10) and originality (F(1,38)=6.53, p=.02, n^2_p =.15) were higher in Trial 2 within the switched hand condition compared to the control condition. **Study 2a:** RAT performance was higher among participants sitting outside of the box (M=6.73, SD=0.50), compared to those seated inside the box (M=5.08, SD=0.51), as well as control participants (M=5.43, SD=0.35), F(1,99)=3.93, p <.05, n^2_p = .06). **Study 2b:** Deviation from example Droodle captions was higher in the free-walking group (M=6.24, SD=0.94), compared to the rectangular-walking group (M=5.68, SD=0.95), and control group (M=5.52, SD=0.96), (F(2,97)=5.34, p=.01, n^2_p =1.00). Originality scores were also highest in the free-walking group (F(1,97)=10.23, p<.01, n^2_p =1.00). Deviation from example Lego representations was higher in the free-walking group (M=7.36, SD=2.84), compared to the rectangular-walking (M=9.32, SD=3.49), and control groups (M=8.36, SD=2.98; F(2,101)= 3.40,

				sitting outside a 5x5 cardboard box Group 3. Completed the RAT sitting in a normal lab space (control) **Study 2b:** Group 1. Participants read task instructions and spent 2-min walking along a 6x8 rectangular path while thinking about possible answers. Group 2. Participants read task instructions and spent 2-min walking freely and thinking. Group 3. Participants read task instructions and spent 2-min sitting and thinking (control). **Study 4:** Group 1. Participants completed the RAT and Lego Task after combining paper from a left-positioned stack with paper from a right stack and placing the combination in the middle	flexibility, and originality. Study 4: RAT (5-item) and Lego Task	p=.04, n^2_p =0.06). Originality scores were also highest in the free-walking group (F(1,101)=5.22, p<.02, n^2_p =0.05. Fluency and flexibility scores were not statistically significant across conditions(F_s<0.89), nor were originality scores between the rectangular-walking and sitting conditions (F<1.63). **Study 4:** RAT performance was higher among participants combining the paper (M=2.78, SD=1.19), than those in the non-combination condition (M=1.92, SD= 0.97; F(1,62)=8.92, p=.004, n^2_p =.13. Lego Task scores were not meaningfully different between groups (Fs<2.98).

				of the stacks for 2-min. Group 2. Completed the RAT and Lego Task after placing paper from either the right or the left (counterbalanced) stack to the middle.		
Slepian & Ambady (2012)	Study 1: N = 30 (37% m, 63% f) Study 2: N=30 (47% m, 53% f) Study 3: N=150 (54% m, 46% f) Undergraduate	Experimental: (Pilot Study) Between-subjects	**Study 1 & 2** Line drawing manipulation Self-reported mood	**Study 1 & 2:** Group 1. Fluid condition: Drew three fluid (curved) figures) Group 2. Rigid condition: Drew three rigid (straight-lines) figures	**Study 1** AUT (1 task x 1-min) assessed for fluency and originality **Study 2** Category Inclusiveness Task assessed for associative flexibility **Study 3** Remote Associates Task (RAT; 15 x 5 seconds) for 75 participants Graduate Record Examination (GRE) math problems (6 x 1-min) for 75 participants	Participants whom were randomized into the fluid condition demonstrated higher fluency (*t*(28)= 2.71, p<.01) and originality (*t*(28)= 2.29, p<.03) than those in the rigid condition Participants whom were randomized into the fluid condition demonstrated higher associative flexibility for weak (*t*(28)= 2.19, p<.04) and moderate exemplars (*t*(28)= 3.10, p<.004) than those in the rigid condition. Participants whom were randomized into the fluid condition demonstrated higher performance on the RAT than those in the rigid condition (*t*(65)= 2.13, p<.04), with no differences between conditions on GRE problem performance (*t*(73)= 0.34, p = .74)
Thomas & Lleras (2009)	N = 52 Undergraduate (no range or mean values reported)	Experimental Between-subjects	“Exercise breaks” during insight problem solving	Swing group: Swung arms back and forth Stretch group: raised arms to sides (abduction	Insight performance (Maier’s (1931) two-string problem) Metrics scored:	A log-rank survival analysis confirmed that the swing group and stretch group achieved statistically significantly different solution rates, with the swing group outperforming the stretch group on the insight task [x^2 (1,52) = 3.95, p = .047].

				from torso) in a stretching movement) There were eight 2-min intervals, with all intervals consisting of 20-seconds of movement and 100-seconds of insight problem-solving	Success/Failure # of attempts	
Vallée-Tourangeau, Steffensen, Vallée-Tourangeau, & Sirota (2016)	Study 1: N = 50 (6 m; 44f) Model condition: n = 24 Sketching condition: n = 26 Study 2: (9 m; 38 f) Model condition: n = 24 Sketching condition: n = 23 Undergraduate and postgraduate students Study 1: $\bar{X}$= 24.2, SD = 8.1) Study 2: $\bar{X}$= 21.5, SD = 4.73)	Experimental: between-subjects	Study 1: Interactivity manipulation Working memory assessment Need for Cognition Scale Actively Open-minded Thinking Scale Study 2: Interactivity manipulation Batey (2007) Biographical Inventory of Creative Behaviors (BICB) Barratt Impulsiveness Scale Subjective Numeracy Scale Mathematics Anxiety Scale Alternative Uses task- *Brick* (only	In Study 1 only, , each participant initially used a pen and paper to sketch potential solutions to the problem for 3-min (during which, no participant was able to solve the task). Study 1: Artefact group. Participants used materials build a model, using 20 pipe cleaners and 17 zebra paper clips (Study 2: 4 metal hoops and 17 animal figurines), of potential solutions for 10-min. Drawing group. Participants could sketch solutions using a	17A Insight Problem Instructions: "How do you put animals in four enclosures in such a manner that there is an odd number of animals in each of the four pens?"	Study 1: In the model-building group. ten participants provided a correct or partially correct solution to the 17A problem, whereas none in the sketching condition solved the problem. Barnard's exact unconditional test indicated a statistically significant effect (3.64, $p < .001$). Study 2: In the model-building group, 13 participants solved the 17A insight problem correctly, compared to 14 in the sketching group. This difference in outcome performance was statistically significant, χ^2 (1, N = 47) = 6.88, p = .009, Cramer's V = .383. The model-building group in Study 2 outperformed the model-building group in Study 1, with statistically significant differences in achievement of correct solutions, χ^2 (1, N = 94) = 6.97, p = .008, Cramer's V = .272. In both groups, AUT fluency was statistically significantly correlated with attainment of correct solutions (model-building: r_{pb} (21)= .43, p = .040; sketching: r_{pb} (22)= .47, p = .022). Additionally, BICB scores were statistically significantly correlated with solution rate in the model-building (r_{pb} (22) = .45, p=.029, but not the sketching group (r_{pb} (21)= .35, p = .097.

			scored for fluency)	stylus and electronic tablet for 10-min (Study 2: Participants were permitted to view a picture of the materials given to the model-building group).		
Wang, Lu, Runco, & Hao (2018)	N= 41 (3 m; 38 f) $\bar{X}$ age= 21.00, SD = 1.98; university undergraduates	Experimental: Between- and within-subjects mixed design	Runco Ideational Behavior Scale (RIBS) Valence and Arousal ratings (SAM) Post-task ratings of difficulty, depletion, and perception of embodiment	Between-subject conditions: Break condition: presented walls appeared in the middle of each virtual reality (VR) corridor. Participants broke the wall by clicking the "back" button on the game controller, or "knocking the wall down." No-break condition: participants were presented with empty corridors (no walls)	Two AUT divergent thinking tasks were performed using virtual reality routes and were assessed across fluency, flexibility, originality, and persistence Within-subject conditions During walking: (oral solutions while playing the game) After walking: oral solutions were provided after walking	Results indicated a statistically significant main effect of condition on AUT fluency ($F(1, 39)= 16.14$, $p < 0.001$, $\eta p2 = 0.29$), flexibility, ($F(1, 39)= 10.71$, $p<0.01$, $\eta p2=0.22$) persistence, ($F(1, 39)= 4.67$, $p<.05$, $\eta p2 = 0.11$), and originality scores ($F(1, 39) =18.98$, $p<0.001$, $\eta p2=0.33$). Participants in the "break condition" outperformed those in the "no break" condition ($p<.01$ for fluency, flexibility, and originality; $p<.05$ for persistence; results shown in figure). Participants spent longer generating ideas whilst walking than when reporting AUT uses after walking ($F(1, 39)=196.05$, $p< 0.001$, $\eta p2 =0.83$). Additionally, participants spent longer reporting ideas in the "break" versus "no-break" condition ($F(1, 39)=9.93$, $p< 0.003$, $\eta p2 =0.2$).
Weller, Villejoubert, & Vallée-Tourangeau (2011)	N=50 (20 m; 30 f) $\bar{X}$ age= 27.84, SD = 12.11; university students and staff	Experimental: between-subjects	Static versus interactive manipulation Numeracy test National Adult	Group 1. Static condition: presented problem was observed, and participants informed researchers	Matchsticks insight problem (4 problems in each category (16 problems total); 3-min each) scored for	There were statistically significant main effects for problem category (out of 4 possible categories) and group, as well as a statistically significant interaction effect $F(3, 144) = 5.03$, $MSE = .079$, $p = .002$. Statistically significant differences in correct solution rate were

			Reading Test Beta 3 Test (visuo-spatial reasoning)	which matchstick could be moved to solve the insight tasks. Group 2. Interactive condition: presented problem was observed, and participants manipulated the matchsticks to solve the insight tasks.	percentage of correct solution rate	observed between Type A and Type C (p= 0.002) problems and Type B and Type C problems alone (p=0.03), with the interactive group outperforming the static group. Interactive group participants achieved a higher solution rate for Type C problems (30%) than the static group (12%). The largest difference between groups was observed for Type D problems (Interactive group: 50%; Static group: 20%). Note, these percentages were obtained from figure one in the manuscript.
Yuan, Lu, & Hao (2018)	N=108 (23 m; 85 f) $\bar{X}$ age= 22.05, SD = 2.56; range 18-28 University students	Experimental: between-subject	Emotional Induction video clip (2-min) Valence and Arousal (Self-Assessment Maniken Scale), self-reported enjoyment, power, and effort Action manipulation: Seated arm flexion or arm extension while holding a ball	Four between-subjects conditions 1: approach arm action-positive emotional induction (n=26) 2: approach-negative (n=28) 3: avoidance arm action-positive emotional induction (n=26) 4: approach-negative (n=28)	Two AUT problems (brick and chopsticks) in 10min (5-min per problem), with 1-min break between each problem	There was a statistically significant main effect of action for fluency, F (1, 104) = 4.83, p < .05, ηp2 = 0.04. Arm flexion resulted in more ideas (M = 8.47, SD = 4.30) than arm extension (M=7.08, SD=2.82). Also, there was a statistically significant interaction effect of action × emotion on fluency was observed, F (1, 104) = 11.02, p < .01, ηp2 = 0.10. Arm flexion plus negative emotion (M = 9.98, SD = 4.55) related to higher fluency than positive emotional induction (M = 7.70, SD = 3.60), t (52) = 32.62, p < .05, Cohen's d=0.73. Arm extension condition, plus negative emotion indicated lower fluency (M = 6.29, SD = 2.80) than with positive emotion (M = 7.82, SD = 2.68), t (52) = −0.2.01, p < .05, Cohen's d = −0.56 (see Fig. 2). There was no statistically significant main effect of action on originality, however, arm flexion participants with negative emotion demonstrated higher originality (M=4.73, SD=3.35) than those with positive emotion (M=3.11, SD = 2.22), t (52) = 2.12, p < .05, Cohen's d = 0.59. There were no significant differences between emotional induction

						among those in the extension condition. Arm flexion plus negative emotion resulted in higher flexibility (M=5.36, SD=1.27) positive emotion (M=4.46, SD=1.45), t (52)=2.43, p < .05, Cohen's d=0.67. However, there were no significant differences between emotional induction extension condition participants, *t* (52) = 1.32, p > .05.
Zhou et al. (2017)	**Study 1a & 1b.** N=63 (21 m; 42 f) **Study 2a & 2b.** N=60 (13m; 47 f; 1 f excluded in 2b.) **Study 1a & 1b:** $\bar{X}$ age= 21.25 years; range 18-25) [1b. Same participants] **Study 2a & 2b.** $\bar{X}$ age= 20.98 years; range 18-24) [2b. Same participants; One was excluded; thus, $\bar{X}$ age= 21.00 years]	Experimental: within-subject (counterbalanced order of conditions, with 2-min break between each)	**Study 1a & 1b:** Ambulatory-based bodily state manipulations Subjective rating of preference for each bodily state Walking speed **Study 2a & 2b.** Physical position-based bodily state manipulations Subjective rating of preference for each bodily state	**1a & 1b)** Order of conditions counterbalanced. Group 1. Standing condition: Participants stood in the center of the lab-space while completing the DIT. Group 2. Roaming condition: participants completed the task while freely roaming. Group 3. Figure-of-8 Walk test condition: participants completed the task while walking in an 8-shaped configuration **2a & 2b)** Order of conditions	1a) Oral DIT (design-improvement) divergent thinking task scored across task completion, and originality 1b) CIT divergent thinking and imagination task (10 trails; 1-min allocated to each trial) scored across fluency, flexibility, and novelty **2a)** Oral AUT (pencil) divergent thinking task scored across fluency, flexibility, and originality (10 trails; 1-min allocated to each trial) **2b)** Oral FCT	**1a)** Completion rates were highest in the roaming condition (M = 90.63%, SE = 0.01) compared to non-roaming (M = 83.17%, SE = 0.02) and standing (M = 75.24%, SE = 0.02; p < 0.001), with a statistically significant main effect for condition (F(2,124) = 38.60, p < 0.001, n^2= 0.384). Statistically significant main effects (F(2,124) = 61.04, p < 0.001, n^2 = 0.496) indicated originality was highest in the roaming condition (M = 3.35, SE = 0.04), compared to figure-8 walking (M = 3.08, SE = 0.03), and standing (M = 2.85, SE = 0.04, p<.001). **1b)** Statistically significant main effects were observed for fluency (F(2,124) = 90.69, p < 0.001, n^2= 0.594), flexibility, (F(2,124) = 60.06, p < 0.001, n^2= 0.492) and originality (F(2,124) = 165.92, p < 0.001, n^2= 0.728). Fluency, flexibility, and originality were highest in the roaming condition, compared to constrained walking and standing (p<.001). Constrained walking was also associated with higher fluency, flexibility, and originality than standing (p<.001) **2a)** Statistically significant main effects were determined for fluency, (F(2,118) = 34.37, p < 0.001, n^2= 0.368), flexibility, (F(2,118) = 52.14,

				counterbalanced. Group 1. Standing condition: Participants stood in the center of the lab-space while completing the AUT. Group 2. Sitting condition: participants completed the task while sitting in a chair with their hands on their laps. Group 3. Lying condition: participants completed the task while lying on a bed with their hands parallel with their bodies.	imaginative thinking task (geometric shape combinations) scored across completion rates and originality (10 trails; 2-min allocated to each trial)	$p < 0.001$, $n^2 = 0.469$), and originality ($F(2,118) = 78.06$, $p < 0.001$, $n^2 = 0.570$). Fluency, flexibility, and originality were highest in the standing condition, compared to sitting and lying ($p<.001$). No statistically significant differences were observed between sitting and lying on any of the dependent measures. **2b)** Completion rates were highest in the standing condition (M = 80.00%, SE = 0.03) compared to sitting (M = 74.07%, SE = 0.03) and lying (M = 71.86%, SE = 0.03; $p < 0.001$), with a statistically significant main effect for condition $F(2,116) = 6.59$, $p < 0.005$, $n^2 = 0.102$). Originality was highest in the standing condition (M = 3.09, SE = 0.04) compared to sitting (M = 2.51, SE = 0.06) and lying (M = 2.50, SE = 0.07; $p < 0.001$), with a statistically significant main effect for condition $F(2,116) = 39.76$, $p < 0.001$, $n^2 = 0.407$). No statistically significant differences were observed between sitting and lying on any of the dependent measures.

CHAPTER V

EXPERIMENTAL STUDIES

I. EXPERIMENTAL EFFECTS OF ACUTE EXERCISE AND MUSIC LISTENING ON COGNITIVE CREATIVITY

Abstract

The purpose of this study was to extend previous experimental work suggesting that both exercise and music-based interventions may influence creativity processes, by investigating the independent influences of exercise or music stimuli on verbal creative performances in the laboratory environment. Thirty-two students at the University of Mississippi participated in this within-subject intervention, which included three laboratory visits per participant. Individuals participated in three 15-minute, randomized experimental conditions: Treadmill walking, self-selected music, or a seated control period, and subsequently completed four creativity assessments during each visit (three tests of divergent thinking, and one test of convergent thinking), with the order of divergent thinking tasks counterbalanced. Creativity task performance was independently scored across four dependent parameters, which included *fluency* (i.e., total number of ideas), *flexibility* (i.e. total number of categories), *originality* (responses thought of by $<5\%$ of the sample), and *elaboration* (i.e. degree of supplementary detail included per idea). Repeated Measures ANOVAs indicated that creativity scores for *fluency* ($F(2, 60)=0.63$, $p=.94$), *flexibility* ($F(2, 60)=0.64$, $p=.53$), *originality* ($F(2, 60)=0.23$, $p=.78$), and *elaboration* ($F(2, 60)=2.74$, $p=.073$), were not statistically significant across the visits. The present study further highlights the critical need for improvement in the assessment and evaluation of laboratory-assessed cognitive creativity.

Introduction

Research examining the shared pathways between emotion and arousal, associative memory, and creativity potential has yet to evaluate the distinct influence of music and ambulatory exercise on these relationships. A commitment to making sound empirical decisions in scientific investigation must be applied to creativity research, if the convoluted field is to move past its current restraints.[384] Attempts to confine creativity to a scientifically testable, operational definition are lacking, beyond the general agreement between classic and modern research that delineates creativity as a complex cognitive process capable of producing novel and worthwhile outcomes.[385,386] Methodologically, this embeds unavoidable limitations to truly sufficient and consistent measurements of such an opaque construct. While many researchers have devoted their professional careers to the ambitious undertaking of mechanistically and practically describing the correlates of creativity, many findings remain equivocal across disciplines. Even less experimental creativity research has been conducted with exercise assessed as a potential predictor, despite a burgeoning of research examining the effects of exercise on other cognitive parameters, such as executive function and memory. To date, only thirteen research experiments[387-400] have been conducted to assess the plausible link between exercise and creativity, with only one study evaluating the distinct and combined influence of music and exercise on figural (i.e. picture-based) creative performance.[390] Physical activity is suggested to influence neurotransmitter release,[113] higher-order cognitions, including reasoning, goal-setting, and memory function,[114,401,402] as well as affect and motivational responses, which may drive behavioral and cognitive responses,[113] including the generation of creative outputs. Although not an exhaustive list, more work has identified associations between cognitive creativity and functional brain changes in musically talented individuals.[90,108,403-408] Nevertheless, our current inquiries are warranted, as surprisingly less research has examined the impact of everyday music listening on creative performance. To this end, the following sections will discuss previously hypothesized influences of exercise and music on creativity, harmonizing the scientific rationale for this investigation.

Music Listening and Creativity

The influences of listening to music on affect and arousal have been widely demonstrated by numerous experiments designed to examine this association spanning a variety of research disciplines. In fact, music has been cited as the language of emotion.[409] The emotive power of music listening may increase cognitive performance across age and culture.[410,411] Passive musical stimuli, which involve listening alone, in contrast to the active composition of music[412], may implicitly cue memory associations and autobiographical memory, namely self-judgments colored by relevance to past experiences[413,414]. One mechanism by which this process may occur is music-associated activation of limbic system and paralimbic structures including the amygdala and hippocampus.[415-418] Increased limbic activity may facilitate memory regulation and emotional processing within perceptual memory systems[414], specifically areas involved in abstract memory formation and the organization of auditory information[418]. Further, music listening potentially promotes modulation of cerebral blood flow, which has been implicated in affect and emotional regulation.[415,419] Specifically, because the hippocampus and amygdala are known to process both intensely positive and negative emotions, decreases in cerebral blood flow in these regions, coupled with simultaneously increased blood flow in the midbrain may blunt, or even inhibit, negative emotions, and enhance the pleasurable responses associated with positive affect.[420] Distributed neural activation of the Default Mode Network (DMN) is suggested to play a role in cognitive abstraction, mind-wandering, episodic future-oriented thinking, linkages of diffuse conceptual features,[38] and free-flowing thought processes. Functional coupling between the DMN and Executive Control Network (ECN), allows for DMN-mediated optimal search for infinite creative solutions, and ECN-governed deliberation and appropriate response selection of creative products that are both original and meaningful in line with task demands[43]. Music-associated concurrent activation and deactivation of distinct neural sites have been implicated in cognition, memory, attention, arousal, and emotional reactivity. Further, self-reports of intense experiential episodic memories have been associated with DMN activity, illustrating the dynamic role functional brain connections play in mediating personal reactivity to, and appraisal of, musical stimuli.[421] Crucially, listening to preferred music is perhaps an impetus for DMN activation, and subsequent creative thinking processes, which was of primary interest for the present study.[421]

Personal experiences underlying learning and memory are guided by emotions, which are seamlessly interwoven into the fabric of human experience. Emotional relevance primes the acquisition of new memories, and promotes their consolidation into long-term memory.[401] Affect and psychological arousal may profoundly mediate one's ability to use salient events from the past to solve problems by mapping preexisting knowledge to contextually novel domains. Music has also been suggested to drive motivational state and improvisational creativity via an increase in medial prefrontal cortex activity.[90] Thus, the potential for self-selected music listening to prime creativity is an important avenue for continued research efforts.[90,108,407,421,422]

Exercise and Creativity

Physical activities have been shown to induce synaptic release of neurotransmitters, such as dopamine, which influence both affect and arousal. Exercise-related modulation of dopaminergic (and associated "motivational" neurotransmitter)[423] activity may partially mediate creative capacities. Exercise mediated dopamine release in the basal ganglia and prefrontal cortex is associated with arousal, cognitive control, and prepotent response inhibition.[77,113]

Prefrontal connections stimulate comprehension, planning, and reward perception in goal-motivated pursuits.[77] Additionally, exercise may advance neuronal growth and development in critical brain regions linked with memory, emotional responses, and creative mentation, justifying the need for continued empirical work on these associations in the context of creativity.

Physical activity has been identified as a mind-freeing activity. Physical exercise requires effort, attention, and self-regulation of both simple and complex movements.[402,424,425] Although, despite these exercise-induced mental and motor control mechanisms, creative proliferation of ideas may also be fostered by self-awareness,[426] as well as the enhancement of associative memory, which has been linked with aerobic exercise.[427,428] The plausibility for associative memory to be instrumental in sparking creativity is important to consider, as this aspect of cognition is distinct from prefrontal-parietal connections that are suggested to support fixated focus. While performance on certain creativity assessments may be sensitive to distraction, most creative activities do not demand strong cognitive control. For example, convergent creative capacity may be impaired when walking, perhaps due to executive function requirements for dual-task processing of varied stimuli, coupled with the challenge of correctly converging on a unified solution[388]. Although, for tasks which involve production of many thoughts or solutions, relaxing inhibitory competition, or broadening the scope of memories accessible for retrieval, may cue previously subconscious, or hidden, associations, illuminating a rich cognitive landscape for ideation.[388] Taken together, much work has demonstrated that both exercise and music-based interventions may be influential on mechanisms underlying creativity processes, with less research investigating the direct influence of these conditions on creative production in the laboratory environment. Therefore, the principal aim of this study was to examine the individual effects of exercise or music on creativity among college students.

Methods

General Procedure

This study was approved by the institutional review board at the University of Mississippi and participants provided written informed consent before any data collection began. The experiment was conducted utilizing a within-subject, counterbalanced design. Participants completed three laboratory visits, over a period of 5-12 days, with at least 24 hours between visits. We recruited 33 participants via a convenience-based sampling approach. One individual failed to complete all three visits, thus, 32 participants comprised the analytic sample, which included 96 total visits to the laboratory (32 participants x 3 experimental visits). The sample size for this within-subject experimental design is similar to other research[388], and was deemed appropriate following an a-priori power analysis, considering data from Oppezzo and Schwartz,[388] with inputs of d=0.25, alpha=0.05, and power of .80, 30 participants were sufficient to achieve adequate statistical power.

Participants were excluded if they were current smokers, were taking medication for depression or anxiety, and/or drank alcohol, smoked marijuana, or consumed any illegal drugs during the past 48 hours. Participants were asked to reschedule their visit to another day if they had participated in exercise activities 6 hours prior to their laboratory session or consumed any caffeine three hours prior to the study. Before leaving the laboratory, height (cm) and weight (kg) were recorded. Height was measured at baseline only, while weight was measured at the end of each visit.

Heart rate was monitored continuously during each visit using a chest-mounted Polar HR monitor. After first putting on the heart-rate monitor, verbal instructions detailing the completion of three distinct surveys were given to participants at baseline, emphasizing the importance for reporting how they were feeling in the present moment. The visual Maniken Scale[429] was employed, as it is a feasible, and appropriate measure for assessing experienced pleasure, felt arousal, and dominance in reference to self-reported affective valence and intensity. The Modified Mental Fatigue Scale, is a 10-item scale, which was employed to evaluate various components of present fatigue, and their potential influence on participants' physical and cognitive performance.[430] The 20-item State Trait Anxiety Inventory (STAI) was also administered to evaluate present anxiety prior to both exercise and creativity tasks.[431]

Participants responded to these surveys alone, in a laboratory space, free from distraction. As noted in Table 1, various demographic and behavioral parameters were assessed via survey instruments to provide characteristics of our sample. This included the following variables: age, gender, race-ethnicity, body mass index (BMI), anxiety (STAI), and habitual physical activity.[432-434]

Experimental Manipulations

Condition A- Exercise. Upon survey completion, a resting heart rate was recorded, and the participant was instructed to, "Please walk on the treadmill at a pace of at least 3.0 miles per hour or faster, but one that you can maintain for 15-minutes. This might be a treadmill speed similar to the pace you would walk if you were late to class, but it should not be a run, nor should the level of exertion make you feel uncomfortable." Self-selected, versus researcher-imposed treadmill speed, was chosen to ensure changes in affect would not occur as a consequence of an unenjoyable exercise bout[435]. Participants were informed that the researcher would be exiting the laboratory during the exercise bout but would return briefly at the midpoint (7.5 minutes) of the 15-minute walk, and during the final minute, to record heart rate and rating of perceived exertion, which ranges from a minimal rating of 6, or no exertion, to 20, or maximal exertion (RPE BORG). Participants maintained the same speed throughout the exercise period.

Condition B-Music. Upon survey completion, a resting heart rate was recorded, and participants were asked to put on Bluetooth headphones supplied by the researcher and sit quietly for 15 minutes while listening to self-selected music through their Smart phones. Similar to the exercise condition, self-selected, versus researcher-selected music, was chosen to ensure changes in affect would not occur as a consequence of an unenjoyable listening experience, which we did not anticipate would confound creativity performances. Listening to a researcher-imposed musical selection of positive valence and high arousal (e.g. "happy music") has been shown to enhance divergent thinking compared to silence. However, no statistically significant differences were determined when the "happy music" condition was compared to high positive valence and low arousal (e.g. "calm music"), high negative valence and low arousal (e.g. "sad music") or low valence and high arousal (e.g. "anxious music")[436]. We did not require participants to self-select music in line with any particular emotion, although we expect participants to select personally enjoyable or entertaining songs to listen to during their visit. This music could be streamed from iTunes, Spotify, Pandora, YouTube, or any multimedia outlet of the participants' preference. The principal investigator exited the laboratory but returned briefly at the midpoint of the 15-minute session, and during the final minute, to record heart rate and RPE.

Condition C- Control. Upon survey completion, a resting heart rate was recorded, and participants were asked to put on Bluetooth headphones supplied by the researcher and listen to low-volume white noise to minimize distractions. Further, participants were asked to, "Please sit quietly for 15 minutes while passively browsing social media on your Smart phones. Passive browsing may include viewing pictures and reading messages or posts. Please avoid all active online communication, such as texting, messaging, or commenting/replying to comments. The principal investigator exited the laboratory but returned briefly at the midpoint of the 15-minute session, and during the final minute, to record heart rate and RPE.

Assessment of Creative Performance

The four creativity assessments described below were counterbalanced and administered during each session. However, only one problem or scenario was given for each assessment during each visit (i.e. every participant completed four creativity tests per visit). Depending on the order of randomization, participants either exercised for 15 minutes (at a speed of at least 3.0 mph), listened to a self-selected music playlist for 15 minutes, or rested while passively browsing social media for 15 minutes, prior to completing the creativity assessments.

The Alternative Uses Task (AUT)[437]. This assessment measures divergent creative thinking, or the ability to generate as many novel responses as possible after being presented with a single prompt or stimulus.

"You will be asked to generate unusual and original uses of given conventional everyday objects. Here we are most concerned with the originality facet of creativity. The example word given is "brick." The normal use of a brick would be for construction and would not be acceptable in this case. An unusual and original use for a brick might be weapon or a doorstop. You will have three minutes to complete this task, so please think creatively and quickly. Now please generate as many unusual and original uses for the household item….toothbrush, bucket, or pen (depending on randomization)."

Realistic Presented Problem (RPP) Runco and Okuda[438]. The three RPP tests were originally used by Runco and Okuda,[438] but were adapted for use within this specific sample.

General Instructions: "Next, we will describe a problem, which could occur at school or work. Your task is to first read about the problem and then try to write down as many solutions as you can in three minutes. Please try to be creative and provide only original responses. Creative responses are unusual and worthwhile. An original idea is one that is thought of by no one else."

Tasks. Similar to the text above, only one problem or scenario per creativity task was provided to each participant during each visit (i.e. every participant completed four creativity tasks per visit).

A. Your favorite TV show was on last night. You were so entertained by it that you forgot to do your homework. You are about to walk into your first class when you realize you are supposed to turn in an assignment today. What are you going to do? Tell the professor you forgot. Leave to finish the assignment, and turn it in late, ask a friend to help you? There are many answers to this problem, all of them legitimate…now please turn the page, take your time, have fun, and remember to try to think of as many original ideas as possible.

B. Your friend Jim sits next to you in class. Jim really likes to talk to you and often bothers you while you are doing your work. Sometimes he distracts you and you miss an important part of the lecture, and many times you don't finish your work because he is bothering you. What should you do? How would you solve this problem? Remember to list as many ideas and solutions as you can.

C. It's a beautiful day, and a friend wants to go on a day trip. Unfortunately, you have a big project due tomorrow, and it will require all day to complete. You'd rather enjoy the weekend by spending time with your friend. What are you going to do? Try to think of as many ideas and solutions as you can.

Realistic Problem Generation (RPG)[438]. The three versions of the RPG were adapted from the following references.[438-441] General Instructions: "I am going to provide you with a prompt related to your experiences here at the University. Your task is to try to write down as many solutions to issues you determine are relevant in three minutes. Please try to be creative and provide only original responses. Creative responses are unusual and worthwhile. An original idea is one that is thought of by no one else."

Tasks. In line with the previously described RPP tasks, only one problem or scenario per RPG task was provided to each participant during each visit (i.e. every participant completed four creativity tasks per visit).

A. "List different issues regarding the academic environment at Ole Miss that are important to you. These could include improvements you'd hope to see go into effect regarding the courses, student development, policies, professors, or whatever. Try to be as specific as possible and think of as many improvements as you can in three minutes. There are no wrong answers."

B. "List different issues regarding the campus environment at Ole Miss that are important to you. These could include improvements you'd hope to see go into effect regarding involvement opportunities, residence life, student leadership and outreach, intramurals participation, organization and club membership, or whatever. Try to be specific and think of as many improvements as you can in three minutes. There are no wrong answers."

C. "List different issues regarding the health and wellness at Ole Miss that are important to you. These could include improvements you'd hope to see go into effect regarding involvement opportunities, campus-wide promotion, health fairs and events, student health services, professional knowledge and awareness, your personal health, or whatever. Try to be specific and think of as many improvements as you can in three minutes. There are no wrong answers."

The Remote Associates Task (RAT)[442]. The RAT consisted of 10 three-word letter strings of equal difficulty level, based on normative data from Bowden & Jung-Beeman[442], for each visit. Therefore, the 30 utilized letter strings are presented herein. Participants will be told that they will "see three stimulus words and that they should attempt to generate a fourth word, which, when combined with each of the three stimulus words, will result in word pairs that make up a common compound word or phrase."[442] The RAT was always the final creativity assessment participants completed before leaving the laboratory

Statistical Analysis

Stata SE Version 12 was used to calculate univariate sample characteristics shown in Table 1. SPSS v.24 was used to run One-Way Repeated Measures ANOVAs (1x3) of mean differences between each condition (Exercise, Music, and Creativity) on fluency, flexibility, originality, and elaboration, respectively. For all analyses, statistical significance was established as a nominal alpha of 0.05.

Results

Demographic characteristics of the sample are shown in Table 1. The majority (62.5%) of participants were female, undergraduates (56.3%), self-reported "A-level" students (56.3%), from the question, *"On average, would you say you earn A's, B's, C's, or D's in your classes?"* (56.3%). Additionally, the sample was fairly active, as the mean min/week of self-reported moderate-to-vigorous physical activity was 265. Table 3 shows the means and standard deviations for physical and affect measures. All measures were similar across conditions, aside from heart rate during the final minute of the 15-min Exercise condition ($p<.001$), and one minute following the Exercise condition ($p<.001$) and post-Exercise arousal ($p=0.02$).

Creativity task performance was scored in accordance with four dependent parameters. These variables included *fluency* (i.e., total number of ideas), flexibility (i.e. total number of categories) originality (responses thought of by <5% of the sample), and *elaboration* (i.e. degree of supplementary detail included per idea). A point for originality was awarded for any response generated by <5% of individuals in the sample. Total originality was then calculated as a summation of points per original response. Appendix A details a complete explanation of how fluency, flexibility, and elaboration parameters were scored for this study. All participant responses were transcribed for every visit, and each divergent thinking creativity assessment (AUT, RPP, RPG) was subsequently scored by the primary investigator. An acceptable degree of agreement was achieved between the primary investigator and three independent scorers (ICC= 0.903; 0.836; 0.938 between raters 1-2, 1-3, and 1-4, respectively).

Table 2 displays results from the Repeated Measures ANOVAs indicating that *fluency* (F(2, 60)=0.63, p=.94), *flexibility* (F(2, 60)=0.64, p=.53), *originality* (F(2, 60)=0.23, p=.78), and elaboration (F(2, 60)=2.74, p=.073), scores on the AUT were not statistically significant across the visits. However, when corrected for outliers (i.e. removal of participants scoring 3 standard deviations above the mean on creative task performance), *elaboration* became statistically significant (F(2, 54)=4.9, p=.02). Bonferroni post-hoc tests were performed to evaluate effects by condition, with results demonstrating mean elaboration was highest within the Exercise condition ($\bar{X}$=4.1; 95% CI: 2.9-5.3) when compared to Music ($\bar{X}$=2.6; 95% CI: 1.9-3.4) and Control conditions ($\bar{X}$=3.1; 95% CI: 2.1-4.2). Additionally, RAT scores were not statistically significantly different across the visits for attempted word triads (F(2, 60)=0.02, p=0.98), or for correctly solved word triads (F(2, 60)=0.38, p=0.69). Similarly, scores on the RPP and RPG were not statistically significant across the visits (see Table 2).

Discussion

Creative performance was not significantly influenced by our experimentally imposed conditions, suggesting that the effects of music and exercise on creativity were marginal at best within this sample. Although previous work highlights the role of listening to music[390] and movement[387-389] on the generative processes of creativity, we failed to discern similar benefits. However, we did demonstrate a statically significant elevation of post-exercise arousal, although this change was not associated with divergent and convergent creativity performance in this sample. This may indicate that activated mental states may not have a direct influence on certain assessments of creativity, or perhaps that the affectual modulation was not sufficient to facilitate creativity performance in line with increasing arousal. We extended the body of evidence examining the influences of passive music listening and exercise on creative performance, by utilizing verbal assessments of divergent and convergent creative thinking, which is distinct from the only experiment, to our knowledge, which manipulated both music listening and exercise to evaluate associated changes in figural (i.e. picture-based) creativity.[390] Our decision to assess verbal creativity may have practical implications, as figural tasks potentially demand more domain-specific abilities in artistic or spatial competencies, while verbal assessments may be more appropriate for general college-student populations.

The results of this study certainly do not rule out the possibility for exercise and/or music of a different dosage, modality, intensity, etc. to act as a catalyst for acute creativity, but we must now venture down other avenues of scientific plausibility. Previous exercise and creativity research has shown flexibility performance on the AUT was statistically significantly augmented during rest, when compared to intense cycling exercise, but not moderate-intensity exercise.[387] This effect was not different between inactive participants, or those habituated to exercise. Importantly, acute exercise may deplete psychological resources, and direct metabolic resources towards sustaining the physical movement. In theory, higher intensity exercise may potentially impair performance on laboratory measures of divergent and convergent thinking. Other research utilizing an ambulatory-based protocol, has shown that while convergent thinking performance may decrease during walking, divergent thinking and novel, high-quality analogy ideation may be increased when walking. This study also indicated an enriched environment may play a beneficial role in enhancing novelty, albeit perhaps at the expense of high-quality responses.[388] We did not assess creativity during walking, but perhaps moderate-intensity exercise is capable of inducing a transient augmentation of certain aspects of creative thinking during the bout itself.

However, a series of experiments should be conducted to confirm or refute this hypothesis. Conversely, high-intensity exercise is also a worthwhile stimulus for future research to consider, as our results indicate that, despite statistically significant elevation of arousal from pre-to-post exercise, as well as a 35 bpm increase in heart-rate during exercise, subsequent creativity performance was not facilitated by these physiological responses.

No exercise and creativity experiment, to our knowledge has allowed for participant self-selection of music. To this end, we wanted to explore the utility of participant-selected musical influences on creativity, examining whether the relationship would hold true in the absence of acute exercise accompaniment. Perhaps the self-selected music stimulus and social media exposure elicited emotional responses, either too similar or distinct, which failed to reach a sufficient "threshold" of intensity to differentially impact creativity per our protocol. Forthcoming research should demonstrate if an intensity "threshold" hypothesis holds true for experimenter-imposed music and/or social media selections as well, or if these stimuli demonstrate comparable efficacy in empirical evaluations of acute creative thinking. Past work has suggested a state of relaxed attention, or broadening of conceptual focus, may promote creative performance on tasks of divergent thinking[443]. It is possible exercise and/or listening to music may have influenced a cognitive shift to narrowed attention, alternative to what we initially expected. Attentional constrictions, either exercise or music induced, may have limited the ability for participants to retrieve task-appropriate memories across a spectrum of experiences. Thus, asking participants to exercise or listen to music for 15-minutes, and immediately begin creativity assessments, may have left individuals in a state of narrowed perceptual attention, which would have impeded creativity performance on our selected assessments of creative capacity. An alternative time-related explanation may be the lack of an allocated incubation period for participants to cogitate creative responses to tasks. Recent work indicates creative thinking may be facilitated via subconscious mental processes stimulated during time spent engaged in cognitively undemanding activities.[444] Such activities must be distinct from the task at hand, meaning if we had strategically positioned exercise or music to serve as an incubation period following experimental task instructions provided for each creativity assessment, participants would have been randomized to participate in 15 minutes of "mind-freeing" behavior, potentially engendering more creative responses.

Aside from deducing scientifically plausible inferences from the results of this study, comprehensive evaluations must also subject the traditional theories of creativity research to careful scrutiny. Devoting time and resources to empirical investigations of creativity seems an important endeavor for the future of business, education, health, and society at large. However, it is worth considering whether creativity *necessarily* influences productivity and achievement in these domains. Creativity may be embedded in a variety of metacognitive processes, including an enhanced ability to access working memory, as well as the integration of critical thinking and problem-solving skills, or may serve as a downstream by-product of these factors. Thus, researchers must ask if creativity is a driving factor, or a mere by-product of higher-order cognition. In other words, improved capacity for experiential recall could influence the generation of new ideas, irrespective of creative ability. In this vein, it is reasonable to suggest creative thought manifests as a mediating variable, or even a natural constituent of working memory processes, but may not principally dictate acute outcomes of interest in the laboratory.

Nevertheless, this study demonstrates notable strengths, specifically in the thorough scoring method we implemented. Discrepancies between participant scores were resolved between the raters when necessary. We also chose to counterbalance the order of assessments, a methodological practice not routinely implemented in other experiments,[387,388,398] but, nevertheless, important in limiting the risk for fatigue or testing effects to negatively influence creative performance. In contrast to past work,[387] the RAT was always the final creativity assessment, although the specific assessment forms were counterbalanced across visits. The RAT requires participants to solve triads with a single unifying term, thus, this measure of convergent thinking may be more difficult for participants to solve. We hoped to avoid task-related decreases in affect and mental fatigue by assessing convergent thinking performance at the end of each visit, which could provide a more reliable estimate of convergent creativity performance following exercise. However, despite counterbalancing the order of divergent thinking tasks, an anticipatory effect may have influenced motivation across the three visits. Although the participants were given new forms of the four creativity tasks during every visit, they may have become accustomed to the type of divergent and convergent thinking assignments they would be asked to complete. Notably, however, we statistically evaluated the potential for a task-order effect to emerge, perhaps due to an aforementioned decay in motivation or increased task habituation, but no statistically significant findings confirmed our assumptions. We also controlled for outlier effects, defining outliers as participants whom scored exceptionally high or low on creativity tasks (±3 SDs; also considered outliers using the "labeling" rule approach). These participants were removed from the data set in a separate analysis, indicating creative outliers were statistically significantly different from the remainder of the sample. This is to be expected, as outliers, by definition, portend disproportionate weights to data points. However, it is interesting to point out that perhaps such divergent individuals warrant further attention. What is it that influences extreme scores? If the vast majority of participants are expected to follow a "normal" distribution across a range of creative performances, perhaps researchers should carefully evaluate under- and over-achievers to approach more precise interpretations of the factors or individual differences underlying creative ability. Thus, the statistically significant elaboration differences demonstrated herein may indicate there is some individual variability in creative capacity, but that this result is not a likely consequence of exercise or musical stimuli.

"You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete (R. Buckminster Fuller, St. Martin's Griffin, 1982, as cited in Connery, 2008[445])." The emphasis here lies in acknowledging the imminent need for improvement in the assessment and evaluation of creativity. While there is no cause for discrediting the rich history of quality creativity research, perhaps traditional methodologies should be used to *create* appropriate and meaningful new strategies for the practical measurement and interpretation of experimental creativity. Should the burgeoning field of exercise, music, and creativity continue to progress, caution must be exercised regarding the utilization of ubiquitous laboratory measurements designed to assess creativity. These working models, which have long dictated creativity research, may lie within an acceptable range of approximation. However, if researchers hope to someday propose causal and predictive mechanisms for creativity, guesswork must be displaced with continued scientific rigor. In contrast, the pervasive assumption that null findings are tantamount to poor methodological quality depreciates our explanations of outcomes, however rigorous the study may be, and buries the field in a dangerous avalanche of speculation. It is quite possible we have become conditioned to will the manifestation of relationships, where none exist. As a final summarizing thought, progress seems to be halted by unremitting attempts to redefine every aspect of creativity research in alignment with novel theories or innovative study designs, which does little for verifying or questioning current methods. There is much to build from, and even more to discover, which is part of what makes creative science so captivating. To this end, it is better when strides are made, both with high-quality methods, recognition of the exigent contributions in the field, and honest discourse on the limitations we continue to face as creativity researchers.

In conclusion, in this experiment, we did not observe any differential effect of acute exercise or passive music listening on creative thinking performance. We have discussed various reasons for this observation as well as highlighted areas in need of future research. Until such further work is conducted, it remains unclear as to whether acute exercise may influence creativity and whether there is a potential differential effect of exercise and music exposure on creative thinking.

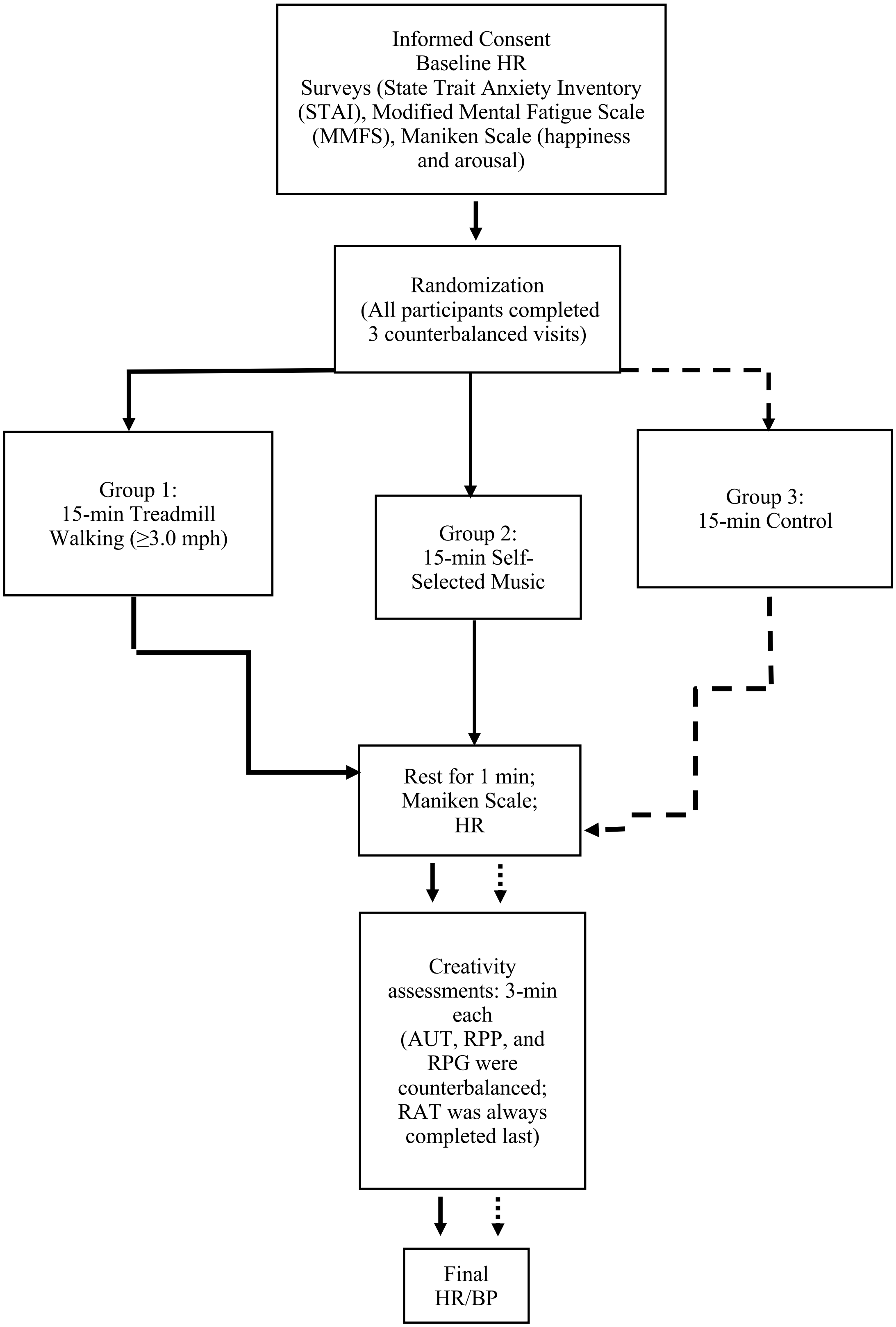


Figure 5-1.1. Schematic of the study design (dashed line is control visit activities).

Table 5-1.1. Characteristics of the study sample

Variable	Point Estimate	Standard Deviation (SD)
Gender (% Female)	62.5	
Age (mean years)	23.1	3.39
Race (% Caucasian)	59.4	
Education (% Undergraduate)	56.3	
Major (% Exercise Science)	71.9	
GPA (% A student)	56.3	
Hunger (average rating on 1-5 Likert-scale)	2.2	1.0
BMI (kg/m^2)	24.2	4.0
Total PA (minutes per week)	265	171.9
Dominant hand (% Right)	90.6	
Baseline MMFS (Visits 1-3)	16.9	8.45
Baseline STAI (Visits 1-3)	30.7	9.2

GPA = grade point average
PA= physical activity
BMI = body mass index
MMFS = Modified Mental Fatigue Scale
STAI- State Trait Anxiety Inventory

Table 5-1.2. Creativity scores (means (sd)) across the three experimental conditions.

AUT	**Exercise**	**Music**	**White Noise/Control**	**F(df), P-Value†**
Fluency	6.7 (2.6)	6.6 (2.7)	7.1 (3.1)	.063 (2,60), P=0.94
Flexibility	5.0 (2.2)	5.4 (2.3)	5.7 (2.5)	0.64 (2,60), P=0.53
Originality	2.1 (1.4)	1.9 (1.5)	2.1 (1.8)	0.23 (2,60), P=0.79
Elaboration	4.2 (3.1)	2.7 (1.9)	3.1 (2.6)	2.74 (2,60), P=.073
RPP				
Fluency	4.7 (1.4)	4.6 (1.5)	4.96 (1.9)	1.03 (2,60), P=0.36
Flexibility	3.6 (1.7)	4.1 (1.8)	3.6 (1.5)	0.82 (2,60), P=0.45
Originality	1.6 (1.5)	1.3 (1.3)	1.7 (2.1)	0.17 (2,58), P=0.80
Elaboration	3 (2.0)	3.3 (1.7)	3.3 (1.6)	0.55 (2,60), P=0.58
RPG				
Fluency	4.1 (2.2)	4.3 (1.98)	4.9 (2.5)	1.1 (2,60), P=0.34
Flexibility	2.97 (1.7)	3.0 (1.6)	3.4 (1.9)	0.52 (2,60), P=0.59
Originality	2.9 (1.97)	2.3 (1.6)	2.9 (2.1)	0.99 (2,60), P=0.34
Elaboration	2.9 (1.8)	3.1 (1.6)	2.8 (1.4)	1.3 (2,60), P=0.28
RAT				
Attempted to Solve	5.3 (2.2)	5.6 (2.9)	5.63 (2.9)	0.02 (2,60), P=0.98
Correct Responses	3.4 (1.8)	3.1 (2.3)	3.06 (2.3)	0.38 (2,60), P=0.69

AUT – Alternative Use Task
RPP - Realistic Presented Problem
RPG – Realistic Problem Generation
RAT – Remote Associates Test
† For each creativity subscale (e.g., fluency), a one-way repeated measures ANOVA was computed to calculate the respective F-value (df; degrees of freedom) and P-value

Table 5-1.3. Mean and Standard Deviations for physical and affect measures.

Average	Exercise	SD	Music	SD	Control	SD	*P-value
Baseline HR (bpm)	75.3	12.5	74.9	10.1	76.0	13.1	0.74
HR in the Final Minute of the 15-min Condition (bpm)	115.1	20.3	75.1	12.5	75.3	12.5	<.001
Treadmill Speed (mph)	3.3	0.27	0	0	0	0	N/A
HR 1-min Post Condition (bpm)	86	18.1	75.5	11.7	74.0	9.3	<.001
HR Post-Creativity Assessments (bpm)	81	13.4	78.9	10.5	78.3	11.9	0.38
RPE (mid 7.5)	10.7	1.4	6.0	0	6.0	0	N/A
RPE (end of 15-min condition)	11.4	1.4	6.0	0	6.0	0	N/A
Pre-Happiness (Maniken Scale)	7.1	1.2	6.9	1.5	6.8	1.3	0.68
Pre-Arousal (Maniken Scale)	4.5	1.6	4.4	2	4.6	1.8	0.89
Post-Happiness (Maniken Scale)	7.2	1.3	7.2	1.5	7.0	1.2	0.56
Post-Arousal (Maniken Scale)	5.3	1.9	4.6	1.9	4.0	2.0	0.02

mph= miles per hour
RPE= rating of perceived exertion
*The P-values were calculated from a one-way repeated measures ANOVA analysis.

Table 5-1.4. Creativity Assessment Scoring Information

Fluency- Total number of generated ideas e.g. weapon, doorstop, flowerpot = fluency score of 3 **Flexibility**-Total number of categories utilized per idea
Bucket Category 1: Hold things (toy chest, candy, laundry) Category 2: Planter (still holding something, but it is growing) Toothbrush Category 1: clean/scrub (dishes, grout/tiles, rings/jewelry) Category 2: Fake eyelashes Category 3: stirring stick
Elaboration-specific supplementary details Example 1: Use as a weapon to break into a car (1 point for "to break into a car") Use a flowerpot for a mini gardening activity with my children (2 points for ("mini-gardening activity" and "with my children") Example 2 I will sit outside to work on my project (1 point for outside) I will sit outside at the local park to work on my project (2 points for outside and local park) I will sit outside at the local park to work on my project, but take breaks to spend time with my friend (3 points for outside, park, and taking breaks)

II. IS ENGAGEMENT IN PHYSICAL ACTIVITY AND CREATIVE ACTIVITY MUTUALLY EXCLUSIVE? AN EVALUATION OF GENERAL AND DOMAIN-SPECIFIC RELATIONSHIPS

Abstract

The purpose of this study was to examine the relationship between physical activity and creative behaviors, with a specific focus on whether higher physical activity participation is associated with higher domain-specific creativity, and increased involvement in creative activities. A random sample of 612 college students, ages 18-35, enrolled at a large Southeastern university, were recruited via an anonymous email invitation. Creative behaviors were assessed via two self-report questionnaires. The Kaufman Domains of Creativity Scale (K-DOCS) is a 50-item self-report questionnaire assessing five domains of creativity relevant to college student populations. The five domains emphasized in this instrument are Self/Everyday, Scholarly, Performance, Mechanical/Scientific, and Artistic. Item ratings were summed for each distinct domain, with higher scores indicative of higher domain creativity. The Biographical Inventory of Creative Behaviors (BICB) was also used. The BICB is a 34-item list of behaviors, which asks participants to honestly select which activities they have been involved in over the past 12 months. A composite creativity score was calculated from individual BICB responses, which ranged from 0-34 total points. Higher scores were indicative of higher participation in creative activities. Self-reported physical activity habits were assessed with the Physical Activity Vital Sign (PAVS) questionnaire. In addition, participants reported their current feelings towards physical activity participation (i.e., general level of enjoyment), as well as whether they were currently more, less, or as physically active as they were six months ago. One-week test–retest reliability was established on 10% of the participants. Of the multiple regression analyses that

were conducted to examine the hypothesized relationship, between physical activity and creative activities, physical activity participation did not meaningfully influence domain-general or domain-specific creative activities. However, additional selected independent variables, such as degree of exercise enjoyment and academic major were statistically significantly associated with self-reported creative activities. No study, be it cross-sectional or experimental, has investigated the plausible relationship between physical activity and self-reported creative activities; thus, this project should primarily serve to identify more inclusive, yet parsimonious research hypotheses to further scientific knowledge in this under-investigated area.

Introduction

The measurement of acute creativity is difficult to empirically resolve. It is inherently challenging to oblige participants to complete a battery of divergent and convergent thinking creativity assessments, with the results of few, abbreviated laboratory visits proposed to have translational impact on ecological creative capacity and related outcomes. Nevertheless, empirical work is necessary to advance the field and further explore behavioral and biological correlates of creativity. The allure of this necessity has driven scientists, of numerous academic affiliations, to seek the epicenter of human creativity in the development of promising models disseminated by (but not limited to) research endeavors in neuroscience, psychology and, more recently, kinesiology and health promotion[161-166,169,171]. Neuroimaging studies assessing acute laboratory creativity have demonstrated that enhanced executive functioning may be essential for both discarding conventional and, by nature, less original task responses[446]. Conventional, or common responses may be displaced by creative ideas over time, suggesting that the creative process may be partitioned into an early stage, more contingent on memories, followed by a later stage, which transforms those prior experiences into unfamiliar, truly creative ideas[323]. Neuroscientific work has also shown prefrontal and temporal activations are associated with processes important for open-ended, divergent ideation[447].

Divergent thinking is suggested to be a necessary, albeit incomplete, component of creativity[448], as it involves the generation of novel and original ideas. Divergent ideas are expected to be distinct from thoughts which are readily accessible through recalled personal experiences, which are often defined as convergent thinking, another essential component of creative thinking[449]. Convergent problem-solving involves completing complex tasks that require a specific and unifying correct answer to be creatively determined by the respondent[449]. Interestingly, top-down attentional processing, or internally-directed attention (as opposed to externally directed) has been linked to frontal and parietal activations during both convergent and divergent thinking assessments. Stated explicitly, divergent tasks requiring participants to manipulate items within a personal mental space (i.e., brainstorming ideas for alternative uses for a toothpick), may activate similar cognitive processes as an atypical convergent thinking task (finding an anagram for the word "TRAP"). Notably, however, selection of the creativity assessment may result in differential neural activation patterns, with traditionally administered convergent thinking or insight tasks (e.g. completing word triads[376,450]) suggested to demand increased bottom-up, or externally-oriented attention. Externally-focused attentional processing has been shown to initiate desynchronization of EEG alpha power in frontal areas[447].

The depth of scientific uncertainty is magnified as alternative work presents opposition to the aforementioned, favorable associations between cortical stimulation and creative thinking. Previous studies indicate that cortical activation may, in fact, diminish creative thinking, as higher-order neural stimulation shunts resources to frontal regions, which effectively impedes remote, associative thinking[451]. Moreover, uncontrollable stressors[452] and high arousal[453] have traditionally been assumed to undermine creative performances. Although, some authors have proposed that individuals whom are particularly creative may be more vulnerable to excitement and related cognitive over-stimulation[454]. This cognitive supra-stimulation contributes to a reduced ability to exclude distracting information[455], which may be partially explained by the tendency for creative individuals to be receptive to a combination of external stimuli, and be less inclined to fixate only on salient task cues[456]. To this end, while increased sensitivity to task-irrelevant stimuli may be facilitative in some aspects, actually serving to promote creative thinking, the inability to disengage distracting information can impair information processing and delay response time[457]. Studies have shown lower variability in cortical arousal within creative subjects, demonstrating differences in high and low creative individuals at baseline, and during the task itself. Specifically, while creative people may show increased cortical activation at baseline, activation does not continue to increase during convergent or divergent thinking exercises. The opposite trend is suggested for low-scoring, or less creative, participants[458].

Despite encouraging evidence supporting the putative role of executive function and cortical involvement to mediate the genesis and expression of spontaneous creativity, it is difficult to assert definitive claims localizing the neuroanatomical correlates of creative processes[446]. One reason for these discrepancies may be the encapsulating scope of creative activities across a multitude of domains. Creative behaviors are exemplified in the arts and sciences, writing and computing, dance and design, and are characteristic of even the most mundane, daily tasks[459]. Despite the absence of rewards and recognition, many individuals intrinsically[460] enjoy engaging in what might be conceptualized as divergent creative tasks, such as writing poetry or learning to play a musical instrument, or perhaps convergent tasks, such as solving mathematical puzzles (e.g. Sudoku) or completing crossword puzzles. Alternatively, some may enjoy creative productions under a more prosocial lens[461], by appreciating the creativity of others by enjoying an afternoon exploring an art museum, while others derive pleasure from fostering creativity, as they aim to teach someone else a new technique or skill[459]. Extensive research across creative domains produces findings that make the field more inclusive and representative of the varied complexities of the most celebrated human abilities, but also complicate the search for precise biological mechanisms underlying the enigma of creativity.

Taken together, a unitary, biological explanation for creativity has yet to offer all-inclusive proof pinpointing the locus of creative cognition. The causes, conceptualizations and consequences of creativity are not singular constructs, and thus, cannot be logically reduced into a *one-mind fits all* psychometric model. In line with Sawyer's critical review[462], it should be recognized that creativity integrates activity from the entire brain to satisfy various cognitive demands. Notably, specific tasks may differentially activate certain regions, but the spectrum of creative performance appears to span the majority of the human brain. Domain-specific expertise, which is a controversial topic across creativity literature, highlights the importance of prolonged training and study towards proficiency in the context of focused, individual pursuits[463]. However, the importance of creative generality is paramount as well, as many problems necessitate mental search across a vast solution space, meaning domain-expertise may confine, rather than refine creative problem-solving in certain situations. Associative, inclusive search strategies favor the integration of knowledge precepts across multiple domains not contingent upon the depth of prior knowledge[464]. To this end, general verbal strategies may aid creative communication in a business deal, or general math skills may allow a farmer to determine the amount of grain needed to feed his or her livestock. Regardless of whether creativity is always domain-specific, or is perhaps better encapsulated using more general terminology, the importance of individual differences in skill and motivation should not be overlooked as potential sources of illumination along an obscure pathway leading researchers towards a less nuanced understanding of creative neuroscience[462].

Individual differences in complex neural activation patterns, stress and arousal, information processing and executive function capacity, and task-demand (among other proposed correlates) preclude the systematic determinacy of the most salient, and perhaps modifiable, predictors human creativity. Therefore, the aim of this study is not to manipulate acute physical activity participation with the intent to identify brain regions which may subserve performance on researcher-imposed creativity tasks, but to instead ask an essential question, which, to our knowledge, has yet to be empirically evaluated in health behavior research. Does self-reported level of physical activity participation correlate with increased domain-specificity and engagement in creative behaviors among a large sample of college students? In light of recent studies showcasing the utility for physical activity to augment transient creative task performances, particularly on divergent thinking measures[169], the present investigation is a warranted addition to previous work. The creative person is just as important as the underlying creative process, and tendencies to engage in future creative behaviors may be moderated by personal experiences of successes or failures related to previous creative attempts[454,465]. This study emphasizes the value of evaluating participants' present perceptions of their creative behaviors and task-specific expertise to better understand differences in the self-assessment of creative accomplishments and abilities. Our investigation is also a necessary preamble to a more tailored and adaptive search for both individual- and population-level mechanisms underlying creative perceptions and processes in the context of personal health promotion.

Methods

Design and Participants

This study was approved by the university's Institutional Review Board, and participants provided anonymous consent by submitting the survey via Qualtrics software. The study design involved an analysis of physical activity participation and creative behaviors and accomplishments, beginning in March and ending in April of 2018. Research participants were recruited via dissemination of a mass email, sent anonymously to a random sample of 25% of currently enrolled undergraduate and graduate students, ages 18-35, of both genders, at a large Southeastern university. The survey tool was comprised of questions regarding participant demographics, physical activity behavior over the past month, and subjective evaluation of creative attributes. There were 612 participants, with 413 females, 195 men, and four individuals who declined to report their gender. Mean age of participants was 21.4 years (*SD* 2.9). There were 14 Hispanic students (2.3%), 475 Non-Hispanic White students (78%), 48 Non-Hispanic

Black students (7.9%), 39 Asian students (6.4%), 25 bi-racial or multi-ethnicity students 4.1%, and 10 students who declined to report their ethnicity (1.6%).

Data collection and recruitment efforts were terminated after 639 survey respondents had completed the questionnaires. Notably, among the 639 participants, there was no missing data, as the questionnaire was designed on Qualtrics to ensure that each question was answered before respondents could progress to subsequent survey items. However, due to misreporting and/or provision of ambiguous responses, data from 27 participants was deleted form subsequent analyses. Whenever possible, questions maintained a yes/no, short multiple-choice, Likert scale, or "check all that apply" format. All questions were written clearly, and, following pilot testing to confirm face validity and content validity, limit respondent burden[466], as well as minimize the likelihood for participant non-response due to vague terminology, all ambiguous items were explicitly defined or revised appropriately. A subset of 10% of the 612 participants completed the creativity-specific questionnaires again one-week later for test-retest reliability purposes.

Measurement of Creativity

Kaufman Domains of Creativity Scale (K-DOCS) is a 50-item self-report questionnaire assessing five domains of creativity relevant to college student populations. The five domains emphasized in this instrument are Self/Everyday (Items 1-11), Scholarly (Items 12-22), Performance (Items 23-32), Mechanical/Scientific (Items 33-41) and Artistic (Items 42-50). A sample item assessing Self/Everyday creativity is "*Being able to work through my personal problems in a healthy way*;" A sample item assessing Scholarly creativity is "*Debating a controversial topic from my own perspective*;" A sample item assessing Performance is "*Writing a poem*;" A sample item for Mechanical/Scientific is "*Helping to carry out or design a scientific experiment*;" and lastly, a sample item for Artistic is "*Drawing a picture of something I've never actually seen (like an alien)*."

Instructions for this measure asked participants, *"Compared to people of approximately your age and life experience, how creative would you rate yourself for each of the following acts? For acts that you have not specifically done, estimate your creative potential based on your performance on similar tasks."* Response options range from one to five, with one described as "much less creative" and five described as "much more creative." Response option three is a neutral anchor, stated as "neither more nor less creative" for neutral. Item ratings were summed for each distinct domain, with higher scores indicative of higher domain creativity (Self/Everyday: range 11-55; Scholarly: range 10-50; Performance: range 9-45; Mechanical/Scientific: range 8-40; Artistic: range 8-40). Internal consistency of the scale was established with the original sample data utilized by Kaufman, with evidence of adequate internal consistency for each of the five distinct scales exceeding $\alpha = 0.80$[459]. Cronbach's alpha, was also calculated among the present sample with internal reliabilities for each domain reported as follows: Self/Everyday (0.78), Scholarly (0.88), Performance (0.88), Mechanical/Scientific (0.89) and Artistic (0.86). The aggregate test-retest reliability assessment (ICC) of the present sample was 0.78 (range: 0.72 to 0.86) for the K-DOCS.

Unlike the K-DOCS, The Biographical Inventory of Creative Behaviors (BICB)[467] does not categorize creative activities into specific domains. The BICB is a 34-item list of behaviors, which asks participants to honestly select which activities they have been involved in over the past 12 months. Three BICB sample items include *"In the past twelve months, have you… 'Delivered a speech,' 'Organized an event, show, performance or activity,' or 'Mentored/Coached someone else to improve their performance.'"* The BICB has demonstrated adequate reliability, with Cronbach's alpha's reaching ($\alpha = 0.74$)[467], ($\alpha = 0.78$)[468] 0.76[469], and 0.89[470]. Cronbach's alpha for our sample demonstrated adequate internal reliability as well (α =

0.81). The BICB is dichotomized into two distinct categories for each individual item, with a '0' score indicating no involvement, and a '1' score corresponding to some level of involvement in the select activity over the past year. This binary scoring strategy, allows for a simple summation of a composite creativity score, ranging from 0-34, with higher scores indicative of higher creativity behavior. The aggregate test-retest reliability assessment (ICC) of the present sample was 0.78 for the BICB.

Measurement of Physical Activity

Self-reported physical activity habits were evaluated using the brief Physical Activity Vital Sign assessment (PAVS)[471]. The PAVS contains two questions: 1) "*On average, how many days per week do you participate in moderate to vigorous intensity physical activity,"* and 2) "*How many minutes, on average do you engage in this physical activity on one of those days?*" This questionnaire has been shown to exhibit adequate reliability($r = 0.83$)[472], and strong concurrent validity[472,473] with the Modifiable activity Questionnaire (MAQ) ($r = 0.71$)[474], and is correlated with accelerometer-assessed number of days ⩾30bout-min MVPA (r=0.52, P<0.001)[473,475]. The aggregate test-retest reliability assessment (ICC) of the present sample was 0.91 for the PAVS.

In addition, participants reported their current feelings towards physical activity participation (i.e., general level of enjoyment), as well as whether they were currently more, less, or as physically active as they were six months ago (adapted from CDC, NHANES PAQ500). Lastly, participants were asked to indicate whether or not they engaged in previous physical exercise before taking the survey. Related to this item, individuals reported how long they exercised, as well as the exercise modality they chose and how difficult/strenuous their prior exercise session had been (participants whom did not exercise were instructed to select the option “I did not exercise today,” or ‘0’ for the question requiring a numerical response for exercise duration).

Statistical Analyses

All statistical analyses were computed in Stata (v. 12.0; StataCorp LP, College Station, TX). Means and standard deviations were calculated for continuous variables and proportions were calculated for categorical variables. Independent variables included age, gender, race-ethnicity, educational level, current grade-point average, college major, prior exercise on the day of survey completion, and self-reported MVPA derived from the PAVS survey.

Six multivariable linear regression analyses were conducted to examine the association between physical activity and creative behaviors (outcome variable). One multivariable linear regression was used for total creativity score, and five multivariable linear regression models were computed for each sub-domain of the K-DOCS assessment. There were no concerns with multicollinearity, as the highest correlation between any of the 5 creativity domains was, $r = 0.35$ (e.g. Scholarly and Mechanical/Scientific), and the average variance inflation factor (VIF) was 2.4.

Results

Table 1 shows the demographic characteristics of the analyzed sample (N=612). On average, participants were 21.4 years-old, with the majority of participants being female (68%) and non-Hispanic Caucasian (78%).

Table 2 highlights the results from the six multivariable linear regression analyses evaluating the relationship between physical activity (independent variable) and creative behaviors (outcome variable. Of the six analyses that were conducted to examine this hypothesized relationship, none reached statistical significance. The multivariable linear regression computed for total creativity score (BICB) demonstrated that female gender (b (unstandardized beta coefficient)= 0.94; 95% confidence interval (CI): 0.06, 1.83, *p* = .04) and GPA (b=0.88; 95% CI: -1.69, -0.06, *p* = .03) were statistically significant covariates independently associated with total creativity score on the BIBS.

Domain-Specific Creativity Outcome Results

Self/Everyday Creativity. The multivariable linear regression models computed for domain-specific creativity scores indicated that, among participants scoring higher on *Self/Everyday* creativity (K-DOCS), higher self-reported enjoyment of physical activity (b = 3.14; 95% CI: 1.04, 5.23, *p* = .003), as well as increased time elapsed since prior exercise participation (>2 hours; b = 1.16; 95% CI: 0.06, 2.27, *p* = .04), were covariates independently associated with enhanced *Self/Everyday* domain performance.

Scholarly Creativity. Among individuals scoring higher on *Scholarly* (K-DOCS) creativity (K-DOCS), female gender (b = -1.55; 95% CI: -2.88, -0.12, *p* = .03), and majoring in science (b = -2.74; 95% CI: -4.97, -0.50, *p* = .02), education (B = -3.58; 95% CI: -6.42, -0.73, *p* = .01), business (b = -2.40; 95% CI: -4.41, -0.40, *p* = .02) and health/medicine (b = -2.59; 95% CI: -4.66, -0.53, *p* = .01), were negatively associated with creativity performance. Although, higher average GPA was positively associated with increased creativity scores (b = 1.67; 95% CI: 0.36, 2.98, *p* = .01).

Performance Creativity. For participants scoring higher on *Performance* (K-DOCS) creativity, GPA (b = -2.39; 95% CI: -3.83, -.95, *p* = .001), and prior exercise on the day of taking the creativity surveys (b = -2.09; 95% CI: -4.08, -0.11, *p* = .04) were negatively associated with *Performance* domain score.

Mechanical/Scientific Creativity. The academic covariates, math (b = 7.23; 95% CI: 3.28, 11.19, *p* <.001), science (b = 3.35; 95% CI: 1.21, 5.50, *p* = .002), technology (b = 8.90; 95% CI: 4.61, 13.19, *p* <.001), and health/medicine major (b = 2.33; 95% CI: 0.35, 4.31, *p* =

.02), as well as enjoyment of physical activity (b = 2.87; 95% CI: 0.15, 5.60, p = .04) were positively associated with higher *Mechanical/Scientific* (K-DOCS) creativity scores. In contrast, female gender (b = -3.17; 95% CI: -4.54, -1.81, p <.001), the academic majors arts & humanities (b = -2.54; 95% CI: -4.82, -0.25, p = .03), and education (b = -3.12; 95% CI: -5.86, -0.39, p = .03), as well as prior exercise on the day of survey completion (b = -1.78; 95% CI: -3.51, -0.05, p = .04), were covariates negatively related to *Mechanical/Scientific* creativity.

Artistic Creativity. Lastly, for the creative domain, *Artistic* (K-DOCS), higher GPA (b = -1.43; 95% CI: -2.64, -0.21, p = .02), majoring in science (b = -2.24; 95% CI: -4.31, -0.16, p = .04) and graduate level enrollment status (b = -3.27; 95% CI: -5.40- -1.15, p = .003) were negatively associated with creativity scores. Alternatively, female gender (b = 2.52; 95% CI: 1.19, 3.84, p <.001) was positively associated with higher domain scores for *Artistic* creativity.

Sensitivity Results. Sensitivity analyses were also computed with BICB dichotomized into high and low creativity, using a cut-point of 15 (range 0-30 for our sample) points. The logistic regression was not statistically significant regarding the relationship between physical activity and creativity (OR: 1.41; 95% CI: 0.68 - 2.91, p = .36). Additionally, PAVS scores and hours since previous exercise participation were included in the multivariable regression models as continuous variables, but expressing the covariates both categorically and continuously did not alter the statistical significance of any of the six models reported.

Discussion

The purpose of this study was to explore the possibility for a relationship to exist between physical activity and self-reported engagement in both general and domain-specific creative activities. We posited that increased time spent engaging in habitual physical activity would correlate with higher scores on reliable and valid survey measures assessing self-reported creative products and behaviors. We also hypothesized that lower levels of physical activity would correspond to lower subjective creativity ratings among university students. Physical activity is suggested to modify neuroanatomical correlates of higher-order cognitions relevant to creative thinking, namely executive function and memory performance[446,476]. However, our hypotheses were not supported upon analyses of the present data. We have highlighted the ineludible responsibility for scientific research to identify the antecedents of creativity attributed to the "creative person," which is arguably as critical for exposition as is an elucidation of isolated brain mechanisms underpinning neurobiological creative processes. Our results indicate that, within our young adult sample, self-reported physical activity engagement is not meaningfully associated with self-reported engagement and degree of import assigned to a variety of creative behaviors and disciplines. However, subjective enjoyment of physical activity participation appeared to be positively associated with *Self/Everyday* and *Mechanical/Scientific* domain-specific creativity ratings, but no physical activity measure was uniformly related to the creative outcomes assessed herein.

This study is a useful and timely addition to direct emerging research devoted to the proposed role between physical activity participation and general, as well as domain-specific, creativity. To date, there is substantive dissention between alternate viewpoints that creativity may be more of a global construct, versus the suggestion that creativity is pronounced in specific areas of merit. Some researchers claim that creative capacity is a transferrable quality, in that creative people may demonstrate creative behaviors across a variety of seemingly disconnected fields (e.g., science, art, and creative writing)[477]. In fact, most research agendas are predicated on the assumption that creativity is acutely measurable, and can be identified within a variety of individuals, using a battery of preselected assessments which capture normative cognitive skills attributable to the broad construct of human creativity[478]. In contrast, a knowledge-based theory of creativity suggests that increased awareness and understanding of content within a focused skill area promotes creativity. Support for this argument has identified linear relationships between heightened domain-specific knowledge and heightened domain-specific creativity outcomes[479,480]. Recently, An and Runco (2016) suggested that domain-specific aspects of creative performance may be reinforced by general creative capacity, particularly when accounting for personal characteristics[481]. To this end, we evaluated multiple aspects of the creative person. Interestingly, math, science, technology, and health and medicine academic majors were statistically significantly associated with increased domain-specific self-ratings of *Mechanical/Scientific* creativity, whereas academic major and GPA were not statistically significantly associated with *Self/Everyday* creativity. This finding aligns with previous work emphasizing the relative unimportance of grades on creative performances, suggesting that the prediction of college success is componential and must be assessed with practical measures that transcend rote grade-centric determinants[482,483].

There are several putative explanations for our findings. We assessed both physical activity engagement and creative activities using subjective measures. Although these measures are confirmed to be reliable and valid, subjectivity may be insufficient to wholly account for the nuances inherent in the proposed relationship between physical activity and creativity. Additionally, albeit speculative, inclinations to engage in sustained creative behaviors over time may be moderated by personal experiences of successes or failures related to previous creative attempts[454,465]. Cross-sectional data only allows researchers to identify perceived engagement in creative behaviors at a single time-point. Although the BICB assesses creative behaviors executed over the last twelve months, recall bias may have contributed to erroneous responses for some participants. Notably, however, we chose to re-sample a subset of 10% of survey respondents, achieving adequate test-retest reliability on all outcome measures. Additionally, the college students measured in the present sample may, in fact, be creative, but engage in few of the listed creative behaviors, as evidenced by a relatively low mean score of 8.3 on the BICB. The maximum possible score is 34, which would indicate an individual had completed all 34 creative activities in a year's time. Admittedly, distributing a more comprehensive battery of questionnaires, including a brief assessment of acute creativity performance on an established test of divergent thinking, convergent thinking, or insight creativity, and/or evaluation of intrinsic motivation and personality characteristics would have been enlightening. Historically seminal research has ascribed creative motivations to social-psychological factors, which are thought to direct intrinsic interest within certain people (i.e., person-centered), and within specific contexts (i.e., context-centered)[484]. Specifically, Sternberg & Lubart's investment theory of creativity claims there are six essential characteristics of creators: intelligence, intellectual styles, knowledge, motivation, personality (person-centered), and environment (context-centered)[484-486]. Despite strong rationale for including comprehensive measures, we were hesitant to employ such an exhaustive questionnaire, as we expected a time-consuming survey would exponentiate participant burden and inversely correlate with response-rates. Although inclusion of these parameters may be warranted in future studies evaluating this topic, we felt it was sensible to first determine whether a relationship between physical activity and creative behaviors was observable via a cross-sectional design. However, we do encourage researchers to consider drawing from these suggested parameters, as well as other potentially relevant variables to refine future evaluations of physical activity and creativity.

At this point, we cannot be certain whether or not physical activity and creativity are meaningfully associated. However, given the data presented herein, it may be prudent to continue studying the likely link between enjoyable activities and creativity. Much creativity research suggests creativity is enhanced via stimuli that engenders activating moods (e.g., anger, happiness, stress, interest)[487], sometimes of either a positive or negative valence,[287] and is contingent upon the nature of the creative task environment[488] and the goals set by the individual[489]. Physical activity is certainly capable of activating both positive and negative mood states[194], but physical activity nonadherence and failed behavioral goals may preclude the extent of physical and psychological benefits achievable through bodily movement[490]. Moreover, how many times has a lack of persistence on difficult, yet groundbreaking ventures prevented the actualization of truly creative outcomes for individuals?[491] As individual differences may predict degree of persistence and success in physical activity participation and creativity, perhaps research should concentrate on designing joint-protocols which explicitly associate compliance with physical and creative behaviors to determine if a reciprocal relationship manifests when adherence to personal achievement goals, set within the physical activity environment, directly contribute to creativity outcomes, and whether sustained perseverance in creative pursuits yields perseverance in physical behaviors (e.g. exercise participation) as well. Moreover, research should continue to examine the role of individual differences in creativity, not only ascribed to motivation, personality, and mood activation, but also to brain activation, information-processing, executive function and memory capacity, as well as various potential neural mechanisms discussed in the introduction. Despite the aforementioned limitations, this project is a pioneering foray into continued scientific discourse on the topic of physical activity associations with creative activities. We measured multiple creativity outcomes (general, and five domain-specific indices), as well as various diverse, suspected correlates of creativity in college-aged populations. No study, be it cross-sectional or experimental, has investigated the plausible relationship between physical activity and creative activities; thus, this project should primarily serve to instigate the generation of more inclusive, yet parsimonious research hypotheses to further scientific knowledge in this under-investigated area.

Table 5-2.1. Characteristics of the study sample (N=612).

Study Variable	*Mean/proportion*	*Standard deviation*
Age, mean years	21.40	2.91
Gender, % female	67.93	
GPA, mean	3.40	0.51
Education, % undergraduate students	82.84	
Major, % Business	23.20	
Race-ethnicity, % Caucasian	77.74	
MVPA, mean minutes/week	176.94	199.54
Exercise Enjoyment, % Yes	58.50	
Exercised prior to survey, % No	75.33	
Hours since last exercise session, mean	10.0	19.84
Use of mental imagery techniques, % most of the time	38.73	
BICB score (0-34), mean	8.26	4.81
K-DOCS domain, mean Self/Everyday (11-55)	39.46	5.93
K-DOCS domain, mean Scholarly (10-50)	34.46	7.91
K-DOCS domain, mean Performance (9-45)	26.12	8.72
K-DOCS domain, mean Mechanical/Scientific (8-40)	22.97	8.14
K-DOCS domain, mean Artistic (8-40)	27.14	7.41

Grade-point average (GPA)
Moderate-to-vigorous physical activity (MVPA)
Biographical Inventory of Creative Behaviors (BICB)
Kaufman Domain Scale (K-DOCS)

Values in parentheses represent the possible range for the corresponding creativity variable.

Independent Variables for the Six Regression Models	**BICB**	**K-DOCS Self-Everyday**	**K-DOCS Scholarly**	**K-DOCS Performance**	**K-DOCS Mechanical/ Scientific**	**K-DOCS Artistic**
PA Variable (PAVS)	0.07 (-0.82 - 0.97)	0.15 (-0.92 - 1.22)	0.83 (-0.62 - 2.27)	-0.34 (-1.93 - 1.25)	-1.24 (-2.62 - 0.15)	0.73 (-0.62 - 2.07
Exercise-Related Covariates						
Enjoyment of PA vs. No Enjoyment	1.07 (-0.69 - 2.83)	**3.14** **(1.04 - 5.23)**	1.95 (-0.89 - 4.79)	2.08 (-1.05 - 5.20)	**2.87** **(0.15 - 5.60**)	0.06 (-2.58 - 2.70)
Exercised Prior to Survey (vs. No Exercise)	0.31 (-0.80 -1 .43)	-0.60 (-1.93 - 0.73)	-0.87 (-2.67 - 0.93)	**-2.09** **(-4.08 - -0.11)**	**-1.78** **(-3.51 - -0.05)**	-1.34 (-3.00 - 0.35)
1-2 Hours since last PA session (vs. 0-1 hour)	-0.25 (-1.80 -1.29)	1.19 (-0.66 - 3.03)	1.37 (-1.12 - 3.87)	2.56 (-0.19 - 5.31)	1.20 (-1.20 - 3.60)	0.00 (-2.32 - 2.32)
2+ Hours Since Last PA Session (vs. 0-1 hour)	0.34 (-0.58 - 1.27)	**1.16** **(0.06 - 2.27)**	-0.25 (-1.75 - 1.24)	1.05 (-0.60 - 2.69)	0.24 (-1.20 - 1.67)	0.62 (-0.77 – 2.01)
Demographic Covariates						
Age (1-year increase)	-0.05 (-0.22 - 0.13)	0.08 (0.29 - 0.13)	0.17 (-0.11 - 0.46)	0.02 (-0.29 - 0.34)	0.06 (-0.22 - 0.33)	0.10 (-0.36 - 0.17)
Education level: Graduate Student (vs. Undergraduate)	-0.12 (-1.53 - 1.30)	-0.32 (-2.01 - 1.37)	0.14 (-2.15 - 2.43)	-1.93 (-4.44 - 0.59)	-2.12 (-4.31 - 0.08)	**-3.27** **(-5.40- -1.15)**
Female Gender (vs. Male)	**0.94** **(0.06 - 1.83)**	-0.34 (-1.39 - 0.72)	**-1.55** **(-2.88 - -0.12)**	-0.26 (-1.83 - 1.31)	**-3.17** **(-4.54 - -1.81)**	**2.52** **(1.19 - 3.84)**
Race-Ethnicity (vs. Hispanic)						
Black	0.32 (-2.60 - 3.24)	1.89 (-1.60 - 5.37)	1.63 (-3.09 - 6.35)	5.27 (0.08 - 10.46)	2.41 (-2.12 - 6.93)	-0.00 (-4.39 - 4.38)
White	-0.67 -3.25 - 1.9	-0.13 (-3.23 - 2.93)	-2.27 (-6.43-1.90)	-0.57 (-5.16 - 4.01)	-0.83 (-4.82 - 3.17)	-1.56 (-5.43 - 2.31)
Asian	1.22 (-1.78 - 4.21)	0.45 (-3.13 - 4.03)	-1.98 (-6.81-2.86)	2.84 (-2.48 - 8.17)	-0.09 (-4.74 - 4.55)	0.14 (-4.35 - 4.64)
Bi-racial or multi-racial	-1.42 (-4.63 - 1.79)	-2.22 (-6.04 - 1.61)	-1.77 (-6.96 - 3.41)	1.91 (-3.80 - 7.61)	0.68 (-4.29 - 5.65)	1.46 (-3.36 - 6.27)
Declined to report race	-0.40 (-4.80 - 4.00)	-0.70 (-5.96 - 4.56)	-1.37 (-8.48 - 5.74)	0.59 (-7.24 - 8.41)	-1.55 (-8.38-5.27)	-2.31 (-8.91 - 4.30)
Academics-Related Covariates						
GPA (0.1-unit increase)	**-0.88** **(-1.69 - -0.06)**	-0.12 (-1.09 - 0.85)	**1.67** **(0.36 - 2.98)**	**-2.39** **(-3.83 - -.95)**	-0.47 (-1.73 - 0.79	**-1.43** **(-2.64 - -0.21)**
Academic Major (vs. other major)						
Math	-1.60 (-4.15 - 0.95)	-0.69 (-3.74 - 2.35)	-1.06 (-5.18 - 3.06)	-3.59 (-8.13 - 0.94)	**7.23** **(3.28 - 11.19)**	0.39 (-3.44 - 4.22)
Science	-0.31 (-1.69 - 1.07)	-1.16 (-2.81 - 0.49)	**-2.74** **(-4.97 - -0.50)**	-1.62 (-4.08 - 0.84)	**3.35** **(1.21 - 5.50)**	**-2.24** **(-4.31 - -0.16)**
Arts & Humanities	0.73 (-0.74 - 2.21)	0.13 (-1.63 - 1.89)	2.04 (-0.34 - 4.42)	-0.10 (-2.72 - 2.52)	**-2.54** **(-4.82 - -0.25)**	-1.01 (-3.23 - 1.20)
Education	0.76 (-1.01 - 2.52)	0.02 (-2.09 – 0.78)	**-3.58** **(-6.42 - -0.73)**	-0.39 (-3.53 - 2.74)	**-3.12** **(-5.86 - -0.39)**	-0.43 (-3.07 - 2.22)
Technology	-0.37 (-2.40 - 3.13)	-2.29 (-5.60 - 1.01)	-2.49 (-6.96 - 1.98)	0.92 (-4.00 - 5.84)	**8.90** **(4.61 - 13.19)**	-1.02 (-5.17 - 3.14)

Business	-0.75 (-1.99 - 0.49)	-0.71 (-2.19 - 0.78)	**-2.40 (-4.41 - -0.40)**	-1.45 (-3.66 - 0.76)	0.40 (-1.55 - 2.32)	-1.33 (-3.20 - 0.53)
Health & Medicine	-1.01 (-2.32 - 0.24	-0.17 (-1.69 - 1.36)	**-2.59 (-4.66 – -0.53)**	-1.82 (-4.09 - 0.45)	**2.33 (0.35 - 4.31)**	-1.18 (-3.10 - 0.74)

Table 5-1.2. Multivariable linear regression evaluating the association between physical activity and creative behaviors (N=612).
Physical Activity (PA)
Grade-point average (GPA)
Physical Activity Vital Sign Survey (PAVS)
Biographical Inventory of Creative Behaviors (BICB)
Kaufman Domain Scale (K-DOCS)

Bolded typeface (P<.05, 95% CI)

Six multivariable linear regression analyses were conducted to examine the association between self-reported physical activity (PAVS) and creative behaviors (outcome variable). The results reported in Table 2 include the total BICB score as a continuous outcome, PAVS is dichotomized into does not meet PA guidelines/does meet guidelines (≥150 min./wk.), and hours since last exercise session is split (0-0.99= 0, 1-2=1, >2=2).

III. AN EXPERIMENTAL COMPARISON OF CREATIVE IDEATION ACROSS EMBEDDED AND EMBODIED INCUBATION PERIODS

Abstract

The primary objective of this study was to contribute to emerging research investigating the effects of physical exercise on divergent creativity performance. Specifically, we aimed to determine whether acute exercise during the creative incubation period may augment ideational fluency and originality from baseline to a subsequent post-exercise assessment. Thirty-two students at the University of Mississippi participated in this two-visit, within-subject intervention. Individuals consented to participate in two randomized, and counterbalanced, experimental conditions, consisting of 15-minutes of treadmill walking and a seated control incubation period. Creativity was assessed at baseline and post-exercise (and control) via the Instances Creativity Task (ICT) with the order of ICT counterbalanced across the visits. Creativity task performance was independently scored across two dependent parameters, which included *fluency* (i.e., total number of ideas) and *originality* (responses thought of by <10% of the sample). Memory of baseline ICT ideas was also included as a dependent outcome to determine whether recall of previous responses positively or negatively influenced ability to conceive novel ideas upon post-condition evaluation. Repeated Measures ANOVAs indicated that creativity scores for changes in *fluency* ($F(1,31)=2.90$, $p=.10$) were not statistically significant across the experimental conditions. *Originality* scores were higher at baseline and follow-up when compared to the exercise condition ($F(1,31)=6.82$, $p=.01$). However, there was no statistically significant condition x time interaction effect ($F(1, 31)=1.78$, $p=.19$), indicating

that the change between the two exercise and control conditions was not statistically different. Further analyses demonstrated no statistically significant difference between the experimental conditions on *recall* score ($F(1,31)=1.04$, $p=.32$). All models indicated statistically significant main effects for time: *fluency* ($F(1,31)=131.17$, $p<.001$); *originality* ($F(1,31)$ 36.54, $p<.001$); *recall* ($F(1,31)=51.75$, $p<.001$). These findings suggest that both seated and ambulatory creative incubation periods may similarly enhance subsequent divergent thinking performance. The present study highlights the putative utility for focused internal attention, or “embedded incubation” to facilitate ideational capacity, specifically augmenting the *originality* of creative responses.

Introduction

Intentionally shifting attention from one task to the next may be conducive to creative problem-solving[492]. Although task-switching tends to promote vulnerability to extraneous distractions, as well as exacerbates errors in recall and memory function[493], the ability to seamlessly transition from one task to the next may exert a profound influence on creative ingenuity. One of the postulates of successful creative thinking is that individuals must eschew fixation on redundant ideas, convention, and possibly restrictive instructions to develop unique and novel solutions. To this end, creativity may be stimulated by employing mental switch-strategies to mitigate the risk of deleterious cognitive fixation. Notably, Duncker 's (1945) seminal research experiment designed to evaluate insight creativity and "functional fixedness [494]." Duncker devised a revolutionary insight creativity problem that was uniquely designed to induce functional fixedness, which is demarcated by failures to successfully devise an appropriately abstract solution due to hyper-focused attention on the most striking features of a confining problem [494].

Duncker's classic experimental task remains widely employed in modern experimental creativity research[492,495,496]. The "candle problem" introduces participants to a difficult task requiring the unconventional usage of a candle, matchbox, and another box filled with thumbtacks. Per task instructions, the candle must be affixed to the wall, but, when lit, must not drip any wax onto the floor. Interestingly, the conventional purpose of the box of thumbtacks as a storage container prevents many participants from developing a plan to empty the box and creatively utilize the tacks to instead pin the box to the wall. Of note, transforming the box into a candleholder and reservoir to catch melting wax[494] is accomplished much faster when the box and thumbtacks are presented separately[497]. The faster solution rate that emerges when shown an emptied box of tacks signifies the utility for mode of problem delivery to influence functional-fixedness and subsequent task performance. As indicated previously, impasses in problem-solving are expected to occur when individuals become hyper-focused on salient features of the task [498]. As creativity often requires a manipulation of paradigmatic concepts and the restructuring of problems into abstract components, overcoming fixation is perhaps critical for extraordinary creativity.

Similar to the candle problem, the creativity tasks administered for this study were designed to induce functional fixation, and were adapted from the Instances Creativity Task (ICT)[499], which evaluates participants' ability to conceptualize and identify "instances" of target items (e.g. instances of items which are round or square). Divergent thinking is not only characterized by fluent idea generation, but is also recognized as the capacity for rule-congruent ideation; thus, divergent thinking responses must satisfy specific instructional prompts [500]. For example, the well-established Alternative Uses Task[437] requires participants to imagine uncommon uses for commonly encountered items (e.g. alternatively using a pen as a light saber). To this end, the classic ICT was modified to impose restrictive rules, which would, theoretically, further amplify the threat of fixation failure. These rules were also instated to ensure the divergent thinking task would be sufficiently difficult, require an intensive degree of prepotent response inhibition and deliberation, and would warrant the inclusion of an incubation period to bolster effortful creative cognitions[501].

A potential strategy that warrants evaluation, is the utility for exercise participation to prevent, or attenuate, functional fixedness. Experimental research investigating the effects of exercise on creativity are sparse, yet encouraging evidence exists that highlights the potential for acute, moderate-intensity exercise to enhance divergent thinking[344], which is defined as the capacity to think of as many diverse ideas as possible from a singular cue or stimulus [502].

Researchers have suggested that an implicit distribution of effort across a period integrating conscious and subconscious cognitive processes may facilitate problem-solving[503]. Specifically, time spent consciously disengaged from the restrictive task at hand is known as creative incubation,[504] and may be instrumental to counteracting the threat of fixation failure. Moreover, recall failure may actually serve as an asset in the context of incubation, as individuals will be inclined to forget inappropriate ideas[505]. Thus, theoretically, an incubation period of sufficient duration should subserve creative thinking.

Taken together, the purpose of this experiment was to determine whether treadmill walking, when employed as a creative incubation period, is a sufficient stimulus to facilitate cognitive disengagement from an initial, fixation-inducing creativity assessment. Additionally, we evaluated whether exercise during the incubation period enhances later performance on the same creativity assessment, compared to a time-matched sedentary incubation period. Previous experimental work investigating the relationship between physical activity and creativity has yet to focus on exercise as an incubation period, often utilizing multiple test-forms to evaluate acute creativity at multiple time-points[344,387,389], or assessing creativity at a single time-point relative to exercise participation[391,392]. The practical significance of an exercise incubation period may facilitate optimal mind-wandering, and is perhaps best exemplified by Mozart's personal anecdote:

> *"When I am, as it were, completely myself, entirely alone, and of good cheer - say traveling in a carriage, or walking after a good meal, or during the night when I cannot sleep; it is on such occasions that my ideas flow best and most abundantly[506]."*

Despite compelling anecdotal support, no study, to date, has empirically examined the broadly presumed value of exercise-specific incubation periods for creative ideation. Therefore, the chief objective of this experiment is to be the first to provide preliminary evidence for, or against, the role of embodied incubation to meaningfully impact acute creativity performance.

Method

Study Design and Participant Selection

This study was approved by the institutional review board at the University of Mississippi and participants provided written informed consent prior to the commencement of data collection. The present experiment was conducted utilizing a within-subject, counterbalanced design. Participants completed two laboratory visits, over a period of 24-74 hours, with at least 24 hours between visits. We recruited 33 participants via a convenience-based sampling approach. One individual failed to comply with the research protocol, thus 32 participants comprised the analytic sample, which included 64 total visits to the laboratory (32 participants x 2 experimental visits). The sample size for this within-subject experimental design is similar to other research[344], and was deemed appropriate following an a-priori power analysis, considering data from Oppezzo and Schwartz (2014) with inputs of d=0.25, alpha=0.05, and power of .80. For this experiment, a sample size of 24 participants was determined sufficient to achieve adequate statistical power. We recruited in excess of the suggested minimum sample size to counteract potential attrition and/or participant non-compliance with the study procedures.

Participants were excluded if they reported injury or mobility limitations which would preclude them from safely participating in ambulatory exercise (assessed via the PAR-Q), were current smokers, were taking medication for depression or anxiety, and/or drank alcohol, smoked marijuana, or consumed any illegal drugs within the past 48 hours. Participants were asked to reschedule their visit to another day if they had participated in exercise activities five hours prior to their laboratory session or consumed any caffeine three hours prior to the study. Heart rate

(HR) was monitored continuously during each visit using a chest-mounted Polar HR monitor. Before leaving the laboratory, height (cm) and weight (kg) were recorded.

Assessments and Measures

Before random assignment into the exercise or control group (counterbalanced order), participants were asked to complete the Positive and Negative Affect Scale (PANAS), which is a 20-item assessment of subjective pleasure and distress within the present context[507]. This affective outcome was assessed as mood state has been shown to influence creativity performance [508,509]. At this time, they also completed the 34-item Biographical Inventory of Creative Behaviors (BICB) [467], which has been promoted as an imperative addition to experimental creativity assessment, as this survey measures self-ratings of engagement in creative activities, distinct from intellectual ability alone[510,511].

Participants were given explicit instructions for the Instances Creativity Task (ICT)[499], which was counterbalanced across both visits. At baseline, participants were asked to think of as many examples of items that were square or round (counterbalanced order) within two-minutes. Verbatim instructions for the "square" and "round" ICT assessments are detailed in Appendix A. After the two-minute ICT, participants were randomized into the exercise or control condition (see Figure 1).

Measures for the exercise experimental condition. After completing the initial ICT, a resting HR was recorded, and participants were instructed to, "Please walk on the treadmill at a range of your heart-rate, which will be ____ to ____ beats per minute for this session (e.g. 120-130 beats per minute)." A target HR range of 30-40% was calculated utilizing the Karvonen formula (1957), which was developed to calculate exercise HR at a pre-selected percentage of exercise training intensity (HRmax – Hrrest) + HRrest x .30; HRmax – Hrrest) + HRrest x .40)[512].

Moderate intensity exercise was selected as an adequate [388,392] and relatively safe exercise stimulus for this study.

Participants were informed that the researcher would be exiting the laboratory during the exercise bout but would return briefly at the midpoint (7.5 minutes) of the 15-minute walk, and during the final minute, to record HR and rating of perceived exertion (RPE), which ranges from a minimal rating of six, or no exertion, to 20, or maximal exertion (RPE BORG). Finally, participants were encouraged to consider trying to memorize all the ideas that they were able to think of for things that are round/square, and also to try to think of new ideas, as the exact same creativity evaluation would occur following 15-minutes of walking. Importantly, participants were not forced to think about their initial ideas, as creative incubation periods are conducive to mind-wandering and intentional time-off-task.

After 15 minutes of walking, participants were asked to sit for five additional minutes. Immediately following five minutes of rest, a resting HR was recorded, and participants were given the following instructions, *"You will now have two-minutes to recall your ideas for things that are originally round/square, and to come up with new ideas. Do you understand?"* The researcher exited the room and returned after two-minutes to deliver final experimental instructions, which were: *"Now you will have an additional two-minutes to come up with only completely new ideas that you haven't yet written down."*

Measures for the control experimental condition. After completing the ICT, a resting HR was recorded, and participants were asked to "*Please sit quietly for 20 minutes (matched to the 15-minute exercise period, plus 5 minutes of rest)."* Participants were also given blank paper and pictorial instructions to make an origami swan and rose. Participants were also offered the choice to, *"Feel free to practice your origami skills, but if you choose not to engage in this activity, you may simply sit quietly instead."* Additionally, participants were encouraged to consider trying to memorize all of the ideas that they were able to think of for things that are round/square, and also to try to think of new ideas, as the exact same creativity evaluation would occur following 20 minutes of sitting. Again, participants were not forced to think about their initial ideas. The principal investigator exited the laboratory but returned briefly at the midpoint of the seated condition, and during the final minute to record HR and RPE.

A resting HR was recorded at the conclusion of the 20-minute rest, and participants were given the following instructions, *"You will now have two-minutes to recall your ideas for things that are originally round/square, and to come up with new ideas. Do you understand?"* The researcher then exited the room and returned after two-minutes to deliver final experimental instructions, which were: *"Now you will have an additional two-minutes to come up with only completely new ideas that you haven't yet written down."*

Creativity Scoring

Originality scores were calculated pre- and post-incubation via transcribing the responses generated from all participants whom comprised the present sample. Responses that were given by only 10% of the entire sample were given one point for originality, which is consistent with earlier divergent thinking scoring methods [448]. Originality was independently scored by the principal investigator, as well as two additional (blinded) independent raters. Any discrepancies in scoring originality were resolved between the raters.

Fluency scores were calculated pre- and post-incubation, and are simply denoted by the total of all responses provided by the participant (e.g., generating twelve total ideas for items that are originally round/square).

Data Analysis

SPSS v.25 was used to calculate univariate sample characteristics shown in Table 1, and was also used to a conduct a Two-Way Repeated Measures ANOVA (2x2) of mean differences between each condition (exercise and control conditions) on the *fluency*, *originality*, and *recall* of creative ideas assessed at baseline and post-incubation (see Table 2). That is, for the 2 x 2 RM-ANOVA, one factor was condition (exercise and control) and the other factor was time (baseline and post-incubation). For all analyses, statistical significance was established as a nominal alpha of 0.05.

Results

Table 1 displays demographic characteristics of the analyzed sample (N=32). On average, participants were 22.66 years-old, female (56%) undergraduate students (66%), and non-Hispanic Caucasian (78%).

Table 2 highlights results from three RM-ANOVA analyses conducted to evaluate differences between the exercise and control incubation protocol on the average change in *fluency*, *originality*, and *recall* performances for the ICT. Of the three analytic models that were conducted to examine the proposed incubation effects, all models indicated statistically significant main effects for time: *fluency* ($F(1,31)=131.17$, $p<.001$); *originality* ($F(1,31)$ 36.54, $p<.001$); and *recall* ($F(1,31)=51.75$, $p<.001$). That is, average creativity scores were enhanced following incubation, within this sample, and for both experimental conditions. Notably, the average change in *fluency* ($F(1, 31)=2.51$, $p = .12$) and *recall* scores ($F(1, 31)=0.00$, $p=1.0$) were not statistically significant across the experimental conditions. *Originality* scores were higher at baseline and follow-up when compared to the exercise condition ($F(1,31)=6.82$, $p=.01$). However, there was no statistically significant condition x time interaction effect ($F(1, 31)=1.78$, $p=.19$), as the change between the two exercise and control conditions was not statistically different.

Further analyses demonstrated that when BICB scores were included as a covariate in each statistical model, the results remained unchanged, meaning self-reported creativity did not play a statistically significant role in divergent thinking performance across the two experimental conditions. Additional analyses also indicated that recall was a statistically significant moderator of the time effect for ICT fluency performance following incubation for both groups. Specifically, the difference between total post-incubation fluency *recall* scores, compared to the difference between post-incubation fluency *new response generation* scores was statistically significant ($F(1,31)=22.16$, $p<.001$). Thus, recall scores contributed to post-incubation fluency to a greater extent than new responses. However, this outcome was not statistically different between the exercise and control groups, as the unique contribution of remembered ideas and new ideas was similar across both the exercise and control conditions ($F(1,31)=3.25$, $p=.08$).

Discussion

We aimed to determine whether treadmill walking during creative incubation may facilitate embodied (walking) and/or embedded (seated control) mind-wandering from a baseline creativity assessment modified to induce functional-fixation. We also evaluated the distinct effects of embodied and embedded-incubation periods on subsequent divergent thinking performance on the same creativity task administered at baseline. From the results analyzed herein, we can conclude that, for this sample, average creativity scores were enhanced following incubation within both experimental conditions. Additionally, while the proportion of *new response generation* did not differ across the two conditions when considering total post-incubation *fluency* performance, it appears that, when seated, more control participants' new ideas were also highly original. Notably, however, originality scores were elevated both at baseline and post-incubation for the control condition, indicating originality performance within the control condition statistically increased to the same extent as the exercise condition, given that the condition x time interaction term was not statistically significant.

The ideational endowment of the creative mind is somewhat paradoxical, as creative incubation affords purposeful time off-task to ultimately enhance problem-solving. Both physical and psychological stimulation may be achieved via mind-freeing, embodied distractions, which have yet to be experimentally tested. This study demonstrated that creative *fluency*, or the ability to brainstorm a large quantity of ideas, was improved following a moderate-intensity walking protocol, but was similarly improved following a sedentary incubation interval. Time effects were also apparent for *recall* performance, as well as creative *originality* scores. The rules imposed for the ICT were intended to induce a mental impasse (e.g. "…only list things that are *originally* square/round.") and limit participants' potentiality to produce both creative and task-appropriate ideas. Importantly, the selection of difficult assessment standards replicates real-world challenges college-aged individuals may face daily, such as completing a task project in accordance with objective guidelines for successful performance, while showcasing personal interests, skills, and creative thinking abilities. Incubation-associated improvements have been shown to manifest principally for repeated-exposure problems or assessments, meaning that, related to the current project, an incubation period may only be warranted when an interval of time off-task is immediately followed by a return to time on-task[504]. For example, an incubation period would likely be fruitless if a break from studying were followed by an attempt to finish an art project.

Past research suggests that divergent thinking may be undermined by proactive memory interference. Ruminating on previously conceived ideas may inhibit the acknowledgement of novel and potentially original thoughts essential to creativity [513]. The outcomes of the present project similarly indicate proactive interference may have limited participants' ability to produce new ideas consistent with task requirements. ICT recall scores, following both the exercise- and seated-incubation condition, appeared to drive post-incubation fluency, when compared to new responses. As reliance on memory was especially important for task-performance, individuals in both experimental conditions may have experienced a degree of functional-fixation sufficient to promote recall of ideas at the expense of instrumental working memory search-strategies. Working memory is necessary for creative ideation, as updating and task-switching, attentional control, and selective retrieval of distant associative elements are assets to generating fluent and original responses to prompts delimited by strict criteria. Thus, perhaps detrimental rumination undermined working memory accessibility for the present divergent thinking assessment.

Additionally, previous work posits that the desired effects of incubation periods are actualized when incubation intervals consist of non-demanding activities[514]. Cognitively demanding tasks are expected to nullify many proposed benefits of incubation on creative thinking [514]. This experiment highlights the plausibility for both embedded and embodied incubation to equally activate subsequent creativity. Embedded incubation may be preferred when mental search strategies employed require focused attentional navigation through an internal perceptual space [515]. An internally-directed search may be essential when spatial representations of round and square objects must be exclusively imagined and manipulated in inner, or embedded, cognitive environments. Further, heightened awareness of external cues may also be facilitated within non-moving, or minimally-moving, physical conditions. For example, when contemplating "originally square" items, perhaps a seated control condition facilitates awareness of walls, computer screens, or other salient contextual features, which may then be evaluated for appropriateness and extrapolated to other sensory cues to satisfy task demands. This explanation may partially account for why embodied incubation while participating in tasks with low attentional demand, such as walking, does not appear to meaningfully benefit creativity in excess of sedentary behavior. Another potential explanation for this finding is the modality of embodied incubation selected for this experiment. Perhaps individuals would be capable of engaging in efficacious mind-wandering if given the opportunity to freely walk in a "natural" (i.e. outdoor) environment, or to roam unconstrained, both of which have been shown to positively influence divergent thinking performance[388,389,516].

Limitations of the Present Study

Future research should aim to overcome the limitations of the present study, including our decision to measure a singular aspect of human creativity (divergent thinking), as well as our evaluation of a homogenous sample of college students, precluding generalizability to a broader population. Participants may also have responded more creatively post-incubation, simply due to repeated exposure of the stimulus. However, we do not view this as a threat to the internal validity of this experiment, as the nature of incubation requires repeated exposure to the same problem. Additionally, our decision to include an origami task to entertain participants during the seated control condition may have offered low-level, albeit enjoyable mental stimulation, which could arguably obscure differences in the extent of mind-wandering expected during engagement in exercise versus seated rest. However, due to the risk of negative affectual responses associated with boredom, we felt that employing a potentially pleasant control task was necessary to overcome anticipated confounding effects of negative, deactivating changes in mood state, which could influence subsequent creativity[508,509]. Critically, we did not force or encourage individuals to participate in the origami task, explicitly stating that the task was optional and was in unrelated to the main objectives of the experiment.

Conclusions and Future Research

This study offers a novel contribution to exercise psychology and health promotion by providing insight on the plausible role of "embodied" and "embedded mind-wandering" on creative thinking. Continued research should examine exercise prescriptions of various intensities, modalities and motor-skill demand to evaluate whether repetitive or coordinated motion (e.g., shooting free throws for accuracy or learning a choreographed dance) is perhaps sufficient to induce a robust incubation effect. Conversely, such stimuli may minimize mind-wandering during movement that requires sustained cognitive engagement to successfully perform the exercise. Research must also consider the likelihood that exercise may not, in fact, appreciably activate certain aspects of creative incubation beyond time-matched seated activities. Clearly, much work remains to be conducted on this novel line of inquiry, and we are confident this experiment is an invaluable primer for continued research.

Table 1. Descriptive Statistics.

Variable	N	Point Estimate	SD
Percent Female vs. Male Gender	32	56.25	
Percent Undergraduate vs. Graduate Student	32	65.62	
Percent Right-Hand vs. Left-Hand Dominant	32	75.00	
Race-ethnicity, Percent Caucasian	32	78.12	
Age, years	32	22.66	3.23
GPA, 0.0-4.0	32	3.36	0.44
PAVS PA		223.13	171.30
BMI (kg/m^2)	32	25.61	5.16
PANAS Positive (EX), 0-50	32	29.94	8.47
PANAS Negative (EX), 0-50	32	11.28	1.95
PANAS Positive (CO), 0-50	32	29.16	7.91
PANAS Negative (CO), 0-50	32	12.00	3.02
BICB, 0-34	32	6.44	2.88

Note. GPA = grade-point average; PAVS = Physical Activity Vital Sign; PA = physical activity; BMI = body mass index; PANAS = Positive and Negative Affect Scale; EX = Exercise Condition; CO = Control Condition; BICB = Biographical Inventory of Creative Behaviors

Table 2. Instances Creativity Task (ICT) scores (means (sd)) across the two experimental incubation conditions.

ICT	**Exercise (Baseline)**	**Exercise (Post)**	**Control (Baseline)**	**Control (Post)**
Fluency	5.41 (1.90)	9.91 (3.21)	5.88 (2.39)	11.56 (4.17)
Originality	1.03 (1.06)	1.91 (1.35)	1.34 (1.26)	3.00 (2.21)
Recall	5.41 (total baseline fluency)	4.13 (1.45)	5.88 (total baseline fluency)	4.59 (1.83)
F(df), P-Value†	**Mean Change (EX vs. CO)**	**Condition**	**Time**	**Condition x Time**
Fluency	EX = + 4.5 vs. CO = + 5.68	F(1, 31)=2.90, p=.10	F(1, 31)=131.17, p<.001	F(1, 31)=2.51, p = .12
Originality	EX = + 0.88 vs. CO = + 1.66	F(1, 31)=6.82, p=.01	F(1, 31)=36.54, p<.001	F(1, 31)=1.78, p=.19
Recall	EX = - 1.29 vs. CO = -1.29	F(1, 31)=1.04, p=.32	F(1, 31)=51.75, p<.001	F(1, 31)=0.00, p=1.0

Note. EX = Exercise Condition; CO = Control Condition

† For each creativity metric (e.g., fluency), a 2x2 Repeated Measures ANOVA (RM-ANOVA) was computed to calculate the respective F-value (df; degrees of freedom) and P-value.

Appendix A

Instances Creativity Task Instructions

Square

Verbatim script: “I am going to read you some instructions for an assessment you will complete now. Please list things that are square. You will have two minutes to list as many things as possible that are square. Importantly, you must only list things that are originally square. For example, a piece of paper is not normally square. Its dimensions are 8.5 x 11 inches, which is more rectangular. Paper can be cut to appear square, but it is not originally square. Additionally, listing different types of paper is not acceptable, meaning construction paper, notebook paper, and printer paper would all be considered the same. You will be scored based on how many original ideas you can come up with, as well as the variety of these ideas. You will need to think quickly, as your two minutes will begin as soon as I leave the room. Do you have any questions?”

Round

Verbatim script: “I am going to read you some instructions for an assessment you will complete now. Please list things that are round. You will have 2-minutes to list as many things as possible that are round. Importantly, you must only list things that are originally round. For example, a rock is not normally round, as its texture is not uniformly round. There are many different types of rocks, but they must be altered by a jeweler, geologist, etc, to appear round. Additionally, listing many different types of rocks is not acceptable, meaning a boulder, a pebble, and a stone would all be considered the same. You will be scored based on how many original ideas you can come up with, as well as the variety of these ideas. You will need to think quickly, as your two minutes will begin as soon as I leave the room. Do you have any questions?

IV. EXPERIMENTAL EFFECTS OF ACUTE EXERCISE ON VERBAL, MATHEMATICAL, AND SPATIAL INSIGHT CREATIVITY

Abstract

This experiment was designed to accommodate the diversified verbal, mathematical skills and interests of young adults, which have yet to be collectively evaluated in research projects focused on acute exercise and creativity among college students. Additionally, while emergent research suggests that acute, moderate-intensity exercise is capable of influencing human creativity, the temporal effects of exercise on creativity have not been experimentally investigated. Distinct temporal effects are plausible, as previous work also suggests a temporal effect of acute exercise on both memory and cognition, which are important factors associated with creativity. Thus, the purpose of this study was to examine the temporal effects of acute, moderate-intensity treadmill walking, for 15 minutes, on verbal, mathematical, and spatial insight creativity performance. Among a sample of 20 undergraduate student participants, all twenty individuals completed three randomized laboratory visits in this within-subjects design: control condition, exercise before insight problem-solving, and exercise during insight problem-solving. Participants also completed six insight creativity tasks (two verbal, two mathematical, and two spatial tasks) per visit, with the order of task-presentation randomized and counterbalanced across the three visits. Average insight creativity scores were similar across the three exercise manipulations That is, *verbal insight* ($F(2,18)=.689$, $p=.51$), *mathematical insight* ($F(2,18)=.033$, $p=.97$), and *spatial insight* ($F(2,18)=1.0$, $p=.38$) performance were not statistically significant across the control, exercise before insight problem-solving, and exercise during

insight creativity problem-solving visits. No evidence of a differential temporal effect of moderate-intensity exercise on acute insight creativity performance was demonstrated. Thus, the timing of exercise may not appreciably influence verbal, mathematical or spatial insight creativity.

Introduction

Creative individuals are more likely to take risks, form unlikely associations between conventional designs, are often passionate and extremely motivated to perform well and in accordance with their goals, and tend to adapt or remain resilient in the face of adversity and failure[517-519]. Taken together, creativity may be a personally motivated decision to seek out opportunities for originality, with the means to excel in bringing them to fruition[520]. Domain-general theories of creative thinking and behavior propose that creative individuals are equipped to solve problems by overcoming difficult challenges with a unifying strategy or framework, typically rooted in their personality, or overarching creative abilities[521]. Domain-specific theories dismiss the assertion that creative skills readily transfer across domains of expertise. Consider the revolutionary scientist, Albert Einstein, who communicated his disinterest in verbal cognitions, claiming, "*The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought*[522]." In contrast, arguably the greatest pioneer of creative language, William Shakespeare, in his "A Midsummer Night's Dream," reinforced his chosen livelihood with the prose, "*And as imagination bodies forth/ The forms of things unknown, the poet's pen/ Turns them to shapes and gives to airy nothing/ A local habitation and a name*[523]*."* By and large, evidence of creativity within a specific domain is not reliably predictive of creativity in an unrelated domain[521].

Importantly, however, this does not imply that individuals cannot be creative in multiple domains. For example, Da Vinci's rare talent as a world-renowned painter, did not automatically increase his likelihood of also being an erudite architect, mathematician and engineer, although he certainly excelled in all disciplines with extraordinary creativity[524].

Generalist and domain-specific theories of creativity are unresolved, controversial topics in creativity literature[295,525]. The ongoing debate questions whether a reductionist definition of creativity as a singular constituent of human cognition is wholly appropriate? To this end, calling someone creative would be a misnomer (e.g., the claim, "Picasso was creative."). Perhaps distinguishable "creativities," encapsulating mental processes, problem-solving styles and strategies, as well as domains of expertise are more representative (e.g., "Picasso was a creative artist."). To this end, aptitudes and orientations of thought are known to differ widely among individuals. However, a well-accepted expectation related to the empirical measurement of creativity is that it must manifest in a particular context and under certain parameters[521], which prompted the conception and design of the present experiment.

This experiment was designed to accommodate the diversified verbal, mathematical skills and interests of young adults, which have yet to be collectively evaluated in research projects focused on acute exercise and creativity among college students. Notably, among other factors, acute exercise may be capable of influencing psychological factors related to each of these three parameters in isolation. Although typically assessed pre- and post-exercise, moderate-intensity exercise during verbal learning is suggested to benefit subsequent recall performance[526], and has also conferred positive performance effects on paragraph recall when the exercise bout is completed prior to verbal-task exposure[527]. Further, verbal learning and recall rely on both executive, prefrontal brain functions which may be augmented for up to two hours post-exercise[528], as well as long-term memory associated hippocampal activity[529], which have also been shown to be enhanced following acute exercise[529]. Mathematical performance may be sensitive to acute exercise, with speed and accuracy of computational performance improved in children post-interval running[530], 30-and 40 minutes after walking[531], following 50 minutes of aerobic relay activities[532], as well as after multiple acute, high-intensity exercise exposures[530].

Animal research has shown enhanced spatial learning following exercise, which may be associated with stimulation of neuronal growth[533], primarily hippocampal neurogenesis[534]. In fact, The hippocampus, parahippocampal region and medial entorhinal cortex, which is a structure critically involved in the formation of spatial representations[535], may be specific neural targets stimulated by acute exercise[536,537], Often, structural changes in the brain develop over time, however acute, moderate-intensity exercise may be capable of modulating information-processing via refined psychomotor control and perceptual coordination[306,538]. Additionally, assessments of crystallized intelligence, which evaluate verbal, numerical, and visuospatial ability have been demonstrated to benefit after acute, moderate-intensity exercise, which perhaps enhances retrieval of salient information from memory[539]. Although emerging research suggests that acute, moderate-intensity exercise appears to influence creative performance[388,389], the temporal effects of exercise on creativity have not been explored. Distinct temporal effects are plausible, as previous work also suggests a temporal effect of acute exercise on episodic (or personal/ autobiographical) memory[529,539-541], an integral element of creativity. Thus, the purpose of this experiment was to evaluate the potential temporal effects of acute moderate-intensity exercise on creativity.

Methods

Study Design and Participants

The study procedures were approved by the authors' institutional review board. This experiment employed a within-subjects design. An a-priori power-analysis was conducted, based on related experimental work, with inputs of f=0.337, alpha=0.05, and power of .80, 18 participants were sufficient to achieve adequate statistical power[389]. The principal investigator recruited (via convenience-based sampling) 20 eligible undergraduate student participants whom were between the ages of 19-23 years, were self-reported non-smokers, were not pregnant, had abstained from exercise within the past five hours and caffeine within the past three, reported not taking medication (prescribed or otherwise) known to influence cognition (e.g., Adderall) or mood (e.g., SSRI's), and were assessed for readiness to engage in treadmill exercise via the Physical Activity Readiness Questionnaire (PAR-Q)[542]. Upon provision of written informed consent, participants were randomized into three distinct experimental conditions, which were completed on separate days, with at least 24 hours between each laboratory visit.

Materials Utilized for All Experimental Visits. At baseline, participants completed the 20-item Positive and Negative Affect Scale (PANAS), which measures acute, subjective pleasure and distress[507]. Baseline positive and negative PANAS scores were evaluated as mood state has been shown to influence acute creativity performance[508,509,543,544]. No statistically significant differences in mood state were determined at baseline (see Table 1). At this time, individuals were also given instructions for wearing a chest-mounted Polar heart-rate (HR) monitor, as HR was monitored continuously for the duration of each laboratory visit. Specifically, for each visit, a resting HR was recorded, as well HR at the midpoint (10 minutes) and end (20 minutes) of all experimental manipulations (i.e. seated rest or treadmill exercise visits). Prior to leaving the laboratory, participants' height (cm) and weight (kg) were recorded.

Experimental Visit Details. All participants were individually-assessed and volunteered their time for three separate laboratory visits, which were completed in a randomized, counterbalanced order. For the seated control condition (CO), participants were asked to listen to white noise through headphones for 25 minutes (time-matched to the 20-minute exercise conditions, plus 5 additional minutes of seated rest) before solving the insight creativity tasks, which are detailed in the following section. For the Exercise Before Insight (EBI) condition, participants were asked to walk on a treadmill for 20-minutes prior to the creativity assessments. The researcher exited the laboratory during both the CO and EBI conditions, and re-entered only to record HR and Rating of Perceived Exertion (RPE). Participants in the Exercise During Insight condition (EDI) were asked to walk on a treadmill for 20-minutes *during* completion of the insight creativity assessments. Researchers remained in the laboratory for the entirety of the 20-minute treadmill exercise to ensure participant safety, as well as to administer the insight tasks. Following exercise, individuals participated in five additional minutes of seated rest. Upon five minutes of rest, a resting HR was recorded, and insight creativity performance was measured for the CO and EBI conditions, or height and weight were measured, and participants scheduled subsequent laboratory visits, if necessary.

Regarding the EDI visit, as each insight problem was presented individually (i.e., not as a packet, or battery of assessments), participants began solving the first insight task after 60-90 seconds of treadmill walking, and concluded solving the last insight problem 1-minute to 30-seconds before the 20-minute time limit expired. As individual speed of solution was not of interest for the present investigation, participants, in all experimental conditions, were given instructions for the next insight only when the three minutes allocated to the previous insight task had elapsed. Simply stated, if an individual finished solving a problem in one minute, they would return the clipboard to the researcher (or would sit quietly until the researcher re-entered the room) and continued walking for another two-minutes before instructions for the next problem were provided. This procedure was deemed appropriate to time-match all conditions, and not induce undue cognitive fatigue.

Insight Creativity Task Details. Participants solved six insight creativity tasks during each experimental visit. The order of insight tasks was randomized and counterbalanced across verbal, mathematical, and spatial domains. For each visit, individuals attempted to solve two verbal, two mathematical, and two spatial insight problems, again with the order of presentation randomized for all visits. There were three outcome metrics for this study, including a summed verbal score (range, 0-2), mathematical score (range, 0-2), and a spatial score (range, 0-2). For each question, participants received a point if they correctly answered the question (max score of 2 for each insight category).

As this was a within-subjects protocol, it was critical that no participant attempt an identical problem on discrete visits, as was the rationale for including eighteen total insight tasks. The 18 insight creativity tasks employed for this experiment were retrieved from Dow & Mayer (2004)[545]. The two researchers compiled 67 published (in-print or online) insight problems. Of the problems they retrieved, eleven are mathematical assessments 39 are verbal, and 17 are spatial tasks. All insight problems are freely accessible in the appendix of their 2004 manuscript[545].

Similar to Dow & Mayer's[545] methodology, distinguishing features of verbal, mathematical, and spatial insight, problems will be discussed herein, and replicate examples of the insight tasks selected for this study will be detailed as well. Verbal insight tasks include non-obvious semantic clues, which are often not immediately salient to the problem-solver. An example of one of the six verbal tasks selected for the present study is "*Our basketball team won a game last week by the score of 73-49, and yet not even one man on our team scored as much as a single point. How is that possible?*" The target word is *man*, and participants theoretically arrive at a moment of insight upon the realization that the basketball team must be a women's team, which is the correct response. Mathematical insight not only relies on computational capacity, but also the ability to employ strategies and manipulate obscure patterns to arrive at the correct insight solution. An example of one of the six mathematical tasks selected herein is "*Yesterday I went to the zoo and saw the giraffes and ostriches. Altogether they had 30 eyes and 44 legs. How many animals were there?*" The correct solution is 15 animals, as each animal has two eyes. Knowledge of zoo-animal limbs is irrelevant for deriving a solution to the problem, but may fixate participants on attempting to apply all information provided. Lastly, spatial insight problems deceive participants into fabricating false rules that may preclude the timely achievement of accurate solutions. An example of one of the six spatial tasks we chose to include in this study is Duncker's (1945) classic candle experiment[546]. Participants are shown a photo of materials as well as the following instructions: "*Given the material below, how can you attach the candle to the wall above the table so that the wax does not drip on the table*?" Along with the candle, a box of thumbtacks and matches are provided. Duncker designed this experiment to induce functional-fixedness, as participants tend to be slow to imagine an emptied box of tacks to serve as a makeshift candleholder to tack to the wall, appropriately overcoming self-imposed limits to solving the problem[546].

For both the CO and EBI conditions, the experimental manipulation was completed prior to solving the six insight creativity tasks. Conversely, the EDI visit required completion of the insight tasks *during* treadmill walking. For all visits, participants were given three minutes to endeavor to solve the individual problems presented. Additionally, for all visits, participants provided written answers for each task on the same page (six total pages per visit) as the corresponding instructions. During the EDI visit, participants were given a clipboard along with the instructions and response-sheet, and solved problems while walking. Notably, no adverse events were encountered within the EDI visit, meaning no uncomfortable dizziness, trips, or falls were reported by any participant.

Statistical Analyses

Statistical analyses were computed in SPSS (v. 25. A repeated measures ANOVA (RM-ANOVA) was used to evaluate creativity performance differences across the three experimental differences. Three separate RM-ANOVAs were computed, one for each insight category. Statistical significance was set at an a-priori alpha of 0.05.

Results

Participant demographic characteristics are displayed in Table 1 (N=20). On average, participants were 21 years-old, with the majority of participants being male (60%), right-hand dominant (80%), and non-Hispanic Caucasian (75%).

Results from the three RM-ANOVA's conducted to examine differences between the three experimental conditions (CO, EBI, EDI) and three domains of insight performance (verbal, mathematical, and spatial) are shown in Table 2. Of the three analytic models that were conducted to examine the proposed temporal effects of acute exercise on creativity, all models demonstrate no statistically significant temporal effects. That is, average insight creativity scores were similar across the three exercise manipulations: *verbal insight* ($F(2,18)=.689$, $p=.51$), *mathematical insight* ($F(2,18)=.033$, $p=.97$), and *spatial insight* $F(2,18)=1.0$, $p=.38$ performance. Taken together, seated rest, exercising before solving insight creativity problems, and exercising during solving insight tasks do not appear to effectuate meaningful differences on insight performance within the same individuals. Further analyses indicated that the proportion of correct versus incorrect responses were not different across conditions, with all p-values >.05. There were also no statistically significant differences in task difficulty across experimental conditions (data not shown; all p-values >.05).

Discussion

Previous insight creativity research highlights the importance of efficient memory search and retrieval, prefrontal cortex activity, and coordinated executive functions for successful problem-solving performance[547]. Creative insight is but one of the many subprocesses of the creative mind[548]. A moment of insight is commonly described as a shift from the unknown to the sudden arrival at the solution that is *perceived* to be true, with a correspondingly powerful, "Aha" moment or "Eureka" experience[545]. Creative insight is not as ubiquitously researched as divergent creative thinking, particularly because Aha experiences are quite difficult to pinpoint[548], and thus, evaluate in a laboratory session. However, the purpose of this experiment was not to isolate individual perceptions of Aha moments, but rather to evaluate participants' ability to accurately solve a variety of insight tasks. Both long-term and acute exercise protocols, as well as exercise during and immediately prior to verbal[526-529], mathematical[530-532], and spatial[306,535,536,538] cognitive tasks have been shown to facilitate cognitive performance. Therefore, the primary aim of this study was to be the first to compare the efficacy of seated rest, or treadmill walking either before, or during insight problem-solving, on the number of correct verbal, mathematical, and spatial insight task solutions.

Findings from this study indicate an absence of temporal effects on insight problem-solving. Creativity performance on the selected verbal, mathematical, and spatial insight tasks was similar across the three experimental conditions. Taken together, it appears that exercise, either before, or during insight problem-solving may not differentially affect creative outputs. A potential explanation for these results may be related to higher-order executive functions speculated to play a profound role on insight performance, specifically via core components of executive function, which include inhibition of distracting or task-irrelevant stimuli, updating of content within working memory, and adaptability in shifting attention from narrow to diffuse, when required[113,549]. Although a single session of exercise is proposed to elicit immediate benefits to executive functioning, including inhibition[550-552] and attentional allocation[551], individual responses to acute exercise (e.g., influences of cardiovascular fitness and affect), intrinsic drive to maintain targeted effort towards solving difficult problems, and individual differences in baseline verbal, mathematical, or spatial interests and talents may interact to govern the magnitude of physical activity's effects on select executive functions[553]. Additionally, although physical exercise of varying intensities, modalities, and durations does not globally and unequivocally facilitate the totality of human executive processes, both long and short-term exercise protocols have indicated differential increases in specific executive functions[550]; therefore individual differences must be stringently accounted for in future work.

As the variation within individual responders and non-responders may complicate the interpretation of true and meaningful empirical outcomes, research should seek to further explore the influence of exercise on creative performance by investigating consequent changes (or lack thereof) in "relative-within-subject" individual responses, rather than "absolute" changes in creativity. Taken together, ongoing research should assess improvements, decrements, and stability of select creative parameters at the within-subject level. For example, even if, compared to others, a low-performing individual improves their creativity to a slight degree, or "suboptimal" level, this individual's creativity, relative to themselves was enhanced as a result of the experimental manipulation, which is invaluable information, would be crucial for reinforcing the practical implications of this inchoate discipline. Notably, "within-subject" designs are essentially evaluating "between-subject" differences, meaning that, in using a within-subject design, a repeated measures analysis is conducted to determine "average" differences across the conditions[554].

Despite aims to mitigate some of the potential confounding effects of individual differences by assessing multiple aspects of insight creativity (verbal, mathematical, and spatial) as well as accounting for differences in weight status and habitual physical activity participation, we did not assess self-reported aptitude or engagement in the verbal, math, or spatial activities. Self-report surveys, such as the Biological Inventory of Creative Behaviors[467], which asks individuals to state activities they have actively participated in over the last year, or the Kaufman Domain Scale[459], which assesses self-reported ability in specific areas, would have been useful to include when conducting this project. Nevertheless, this study offers important preliminary evidence for acute, ambulatory exercise to perhaps not appreciably influence insight creativity. As mentioned in the introduction, several exercise-induced structural and neurotropic adaptations occur over time; thus, a chronic exercise-training study may be warranted to further assess the plausibility for exercise to impact creativity. Additionally, as Zhou et al. recently demonstrated with respect to divergent thinking, unconstrained walking[389], or even exercising in preferred, free-living environments may possibly exert disparate effects on insight creativity than those presented herein. In exploring potential strategies to facilitate students' creative insight problem-solving skills, seated rest, as well as moderate-intensity treadmill walking before and during problem-solving failed to differentially influence acute creativity scores. Future research should improve upon our methods employed and aim to elucidate whether structured exercise (either acute or chronic) is capable of stimulating an individual's capacity for creativity (or "creativities").

Table 5-3.1

Descriptive Statistics

Variable	N	Point Estimate	SD
Percent Male vs. Female Gender	20	60.00	
Percent Right-Hand vs. Left-Hand Dominant	20	80.00	
Race-ethnicity, Percent Caucasian	20	75.00	
Age, years	20	21.15	1.04
GPA, 0.0-4.0	20	3.33	0.33
PAVS PA	20	237.25	226.59
BMI (kg/m^2)	20	23.91	3.43
Baseline PANAS Positive (CO), 0-50	20	25.90	7.12
Baseline PANAS Negative (CO), 0-50	20	12.40	3.90
Baseline PANAS Positive (EBI), 0-50	20	26.50	7.47
Baseline PANAS Negative (EBI), 0-50	20	11.85	2.28
Baseline PANAS Positive (EDI), 0-50	20	26.15	8.74
Baseline PANAS Negative (EDI), 0-50	20	13.05	4.20
Treadmill Speed (EBI)	20	3.48	0.27
Treadmill Speed (EDI)	20	3.45	0.27
HR (CO)	20	77.10	10.41
HR (EBI)	20	116.85	17.19
HR (EDI)	20	115.65	17.09

Note. GPA = grade-point average; PAVS = Physical Activity Vital Sign; PA = physical activity; BMI = body mass index; PANAS = Positive and Negative Affect Scale; CO = Control Visit; EBI = Exercise Before Insight Visit; EDI = Exercise During Insight Visit; HR = heart rate at the end of the experimental stimuli (e.g., at the end of the walk).

Table 2. Insight performance (means (sd)) across the three experimental visits.

Visit	Verbal Insight Mean (sd)	Mathematical Insight Mean (sd)	Spatial Insight Mean (sd)
CO	0.85 (0.75)	0.75 (0.64)	0.40 (0.60)
EBI	0.65 (0.75)	0.70 (0.73)	0.35 (0.50)
EDI	0.60 (0.82)	0.75 (0.64)	0.20 (0.41)
F(df), P-Value†	F(2,18)=.689, p=.51	F(2,18)=.033, p=.97	F(2,18)=1.0, p=.38

Note. CO = Control Visit; EBI = Exercise Before Insight Visit; EDI = Exercise During Insight Visit.

CHAPTER VI

DISSERTATION STUDY

PRIMES FOR THE MIND: ADDITIVE EFFECTS OF VERBAL PRIMING AND ACUTE EXERCISE ON CONVERGENT CREATIVITY

Abstract

Background: Positive relationships between anagram performance and select convergent creativity assessments are emerging. Anagram tasks consist of lists of jumbled words that must be mentally reorganized and accurately represented in their true semantic form. Anagram solution rates have been linked to higher-order cognitions, most specifically executive functioning, and are expected to involve flexible problem-solving strategies conducive to creative performance. The Remote Associates Test (RAT) assesses creative convergence on a single, verbal solution by requiring that problem solvers determine one unifying association word within a triad of three unrelated words. The acute effects of moderate-intensity treadmill exercise in combination with an associative anagram problem solving prime on subsequent creativity performance has yet to be empirically investigated, which was this study's purpose. **Methods:** A two-visit, within-subject experiment was conducted among individuals aged 18-35. Verbal creativity (via the RAT) was assessed at the end of each visit. The order of conditions was counterbalanced across the sample, with the exercise condition consisting of an acute 15-minute moderate-intensity treadmill exercise during anagram problem solving. The control condition consisted of 15-minutes of seated rest during anagram problem solving. **Results**: Average RAT performance was higher in the exercise + anagram problem-solving condition

($\bar{X}$ = 10.51, SD = 3.25) compared to anagram-solving + seated rest ($\bar{X}$ = 9.29, SD = 4.12). The difference between conditions was statistically significant, $t(44) = 2.385$, $p = .021$, $d = 0.36$.

Conclusion: The findings of the present experiment demonstrate that acute, moderate-intensity treadmill exercise coupled with anagram problem-solving, prior to RAT completion, is a potential strategy for enhancing verbal convergent creativity.

Introduction

Much like the scientific method, approaching a complex problem requires the formation of a research question and/or hypothesis, and subsequent testing of all suppositions as methodically as possible. Anagram tasks consist of lists of confusing, jumbled words which require thoughtful generation of potential verbal solutions, and systematic evaluation of these solutions via mental reorganization and coherent representation (either in verbal or written form) of the target word[555,556]. Anagram solution rates have been linked to higher-order cognitions, most specifically executive functioning, and are expected to involve flexible problem-solving strategies conducive to creative performance[557].

Cognitive flexibility is associated with effective anagram solving and is also a crucial component of both executive function and numerous creativity assessments[364,558-562]. Successful performance on anagram tasks appears to demand an external locus of attention, which is highlighted by repeated experiences with the acquisition of language, vocabulary, as well as letter frequency recognition. An internal locus of attention also appears to be important for anagram solving, as, following letter recognition, individuals must not only be able to visualize diverse letter reorganizations initially viewed in ambiguous sequences, but must also appropriately match correct patterns of vowels and consonants by manipulating multiple sets of letter configurations within working memory[557]. Positive relationships between anagram performance and Remote Associates Task (RAT) scores have been shown to emerge even when intelligence is partialled out of the model[563]. The RAT, which assesses creative convergence on a single, verbal solution, requires that problem solvers overcome fixation, or hyper-focused attention, on the presented stimulus words, as one unifying association word must be identified within a foundational triad of three seemingly unrelated words[60].

Interestingly, research has shown that high performers on RAT measurements readily implement presented cues for solving challenging problems and are also able to adequately attend to perceptual cues subserving efficacious problem-solving[563]. Early work has provided strong evidence that when anagrams are presented as thematic, cohesive lists, or category sets, this method facilitates anagram problem-solving strategies; perhaps because individuals may be associatively primed to utilize internally-oriented search strategies to first identify previously abstract categories, followed by a conscious re-organization of logical verbal responses[564,565]. To this end, the anagrams chosen for the present study were presented as category sets.

Priming has been shown to activate remote associates advantageous to performance on creativity assessments[559]. Conversely, priming has also been shown to reduce performance on RAT assessments when unrelated associations are presented in combination with stimulus words, leading researchers to the conclusion that activation of previously experienced information may attenuate fixation on examples or confer cognitive benefits to both associative convergence and idea generation[566]. Thus, it appears that the nature of the stimulus is critical for priming creative responses. The retrieval theory of priming suggests that familiar working memory contents, coupled with word targets, represent a cue that, when primed successfully, may reduce response time and aid convergence on correct associate solutions[567]. Importantly, selected primes must be applicable to the upcoming task, otherwise similar resources will be less essential for completion of the target outcome task, and, in turn, the transfer effects of priming would be lost[559,568]. To this point, the present study appropriately addressed this specification by ensuring that priming of an associate term for category lists of anagrams preceded a task requiring convergence on the RAT, which requires semantic association of disparate word triads.

Recent work has shown that RAT problem-solving *during* comfortable, self-selected treadmill walking significantly diminished convergent creativity[344]. Intense cycling exercise has also been shown to diminish convergent creativity on the RAT compared to moderate-intensity exercise and rest among inactive individuals[162]. Per self-control failure theory, the exertion of self-control on one task will deplete cognitive resources necessary for the exertion of self-control on a later task, particularly attributable to reduced motivation and attentional capacity[569]. In accordance with a self-control failure model, intense exercise would undermine task performance on convergent thinking creativity tasks requiring motivation to persist and sustained attention[162]. However, moderate-intensity movement is not expected to result in self-control failure, and, when coupled with an associative cognitive activity[570], may exhibit an additive effect with presented anagram lists by priming subsequent convergent creativity outcomes.

When performed immediately following moderate-intensity exercise, research has shown benefits to cognitive functioning, including self-control, whereas lighter or heavier exercise intensities may not exert a favorable effect on select cognitions assessed following the exercise bout[571]. The convergent validity of the present study may be further strengthened as executive functions related to creativity performance may be facilitated when assessed immediately post-exercise[571]. To this point, unlike Oppezzo & Schwartz (2014)[344], we measured creativity *following* acute, moderate-intensity exercise, and utilized an associative priming anagram task *during* treadmill walking. Relatedly, Leung et al. (2011) demonstrated that embodied, upper-limb movements involving combining paper from a left-positioned stack with paper from a right stack and placing the combination in the middle of the stacks was associated with higher RAT performance when compared to a non-combination group[354]. These findings motivated the present study. Specifically, we aimed to concurrently employ a verbal "combinatory" anagram with more purposeful embodied physical mobility (i.e., treadmill walking) to determine whether moderate-intensity movement coupled with an associative anagram task may confer additive effects to convergent creativity, compared to the potential isolated effects of engaging in a priming associate anagram task alone.

The acute effects of moderate-intensity treadmill exercise in combination with associative anagram problem solving on subsequent RAT performance has yet to be empirically investigated, which was this study's purpose. We hypothesized that moderate-intensity, ambulatory exercise may exert an additive effect on subsequent convergent creativity performance. Motivation for this research project was based on previous work demonstrating that creative behavior may be associated with antecedent priming stimuli[559], and that sufficient neural stimulation may be achieved via moderate-intensity treadmill walking[572,573]. Further, verbal associative priming has never been assessed in the domain of exercise or embodied cognition and creativity. Taken together, our specific research question is stated as follows: Does acute, moderate-intensity treadmill walking while solving anagrams differentially influence associative ability and convergent creativity performance when compared to engaging in only an anagram priming task (and no exercise) prior to RAT assessment? As the objective of this study was not to compare a priming condition to a no-priming condition, but rather, to examine whether exercise may enhance priming effects, our primary research hypothesis was that acute moderate-intensity treadmill walking while solving anagrams would induce an additive effect capable of facilitating convergent creativity, relative to priming alone.

Methods

Study Design and Participants

This experiment employed a within-subject, counterbalanced design. The sample size determined for this within-subject experimental design is similar to other research and was deemed appropriate following an a-priori power analysis, considering data from Colzato et al., with inputs of f=0.24, alpha=0.05, and power of .80, which indicated that 38 participants were sufficient to achieve adequate statistical power. The principal investigator recruited (via non-probability, convenience-based sampling) 45 eligible undergraduate and graduate student participants whom were between the ages of 18-35 years, were not pregnant, self-reported non-smokers, had abstained from exercise within the past five hours and caffeine within the past three hours, had not incurred a concussion within the past 30 days, and were confirmed to be able to safely engage in treadmill exercise. These criteria were used to minimize a potential confounding effect on creativity performance[572,574-579]. The principal investigator also noted individuals who reported taking prescribed medication known to regulate mood or cognition (e.g., SSRI's or Adderall); however, this was not exclusionary criteria. Twelve individuals (27%) reported consuming prescribed mood- or cognition-regulating medication. This study was approved by the authors' institutional review board. Upon provision of written informed consent, participants were randomized into one of two counterbalanced orders (for the experimental conditions described below) and agreed to complete both conditions in the within-subjects design. These two, counterbalanced experimental conditions were completed on separate days, at approximately the same time of day, with at least 24 hours between each laboratory visit.

Materials Utilized for Both Experimental Visits

Surveys

At baseline, participants were instructed to please complete the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+)[580], which ensures that participants should be capable of safely engaging in physical exercise without physician supervision[581], as well as the 20-item Positive and Negative Affect Scale (PANAS), which measures acute, subjective pleasure and distress[507]. Baseline positive and negative PANAS scores were assessed as mood state has been confirmed to impact acute creativity performance[155,509,543,544]. Then, individuals were given instructions for wearing a chest-mounted Polar heart-rate (HR) monitor, as HR was monitored continuously for the duration of each laboratory visit.

The 78-item Creativity Styles Questionnaire-Revised (CSQ-r)[582], consists of eight subscales (Likert-type scales), and was administered at the end of the second (i.e., final) visit to assess various internal and external factors that may have influenced creativity beyond the controlled environment of the research laboratory. For the present study, average internal consistency across the scales, as measured by Cronbach's alpha, was adequate ($\alpha = 0.72$). The scales are described as follows:

1. *Kumar and Holman's Global Measure of Creativity Capacity* (two items), which assesses self-perception of creative capacity. An example item from this scale is, "I consider myself to be a creative person." Reported alpha reliability for this subscale is .76[582].
2. *Belief in Unconscious Processes* (17 items), which measures the degree to which individuals believe creativity to be driven by subconscious factors beyond direct control. An example item from this scale is, "I must be emotionally moved in order to be creative." Reported alpha reliability for this subscale is .70[582].
3. *Use of Techniques* (18 items), which assess whether individuals employ strategies to enhance their creative performance. An example from this scale is, "I typically create new ideas by combining existing ideas." Reported alpha reliability for this subscale is .81[582].
4. *Use of Other People* (nine items), which asks individuals to indicate their tendencies to utilize social connections to foster creativity. An example item from this scale is, "I am at my creative best when I work in a group." Reported alpha reliability for this subscale is .74[582].

5. *Final Product Orientation* (seven items), which represent the extent to which individuals are outcome-motivated in the context of creativity. An example item from this scale is, "I work most creatively when I have deadlines." Reported alpha reliability for this subscale is .45[582].
6. *Environmental Control/Behavioral Self-Regulation* (18 items), which evaluate whether participants utilize discriminative cues to aid their creative pursuits. An example item from this scale is, "I typically have background music when I am engaged in creative work." Reported alpha reliability for this subscale is .83[582].
7. *Superstition* (two items), which signify the level of superstition that influences individual perceptions of creative processes and products. An example item from this scale is "I have a favorite tool (e.g., pen, easel, thinking cap, etc.) without which I would find it hard to concentrate when I am engaged in creative work." Reported alpha reliability for this subscale is .72[582].
8. *Use of the Senses* (five items), which assess utilization of the five senses during creative engagement. An example item from this scale is "I tend to use my sense of taste a lot in my creative work." Reported alpha reliability for this subscale is .76[582].

Anagram Task

The anagram solving tasks employed in this experiment were adapted from Safren (1964)[561] and required participants to unscramble letters to form an existing word (e.g., TRULUVES for VULTURES). We utilized unambiguous category labels at the top of each visually presented list via a unifying word, such as "animals" to orient participants to an associative category for each list of jumbled letters[583]. The importance of our decision to implement categorical classification is twofold; first, categorical exemplars for anagrams (e.g., category: color for the anagrams "edr," "uelb," and "enegr") are expected to reduce the solution time required to solve problems, which was critical for this experiment, as we aimed to minimize the threat of excessive cognitive fatigue resulting from the verbal anagram list. Second, and most importantly, we intended to prime associative strength via presentation of category labels for each list; thus, it is crucial that the initial anagram sets were not too complex that participants would have been unable to decipher the associate anagram solutions within a given category. The unifying label of anagram sets served as a stimulus primer[584] for the provocation of related words from procedural memory processes initially below the level of consciousness.

In total, six anagram lists were presented during each visit (twelve total lists), with the order of the twelve lists counterbalanced across conditions. Lists in each condition (i.e., exercise and control) were matched for difficulty level prior to commencement of data collection. Participants were allocated a maximum of two minutes to complete each list, but when participants completed lists in less time, they would not begin the next list until two minutes had elapsed, to maximize standardization across conditions. Participants were asked to verbalize all responses in both study conditions, as written responses may have posed a risk to participant safety during treadmill walking. Further, this verbal response prompt was congruent with the verbal response prompt employed in our RAT task (described below). Other anagram priming tasks, similar to the one employed in the present experiment, have been shown to effectively prime other cognitive parameters, providing evidence of validity for our evaluated priming task[585-587].

Main Outcome Measure

RAT. Similar to anagram solving, convergent creativity assessed via the RAT does not require expertise specific to any domain of knowledge[558]. Each RAT triad is a composite of three unrelated words (e.g., fish, mine, rush), which must be associated with a singular word linking the triad (e.g., gold). Convergence upon a correct solution demands creativity, as flexible, associative thought process must be activated to broadly link distant terms[588]. Following fifteen minutes of treadmill walking plus anagram solving or sitting plus anagram solving, participants were escorted to a quiet room, free of distraction, where they solved the RAT with only the principal researcher present. RAT triads were selected from publicly available, normative data provided by Bowden & Jung-Beeman (2003)[588]. Participants verbalized their responses to 20 RAT triads during each visit, with the entire list of 20 triads presented to participants for five minutes (i.e., triads were not presented one at a time). The same 20 RAT triads were presented to participants in both study conditions (i.e., exercise and control) and were delimited to exclusively medium difficulty triads relative to average time to solution recorded among a sample of 289 university students (See Appendix A to view the triads utilized for each condition)[588]. The RAT assessment has demonstrated evidence of reliability and validity[588-590].

Experimental and Control Visit Procedures

Every participant completed two visits (within-subjects design) at the University of Mississippi Exercise & Memory Laboratory in the department of Health, Exercise Science and Recreation Management. During these visits, participants were asked to comply with the following protocol:

1. Participants arrived at the laboratory at their scheduled participation time, signed the consent form prior to any data collection procedures, and completed two questionnaires (PAR-Q and PANAS) in a quiet room, free of distraction,

2. Participants, randomized into the exercise visit first, performed moderate-intensity, ambulatory physical activity on a treadmill (moderate intensity; 40-45% of heart-rate reserve[591]) for fifteen minutes and attempted to solve six categorized lists of six distinct anagram problems. This exercise intensity (40-45% HRR) was specifically chosen as it aligns with moderate-

intensity exercise.[591] Participants, randomized into the control visit first, sat quietly on a stool on the treadmill (control condition) and solved six categorized lists of six anagrams for fifteen minutes. Heart rate and perceived exertion were monitored at baseline, at the midpoint, and at the end of the visit. Specifically, for each visit, a resting HR was recorded, as well as HR at the midpoint (7.5 minutes) and end (fifteen minutes) of both experimental manipulations (i.e., treadmill exercise and seated resting conditions).

3. Immediately following exercise or control, participants completed one additional mood questionnaire (PANAS) and subsequently they verbalized their responses to the RAT creativity assessment in a quiet room (same room in which baseline questionnaires were completed) for five minutes, with only the principal researcher present to record responses. At the end of the final visit, participants were asked to complete the CSQ-r.

4. After a minimum interval of 24 hours, participants returned for the second visit and completed the procedure again for the other condition (e.g., if participants were assigned to exercise first, they would return for the control visit).

Statistical Analyses

Statistical analyses were computed using IBM SPSS Statistics for Windows, Version 25.0[592]. Using a paired-samples t-test, the convergent creativity (RAT) scores for the exercise plus anagram priming versus anagram priming-only conditions were compared. Statistical significance was set at $\alpha=0.05$. Determination of potential covariate inclusion (CSQ-r subscale scores) into a RM-ANCOVA model was based on a-priori bivariate analyses (i.e., $r > 0.20$) and a threshold alpha of .05. However, results from the a-priori bivariate analysis were not statistically significant; thus, CSQ-r subscale scores were not included in the final analytic models. Follow-up paired t-test analyses were also computed in JASP (version 0.9.01, Netherlands)[593] to evaluate evidence in support of the alternative hypothesis.

Results

Participant demographic characteristics are displayed in Table 1 (N=45). On average, participants were female (60%), undergraduates, (89%), 21 years-old, and non-Hispanic Caucasian (71%).

As displayed in Table 2, no baseline differences were evident between the two experimental conditions for baseline hours since last food consumption, level of hunger, desire to eat, mood, hours of sleep, or heart rate. As expected, for the control visit, heart rate remained unchanged (70.5 to 80.4 bpm), whereas for the exercise visit, heart rate significantly increased from 73.7 to 128.9 bpm ($p<0.05$). Further, the difference for average number of anagrams solved was not different across both conditions (all p's >.05).

Results from the paired samples t-test conducted to examine differences between the two experimental conditions (anagram-solving + walking, anagram-solving + control) and verbal RAT performance are shown in Figure 1. A statistically significant difference was evident between anagram-solving + walking ($\bar{X}$ = 10.51, SD = 3.25) and anagram-solving + seated rest ($\bar{X}$ = 9.29, SD = 4.12), $t(44) = 2.385$, $p = .021$, d =0.36. These data were also examined by conducting a Bayesian paired samples t-test with a default Cauchy prior of 0.707, which was centered on zero[594]. Data were analyzed in JASP, comparing the fit of the data under the null hypothesis and the alternative hypothesis. An estimated Bayes factor (BF10) suggested that the data were 2.04 in favor of the alternative hypothesis, or rather, 2.04 times more likely to occur under a model including the effect of exercise plus anagram problem-solving rather than a model without it.

Figure 2 displays the within-individual RAT performances across the experimental conditions. Of the 45 participants, 26 individuals (57.8%) scored higher on the RAT following the anagram + exercise condition (dashed lines), with a mean difference of 3.58 RAT items between conditions (SD = 2.02). Fourteen individuals (31.1%) scored higher on the RAT following the anagram only condition (solid lines), with a mean difference of 2.71 RAT items between conditions (SD = 1.94). Five individuals (11.1%) achieved the same RAT score on both visits (mean difference = 0).

Taken together, anagram-solving plus exercising before completing convergent creativity problems, compared to anagram-solving alone appears to effectuate meaningful differences on creative performance within the same individuals, with preliminary anecdotal evidence for the alternative hypothesis[595].

Discussion

In supraliminal priming tasks, participants are aware of task-associated stimuli, but are uniformed of the true objective of the task as an implicit prime[596]. Previous research offers converging evidence in support of the position that internal mental representations guide behavior, and that behavior is malleable, even on a subconscious level[596]. Behavioral supraliminal primes, such as the categorized anagram sets utilized in the present experiment, stand as a promising direction for continued research to evaluate in the context of human creativity. In its essence, a verbal priming paradigm is successful when an assimilation emerges between subtle presentation of prime words and target behavior[597]. To date, one plausible theoretical mechanism for this assimilation effect is prospective *automatic spreading activation*, wherein a verbal prime is suggested to induce instantaneous activation of distributed conceptual pathways that are linked in semantic meaning. Related to the present study, a categorical exemplar for an anagram list (e.g., color) may activate associated knowledge of semantic information relative to the prime (e.g., magenta, indigo, gold), thus easing cognitive processing demands should those words be presented, albeit in a jumbled, unrecognizable arrangement. The assimilatory effects of the initial anagram prime on the subsequent creativity task is of greater interest, however[598,599]. Perhaps *automatic spreading activation* prompts translation to a separate task. For example, familiarity with presentation of cue words may activate potential target words in semantic memory on an initial anagram task, and repeated activation of semantic networks occur more rapidly on a subsequent RAT task involving similar cue presentation (i.e., three unrelated cue words are presented from which participants must derive a single, related target word).

Notably, this explanation is not wholly sufficient, as although priming effects have repeatedly been shown to be robust when the prime is congruent to the target, often formally referred to as a *congruence priming effect*[600], there are various indicators of congruency that must not be discounted. Andrews, Lo, and Xia intercalate empirical caution when interpreting priming effects[601]. Specifically, semantic *and* associative congruence appear sufficient to elicit favorable priming effects, and while the two often covary, they have been erroneously mistaken as identical constructs[601,602]. Semantic similarity is evident in the meaning of words, while associative similarity is evident in the probability that one word will cue a mental representation based on common word usage[602]. To illustrate this distinction, the pair *color-blue* is semantically similar, while the pair *blue-bird* is associatively related. Therefore, a consideration of both semantic and associative priming is integral to comprehensive interpretation of this project, as both semantic and associative priming may have played a large role in the anagram manipulations, with associative priming likely exerting a greater effect on subsequent RAT performance.

Mednick (1962) posited that the magnitude of possible associations among presented stimuli will determine the nature of response[558]. Associations may be facilitated not only by semantic and associative verbal similarities, but also by the similarity achieved between cognitive states during priming, and during creative assessment. Newly activated streams of mentation during an exercise manipulation coupled with anagram task-completion may have provided sufficient neural stimulation to activate problem-solving strategies beneficial to the RAT. Physical exercise has been shown to activate the prefrontal cortex,[573] with the dorsolateral region of the prefrontal cortex implicated in thinking of distant solutions, without disrupting attentional allocation to the problem at hand[603]. Additionally, visual processing was a primary component of this project, as participants were shown the anagram problems and RAT triads and were permitted to verbalize (but not write) their responses to these visual stimuli. Verbalizing solutions to difficult creativity problems has been shown to enhance task performance[604]. Visual processing has also been shown to activate both the ventrolateral prefrontal cortex and medial prefrontal cortex[605]. The ventrolateral prefrontal cortex is associated with creative ideation, while the medial prefrontal cortex is a critical region within the default mode network, which is thought to direct internally-oriented attention[603]. Further, high internal processing may reflect frontal alpha synchronization as working memory and long-term memory strategies are employed when solving the anagram task and RAT, which involve visual manipulation and recombination of letters and words, as well as the systematic search and evaluation of logical solutions[606]. Although exercise and anagram problem solving may augment cortical activation and behavioral arousal[572], lending plausibility to the aforementioned additive effects on creativity, acute cognitive enhancement may also be engendered via transient facilitation of neural efficiency[607]. Initial, exercise-induced increases in prefrontal activation and regulation of executive control[572] coupled with repetitive prefrontal modulation of components of executive function, such as working memory and flexibility during successive anagram problem-solving[557,608], may briefly reduce subsequent cortical activity[607]. Such an occurrence may be a mechanistic indication of strong cohesion between anagram priming stimuli and implicit cognitive representations subserving RAT performance[609]. In this vein, behavioral priming may operate in parallel to repeated neural activations driving a reduction in neural activity[607], denoting synchronization and efficiency of neural networks recruited during the completion of subsequent, associated cognitive tasks (i.e., RAT triads).

We propose a final, conceivable theoretical mechanism that highlights the unique role for heightened executive processing during convergent creativity tasks requiring analytic reasoning[610]. According to dual-process theories, Type 1 mental processes are generally automatized, whereas Type 2 processes are contingent upon components of executive control, such as working memory and response inhibition.[611] Type 2 processing may be paramount to solving complex problems, such as the RAT, as an individual must be able to establish coherence between remotely associated concepts, maintain possible response confederates in working memory, and analyze solutions for accuracy in light of all three stimulus words. As previously stated, acute exercise has been shown to amplify complex cognitions (i.e., executive functions)[572,612]. Thus, executive control amplification may have been compounded by the anagram prime employed in the present experiment, as successful anagram problem-solving warrants an ability to manipulate letters to establish semantic coherence. Furthermore, working memory utilization is needed to maintain and manipulate ideas for reasoned solutions that align well with each presented categorical list label. Relatedly, creative analogical reasoning and RAT performance have been shown to associate with standard analytical reasoning assessments[610], which may provide additional insight into why employing executive-control dependent Type 2 processing (theoretically enhanced with acute exercise) during anagram solving plus treadmill walking, may serve as a superior priming catalyst for convergent creativity.

Despite the novelty and practical applicability of this study, certain limitations should be addressed. We aimed to select a prime that would be challenging to participants, but not so difficult to negatively influence performance. Based on our results, we feel that the anagram task appropriately addressed these aims, as no individual solved all 36 problems correctly within the allocated time-constraints; however, on average, all individuals correctly solved over 80% of the presented anagrams across both conditions. A potential criticism of the anagram priming manipulation is that the anagram lists may have served as both semantic and associative primes. Perhaps a larger priming effect would have been observed across both conditions if we had selected only associative primes. This is an interesting prospect for future research in this area; although, it appears that verbal priming, in general, when coupled with exercise, prompts verbal convergent creativity. Another potential criticism is that individuals may prefer self-selected ambulatory activity, which is executed at a lower speed than 40-45% of HRR. Previous research however, has shown that light-intensity walking impedes convergent thinking performance, perhaps because neural activation is not sufficient in the prefrontal cortex. We speculate that the favorable effects of the exercise manipulation on creativity, hinge, in part, on sufficient neural stimulation accomplished via moderate-intensity treadmill walking, coupled with active problem-solving. Future research should examine specific neural mechanisms underlying additive effects of exercise and priming on creativity.

Light-intensity ambulatory exercise has previously been shown to impair convergent creativity among healthy college students[344], while other work has demonstrated no statistically significant differences between moderate-intensity exercise and rest on convergent creativity among similar populations[613,614]. This is the first experiment demonstrating a favorable effect of exercise on subsequent convergent thinking. Notably, however, this favorable effect is likely driven by the additive influence of exercise plus anagram problem-solving. Future work should examine other strategies that may be utilized in combination with exercise to enhance creativity performance. One such strategy may be to examine the Deese/Reodiger-McDermott (DRM)[615,616] illusion in the context of exercise and priming on convergent thinking performance. During the DRM procedure, participants may study words such as *cushion, pillow, sofa, and chair*, which serve as associates of the critical lure, *couch*. Individuals often remember the lure word during subsequent recall assessment. Participants may spontaneously generate verbal associates to the cue words[617], or false memories may emerge as the lures are congruent with the "gist" of the cue-words studied[618]. This is particularly interesting when considering RAT priming, wherein, essentially, the inverse of the DRM must occur. Upon presentation of three unrelated cue words, participants are asked to generate an associate word. Perhaps by priming the spontaneous generation of associates, or orienting participants toward the peripheral features of the task (i.e., the gist clues), the number and speed of correct RAT solutions may be positively influenced. Further, exercise may be considered as a potential additive component, if the exercise is completed during the DRM procedure, as exercise prior to DRM manipulations has been shown to improve accurate recall performance, thus minimizing the occurrence of false memories[619].

In conclusion, this experiment offers a novel contribution to extant exercise and creativity literature, suggesting a potential additive effect of exercise plus verbal priming on convergent creativity performance. Specifically, the findings of the present experiment demonstrate that acute, moderate-intensity treadmill exercise coupled with anagram problem-solving, prior to RAT completion, is a potential strategy for enhancing verbal convergent creativity, as evidenced by our observation that Average RAT performance was higher following the anagram plus exercise condition ($\bar{X}$ = 10.51). compared to anagram-solving plus seated rest ($\bar{X}$ = 9.29). Future experimental work is warranted to flush out the precise mechanisms underlying these additive effects, as well as to establish novel exercise and priming strategies to benefit creativity performance.

Table 1. Demographic Characteristics (N=45).

Variable	Point Estimate (SD)
Gender, % female	60
Education, % undergraduate	88.89
Race, % Caucasian	71.11
Handedness, % right-handed	91.11
Major, % EXSC	77.78
Age, mean years	21.1 (1.89)
GPA (0.0-4.0), mean	3.43 (0.46)
BMI, mean kg/m^2	25.76 (5.69)

Note. EXSC = exercise science; GPA = grade-point average; BMI = body mass index

Table 2. Visit characteristics (N=45).

Variable	**Exercise: $\bar{X}$ (SD)**	**Control: $\bar{X}$ (SD)**
Last food eaten, hours	5.38 (4.61)	4.72 (2.09)
Hunger (1-5)	2.4 (1.34)	2.23 (1.03)
Desire to eat (1-5)	3.18 (1.39)	2.98 (1.37)
Sleep, hours	6.75 (1.22)	7.05 (1.53)
Baseline positive PANAS (10-50)	28.31 (7.53)	28.55 (7.80)
Baseline negative PANAS (10-50)	11.76 (2.40)	11.00 (1.40)
HR rest	73.75 (13.15)	75.91 (14.64)
HR midpoint	123.13 (12.84)	78.27 (15.69)
HR end	128.89 (9.56)	80.45 (13.98)
HR, 5 minutes post	80.43 (12.77)	74.05 (14.43)
Treadmill speed	3.64 (0.40)	0
RPE mid (6-20)	10.42 (1.90)	6.07 (0.25)
RPE end (6-20)	11.24 (1.80)	6.05 (0.21)
Post positive PANAS (10-50)	32.067 (9.94)	28.91 (8.31)
Post negative PANAS (10-50)	11.0 (1.40)	10.69 (1.47)
Correct anagram solutions (0-36)	29.93 (3.63)	30.78 (3.80)
Total time to anagram solution (up to 12 minutes)	8.06 (1.76)	6.90 (2.11)
RAT correct (0-20)	10.51 (3.25)	9.29 (4.12)

Note. PANAS = Positive and Negative Affect Schedule; HR = heart rate; RPE = rating of perceived exertion; RAT = Remote Associates Test; $\bar{X} = mean$

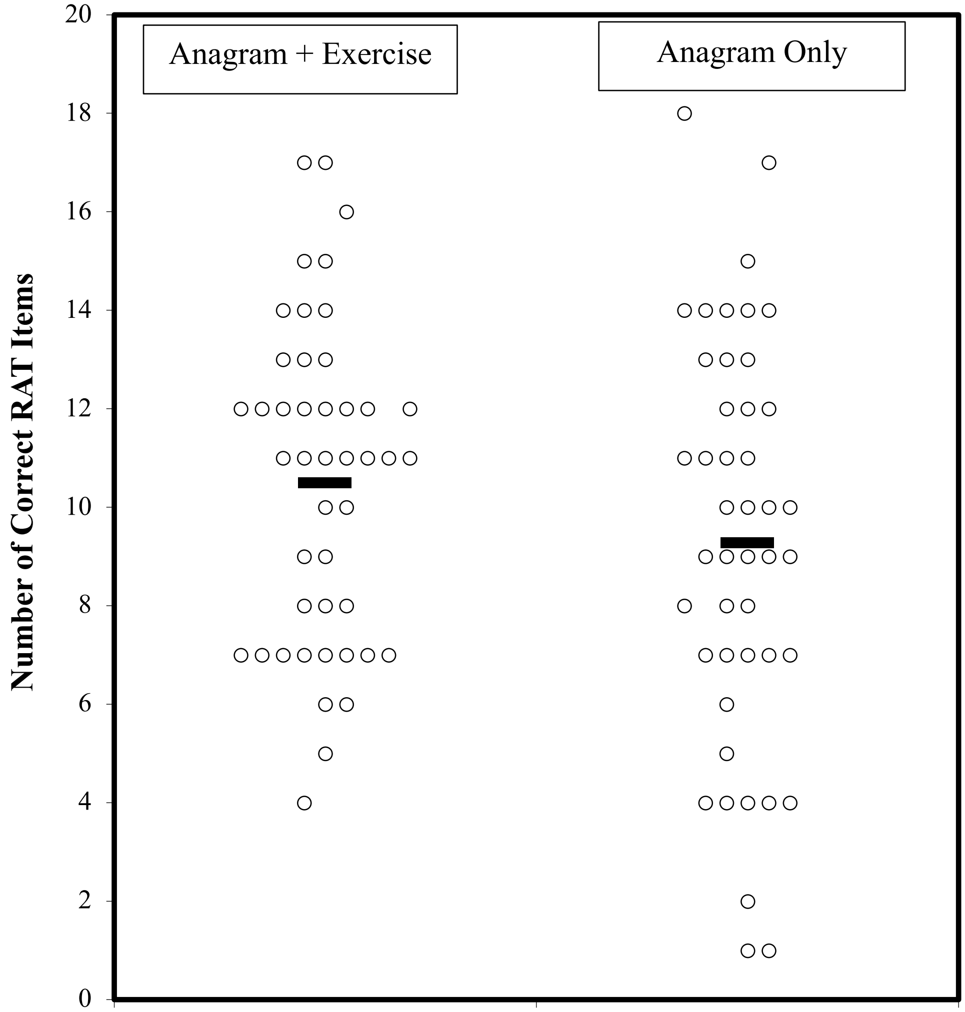


Figure 1. RAT performance (# of correct items) across experimental conditions. Data from 45 participants demonstrates that 26 individuals scored higher on the RAT following the anagram + exercise condition with a mean difference of 3.58 RAT items between conditions (SD = 2.02). The average number of anagrams solved correctly in the anagram + exercise condition was 10.51 items (SD = 3.25), whereas the average number of anagrams solved correctly in the anagram only condition was 9.29 items (SD=4.12).

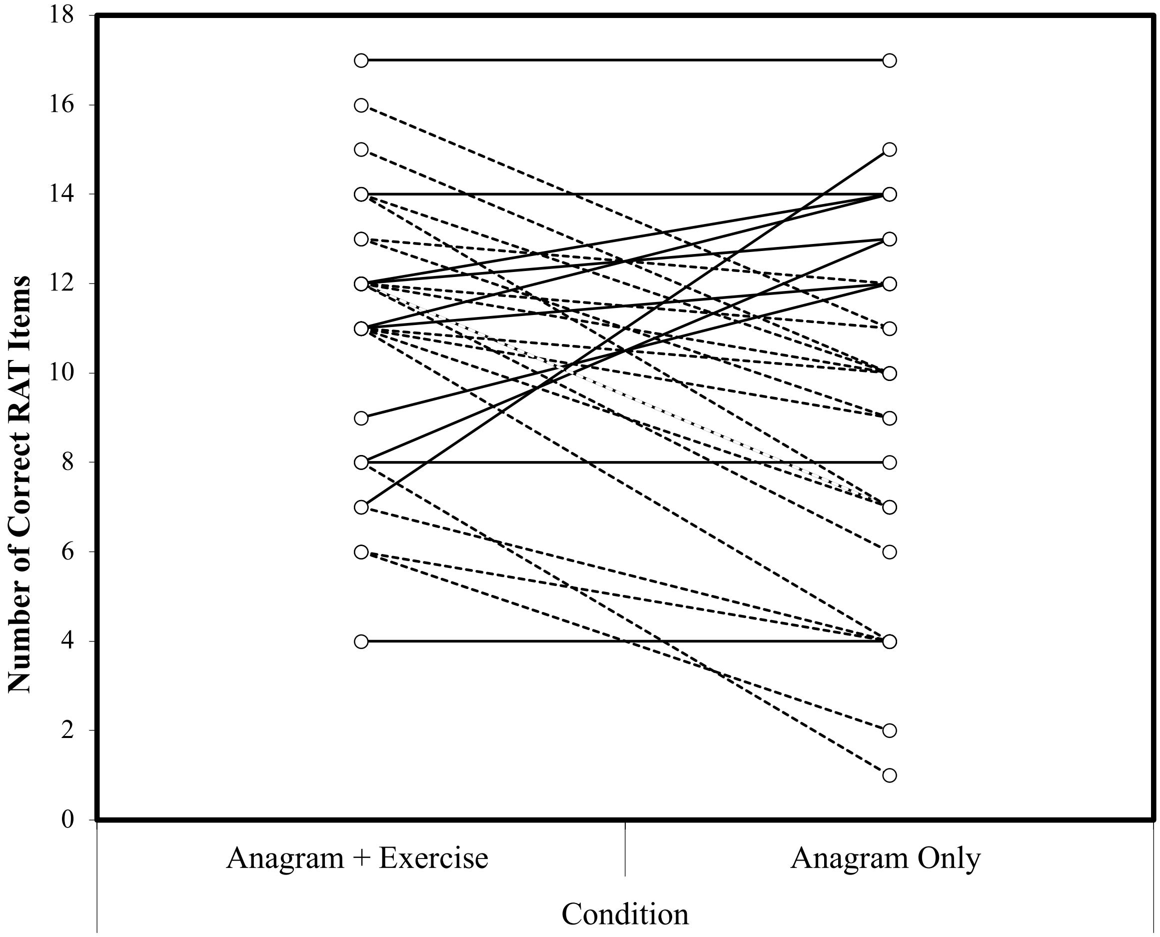


Figure 2. RAT performance (# of correct items) differences across experimental conditions. Data from 45 participants demonstrates that 26 individuals (57.8%) scored higher on the RAT following the anagram + exercise condition (dashed lines), with a mean difference of 3.58 RAT items between conditions (SD = 2.02). Fourteen individuals (31.1%) scored higher on the RAT following the anagram only condition (solid lines), with a mean difference of 2.71 RAT items between conditions (SD = 1.94). Five individuals (11.1%) achieved the same RAT score on both visits (mean difference = 0). A single, dotted line represents data from two individuals whom performed the same across visits, with an anagram + exercise condition score of twelve on the RAT and an anagram only condition score of seven.

CHAPTER VII

DISSERTATION CONCLUSIONS

This dissertation manuscript is the culmination of three years of research examining unique, exercise-induced mechanisms underlying creativity. Initially, the experimental work providing impetus for this line of research focused on the broader relationship between exercise and cognition, specifically exercise and memory relationships. Human memory systems are recognized as foundational components of creativity; thus, a familiarity with exercise and memory research assembled the platform of interest from which related interests emerged.

Chapter One introduces creativity as an illusory construct, with a rich history of empirical attempts (and failures) to adjudicate univocal recommendations for defining, measuring, and evaluating its importance to society, relative to both intrapersonal and interpersonal frameworks. The thesis of Chapter One emphasizes the accessibility of creativity to all individuals. However, accessibility is not to be confused with attainment, as there are several cognitive prerequisites necessary for the actualization of creativity, such as motivation and skill.

Chapter Two examines extant literature evaluating interactions between physical exercise and creative cognitions. A mere thirteen empirical studies were published examining this relationship, with the evidence provided raising questions pertaining to the methodological rigor of this line of investigation. However, several important conclusions were formulated from this systematic review. First, it was demonstrated that weak to modest support exists for acute, moderate-intensity exercise to benefit creativity. Second, substantial methodological biases were expected to contribute to specious arguments inflating (or underestimating) the utility of structured physical movement as a stimulus for creativity. Third, the mechanistic underpinnings of the proposed association between exercise and creativity are poorly understood and warrant elucidation.

Chapter Three discusses the plausibility for a variety of mechanisms capable of reinforcing the psychological and physiological pathways which may endorse an exercise-creativity connection. Although speculative thus far, the mechanisms delineated for creative skill, creative drive, and creative performance are supported by research in behavioral neuroscience, cognitive psychology, and exercise physiology.

Chapter Four substitutes physical exercise for physical movement and evaluates the putative importance of the mind-body connection to the expression of creativity. Embodied perspectives hypothesize that bodily movement may activate or accentuate prerequisite thought processes for higher-order cognitions, including creativity. Twenty manuscripts (with several experiments employing multi-experimental designs) were extracted, with no evidence of a detrimental effect of embodied creativity. Research exploring embodied movement on convergent thinking (seven experiments) and insight problem-solving (five experiments) demonstrated universally favorable outcomes, while twelve of fourteen experiments provided evidence for movement to favorably influence originality in divergent thinking. Once again, despite unambiguous theoretical justification, research programs appeared to circumvent mechanistic clarification for embodied creativity. Further, without the utilization of adequate control groups, outcomes observed may be vulnerable to conclusions largely based on conjecture.

Chapter Five demonstrates the collection of research conducted at the University of Mississippi that empirically investigates the link between moderate intensity exercise prior to creativity assessment. The first research experiment assessed the independent influences of moderate-intensity treadmill exercise or self-selected music listening on verbal creativity. Both divergent and convergent thinking were evaluated in this within-subjects experiment, with no statistically significant findings evident for exercise or music listening to influence creativity. The second research pursuit was a cross-sectional study designed to examine the relationship between self-reported engagement in physical activity and creative behaviors among a random sample of 612 University of Mississippi students. Again, physical activity was shown to exert no statistically significant influence on creativity outcomes in this cross-sectional study. The third research study experimentally assessed the effects of moderate-intensity treadmill exercise completed during the incubation period (a "rest-interval" or brief break from the cognitive task) on divergent creativity. This within-subjects experiment provided no statistically significant evidence for creativity performance to differ across conditions (exercise vs. control); however, creativity was enhanced from baseline to post-incubation within both experimental conditions, extending previous work demonstrating the facilitative effects of an incubation period on creative ideation. The fourth research experiment aimed to identify differential effects of acute exercise on mathematical, spatial, and verbal insight creativity employing a within-subjects protocol. However, no statistically significant differential effects were observed, as insight performances (verbal, mathematical, and spatial) were not statistically significant across the control, exercise before insight problem-solving, and exercise during insight creativity problem-solving conditions.

The sixth, and final, within-subjects dissertation experiment was the first to provide statistically significant evidence for acute, moderate-intensity treadmill exercise coupled with anagram problem-solving to prime subsequent RAT completion compared to a non-exercise, priming only condition. Thus, although not a paragon for creativity enhancement, the additive effects of exercise plus priming may be one viable strategy for enhancing verbal convergent creativity. Future research is warranted to explore a variety of priming effects on the relationship between exercise, embodied interventions, and creativity.

LIST OF REFERENCES

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1. Dietrich A. Who's afraid of a cognitive neuroscience of creativity? *Methods.* 2007;42(1):22-27.
2. Csikszentmihalyi M. Creativity and genius: A systems perspective. *The Systems Model of Creativity*: Springer; 2014:99-125.
3. Vartanian O, Bristol AS, Kaufman JC. *Neuroscience of creativity.* Mit Press; 2013.
4. Runco MA. *Divergent thinking.* Ablex Norwood, NJ; 1991.
5. Taft R, Rossiter JR. The Remote Associates Test: divergent or convergent thinking? *Psychological Reports.* 1966;19(3_suppl):1313-1314.
6. Kaufman JC, Baer J. The amusement park theoretical (APT) model of creativity. *The International Journal of Creativity & Problem Solving.* 2004;14(2):15-25.
7. Baer J, Kaufman JC. Gender differences in creativity. *The Journal of Creative Behavior.* 2008;42(2):75-105.
8. Sternberg RJ. *Handbook of creativity.* Cambridge University Press; 1999.
9. Smith GJ. How should creativity be defined? *Creativity Research Journal.* 2005;17(2-3):293-295.
10. Coren S. Differences in divergent thinking as a function of handedness and sex. *The American journal of psychology.* 1995:311-325.
11. Witelson SF, Goldsmith CH. The relationship of hand preference to anatomy of the corpus callosum in men. *Brain research.* 1991;545(1):175-182.
12. Kertesz A, Polk M, Howell J, Black S. Cerebral dominance, sex, and callosal size on MRI. *Neurology.* 1986;36(4):316.
13. Galaburda AM, Corsiglia J, Rosen GD, Sherman GF. Planum temporale asymmetry, reappraisal since Geschwind and Levitsky. *Neuropsychologia.* 1987;25(6):853-868.
14. Singh J. Creativity and lateralization of the brain. *Indian Journal of Health and Wellbeing.* 2015;6(11):1142.
15. Conti R, Collins MA, Picariello ML. The impact of competition on intrinsic motivation and creativity: considering gender, gender segregation and gender role orientation. *Personality and individual differences.* 2001;31(8):1273-1289.
16. Kessler RC, Berglund P, Demler O, Jin R, Merikangas KR, Walters EE. Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the National Comorbidity Survey Replication. *Archives of general psychiatry.* 2005;62(6):593-602.
17. Garavan H, Hester R, Murphy K, Fassbender C, Kelly C. Individual differences in the functional neuroanatomy of inhibitory control. *Brain research.* 2006;1105(1):130-142.
18. Pinker S. The science of gender and science. Pinker vs. Spelke: A debate. *Mind Brain and Behavior Initiative (MBB), Harvard University. Retrieved from http://edge. org/3rd_culture/debate05/debate05_index. html.* 2005.
19. Proudfoot D, Kay AC, Koval CZ. A gender bias in the attribution of creativity: archival and experimental evidence for the perceived association between masculinity and creative thinking. *Psychological science.* 2015;26(11):1751-1761.
20. Lombardo BJ, Roddy DJ. Cultivating organizational creativity in an age of complexity: A companion study to the IBM 2010 Global Chief Human Resource Officer Study. 2010.

21. Jonason PK, Abboud R, Tomé J, Dummett M, Hazer A. The Dark Triad traits and individual differences in self-reported and other-rated creativity. *Personality and Individual Differences.* 2017;117:150-154.
22. Allen JP. Technology and Inequality: Concentrated Wealth in a Digital World. Springer; 2017.
23. Fink A, Benedek M. EEG alpha power and creative ideation. *Neuroscience & Biobehavioral Reviews.* 2014;44:111-123.
24. Dietrich A, Kanso R. A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychological bulletin.* 2010;136(5):822.
25. Petsche H, Kaplan S, Von Stein A, Filz O. The possible meaning of the upper and lower alpha frequency ranges for cognitive and creative tasks. *International journal of psychophysiology.* 1997;26(1):77-97.
26. Shah C, Erhard K, Ortheil HJ, Kaza E, Kessler C, Lotze M. Neural correlates of creative writing: an fMRI study. *Human brain mapping.* 2013;34(5):1088-1101.
27. Finke RA, Ward TB, Smith SM. Creative cognition: Theory, research, and applications. 1992.
28. Puryear JS, Kettler T, Rinn AN. Relationships of personality to differential conceptions of creativity: a systematic review. *Psychology of Aesthetics, Creativity, and the Arts.* 2017;11(1):59.
29. Feist GJ. A meta-analysis of personality in scientific and artistic creativity. *Personality and social psychology review.* 1998;2(4):290-309.
30. Duff MC, Kurczek J, Rubin R, Cohen NJ, Tranel D. Hippocampal amnesia disrupts creative thinking. *Hippocampus.* 2013;23(12):1143-1149.
31. Benedek M, Jauk E, Fink A, et al. To create or to recall? Neural mechanisms underlying the generation of creative new ideas. *NeuroImage.* 2014;88:125-133.
32. Madore KP, Addis DR, Schacter DL. Creativity and memory: effects of an episodic-specificity induction on divergent thinking. *Psychological science.* 2015;26(9):1461-1468.
33. Huang F, Fan J, Luo J. The neural basis of novelty and appropriateness in processing of creative chunk decomposition. *Neuroimage.* 2015;113:122-132.
34. Gentner D. Analogy. *A companion to cognitive science.* 1998:107-113.
35. Glucksberg S. The psycholinguistics of metaphor. *Trends in cognitive sciences.* 2003;7(2):92-96.
36. Badre D, Wagner AD. Left ventrolateral prefrontal cortex and the cognitive control of memory. *Neuropsychologia.* 2007;45(13):2883-2901.
37. Dietrich A. The cognitive neuroscience of creativity. *Psychonomic bulletin & review.* 2004;11(6):1011-1026.
38. Buckner RL, Andrews-Hanna JR, Schacter DL. The brain's default network. *Annals of the New York Academy of Sciences.* 2008;1124(1):1-38.
39. Smallwood J, Brown K, Baird B, Schooler JW. Cooperation between the default mode network and the frontal–parietal network in the production of an internal train of thought. *Brain research.* 2012;1428:60-70.

40. Beaty RE, Benedek M, Wilkins RW, et al. Creativity and the default network: A functional connectivity analysis of the creative brain at rest. *Neuropsychologia.* 2014;64:92-98.
41. Gonen-Yaacovi G, de Souza LC, Levy R, Urbanski M, Josse G, Volle E. Rostral and caudal prefrontal contribution to creativity: a meta-analysis of functional imaging data. *Frontiers in human neuroscience.* 2013;7.
42. Takeuchi H, Taki Y, Hashizume H, et al. The association between resting functional connectivity and creativity. *Cerebral Cortex.* 2012;22(12):2921-2929.
43. Chen Q-L, Xu T, Yang W-J, et al. Individual differences in verbal creative thinking are reflected in the precuneus. *Neuropsychologia.* 2015;75:441-449.
44. Luchins AS, Luchins EH. Rigidity of behavior: A variational approach to the effect of Einstellung. 1959.
45. Smith SM, Blankenship SE. Incubation and the persistence of fixation in problem solving. *The American journal of psychology.* 1991:61-87.
46. Kulkarni C, Dow SP, Klemmer SR. Early and repeated exposure to examples improves creative work. *Design thinking research*: Springer; 2014:49-62.
47. Smith SM, Ward TB, Schumacher JS. Constraining effects of examples in a creative generation task. *Memory & cognition.* 1993;21(6):837-845.
48. Nusbaum EC, Silvia PJ. Are intelligence and creativity really so different?: Fluid intelligence, executive processes, and strategy use in divergent thinking. *Intelligence.* 2011;39(1):36-45.
49. Jarosz AF, Colflesh GJ, Wiley J. Uncorking the muse: Alcohol intoxication facilitates creative problem solving. *Consciousness and Cognition.* 2012;21(1):487-493.
50. Hampshire A, Chamberlain SR, Monti MM, Duncan J, Owen AM. The role of the right inferior frontal gyrus: inhibition and attentional control. *Neuroimage.* 2010;50(3):1313-1319.
51. Angello G, Storm BC, Smith SM. Overcoming fixation with repeated memory suppression. *Memory.* 2015;23(3):381-389.
52. Landau JD, Leynes PA. Do explicit memory manipulations affect the memory blocking effect? *The American journal of psychology.* 2006:463-479.
53. Storm BC, Hickman ML. Mental fixation and metacognitive predictions of insight in creative problem solving. *The Quarterly Journal of Experimental Psychology.* 2015;68(4):802-813.
54. Hanslmayr S, Staudigl T, Aslan A, Bäuml K-H. Theta oscillations predict the detrimental effects of memory retrieval. *Cognitive, Affective, & Behavioral Neuroscience.* 2010;10(3):329-338.
55. Storm BC, Patel TN. Forgetting as a consequence and enabler of creative thinking. *Journal of Experimental Psychology: Learning, Memory, and Cognition.* 2014;40(6):1594.
56. McCaffrey T. Innovation relies on the obscure: A key to overcoming the classic problem of functional fixedness. *Psychological science.* 2012;23(3):215-218.

57. Patrick J, Ahmed A. Facilitating representation change in insight problems through training. *Journal of Experimental Psychology: Learning, Memory, and Cognition.* 2014;40(2):532.
58. Bailin S. Creativity or quality: a deceptive choice. *The Journal of Educational Thought (JET)/Revue de la Pensée Educative.* 1987:33-39.
59. Gino F, Ariely D. The dark side of creativity: original thinkers can be more dishonest. *Journal of personality and social psychology.* 2012;102(3):445.
60. Mednick S. The associative basis of the creative process. *Psychological review.* 1962;69(3):220.
61. Beaty RE, Nusbaum EC, Silvia PJ. Does insight problem solving predict real-world creativity? *Psychology of Aesthetics, Creativity, and the Arts.* 2014;8(3):287.
62. Mueller JS, Melwani S, Goncalo JA. The bias against creativity: Why people desire but reject creative ideas. *Psychological science.* 2012;23(1):13-17.
63. Vohs KD, Redden JP, Rahinel R. Physical order produces healthy choices, generosity, and conventionality, whereas disorder produces creativity. *Psychological Science.* 2013;24(9):1860-1867.
64. Abrahamson E, Freedman DH. A Perfect Mess: The Hidden Benefits of Disorder: How Crammed Closets, Cluttered Offices, and OntheFly Planning Make the World a Better Place. *Little, Brown.* 2007.
65. Friedman RS, Förster J. Implicit affective cues and attentional tuning: an integrative review. *Psychological bulletin.* 2010;136(5):875.
66. Elliot AJ, McGregor HA, Gable S. Achievement goals, study strategies, and exam performance: A mediational analysis. *Journal of educational psychology.* 1999;91(3):549.
67. Lichtenfeld S, Elliot AJ, Maier MA, Pekrun R. Fertile green: Green facilitates creative performance. *Personality and Social Psychology Bulletin.* 2012;38(6):784-797.
68. Chiu F-C, Tu PL. The priming effect of military service on creativity performance. *Psychological reports.* 2014;114(2):509-527.
69. Förster J, Friedman RS, Butterbach EB, Sassenberg K. Automatic effects of deviancy cues on creative cognition. *European Journal of Social Psychology.* 2005;35(3):345-359.
70. Rothenberg A. Creative cognitive processes in Kekule's discovery of the structure of the benzene molecule. *The American journal of psychology.* 1995:419-438.
71. Anderson RE, Helstrup T. Visual discovery in mind and on paper. *Memory & cognition.* 1993;21(3):283-293.
72. Norton J. Thought experiments in Einstein’s work. *Horowitz and Massey.* 1991;1991:129-148.
73. Clement JJ. The role of imagistic simulation in scientific thought experiments. *Topics in Cognitive Science.* 2009;1(4):686-710.
74. Luo J. Neural correlates of insight. *Acta Psychologica Sinica.* 2004;36(2):219-234.
75. Haider H, Rose M. How to investigate insight: A proposal. *Methods.* 2007;42(1):49-57.
76. Barr N, Pennycook G, Stolz JA, Fugelsang JA. Reasoned connections: A dual-process perspective on creative thought. *Thinking & Reasoning.* 2015;21(1):61-75.

77. De Dreu CK, Baas M, Nijstad BA. Hedonic tone and activation level in the mood-creativity link: toward a dual pathway to creativity model. *Journal of personality and social psychology.* 2008;94(5):739.
78. Mitchell RL, Phillips LH. The psychological, neurochemical and functional neuroanatomical mediators of the effects of positive and negative mood on executive functions. *Neuropsychologia.* 2007;45(4):617-629.
79. Akinola M, Mendes WB. The dark side of creativity: Biological vulnerability and negative emotions lead to greater artistic creativity. *Personality and Social Psychology Bulletin.* 2008;34(12):1677-1686.
80. George JM, Zhou J. Understanding when bad moods foster creativity and good ones don't: the role of context and clarity of feelings. *Journal of Applied Psychology.* 2002;87(4):687.
81. Wegener DT, Petty RE. Mood management across affective states: the hedonic contingency hypothesis. *Journal of personality and social psychology.* 1994;66(6):1034.
82. Hirt ER, Devers EE, McCrea SM. I want to be creative: exploring the role of hedonic contingency theory in the positive mood-cognitive flexibility link. *Journal of personality and social psychology.* 2008;94(2):214.
83. De Dreu CK, Nijstad BA. Mental set and creative thought in social conflict: threat rigidity versus motivated focus. *Journal of personality and social psychology.* 2008;95(3):648.
84. Roskes M, De Dreu CK, Nijstad BA. Necessity is the mother of invention: avoidance motivation stimulates creativity through cognitive effort. *Journal of personality and social psychology.* 2012;103(2):242.
85. Oleynick VC, Thrash TM, LeFew MC, Moldovan EG, Kieffaber PD. The scientific study of inspiration in the creative process: challenges and opportunities. *Frontiers in human neuroscience.* 2014;8.
86. Amabile TM. *Creativity in context: Update to the social psychology of creativity.* Westview press; 1996.
87. Silvia PJ, Phillips AG. Self-awareness, self-evaluation, and creativity. *Personality and Social Psychology Bulletin.* 2004;30(8):1009-1017.
88. Metzl ES, Morrell MA. The role of creativity in models of resilience: theoretical exploration and practical applications. *Journal of Creativity in Mental Health.* 2008;3(3):303-318.
89. Csikszentmihalyi M. *Flow and the psychology of discovery and invention.* New York: Harper Collins; 1996.
90. Limb CJ, Braun AR. Neural substrates of spontaneous musical performance: an FMRI study of jazz improvisation. *PLoS one.* 2008;3(2):e1679.
91. Dietrich A. Functional neuroanatomy of altered states of consciousness: the transient hypofrontality hypothesis. *Consciousness and cognition.* 2003;12(2):231-256.
92. Breiter HC, Gollub RL, Weisskoff RM, et al. Acute effects of cocaine on human brain activity and emotion. *Neuron.* 1997;19(3):591-611.
93. Dijksterhuis A, Meurs T. Where creativity resides: The generative power of unconscious thought. *Consciousness and cognition.* 2006;15(1):135-146.

94. Dasgupta S. Is creativity a Darwinian process? *Creativity research journal.* 2004;16(4):403-413.
95. Bowers KS, Regehr G, Balthazard C, Parker K. Intuition in the context of discovery. *Cognitive psychology.* 1990;22(1):72-110.
96. Boot N, Baas M, van Gaal S, Cools R, De Dreu CK. Creative Cognition and Dopaminergic Modulation of Fronto-striatal Networks: Integrative Review and Research Agenda. *Neuroscience & Biobehavioral Reviews.* 2017.
97. O'sullivan N, Szczepanowski R, El-Deredy W, Mason L, Bentall RP. fMRI evidence of a relationship between hypomania and both increased goal-sensitivity and positive outcome-expectancy bias. *Neuropsychologia.* 2011;49(10):2825-2835.
98. Ruiter M, Johnson SL. Mania risk and creativity: A multi-method study of the role of motivation. *Journal of affective disorders.* 2015;170:52-58.
99. Canesi M, Rusconi ML, Isaias I, Pezzoli G. Artistic productivity and creative thinking in Parkinson's disease. *European journal of neurology.* 2012;19(3):468-472.
100. Mishkin M, Ungerleider LG. Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys. *Behavioural brain research.* 1982;6(1):57-77.
101. Acosta LMY. Creativity and Neurological Disease. *Current neurology and neuroscience reports.* 2014;14(8):464.
102. Miller BL, Hou CE. Portraits of artists: emergence of visual creativity in dementia. *Archives of Neurology.* 2004;61(6):842-844.
103. de Souza LC, Volle E, Bertoux M, et al. Poor creativity in frontotemporal dementia: a window into the neural bases of the creative mind. *Neuropsychologia.* 2010;48(13):3733-3742.
104. Noble EP. The D 2 dopamine receptor gene: a review of association studies in alcoholism and phenotypes. *Alcohol.* 1998;16(1):33-45.
105. Batukhtina E, Nevidimova T, Vetlugina T, Kokorina N, Bokhan N. Neurophysiological Patterns of Search and Creative Behavior in Patients with Psychoactive Substance-Induced Disorders. *Bulletin of experimental biology and medicine.* 2014;156(5):598.
106. Bengtsson SL, Ullén F, Ehrsson HH, et al. Listening to rhythms activates motor and premotor cortices. *cortex.* 2009;45(1):62-71.
107. Liu S, Chow HM, Xu Y, et al. Neural correlates of lyrical improvisation: an fMRI study of freestyle rap. *Scientific reports.* 2012;2:srep00834.
108. Lopata JA, Nowicki EA, Joanisse MF. Creativity as a distinct trainable mental state: An EEG study of musical improvisation. *Neuropsychologia.* 2017;99:246-258.
109. De Pisapia N, Bacci F, Parrott D, Melcher D. Brain networks for visual creativity: a functional connectivity study of planning a visual artwork. *Scientific reports.* 2016;6.
110. de Bruin EI, van der Zwan JE, Bögels SM. A RCT comparing daily mindfulness meditations, biofeedback exercises, and daily physical exercise on attention control, executive functioning, mindful awareness, self-compassion, and worrying in stressed young adults. *Mindfulness.* 2016;7(5):1182-1192.
111. Hillman CH, Erickson KI, Kramer AF. Be smart, exercise your heart: exercise effects on brain and cognition. *Nature reviews. Neuroscience.* 2008;9(1):58.

112. Aron AR, Durston S, Eagle DM, Logan GD, Stinear CM, Stuphorn V. Converging evidence for a fronto-basal-ganglia network for inhibitory control of action and cognition. *Journal of Neuroscience.* 2007;27(44):11860-11864.
113. Loprinzi PD, Herod SM, Cardinal BJ, Noakes TD. Physical activity and the brain: a review of this dynamic, bi-directional relationship. *Brain Research.* 2013;1539:95-104.
114. Cotman CW, Engesser-Cesar C. Exercise enhances and protects brain function. *Exercise and sport sciences reviews.* 2002;30(2):75-79.
115. Eadie BD, Redila VA, Christie BR. Voluntary exercise alters the cytoarchitecture of the adult dentate gyrus by increasing cellular proliferation, dendritic complexity, and spine density. *Journal of Comparative Neurology.* 2005;486(1):39-47.
116. Neeper SA, Gómez-Pinilla F, Choi J, Cotman CW. Physical activity increases mRNA for brain-derived neurotrophic factor and nerve growth factor in rat brain. *Brain research.* 1996;726(1):49-56.
117. Guilford JP. Creativity. *The American psychologist.* Sep 1950;5(9):444-454.
118. Dietrich A, Kanso R. A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychological bulletin.* Sep 2010;136(5):822-848.
119. Stein MI. Creativity and culture. *The Journal of psychology.* 1953;36(2):311-322.
120. Berkowitz G. Convergent and divergent thinking. *Encyclopedia of Special Education*2014.
121. Wallach MA. Creativity. In: Mussen PH, ed. *Manual of child psychology*. New York: Wiley and Sons; 1970.
122. Runco MA. Commentary: Divergent thinking is not synonymous with creativity. *Psychology of Aesthetics, Creativity, and the Arts.* 2008;2:93-96.
123. Csikszentmihalyi M. 16 implications of a systems perspective for the study of creativity. *Handbook of Creativity*1999.
124. Mumford MD. Where have we been, where are we going? Taking stock in creativity research. *Creativity Research Journal.* 2003;15:107-120.
125. Blanchette DM, Ramocki SP, O'del JN, Casey MS. Aerobic exercise and creative potential: Immediate and residual effects. *Creativity Research Journal.* 2005;17:257-264.
126. L SC, Szapora A, Pannekoek JN, Hommel B. The impact of physical exercise on convergent and divergent thinking. *Frontiers in human neuroscience.* 2013;7:824.
127. Curnow KE, Turner ET. The effect of exercise and music on the creativity of college *The Journal of Creative Behavior.* 1992;26:50-52.
128. Herman-Tofler LR, Tuckman BW. The effects of aerobic training on children's creativity, self-perception, and aerobic power. *Child and adolescent psychiatric clinics of North America.* Oct 1998;7(4):773-790, viii.
129. Gondola JC, Tuckman BW. Effects of a systematic program of exercise on selected measures of creativity. *Percept Mot Skills.* Feb 1985;60(1):53-54.
130. Gondola JC. The enhancement of creativity through long and short term exercise *Journal of Social Behavior & Personality.* 1986;1:77-82.
131. Gondola JC. The effects of a single bout of aerobic dancing on selected tests of creativity. *Journal of Social Behavior & Personality.* 1987;2:275-278.

132. Hinkle JS, Tuckman BW, Sampson JP. The psychology, physiology, and creativity of middle school aerobic exercisers. *Elementary School Guidance & Counseling.* 1993;28:133-145.
133. Oppezzo M, Schwartz DL. Give your ideas some legs: the positive effect of walking on creative thinking. *Journal of experimental psychology. Learning, memory, and cognition.* Jul 2014;40(4):1142-1152.
134. Ramocki SP. Creativity interacts with fitness and exercise. *Physical Educator.* 2002;59:8.
135. Steinberg H, Sykes EA, Moss T, Lowery S, LeBoutillier N, Dewey A. Exercise enhances creativity independently of mood. *British journal of sports medicine.* Sep 1997;31(3):240-245.
136. Tuckman BW, Hinkle JS. An experimental study of the physical and psychological effects of aerobic exercise on schoolchildren. *Health psychology : official journal of the Division of Health Psychology, American Psychological Association.* 1986;5(3):197-207.
137. Zhou Y, Zhang Y, Hommel B, Zhang H. The Impact of Bodily States on Divergent Thinking: Evidence for a Control-Depletion Account. *Frontiers in psychology.* 2017;8:1546.
138. Murad MH, Montori VM, Ioannidis JP, et al. How to read a systematic review and meta-analysis and apply the results to patient care: users' guides to the medical literature. *Jama.* Jul 2014;312(2):171-179.
139. McCutcheon LE. Does running make people more creative? *Journal of Sport Behavior.* 1982;5:202-206.
140. Hallihan GM, Shu LH. Creativity and long-term potentiation: Implications for design. *Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference.* 2011:1-12.
141. Higgins JPT, Green SM. Cochrane Handbook for Systematic Reviews of Interventions. 2008.
142. Torrance EP, Ball OE, Safter HT. Torrance tests of creative thinking. *Scholastic Testing Service.* 1966.
143. Walker E, Hernandez AV, Kattan MW. Meta-analysis: Its strengths and limitations. *Cleveland Clinic journal of medicine.* Jun 2008;75(6):431-439.
144. Plucker JA, Qian M, Schmalensee SL. Is what you see what you really get? Comparison of scoring techniques in the assessment of real-world divergent thinking. *Creativity Research Journal.* 2014;26:135-143.
145. Plucker JA, Qian M, Wang S. Is originality in the eye of the beholder? Comparison of scoring techniques in the assessment of divergent thinking. *Journal of Creative Behavior.* 2011;45:1-22.
146. Silvia PJ, Martin C, Nusbaum EC. A snapshot of creativity: Evaluating a quick and simple method for assessing divergent thinking. *Thinking Skills and Creativity.* 2009;4:79-85.
147. Snyder A, Mitchell J, Bossomaier T, Pallier G. The creativity quotient: an objective scoring of ideational fluency. *Creativity Research Journal.* 2004;16:415-419.

148. Frith E, Sng E, Loprinzi PD. Randomized Controlled Trial Evaluating the Temporal Effects of High-Intensity Exercise on Learning, Short-Term and Long-Term Memory, and Prospective Memory. *Eur J Neurosci.* Sep 18 2017.
149. Sng E, Frith E, Loprinzi PD. Temporal Effects of Acute Walking Exercise on Learning and Memory Function. *American journal of health promotion : AJHP.* Jan 1 2017:890117117749476.
150. Chang YK, Labban JD, Gapin JI, Etnier JL. The effects of acute exercise on cognitive performance: a meta-analysis. *Brain research.* May 9 2012;1453:87-101.
151. Etnier JL, Salazar W, Landers DM, Petruzzello SJ, Han M, Nowell P. The influence of physical fitness and exercise upon cognitive functioning: a meta-analysis. *Journal of sport and Exercise Psychology.* 1997;19:249-277.
152. Loprinzi PD, Kane CJ. Exercise and cognitive function: a randomized controlled trial examining acute exercise and free-living physical activity and sedentary effects. *Mayo Clinic proceedings.* Apr 2015;90(4):450-460.
153. Wilkinson M. Distinguishing between statistical significance and practical/clinical meaningfulness using statistical inference. *Sports medicine.* Mar 2014;44(3):295-301.
154. Conner TS, DeYoung, C. G., Silvia, P. J. . Everyday creative activity as a path to flourishing. . *The Journal of Positive Psychology.* 2018;13(2):181-189.
155. Baas M, De Dreu, C. K., Nijstad, B. A. . A meta-analysis of 25 years of mood-creativity research: Hedonic tone, activation, or regulatory focus?. . *Psychological bulletin, .* 2008;134(6):779.
156. Silvia PJ, Kaufman JC. Creativity and mental illness. . *Cambridge handbook of creativity.* 2010:381-394.
157. Conner TS, DeYoung CG, Silvia PJ. Everyday creative activity as a path to flourishing. *The Journal of Positive Psychology.* 2018;13(2):181-189.
158. Friedman RS, Fishbach A, Förster J, Werth L. Attentional priming effects on creativity. . *Creativity Research Journal.* 2003;15((2-3)):277-286.
159. Simon HA. Creativity in the arts and the sciences. . *The Canyon Review and Stand.* 2001(23):203-220. .
160. Smith GJ. How should creativity be defined?. . *Creativity Research Journal.* 2005;17((2-3)):293-295.
161. Blanchette DM, Ramocki SP, O'del JN, Casey MS. Aerobic exercise and creative potential: Immediate and residual effects. . *Creativity Research Journal.* 2005;17((2-3)):257-264.
162. Colzato LS, Szapora Ozturk A, Pannekoek JN, Hommel B. The impact of physical exercise on convergent and divergent thinking. . *Frontiers in human neuroscience.* 2013(7):824.
163. Curnow KE, Turner ET. The effect of exercise and music on the creativity of college students. . *The Journal of Creative Behavior.* 1992.
164. Gondola JC. The enhancement of creativity through long and short term exercise programs. . *Journal of Social Behavior & Personality.* 1986.
165. Gondola JC. The effects of a single bout of aerobic dancing on selected tests of creativity. . *Journal of Social Behavior & Personality.* 1987.

166. Gondola JC, Tuckman BW. Effects of a systematic program of exercise on selected measures of creativity. . *Perceptual and motor skills.* 1985;60 (1):53-54.
167. Herman-Tofler LR, Tuckman BW. The effects of aerobic training on children's creativity, self-perception, and aerobic power. . *Child and adolescent psychiatric clinics of North America.* 1998; 7(4):773-790.
168. Hinkle JST, B. W. Sampson, J. P. . The psychology, physiology, and creativity of middle school aerobic exercisers. . *Elementary School Guidance & Counseling.* 1993; 28(2): 133-145.
169. Oppezzo M, & Schwartz, D. L. . Give your ideas some legs: The positive effect of walking on creative thinking. . *Journal of experimental psychology: learning, memory, and cognition.* 2014;40(4):1142.
170. Ramocki SP. Creativity interacts with fitness and exercise. . *Physical Educator.* 2002;59(1):8.
171. Steinberg H, Sykes, E. A., Moss, T., Lowery, S., LeBoutillier, N., & Dewey, A. . Exercise enhances creativity independently of mood. . *British Journal of Sports Medicine.* 1997; 31(3):240-245.
172. Tuckman BW, & Hinkle, J. S. . An experimental study of the physical and psychological effects of aerobic exercise on schoolchildren. *Health psychology.* 1986;5(3):197.
173. Zhou Y, Yifei Zhang, Bernhard Hommel, and Hao Zhang. . The Impact of Bodily States on Divergent Thinking: Evidence for a Control-Depletion Account. *Frontiers in psychology* 2017(8):1546.
174. Bassett DS, & Gazzaniga, M.S. . Understanding complexity in the human brain. . *Trends in cognitive sciences,* . 2011;15(5):200-209.
175. Loprinzi PD, Herod, S. M., Cardinal, B. J., & Noakes, T. D. . Physical activity and the brain: a review of this dynamic, bi-directional relationship. . *Brain Research.* 2013;1539:95-104.
176. Verdejo-Garcia A, & Bechara, A. . Neuropsychology of executive functions. . *Psicothema.* 2010;22(2):227-235.
177. Dishman RK, Berthoud, H. R., Booth, F. W., Cotman, C. W., Edgerton, V. R., Fleshner, M. R., ... & Kramer, A. F. . Neurobiology of exercise. . ***Obesity***. 2006;14(3):345-356.
178. Neeper SA, Gomez-Pinilla, F., Choi, J., & Cotman, C. W. . Exercise and brain neurotrophins. . *Nature* 1995;373:109.
179. Oliff HS, Berchtold, N. C., Isackson, P., & Cotman, C. W. . Exercise-induced regulation of brain-derived neurotrophic factor (BDNF) transcripts in the rat hippocampus. . *Brain Res Mol Brain Res.* . 1998;61:147-153.
180. Vivar C PB, & van Praag H. . Running rewires the neuronal network of adult-born dentate granule cells. . *NeuroImage Elsevier BV.* . 2015:29-41.
181. Lanier WL. *The afferentation theory of cerebral arousal Neuroanesthesia.* 1997.
182. Sleiman SF, Henry, J., Al-Haddad, R., El Hayek, L., Haidar, E.A., Stringer, T., ... & Ninan, I. . Exercise promotes the expression of brain derived neurotrophic factor (BDNF) through the action of the ketone body β-hydroxybutyrate. *Elife.* 2016;5.
183. Chaddock L EK, Prakash RS, Kim JS, Voss MW, Vanpatter M, Pontifex MB, Raine LB, Konkel A, Hillman CH, Cohen NJ, & Kramer AF. A neuroimaging investigation of the

association between aerobic fitness, hippocampal volume, and memory performance in pre-adolescent children. . *Brain Res* . 2010;1358:172-183.
184. Chaddock L HC, Buck SM, & Cohen NJ. . Aerobic fitness and executive control of relational memory in preadolescent children. *Med Sci Sports Exerc* 2010;43:344 -329.
185. Voss MW, Nagamatsu, L. S., Liu-Ambrose, T., & Kramer, A. F. . Exercise, brain, and cognition across the life span. . *Journal of applied physiology.* 2011;111(5):1505-1513.
186. Buckner RL, Andrews-Hanna, J. R., and Schacter, D. L. . The brain's default network: anatomy, function, and relevance to disease. . *Ann. N. Y. Acad. Sci.* . 2008;1124:1-38.
187. Schilbach L, Eickhoff, S. B., Rotarska-Jagiela, A., Fink, G. R., & Vogeley, K. . Minds at rest? Social cognition as the default mode of cognizing and its putative relationship to the "default system" of the brain. *Conscious Cogn.* . 2008;17:457-467.
188. Voss MW PR, Erickson KI, Basak C, Chaddock L, Kim JS, Alves H, Heo S, Szabo A, White SM, Wojcicki TR, Mailey EL, Gothe N, Olson EA, McAuley E, & Kramer AF. . Plasticity of brain networks in a randomized intervention trial of exercise training in older adults. . *Front Aging Neurosci* 2010;2 1-17.
189. Blessing EM BF, Schumann A, Brunner F, & Bar KJ. . A data-driven approach to mapping cortical and subcorti- cal intrinsic functional connectivity along the longitudinal hippocampal axis. . *Hum Brain Mapp.* 2015;476:462-476. .
190. Flaherty AW. Frontotemporal and dopaminergic control of idea generation and creative drive. . *Journal of Comparative Neurology.* 2005;493(1):147-153.
191. Atzori M, Cuevas-Olguin, R., Esquivel-Rendon, E., Garcia-Oscos, F., Salgado-Delgado, R.C., Saderi, N., ... & Salgado, H. . Locus ceruleus norepinephrine release: a central regulator of CNS spatio-temporal activation? *Frontiers in synaptic neuroscience.* 2016;8:25.
192. Kempadoo KA, Mosharov, E.V., Choi, S.J., Sulzer, D., & Kandel, E.R. . Dopamine release from the locus coeruleus to the dorsal hippocampus promotes spatial learning and memory. . *Proceedings of the National Academy of Sciences.* 2016;113(51):14835-14840.
193. Bothe N ZE, Dimeo F, Heinz A, Wustenberg T, & Strohle A. . Acute exercise influences reward processing in highly trained and untrained men. . *Med Sci Sports Exerc.* . 2013;45(3):583-591.
194. Ekkekakis P HE, & Parfitt G. . Invited Guest Editorial: Envisioning the next fifty years of research on the exercise-affect relationship. . *Psychol Sport Exerc.* 2013;14(5):751-758.
195. Weng TB, Pierce, G. L., Darling, W. G., Falk, D., Magnotta, V. A., & Voss, M. W. . The Acute Effects of Aerobic Exercise on the Functional Connectivity of Human Brain Networks. . *Brain Plasticity.* 2017;2(2):171-190.
196. Molteni R, Ying, Z., & Gómez-Pinilla, F. . Differential effects of acute and chronic exercise on plasticity-related genes in the rat hippocampus revealed by microarray. . *European Journal of Neuroscience.* 2002;16(6):1107-1116.
197. Meeusen R, Piacentini, M.F., & De Meirleir, K. . Brain microdialysis in exercise research. . *Sports Medicine.* 2001;31(14):965-983.

198. Miyashita T, & Williams, C.L. Epinephrine administration increases neural impulses propagated along the vagus nerve. Role of peripheral β-adrenergic receptors. . *Neurobiology of learning and memory.* 2006;85(2):116-124.
199. McMorris T, Hale, B. J., Corbett, J., Robertson, K., & Hodgson, C.I. . Does acute exercise affect the performance of whole-body, psychomotor skills in an inverted-U fashion? A meta-analytic investigation. . *Physiology & behavior.* 2015;141:180-189.
200. Aston-Jones G, Ennis, M., Pieribone, V.A., Nickell, W.T., & Shipley, M.T. The brain nucleus locus coeruleus: restricted afferent control of a broad efferent network. *Science.* 1986;234(4777):734-737.
201. Roozendaal B, & McGaugh, J.L. (2011). . Memory Modulation. . *Behavioral Neuroscience.* 2011;125(6):797–824. .
202. Devoto P, Flore, G., Saba, P., Fà, M., & Gessa, G.L. Co-release of noradrenaline and dopamine in the cerebral cortex elicited by single train and repeated train stimulation of the locus coeruleus. . *BMC neuroscience.* 2005;6(1):31.
203. Aston-Jones G, & Cohen, J. D. . An integrative theory of locus coeruleus-norepinephrine function: adaptive gain and optimal performance. . *Annu. Rev. Neurosci.* 2005;28:403-450.
204. Grenhoff J NM, Ferre ́ S, Aston-Jones G, & Svensson TH. Noradrenergic modulation of midbrain dopamine cell firing elicited by stimulation of the locus coeruleus in the rat. *J Neural Transm Gen Sect.* . 1993;93(1):11-25. .
205. Preston AR EH. Interplay of hippocampus and prefrontal cortex in memory. . *Curr Biol Elsevier.* . 2013;23(17):R764-773
206. Tulving E. Episodic memory: From mind to brain. *Annual Review of Psychology.* 2002;53:1–25. .
207. Madore K.P. SDL. Remembering the past and imagining the future: Selective effects of an episodic specificity induction on detail generation. . *The Quarterly Journal of Experimental Psychology.* . 2015;69(2):285-298.
208. Madore K.P. SDL. An episodic specificity induction enhances means-end problem solving in young and older adults. . *Psychology and Aging.* 2014;29:913–924. .
209. Sheldon S. MMP, & Moscovitch M. . Episodic memory processes mediated by the medial temporal lobes contribute to open-ended problem solving. *Neuropsychologia.* 2011;49:2439–2447.
210. Madore KP, Addis, D.R., & Schacter, D.L. . Creativity and memory: Effects of an episodic-specificity induction on divergent thinking. *Psychological science.* 2015;26(9):1461-1468.
211. Boccia M, Piccardi, L., Palermo, L., Nori, R., & Palmiero, M. . Where do bright ideas occur in our brain? Meta-analytic evidence from neuroimaging studies of domain-specific creativity. *Frontiers in psychology.* 2015;6:1195.
212. Cho JY. An investigation of design studio performance in relation to creativity, spatial ability, and visual cognitive style. *Thinking Skills and Creativity.* 2017;23:67-78.
213. Fink A, Benedek, M., Koschutnig, K., Pirker, E., Berger, E., Meister, S., ... & Weiss, E. M. . Training of verbal creativity modulates brain activity in regions associated with

language-and memory-related demands. . *Human brain mapping.* 2015;36(10):4104-4115.
214. Sriraman B. Mathematical creativity: psychology, progress and caveats. . *ZDM.* 2017; 49(7):971-975.
215. Sun J, Qunlin Chen, Qinglin Zhang, Yadan Li, Haijiang Li, Dongtao Wei, & Wenjing Yang, and Jiang Qiu. . "Training your brain to be more creative: brain functional and structural changes induced by divergent thinking training." Human brain mapping 37, no. 10 (2016): 3375-3387. *Human brain mapping* 2016;37(10):3375-3387.
216. Kray LJ, Galinsky, A. D., & Wong, E. M. . Thinking within the box: The relational processing style elicited by counterfactual mind-sets. . *Journal of personality and social psychology.* 2006;91(1):33.
217. Aziz-Zadeh L, Liew, S. L., & Dandekar, F. . Exploring the neural correlates of visual creativity. . *Social cognitive and affective neuroscience.* 2012; 8(4):475-480.
218. A D. The cognitive neuroscience of creativity. . *Psychon Bull Rev 11:1011-1026.* 2004;11:1011-1026.
219. Dietrich A KR. A review of EEG, ERP, and neuroimaging studies of creativity and insight. *Psychol Bull* 2010;136:822-848.
220. Shah C, Erhard, K., Ortheil, H. J., Kaza, E., Kessler, C., & Lotze, M. Neural correlates of creative writing: an fMRI study. . *Human brain mapping.* 2013;34(5):1088-1101.
221. Fink A GR, Benedek M, Reishofer G, Hauswirth V, Fally M, Neuper C, Ebner F, & Neubauer AC. The creative brain: Investigation of brain activity during creative problem solving by means of EEG and FMRI. . *Hum Brain Mapp* 2009;30:734- 748.
222. Starchenko MG BN, Pakhomov SV, & Medvedev SV Study of the brain organization of creative thinking. *Fiziol Cheloveka.* 2003;29:151-152.
223. Grabner RH, Ansari, D., Reishofer, G., Stern, E., Ebner, F., & Neuper, C. . Individual differences in mathematical competence predict parietal brain activation during mental calculation. . *Neuroimage.* 2007;38(2):346-356.
224. Houdé O, & Tzourio-Mazoyer, N. . Neural foundations of logical and mathematical cognition. . *Nature Reviews Neuroscience.* 2003;4(6):507.
225. Cappelletti M BB, Kopelman M. Spared numerical abilities in a case of semantic dementia. . *Neuropsychologia* 2001;39:1224-1239.
226. Dehaene S, Molko, N., Cohen, L., & Wilson, A. J. . Arithmetic and the brain. . *Current opinion in neurobiology.* 2004;14(2):218-224.
227. Rivera SM, Reiss, A. L., Eckert, M. A., & Menon, V. . Developmental changes in mental arithmetic: evidence for increased functional specialization in the left inferior parietal cortex. . *Cerebral cortex.* 2005;15(11):1779-1790.
228. Benedek M, Jauk, E., Fink, A., Koschutnig, K., Reishofer, G., Ebner, F., & Neubauer, A. C. 3. To create or to recall? Neural mechanisms underlying the generation of creative new ideas. . *NeuroImage.* 2014;88:125-113.
229. Beaty RE, Benedek M, Silvia PJ, Schacter DL. Creative Cognition and Brain Network Dynamics. *Trends Cogn Sci.* Feb 2016;20(2):87-95.

230. Beaty RE, Christensen, A. P., Benedek, M., Silvia, P. J., & Schacter, D. L. . Creative constraints: Brain activity and network dynamics underlying semantic interference during idea production. . *Neuroimage.* 2017(148):189-196.
231. Voss MW, Erickson, K. I., Prakash, R. S., Chaddock, L., Malkowski, E., Alves, H., ... & Hu, L. . Functional connectivity: a source of variance in the association between cardiorespiratory fitness and cognition? *Neuropsychologia.* 2010;48(5):1394-1406.
232. Andrews-Hanna JR SA, Vincent JL, Lustig C, Head D, Raichle ME, Buckner RL. Disruption of large-scale brain systems in advanced aging. *Neuron.* . 2007;56(5):924-935.
233. Whiteman AS, Young, D.E., Budson, A.E., Stern, C.E., & Schon, K. Entorhinal volume, aerobic fitness, and recognition memory in healthy young adults: a voxel-based morphometry study. *Neuroimage,.* 2016;126:229-238.
234. Erickson KI PR, Voss MW, Chaddock L, Hu L, Morris KS, White SM, Wójcicki TR, & McAuley E, Kramer AF. Aerobic fitness is associated with hippocampal volume in elderly humans. *Hippocampus.* . 2009;19(10):1030-1039.
235. Colcombe SJ, and Kramer, A. F. . Fitness effects on the cognitive function of older adults: a meta-analytic study. . *Psychol. Sci.* . 2003;14:125-130.
236. Loprinzi PD, Edwards, M. K., & Frith, E. . Potential avenues for exercise to activate episodic memory-related pathways: a narrative review. . *European Journal of Neuroscience.* 2017.
237. Loprinzi PD, Frith, E., Edwards, M. K., Sng, E., & Ashpole, N. . The Effects of Exercise on Memory Function Among Young to Middle-Aged Adults: Systematic Review and Recommendations for Future Research. *American Journal of Health Promotion.* 2017.
238. Sng E, Frith, E., & Loprinzi, P. D. . Temporal effects of acute walking exercise on learning and memory function. . *American Journal of Health Promotion.* 2017.
239. Daselaar SM, Prince, S. E., & Cabeza, R. . When less means more: Deactivations during encoding that predict subsequent memory. *Neuroimage.* 2004;23:921-927. .
240. Moriya M, & Sakatani, K. . Effects of Motor Imagery on Cognitive Function and Prefrontal Cortex Activity in Normal Adults Evaluated by NIRS. . *Oxygen Transport to Tissue. Springer, Cham.* 2017;XXXIX:227-231.
241. Chee MW, & Choo, W. C. . Functional imaging of working memory after 24 hr of total sleep deprivation. . *Journal of Neuroscience.* 2004;24: 4560-4567.
242. Velanova K, Lustig, C., Jacoby, L. L., & Buckner, R. L. . Evidence for frontally-mediated controlled processing differences in older adults. . *Cerebral Cortex.* 2007;17:1033-1046. .
243. Talukdar T, Nikolaidis, A., Zwilling, C. E., Paul, E. J., Hillman, C. H., Cohen, N. J., ... & Barbey, A. K. . Aerobic fitness explains individual differences in the functional brain connectome of healthy young adults. . *Cerebral Cortex.* 2017:1-10.
244. Andreasen NC, & Glick, I.D. . Bipolar affective disorder and creativity: implications and clinical management. . *Comprehensive Psychiatry.* 1988;29(3):207-217.
245. Johnson SL, Murray, G., Fredrickson, B., Youngstrom, E.A., Hinshaw, S., Bass, J.M., ... & Salloum, I. . Creativity and bipolar disorder: touched by fire or burning with questions? *Clinical psychology review.* 2012; 32 (1):1-12.

246. Haldane M FS. New insights help define the pathophysiology of bipolar affective disorder: neuroimaging and neuropathology findings. . *Prog Neuropsychopharmacol Biol Psychiatry.* . 2004;28:943-960.
247. Guilford JP, & Christensen, P. R. . The one-way relation between creative potential and IQ. *Journal of Creative Behavior.* 1973;7:247-252. .
248. Karwowski M, & Gralewski, J. . Threshold hypothesis: Fact or artifact? *Thinking Skills and Creativity.* 2013;8: 25-33.
249. Kim KH. Can only intelligent people be creative? A meta-analysis. . *Journal of Secondary Gifted Education.* 2005;16(2-3):57-66.
250. McMorris TE. *Exercise-cognition interaction: Neuroscience perspectives.* . Academic Press.; 2015.
251. Baker SA, Baker, K. A., & Hagg, T. Dopaminergic nigrostriatal projections regulate neural precursor proliferation in the adult mouse subventricular zone. . *European Journal of Neuroscience.* 2004;20:575-579.
252. Castner SA, & Goldman-Rakic, P.S. Enhancement of working memory in aged monkeys by a sensitizing regimen of dopamine D1 receptor stimulation. . *Journal of Neuroscience.* 2004;24:1446-1450.
253. Nutt JG, & Fellman, J.H. Pharmacokinetics of levodopa. *Clinical Neuropharmacology.* 1984;7:35-49. .
254. Winter B, Breitenstein, C., Mooren, F. C., Voelker, K., Fobker, M., Lechtermann, A., ... & Knecht, S. . High impact running improves learning. *Neurobiology of learning and memory.* 2007;87(4):597-609.
255. Amabile TM. *The social psychology of creativity.* . New York: Springer-Verlag.; 1983.
256. Martindale C. Biological bases of creativity. . *Handbook of creativity,* . 1999;2:137-152.
257. Petzinger GM WJ, Akopian G, et al. . Effects of treadmill exercise on dopaminergic transmission in the 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine-lesioned mouse model of basal ganglia injury. . *J Neurosci.* . 2007;27:5291-5300.
258. Petzinger GM, Fisher, B. E., Van Leeuwen, J. E., Vukovic, M., Akopian, G., Meshul, C. K., ... & Jakowec, M. W. . Enhancing neuroplasticity in the basal ganglia: the role of exercise in Parkinson's disease. . *Movement disorders.* 2010;25(S1).
259. Nybo L, & Secher, N. H. . Cerebral perturbations provoked by prolonged exercise. . *Prog Neurobiol.* 2004(72):223-261.
260. Gandevia SC. Spinal and supraspinal factors in human muscle fatigue. . *Physiol Rev.* . 2001;81:1725-1789.
261. Mattson MP, Maudsley, S., & Martin, B. A neural signaling triumvirate that influences ageing and age-related disease: insulin/IGF-1, BDNF and serotonin. *Ageing Res.* 2004;3:445-464.
262. Lin LH, Doherty, D.H., Lile, J.D., Bektesh, S., & Collins, F. GDNF: a glial cell line-derived neurotrophic factor for midbrain dopaminergic neurons *Science.* 1993;260:1130-1132.
263. Tomac A, Lindqvist, E., Lin, L.F.H., ögren, S.O., Young, D., Hoffer, B.J., & Olson, L. Protection and repair of the nigrostriatal dopaminergic system by GDNF in vivo. *Nature.* 1995;373:335-339.

264. Wu SY, Wang, T.F., Yu, L., Jen, C.J., Chuang, J.I., Wu, F.S., ... & Kuo, Y.M. . Running exercise protects the substantia nigra dopaminergic neurons against inflammation-induced degeneration via the activation of BDNF signaling pathway. *Brain, behavior, and immunity.* 2011;25(1):135-146.
265. Adkins DL BJ, Remple MS, Kleim JA. . Motor training induces experience-specific patterns of plasticity across motor cortex and spinal cord. *J Appl Physiol.* 2006;101:1776-1782.
266. Fisher B. SKJ. Activity-dependent factors affecting post-stroke functional outcomes. *Top Stroke Rehabil.* 2001;8:31-44.
267. Toole T. MCG, Warren E., Hubmann M.F., & Panton L. . The effects of loading and unloading treadmill walking on balance, gait, fall risk, and daily function in Parkinsonism. *Neuro Rehabilitation.* 2005;20:307-322. .
268. Will B. GR, Kelche C., & Rosenzweig, M.R. . Recovery from brain injury in animals: relative efficacy of environmental enrichment, physical exercise or formal training (1990-2002) *Prog Neurobiol.* 2004;72:167-182. .
269. Ahmad SO, Park, J.H., Stenho-Bittel, L., & Lau, Y.S. . Effects of endurance exercise on ventral tegmental area neurons in the chronic 1-methyl-4-phenyl-1, 2, 3, 6-tetrahydropyridine and probenecid-treated mice. . *Neuroscience letters.* 2009;450(2):102-105.
270. Takeuchi H, Taki, Y., Sassa, Y., Hashizume, H., Sekiguchi, A., Fukushima, A., & Kawashima, R. . Regional gray matter volume of dopaminergic system associate with creativity: evidence from voxel-based morphometry. . *Neuroimage.* 2010;51(2):578-585.
271. Ingram DK. Age-related decline in physical activity: generalization to nonhumans *Med Sci Sports Exerc.* 2000;32:1623-1629.
272. Salamone JD, & Correa, M. . Motivational views of reinforcement: implications for understanding the behavioral functions of nucleus accumbens dopamine. *Behav Brain Res.* 2002;137:3-25. .
273. Salamone JD, Correa, M., Mingote, S., Weber, S.M. . Nucleus accumbens dopamine and the regulation of effort in food-seeking behavior: implications for studies of natural motivation, psychiatry, and drug abuse. *J Pharm Exp Therap.* 2003;305:1-8.
274. Erickson KI, Raji, C.A., Lopez, O.L., Becker, J.T., Rosano, C., Newman, A.B., ... & Kuller, L.H. . Physical activity predicts gray matter volume in late adulthood The Cardiovascular Health Study. . *Neurology.* 2010;75(16):1415-1422.
275. Voelcker-Rehage C, & Niemann, C. . Structural and functional brain changes related to different types of physical activity across the life span. *Neuroscience & Biobehavioral Reviews.* 2013;37(9):2268-2295.
276. Colcombe S, & Kramer, A.F. . Fitness effects on the cognitive function of older adults: a meta-analytic study. . *Psychological science.* 2003;14(2):125-130.
277. Loprinzi PD, Edwards, M.K., Crush, E., Ikuta, T., & Del Arco, A. . Dose–Response Association Between Physical Activity and Cognitive Function in a National Sample of Older Adults. . *American Journal of Health Promotion.* 2017.

278. Posner J RJA, & Peterson B.S. . The circumplex model of affect: an integrative approach to affective neuroscience, cognitive devel- opment, and psychopathology. *Dev Psychopathol.* 2005;17:715- 734. .
279. Ratey J.J. LJE. The positive impact of physical activity on cognition during adulthood: a review of underlying mechanisms, evidence and recommendations. *Rev Neurosci.* 2011;22:171-185. .
280. Kim SE, Ko, I.G., Kim, B.K., Shin, M.S., Cho, S., Kim, C.J., Kim, S.H., Baek, S.S., & Lee, E.K., Jee, Y.S. . Treadmill exercise prevents aging-induced failure of memory through an increase in neurogenesis and suppression of apoptosis in rat hippocampus *Exp. Gerontol.* 2010;45:357-365.
281. Ferris LT, Williams, J.S., & Shen C.L. The effect of acute exercise on serum brain-derived neurotrophic factor levels and cognitive function. *Med. Sci. Sports Exerc.* 2007;39:728-734. .
282. Kim H, Heo, H. I., Kim, D. H., Ko, I. G., Lee, S. S., Kim, S. E., ... & Shin, M. S. . Treadmill exercise and methylphenidate ameliorate symptoms of attention deficit/hyperactivity disorder through enhancing dopamine synthesis and brain-derived neurotrophic factor expression in spontaneous hypertensive rats. . *Neuroscience letters.* 2011;504(1):35-39.
283. P C. Exercise: a neglected intervention in mental health care? *J Psychiatr Ment Health Nurs* 2004;11(4):476-483.
284. Dweck CS MJ, Good C, Dai DY, Sternberg RJ. Motivational effects on attention, cognition, and performance. . In: Dai DY SR, editors, ed. *Motivation, emotion, and cognition: Integrative perspectives on intellectual functioning and development.* . Mahwah, NJ: Lawrence Erlbaum Associates; 2004:41-55.
285. Cox CM. *Genetic studies of genius: The early mental traits of three hundred geniuses.* . Stanford: Stanford University Press; 1926.
286. Cropley AJ. Creative intelligence: A concept of true giftedness. *European Journal for High Ability.* 1994;5(1):6-23.
287. De Dreu CK, Baas, M., & Nijstad, B.A. Hedonic tone and activation level in the mood-creativity link: toward a dual pathway to creativity model. *Journal of personality and social psychology.* 2008;94(5):739.
288. Knittle K, De Gucht, V., Hurkmans, E., Peeters, A., Ronday, K., Maes, S., & Vlieland, T.V. . Targeting motivation and self-regulation to increase physical activity among patients with rheumatoid arthritis: a randomised controlled trial. *Clinical Rheumatology.* 2015;34(2):231-238.
289. Lewis BA, Williams, D.M., Frayeh, A., & Marcus, B.H. . Self-efficacy versus perceived enjoyment as predictors of physical activity behaviour. *Psychology & health.* 2016;31(4):456-469.
290. Esch T. SGB. The neurobiology of pleasure, reward processes, addiction and their health implications. . *Neuroendocrinol Lett.* 2004;25:235-251. .
291. Esch T. SGB. The neurobiology of stress management. *Neuro Endocrinol Lett.* . 2010;31(1):19-39.

292. Bowton E, Saunders, C., Erreger, K., Sakrikar, D., Matthies, H. J., Sen, N., ... & Blakely, R. D. . Dysregulation of dopamine transporters via dopamine D2 autoreceptors triggers anomalous dopamine efflux associated with attention-deficit hyperactivity disorder. . *Journal of Neuroscience.* 2010;30(17):6048-6057.
293. Yoon MC, Shin, M. S., Kim, T. S., Kim, B. K., Ko, I. G., Sung, Y. H., ... & Kim, C. J. Treadmill exercise suppresses nigrostriatal dopaminergic neuronal loss in 6-hydroxydopamine-induced Parkinson's rats. . *Neuroscience letters.* 2007;423(1):12-17.
294. Hattori S, Naoi, M., & Nishino, H. . Striatal dopamine turnover during treadmill running in the rat: relation to the speed of running. . *Brain research bulletin.* 1994;35(1):41-49.
295. Baer J. The case for domain specificity of creativity. *Creativity research journal.* 1998;11(2):173-177.
296. Deci EL, & Ryan, R. M. . *Intrinsic motivation and self- determination in human behavior.* New York, NY: Plenum Press. ; 1985.
297. Turner JC, Thorpe, P.K., & Meyer, D.K. . Students' reports of motivation and negative affect: A theoretical and empirical analysis. *Journal of Educational Psychology.* 1998;90:758-771.
298. Bowden EM, & Jung-Beeman, M. . Normative data for 144 compound remote associate problems. . *Behavior Research Methods, Instruments, & Computers.* 2003;35(4):634-639.
299. Byron K, & Khazanchi, S. Rewards and creative performance: a meta-analytic test of theoretically derived hypotheses. . *Psychological bulletin.* 2012;138(4):809.
300. Feldhusen JF, & Goh, B.E. . Assessing and accessing creativity: An integrative review of theory, research, and development. . *Creativity Research Journal.* 1995;8(3):231-247.
301. Paulus PB, & Yang, H.C. . Idea generation in groups: A basis for creativity in organizations. . *Organizational Behavior and Human Decision Processes.* 2000;82:76-87. .
302. Karasek R, & Theorell, T. *Healthy work: Stress, productivity, and the reconstruction of working life.* New York: Basic Books; 1990.
303. Yerkes RM, & Dodson, J.D. The relation of strength of stimulus to rapidity of habit-formation. . *Journal of Comparative Neurology and Psychology.* 1908;18:459-482
304. Martins AQ, Kavussanu, M., Willoughby, A., & Ring, C. . Moderate intensity exercise facilitates working memory. . *Psychology of sport and exercise.* 2013;14(3):323-328.
305. Smith PJ, Blumenthal, J.A., Hoffman, B.M., Cooper, H., Strauman, T.A., Welsh-Bohmer, K., et al. . Aerobic exercise and neurocognitive performance: a meta-analytic review of randomized controlled trials. *Psychosomatic Medicine.* 2010;72:239-252.
306. Tomporowski PD. Effects of acute bouts of exercise on cognition. *Acta psychologica.* 2003;112(3):297-324.
307. Pagliari R, & Peyrin, L. Norepinephrine release in the rat frontal cortex under treadmill exercise: a study with microdialysis. *J Appl Physiol* 1995;78(6):2121-2130.
308. Lambourne K, & Tomporowski, P.D. . The effect of exercise-induced arousal on cognitive task performance: a meta-regression analysis. . *Brain Research.* 2010;1341:12-24.

309. Dreu CKD, Nijstad, B.A., & Baas, M. . Behavioral activation links to creativity because of increased cognitive flexibility. . *Social Psychological and Personality Science.* 2011;2(1):72-80.
310. Forster J. Relations between perceptual and conceptual scope: How global versus local processing fits a focus on similarity versus dissimilarity. . *Journal of Experimental Psychology: General.* 2009;138:88-111.
311. Brockett AT, LaMarca, E.A., & Gould, E. . Physical exercise enhances cognitive flexibility as well as astrocytic and synaptic markers in the medial prefrontal cortex. . *PLoS One.* 2015;10(5):e0124859.
312. Cameron HA, & McKay, R.D. Restoring production of hippocampal neurons in old age. *Nature Neuroscience.* 1999;2:894-897. .
313. Cotman CW, & Berchtold, N.C. . Exercise: A behavioural intervention to enhance brain health and plasticity. . *Trends in Neurosciences.* 2002;25(295-301).
314. Churchill JD, Galvez, R., Colcombe, S., Swain, R.A., Kramer, A.F., & Greenough, W.T. Exercise, experience and the aging brain. . *Neurobiology of Aging.* 2002;23(941-955).
315. Masley S, Roetzheim, R., & Gualtieri, T. . Aerobic exercise enhances cognitive flexibility. *Journal of clinical psychology in medical settings.* 2009;16(2):186-193.
316. Kihlstrom J. The cognitive unconscious. *Science.* 1987;237:1445-1452.
317. Leiner H, Leiner, A., & Dow, R. . Does the cerebellum contribute to mental skills? *Behavioral Neuroscience.* 1986;100:443-454. .
318. Ito M. Movement and thought: Identical control mechanisms by the cerebellum. *Trends in Neurosciences* 1993;16:448-450.
319. Klein SB, Cosmides, L., Tooby, J., & Chance, S. . Decisions and the evolution of memory: Multiple systems, multiple functions. *Psychological Review.* 2002;109:306-329.
320. Schmahmann J, & Pandya, D. . The cerebrocerebellar system. In: (Ed.) IJDS, ed. *The cerebellum and cognition (pp. 31-60).* . New York: Academic Press. ; 1997.
321. Andersen B, Korbo, L., & Pakkenberg, B. . A quantitative study of the human cerebellum with unbiased stereological techniques. *The Journal of Comparative Neurology.* 1992;326:549-560.
322. Vandervert LR, Schimpf, P.H., & Liu, H. . How working memory and the cerebellum collaborate to produce creativity and innovation. . *Creativity Research Journal.* 2007;19(1):1-18.
323. Beaty RE, & Silvia, P.J. . Why do ideas get more creative across time? An executive interpretation of the serial order effect in divergent thinking tasks. *Psychology of Aesthetics, Creativity, and the Arts.* 2012;6(4):309.
324. Benedek M, & Neubauer, A.C. . Revisiting Mednick's model on creativity-related differences in associative hierarchies. Evidence for a common path to uncommon thought. . *The Journal of creative behavior.* 2013;47(4): 273-289.
325. Lotze M, Montoya, P., Erb, M., Hülsmann, E., Flor, H., Klose, U., ... & Grodd, W. . Activation of cortical and cerebellar motor areas during executed and imagined hand movements: an fMRI study. . *Journal of cognitive neuroscience.* 1999;11(5):491-501.

326. Ganis G, Thompson, W.L., & Kosslyn, S.M. . Brain areas underlying visual mental imagery and visual perception: an fMRI study. . *Cognitive Brain Research.* 2004;20(2):226-241.
327. Koziol LF, Budding, D. E., & Chidekel, D. . From movement to thought: executive function, embodied cognition, and the cerebellum. . *The Cerebellum.* 2012;11(2):505-525.
328. Di Luca S, & Pesenti, M. . Masked priming effect with canonical finger numeral configurations. *Experimental Brain Research.* 2008;185(1):27–39.
329. Lakoff G. JM. *Metaphors We Live By.* Chicago: University of Chicago Press; 1980.
330. Andres M, Michaux, N., & Pesenti, M. Common substrate for mental arithmetic and finger representation in the parietal cortex. *NeuroImage.* 2012;62(3):1520–1528.
331. Mahon BZ, & Caramazza, A. . A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology-Paris.* 2008;102((1-3)):59-70.
332. Dackermann T, Fischer, U., Nuerk, H.C., Cress, U., & Moeller, K. . Applying embodied cognition: from useful interventions and their theoretical underpinnings to practical applications. *ZDM Mathematics Education.* 2017;49(4):545-557.
333. Wilson M. Six views of embodied cognition. *Psychonomic bulletin & review.* 2002;9(4):625-636.
334. Schmahmann J.D. PDN. The cerebrocerebellar system *Int Review Neurobiology* 1997;41(31–60).
335. Middleton F.A. SPL. Cerebellar projections to the prefrontal cortex of the primate. *J Neuroscience.* 2001;21(2):700–712.
336. C.J. S. The cerebellum and cognition: evidence from functional imaging studies. *The Cerebellum.* 2012;11(2):352-365.
337. Baillieux H. DSHJ, Paquier P.F., De Deyn P.P., Marien P. . Cerebellar neurocognition: insights into the bottom of the brain *Clin Neurol Neurosurg.* 2008;110(8):763–773.
338. Balsters J.H. RN. Symbolic representations of action in the human cerebellum. *NeuroImage.* 2008;43(2):388–398.
339. Koziol LF, Budding, D.E., & Chidekel, D. . From movement to thought: executive function, embodied cognition, and the cerebellum. *The Cerebellum.* 2012;11(2):505-525.
340. Glenberg AM, & Kaschak, M.P. Grounding language in action. *Psychonomic bulletin & review.* 2002;9(3):558-565.
341. Rueschemeyer SA, Lindemann, O., Van Elk, M., & Bekkering, H. . Embodied cognition: the interplay between automatic resonance and selection-for-action mechanisms. *European Journal of Social Psychology.* 2009;39(7):1180-1187.
342. Anderson ML. Neural reuse: A fundamental organizational principle of the brain. *Behavioral and brain sciences.* 2010;33(4):245-266.
343. Gallese VL, G. . The brain’s concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology* 2005;22((3-4)):455 – 479.
344. Oppezzo M, & Schwartz, D.L. Give your ideas some legs: The positive effect of walking on creative thinking. *Journal of experimental psychology: learning, memory, and cognition.* 2014;40(4):1142.

345. Steinberg H, Sykes, E. A., Moss, T., Lowery, S., LeBoutillier, N., & Dewey, A. . Exercise enhances creativity independently of mood *British Journal of Sports Medicine.* 1997; 31(3):240-245.
346. Abraham A, Asquith, S., Ahmed, H., & Bourisly, A.K. Comparing the Efficacy of Four Brief Inductions in Boosting Short-Term Creativity. *Journal of Cognitive Enhancement.* 2018:1-9.
347. Hao N, Yuan, H., Hu, Y., & Grabner, R.H. . Interaction effect of body position and arm posture on creative thinking. *Learning and Individual Differences.* 2014(32):261-265.
348. Hutton E, & Sundar, S.S. . Can video games enhance creativity? Effects of emotion generated by Dance Dance Revolution. *Creativity Research Journal.* 2010;22(3):294-303.
349. Kim J. Physical activity benefits creativity: squeezing a ball for enhancing creativity. *Creativity Research Journal.* 2015;27(4):328-333.
350. Dansky JL, & Silverman, I.W. . Effects of play on associative fluency in preschool-aged children. 1973.
351. Friedman RS, & Förster, J. The influence of approach and avoidance motor actions on creative cognition. *Journal of Experimental Social Psychology.* 2002;38(1):41-55.
352. Goldstein A, Revivo, K., Kreitler, M., & Metuki, N. . Unilateral muscle contractions enhance creative thinking. *Psychonomic bulletin & review.* 2010;17(6):895-899.
353. Kuo CY, & Yeh, Y.Y. . Sensorimotor-Conceptual Integration in Free Walking Enhances Divergent Thinking for Young and Older Adults. *Frontiers in psychology.* 2016;7(1580).
354. Leung AKY, Kim, S., Polman, E., Ong, L.S., Qiu, L., Goncalo, J.A., & Sanchez-Burks, J. . Embodied metaphors and creative “acts”. *Psychological science.* 2012;23(5):502-509.
355. Slepian ML, & Ambady, N. . Fluid movement and creativity. *Journal of Experimental Psychology: General.* 2012;141(4):625.
356. Wang X, Lu, K., Runco, M.A., & Hao, N. . Break the “wall” and become creative: Enacting embodied metaphors in virtual reality. *Consciousness and cognition.* 2018 62(102-109).
357. Hao N, Xue, H., Yuan, H., Wang, Q., & Runco, M.A. . Enhancing creativity: Proper body posture meets proper emotion. *Acta psychologica.* 2017(173):32-40.
358. Fioratou E, & Cowley, S.J. . Insightful thinking: Cognitive dynamics and material artifacts. *Pragmatics & Cognition.* 2009;17(3):549-572.
359. Friedman RS, & Förster, J. The effects of approach and avoidance motor actions on the elements of creative insight. *Journal of Personality and Social Psychology.* 2000;79(4):477.
360. Vallée-Tourangeau F, Steffensen, S.V., Vallée-Tourangeau, G., & Sirota, M. . Insight with hands and things. *Acta psychologica.* 2016;170:195-205.
361. Thomas LE, & Lleras, A. . Swinging into thought: Directed movement guides insight in problem solving. *Psychonomic bulletin & review.* 2009;16(4):719-723.
362. Weller A, Villejoubert, G., & Vallée-Tourangeau, F. . Interactive insight problem solving *Thinking & Reasoning.* 2011;17(4):424-439.
363. Zhou Y, Zhang, Y., Hommel, B., & Zhang, H. . The impact of bodily states on divergent thinking: evidence for a control-depletion account. *Frontiers in psychology.* 2017;8:1546.

364. Benedek M, Jauk, E., Sommer, M., Arendasy, M., & Neubauer, A.C. . Intelligence, creativity, and cognitive control: The common and differential involvement of executive functions in intelligence and creativity. *Intelligence.* 2014;46(73-83).
365. Bramer WM, Rethlefsen, M.L., Kleijnen, J., & Franco, O.H. . Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. *Systematic reviews.* 2017;6(1):245.
366. Marin A, Reimann, M., & Castaño, R. . Metaphors and creativity: Direct, moderating, and mediating effects. *Journal of Consumer Psychology.* 2014;24(2):290-297
367. IJzerman H, Leung, A.K.Y., & Ong, L.S. . Perceptual symbols of creativity: Coldness elicits referential, warmth elicits relational creativity *Acta psychologica.* 2014;148(136-147).
368. Yamaguchi T, & Kadone, H. . Bodily Expression Support for Creative Dance Education by Grasping-Type Musical Interface with Embedded Motion and Grasp Sensors. *Sensors.* 2017;17(5):1171.
369. Santos S, Coutinho, D., Gonçalves, B., Schöllhorn, W., Sampaio, J., & Leite, N. . Differential learning as a key training approach to improve creative and tactical behavior in soccer. *Research quarterly for exercise and sport* 2018;89(1):11-24.
370. Cleland FE, & Gallahue, D.L. . Young children's divergent movement ability. *Perceptual and motor skills.* 1993;77(2):535-544.
371. Higgins JP, & Altman, D.G. Assessing risk of bias in included studies. *Cochrane handbook for systematic reviews of interventions*: Cochrane book series; 2008:187-241.
372. Khasky AD, & Smith, J.C. . Stress, relaxation states, and creativity. *Perceptual and motor skills.* 1999;88(2):409-416.
373. Yuan H, Lu, K., & Hao, N. Interactive effect of motivational motor action and emotion on divergent thinking. *Personality and Individual Differences.* 2018;131:93-98.
374. Kirk E, & Lewis, C. . Gesture facilitates children's creative thinking. *Psychological science.* 2017;28(2):225-232.
375. Guilford JP. The nature of human intelligence. New York: McGrawHill; 1967.
376. Mednick S. The associative basis of creative problem solving process. *Psychol. Rev.* 1962;69:200-232.
377. Bowden EM, Jung-Beeman, M., Fleck, J., & Kounios, J. . New approaches to demystifying insight. *Trends in cognitive sciences.* 2005;9(7):322-328.
378. Maier NR. Reasoning in humans II. The solution of a problem and its appearance in consciousness. *Journal of comparative Psychology.* 1931;12(2):181.
379. Knoblich G, Ohlsson, S., Haider, H., & Rhenius, D. . Constraint relaxation and chunk decomposition in insight problem solving. *Journal of Experimental Psychology: Learning, Memory and Cognition.* 1999;25:1534-1555.
380. Boot WR, Simons, D. J., Stothart, C., & Stutts, C. . The pervasive problem with placebos in psychology: Why active control groups are not sufficient to rule out placebo effects. *Perspectives on Psychological Science.* 2013;8(4):445-454.
381. Silveira JM. Incubation: The effect of interruption timing and length on problem solution and quality of problem processing. *Unpublished doctoral dissertation, University of Oregon.* 1971.

382. Crowther P. *Art and embodiment: from aesthetics to self-consciousness.* Oxford University Press1993.
383. Strack F, Martin, L.L., & Stepper, S. Inhibiting and facilitating conditions of the human smile: A nonobtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology.* 1988;53:768 -777.
384. Shiu E. *Creativity research: An inter-disciplinary and multi-disciplinary research handbook.* Vol 34: Routledge; 2014.
385. Guilford JP. Creativity. *American psychologist.* 1950;5:444.
386. Mumford MD. Where have we been, where are we going? Taking stock in creativity research. *Creativity research journal.* 2003;15(2-3):107-120.
387. Colzato LS, Szapora A, Pannekoek JN, Hommel B. The impact of physical exercise on convergent and divergent thinking. *Frontiers in human neuroscience.* 2013;7.
388. Oppezzo M, Schwartz DL. Give your ideas some legs: The positive effect of walking on creative thinking. *Journal of experimental psychology: learning, memory, and cognition.* 2014;40(4):1142.
389. Zhou Y, Zhang Y, Hommel B, Zhang H. The Impact of Bodily States on Divergent Thinking: Evidence for a Control-Depletion Account. *Frontiers in Psychology.* 2017;8:1546.
390. Curnow KE, Turner ET. The effect of exercise and music on the creativity of college students. *The Journal of Creative Behavior.* 1992;26(1):50-52.
391. Steinberg H, Sykes EA, Moss T, Lowery S, LeBoutillier N, Dewey A. Exercise enhances creativity independently of mood. *British Journal of Sports Medicine.* 1997;31(3):240-245.
392. Blanchette DM, Ramocki SP, O'del JN, Casey MS. Aerobic exercise and creative potential: Immediate and residual effects. *Creativity Research Journal.* 2005;17(2-3):257-264.
393. Gondola JC. The enhancement of creativity through long and short term exercise programs. *Journal of Social Behavior & Personality.* 1986.
394. Gondola JC, Tuckman BW. Effects of a systematic program of exercise on selected measures of creativity. *Perceptual and motor skills.* 1985;60(1):53-54.
395. Tuckman BW, Hinkle JS. An experimental study of the physical and psychological effects of aerobic exercise on schoolchildren. *Health Psychology.* 1986;5(3):197.
396. Gondola JC. The effects of a single bout of aerobic dancing on selected tests of creativity. *Journal of Social Behavior & Personality.* 1987.
397. Hinkle JS, Tuckman BW, Sampson JP. The psychology, physiology, and creativity of middle school aerobic exercisers. *Elementary School Guidance & Counseling.* 1993;28(2):133-145.
398. Ramocki SP. Creativity interacts with fitness and exercise. *Physical Educator.* 2002;59(1):8.
399. McCutcheon LE. Does running make people more creative? *Journal of Sport Behavior.* 1982.

400. Herman-Tofler L, Tuckman B. The effects of aerobic training on children's creativity, self-perception, and aerobic power. *Child and adolescent psychiatric clinics of North America.* 1998;7(4):773-790, viii.
401. Loprinzi PD, Edwards MK, Frith E. Potential avenues for exercise to activate episodic memory-related pathways: a narrative review. *European Journal of Neuroscience.* 2017.
402. Blanchette I, Richards A. The influence of affect on higher level cognition: A review of research on interpretation, judgement, decision making and reasoning. *Cognition & Emotion.* 2010;24(4):561-595.
403. Bashwiner DM, Wertz CJ, Flores RA, Jung RE. Musical creativity "revealed" in brain structure: interplay between motor, default mode, and limbic networks. *Scientific reports.* 2016;6.
404. Beaty RE, Smeekens BA, Silvia PJ, Hodges DA, Kane MJ. A first look at the role of domain-general cognitive and creative abilities in jazz improvisation. *Psychomusicology: Music, Mind, and Brain.* 2013;23(4):262.
405. Duffau H. Jazz improvisation, creativity, and brain plasticity. *World neurosurgery.* 2014;81(3):508-510.
406. Kleinmintz OM, Goldstein P, Mayseless N, Abecasis D, Shamay-Tsoory SG. Expertise in musical improvisation and creativity: The mediation of idea evaluation. *PloS one.* 2014;9(7):e101568.
407. Pinho AL, de Manzano Ö, Fransson P, Eriksson H, Ullén F. Connecting to create: expertise in musical improvisation is associated with increased functional connectivity between premotor and prefrontal areas. *Journal of Neuroscience.* 2014;34(18):6156-6163.
408. Przysinda E, Zeng, T., Maves, K., Arkin, C., & Loui, P. . Jazz musicians reveal role of expectancy in human creativity *Brain and cognition.* 2017;119:45-53.
409. Gabrielsson A, Lindström S. Can strong experiences of music have therapeutic implications. *Music and the mind machine: The psychophysiology and psychopathology of the sense of music.* 1995:195-202.
410. Schellenberg EG, Nakata T, Hunter PG, Tamoto S. Exposure to music and cognitive performance: Tests of children and adults. *Psychology of Music.* 2007;35(1):5-19.
411. Cheung DSK, Lai, C.K.Y., Wong, F.K.Y., & Leung, M.C.P. The effects of the music-with-movement intervention on the cognitive functions of people with moderate dementia: a randomized controlled trial. . *Aging & mental health.* 2018;22(3):306-315.
412. Fritz TH, Halfpaap, J., Grahl, S., Kirkland, A., & Villringer, A. . Musical feedback during exercise machine workout enhances mood. *Frontiers in psychology.* 2013;4:921.
413. Janata P, Tomic, S.T., & Rakowski, S.K. . Characterisation of music-evoked autobiographical memories. . *Memory.* 2007;15(8):845-860.
414. Sheldon S, & Donahue, J. . More than a feeling: Emotional cues impact the access and experience of autobiographical memories. *Memory & cognition.* 2017;45(5):731-744.
415. Blood AJ, Zatorre RJ, Bermudez P, Evans AC. Emotional responses to pleasant and unpleasant music correlate with activity in paralimbic brain regions. *Nature neuroscience.* 1999;2(4):382-387.

416. Frühholz S, Trost, W., & Grandjean, D. . The role of the medial temporal limbic system in processing emotions in voice and music. . *Progress in neurobiology.* 2014;123:1-17.
417. Koelsch S. Towards a neural basis of music-evoked emotions. *Trends in cognitive sciences.* 2010;14(3):131-137.
418. Koelsch S. Brain correlates of music-evoked emotions. *Nature Reviews Neuroscience.* 2014;15(3):170.
419. Baumgartner T, Lutz, K., Schmidt, C. F., & Jäncke, L. (2006). The emotional power of music: how music enhances the feeling of affective pictures. *Brain research.* 2006;1075(1):151-164.
420. Blood AJ, Zatorre RJ. Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *Proceedings of the National Academy of Sciences.* 2001;98(20):11818-11823.
421. Wilkins RW, Hodges DA, Laurienti PJ, Steen M, Burdette JH. Network science and the effects of music preference on functional brain connectivity: from Beethoven to Eminem. *Scientific reports.* Aug 28 2014;4:6130.
422. McPherson MJ, Barrett FS, Lopez-Gonzalez M, Jiradejvong P, Limb CJ. Emotional intent modulates the neural substrates of creativity: an fMRI study of emotionally targeted improvisation in Jazz musicians. *Scientific reports.* 2016;6:18460.
423. Salamone JD, Correa M. The mysterious motivational functions of mesolimbic dopamine. *Neuron.* 2012;76(3):470-485.
424. Nguyen-Michel ST, Unger JB, Hamilton J, Spruijt-Metz D. Associations between physical activity and perceived stress/hassles in college students. *Stress and Health.* 2006;22(3):179-188.
425. Sandi C, Pinelo-Nava MT. Stress and memory: behavioral effects and neurobiological mechanisms. *Neural plasticity.* 2007;2007.
426. Dhiman S. Personal mastery: Our quest for self-actualization, meaning, and highest purpose. *Interbeing.* 2007;1(1):25.
427. Lee TM, Wong ML, Lau BW-M, Chia-Di Lee J, Yau S-Y, So K-F. Aerobic exercise interacts with neurotrophic factors to predict cognitive functioning in adolescents. *Psychoneuroendocrinology.* 2014;39:214-224.
428. van Dongen EV, Kersten IH, Wagner IC, Morris RG, Fernández G. Physical exercise performed four hours after learning improves memory retention and increases hippocampal pattern similarity during retrieval. *Current Biology.* 2016;26(13):1722-1727.
429. Bradley MM, Lang PJ. Measuring emotion: the Self-Assessment Manikin and the Semantic Differential. *Journal of behavior therapy and experimental psychiatry.* Mar 1994;25(1):49-59.
430. Dudai Y. Recall. *Memory: from A to Z*: Oxford University Press; 2004:210-212.
431. Dudai Y. Retrieval. *Memory: from A to Z*: Oxford University Press; 2004:221-225.
432. Bradley MM, Lang PJ. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry.* 1994;25(1):49-59.

433. Greenwood JL, Joy EA, Stanford JB. The Physical Activity Vital Sign: a primary care tool to guide counseling for obesity. *Journal of Physical Activity and Health.* 2010;7(5):571-576.
434. Spielberger CD, Gorsuch RL, Lushene RE, Vagg PR. State-trait anxiety inventory (STAI). *BiB.* 2010;1970:180.
435. Ekkekakis P, Lind E. Exercise does not feel the same when you are overweight: the impact of self-selected and imposed intensity on affect and exertion. *International journal of obesity.* 2006;30(4):652-660.
436. Ritter SM, & Ferguson, S. Happy creativity: Listening to happy music facilitates divergent thinking. . *PloS one.* 2017;12(9):e0182210.
437. Guilford JP. The nature of human intelligence. 1967.
438. Runco MA, Okuda SM. Problem discovery, divergent thinking, and the creative process. *Journal of Youth and Adolescence.* 1988;17(3):211-220.
439. Csikszentmihalyi M, Getzels JW. Creativity and problem finding. *The foundations of aesthetics, art, and art education.* 1988:91-106.
440. Fink A, Benedek M, Koschutnig K, et al. Training of verbal creativity modulates brain activity in regions associated with language-and memory-related demands. *Human brain mapping.* 2015;36(10):4104-4115.
441. Mumford MD, Reiter-Palmon R, Redmond MR. Problem construction and cognition: Applying problem representations in ill-defined domains. 1994.
442. Bowden EM, Jung-Beeman M. Normative data for 144 compound remote associate problems. *Behavior Research Methods.* 2003;35(4):634-639.
443. Friedman RS, Fishbach A, Förster J, Werth L. Attentional priming effects on creativity. *Creativity Research Journal.* 2003;15(2-3):277-286.
444. Ritter SM, Dijksterhuis A. Creativity—the unconscious foundations of the incubation period. *Frontiers in human neuroscience.* 2014;8.
445. Connery NR. Development of next-generation US infrastructure systems: A framework for national policy. *Public Works Management & Policy.* 2008;12(3):479-482.
446. Benedek M, Jauk, E., Fink, A., Koschutnig, K., Reishofer, G., Ebner, F., & Neubauer, A. C. (2014). . To create or to recall? Neural mechanisms underlying the generation of creative new ideas. . *NeuroImage.* 2014;88:125-133.
447. Benedek M, Bergner, S., Könen, T., Fink, A., & Neubauer, A.C. EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. . *Neuropsychologia.* 2011;49(12):3505-3511.
448. Runco MA. Commentary: Divergent thinking is not synonymous with creativity. 2008.
449. Cropley A. In praise of convergent thinking. *Creativity research journal.* 2006;18(3):391-404.
450. Bowden EM, & Jung-Beeman, M. . Normative data for 144 compound remote associate problems. *Behavior Research Methods, Instruments, & Computers.* 2003;35(4):634-639.
451. Kaufman AB, Kornilov, S.A., Bristol, A.S., Tan, M., & Grigorenko, E.L. . The neurobiological foundation of creative cognition. *The Cambridge handbook of creativity.* 2010;216.

452. Byron K, Khazanchi, S., & Nazarian, D. . The relationship between stressors and creativity: A meta-analysis examining competing theoretical models. *ournal of Applied Psychology.* 2010;95(1):201.
453. Heilman KM, Nadeau, S.E., & Beversdorf, D.O. . Creative innovation: possible brain mechanisms. . *Neurocase.* 2003;9(5):369-379.
454. Kaufman AB, Kornilov, S.A., Bristol, A.S., Tan, M., & Grigorenko, E.L. . The neurobiological foundation of creative cognition. . *The Cambridge handbook of creativity.* 2010:216.
455. Martindale C, Anderson, K., Moore, K., & West, A.N. . Creativity, oversensitivity, and rate of habituation. . *Personality and individual differences.* 1996;20(4): 423-427.
456. Cropley AJ. Defining and measuring creativity: Are creativity tests worth using? *Roeper review.* 2000;23(2):72-79.
457. Dorfman L, Martindale, C., Gassimova, V., & Vartanian, O. . Creativity and speed of information processing: A double dissociation involving elementary versus inhibitory cognitive tasks. *Personality and Individual Differences.* 2008;44(6):1382-1390.
458. Martindale C, & Mines, D. . Creativity and cortical activation during creative, intellectual and EEG feedback tasks. *Biological psychology.* 1975;3(2):91-100.
459. Kaufman JC. Counting the muses: Development of the Kaufman Domains of Creativity Scale (K-DOCS). *Psychology of Aesthetics, Creativity, and the Arts.* 2012;6(4):298.
460. Collins MA, & Amabile, T.M. . I5 motivation and creativity. . *Handbook of creativity.* Vol 2971999:1051-1057.
461. Grant AM, & Berry, J.W. . The necessity of others is the mother of invention: Intrinsic and prosocial motivations, perspective taking, and creativity. *Academy of management journal.* 2011;54(1):73-96.
462. Sawyer K. The cognitive neuroscience of creativity: a critical review. . *Creativity research journal.* 2011;23(2):137-154.
463. Baer J. Is creativity domain specific. . *The Cambridge handbook of creativity*2010:321-341.
464. Wiley J. Expertise as mental set: The effects of domain knowledge in creative problem solving. Memory & cognition. *Memory & cognition, 26(4), 716-730.* 1998;26(4): 716-730.
465. Colangelo N, Kerr, B., Hallowell, K., Huesman, R., & Gaeth, J. . The Iowa Inventiveness Inventory: Toward a measure of mechanical inventiveness. . *Creativity Research Journal.* 1992;5(2):158.
466. Yu EC, Fricker, S., & Kopp, B. Can Survey Instructions Relieve Respondent Burden? Paper presented at: AAPOR; May 15, 2015, 2015; Hollywood, Florida.
467. Batey M. *A psychometric investigation of everyday creativity*. Unpublished Doctoral Thesis, University College, London.; 2007.
468. Batey M, & Furnham, A. . The relationship between measures of creativity and schizotypy. . *Personality and Individual Differences.* 2008;45(8):816-821.
469. Silvia PJ, & Nusbaum, E.C. . What's your major? College majors as markers of creativity. . *The International Journal of Creativity and Problem Solving.* 2012;22(2):31-44.

470. Silvia PJ, Wigert, B., Reiter-Palmon, R., & Kaufman, J.C. . Assessing creativity with self-report scales: A review and empirical evaluation. *Psychology of Aesthetics, Creativity, and the Arts.*6(1):19.
471. Greenwood JLJ, E.A., & Stanford, J.B. The Physical Activity Vital Sign: a primary care tool to guide counseling for obesity. . *Journal of Physical Activity and Health.* 2010;7(5):571-576.
472. Fowles J.R. OBMW, Wojcik W.R., d'Entremont L., Shields C.A. . A pilot study: Validity and reliability of the CSEP−PATH PASB-Q and a new leisure time physical activity questionnaire to assess physical activity and sedentary behaviours. *Applied Physiology, Nutrition, and Metabolism.* 2017;42(6):677-680.
473. Ball T.J. JEA, Goh T.L., Hannon, J.C., Gren, L.H., & Shaw, J.M. Validity of two brief primary care physical activity questionnaires with accelerometry in clinic staff. *Prim Health Care Res Dev* 2015;16(1):100-108. .
474. Ball TJ, Joy, E. A., Gren, L.H., & Shaw, J.M. . Peer Reviewed: Concurrent Validity of a Self-Reported Physical Activity "Vital Sign" Questionnaire With Adult Primary Care Patients. . *Preventing chronic disease.* 2016;13.
475. Ball T.J. JEA, Gren L.H., Cunningham R., Shaw J.M. Predictive validity of an adult physical activity "Vital Sign" recorded in electronic health records. *Journal of Physical Activity and Health.* 2016;13(4):403-408.
476. Beaty RE, Benedek, M., Kaufman, S.B., & Silvia, P.J. Default and executive network coupling supports creative idea production. *Scientific reports.* 2015(5):10964.
477. Hocevar D. Dimensionality of creativity. *Psychol Rep.* . 1976(39):869-870.
478. Torrance EP. *The Torrance Tests of Creative Thinking- Norms-technical manual research edition- Verbal tests, forms A and B- Figural tests, forms A and B.* Princeton, NJ, USA Personnel Press.; 1974.
479. Vincent A.S. DBP, Mumford M.D. . Divergent thinking, intelligence, and expertise: A test of alternative models. . *Creativity Research Journal.* (14):163–178. .
480. An D. SY, Carr M. . A comparison of two models of creativity: Divergent thinking and creative expert performance. =. *Personality and Individual Differences.* 2016(90):78–84. .
481. Chang YK. Acute exercise and event-related potential: current status and future prospects. In: McMorris T, ed. *Exercise-Cognition Interaction: A Neurochemical Perspective*. New York: Elsevier Academic Press; 2016:124.
482. Sternberg RJ. The Rainbow Project: Enhancing the SAT through assessments of analytical, practical, and creative skills. *Intelligence.* 2006;34(4):321-350.
483. Sternberg RJ. Finding students who are wise, practical, and creative. *Chronicle of Higher Education.* 2007;53(44).
484. Zhang LF, & Sternberg, R.J. Revisiting the investment theory of creativity. *Creativity Research Journal.* 2011;23(3):229-238.
485. Sternberg RJ, & Lubart, T.I. . An investment theory of creativity and its development. *Human development.* 1991;34(1):1-31.
486. Sternberg RJ, & Lubart, T.I. . Investing in creativity. *American psychologist.* 1996;51(7):677.

487. Lyubomirsky S, King, L., & Diener, E. The benefits of frequent positive affect: Does happiness lead to success? . *Psychological Bulletin.* 2005(131):803– 855.
488. Chen B, Hu, W., & Plucker, J.A. . The effect of mood on problem finding in scientific creativity. *The Journal of Creative Behavior.* 2016;50(4):308-320.
489. Roskes M, De Dreu, C.K., & Nijstad, B.A. Necessity is the mother of invention: Avoidance motivation stimulates creativity through cognitive effort. *Journal of Personality and Social Psychology.* 2012;103(2):242.
490. Hausenblas HA, Carron, A.V., & Mack, D.E. . Application of the theories of reasoned action and planned behavior to exercise behavior: A meta-analysis. *Journal of Sport and Exercise Psychology.* 1997;19(1):36-51.
491. Amabile TM. *How to kill creativity* Vol 87. Boston, MA: Harvard Business School Publishing.; 1998.
492. Lu JG, Akinola, M., & Mason, M.F. "Switching On" creativity: Task switching can increase creativity by reducing cognitive fixation. *Organizational Behavior and Human Decision Processes.* 2017(139):63-75.
493. Einstein GO, McDaniel, M.A., Williford, C.L., Pagan, J.L., & Dismukes, R. Forgetting of intentions in demanding situations is rapid. *Journal of Experimental Psychology: Applied.* 2003;9(3):147–162.
494. Duncker K. On problem solving. *Psychological Monographs.* 1945;58(5, Whole No. 270).
495. Weisberg RW. Insight, problem solving, and creativity: An integration of findings. *Insight* Routledge; 2018:191-215.
496. McCaffrey T. A Visual Representation to Quantitate, Diagnose, and Improve Creativity in Insight Problem Solving. *The Journal of Creative Behavior.* 2016.
497. Morningstar JA. *Drives, Performance, Creativity and Introversion in the Workplace.* 2012.
498. German TP, & Defeyter, M.A Immunity to functional fixedness in young children. *Psychonomic Bulletin & Review.* 2000;7(4):707-712.
499. Wallach MA, & Kogan, N. . *Modes of thinking in young children: A study of the creativity-intelligence distinction.* New York: Holt, Rinehart, & Winston.; 1965.
500. Bousfield WA, & Sedgewick, C.H.W. . An analysis of sequences of restricted associative responses. *The Journal of General Psychology.* 1944;30(2):149-165.
501. Dijksterhuis A, & Meurs, T. Where creativity resides: The generative power of unconscious thought. *Consciousness and Cognition.* 2006;15:135-146.
502. Acar S, & Runco, M.A. Latency predicts category switch in divergent thinking. *Psychology of Aesthetics, Creativity, and the Arts.* 2017;11(1):43.
503. Sio UN, & Ormerod, T.C. . Does incubation enhance problem solving? A meta-analytic review. *Psychological Bulletin.* 2009;135(1):94.
504. Baird B, Smallwood, J., Mrazek, M.D., Kam, J.W., Franklin, M.S., & Schooler, J.W. Inspired by distraction: mind wandering facilitates creative incubation. *Psychological science.* 2012;23(10):1117-1122.
505. Smith SM, & Blankenship, S.E. Incubation and the persistence of fixation in problem solving. *American Journal of Psychology.* 1991(104):61–87.

506. Holmes E. *The life of Mozart including his correspondence.* Chapman and Hall; 1878.
507. Watson D, Clark, L.A., & Tellegen, A. . Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of personality and social psychology.* 1988b;54(6):1063.
508. Baas M, De Dreu, C. K., Nijstad, B. A. . A meta-analysis of 25 years of mood-creativity research: Hedonic tone, activation, or regulatory focus?. *Psychological bulletin,.* 2008;134(6):779.
509. Davis MA. Understanding the relationship between mood and creativity: A meta-analysis *Organizational behavior and human decision processes.* 2009;108(1):25-38.
510. Batey M, & Furnham, A. . The relationship between measures of creativity and schizotypy. *Personality and Individual Differences.* 2008;45(8):816-821.
511. Batey M, & Furnham, A. Creativity, intelligence and personality: A critical review of the scattered literature *Genetic, General and Social Psychology Monographs.* 2006;132(355–429).
512. Karvonen MJ, Kentala, E., & Mustala, O The effects of training heart rate: A longitudinal study. *Annals Medicinae Experimentalis et Biologiae Fenniae.* 1957;35:307-315.
513. Benedek M, Jauk, E., Sommer, M., Arendasy, M., & Neubauer, A.C. . Intelligence, creativity, and cognitive control: The common and differential involvement of executive functions in intelligence and creativity. *Intelligence.* 2014;46:73-83.
514. Sio UN, & Ormerod, T.C. Does incubation enhance problem solving? A meta-analytic review. *Psychological Bulletin.* 2009;135:94–120.
515. Kristensen T. The physical context of creativity. *Creativity and innovation management.* 2004;13(2):89-96.
516. Oppezzo M, & Schwartz, D. L. . Give your ideas some legs: The positive effect of walking on creative thinking. *Journal of experimental psychology: learning, memory, and cognition.* 2014;40(4):1142.
517. Heilman KM. *Creativity and the Brain.* Vol 1. New York: Psychology Press; 2005.
518. Hill KG, & Amabile, T.M. A social psychological perspective on creativity: Intrinsic motivation and creativity in the classroom and workplace. *Understanding and recognizing creativity: The emergence of a discipline*1993:400-432.
519. Bristol AS, & Viskontas, I.V. . Dynamic Processes Within Associative Memory Stores: Piecing Together the Neural Basis of Creative Cognition. In: Kaufman JCB, J, ed. *Creativity and reason in cognitive development*. New York, NY: Cambridge University Press; 2006:60-80.
520. Sternberg RJ. What is the common thread of creativity? Its dialectical relation to intelligence and wisdom. *American Psychologist.* 2001;56(4):360.
521. Baer J. Is creativity domain specific. *The Cambridge handbook of creativity*2010:321-341.
522. Einstein A. Letter to Jacques Hadamard *The Creative Process: Reflections in Inventions in the Arts and Sciences* Los Angeles: University of California Press, 1980; 1952:43-44.
523. Shakespeare W. *A Midsummer Night's Dream.* Vol 2. London: Methuen, 1979; 1979.
524. Da Vinci L. *The notebooks of Leonardo da Vinci* Vol 1: Courier Corporation; 2012.

525. Plucker JA, Beghetto, R.A. . Why creativity is domain general, why it looks domain specific, and why the distinction does not matter. In: Sternberg RJ, Grigorenko, E.G., Singer, J.L., ed. *Creativity: From Potential to Realization*. Washington, DC American Psychological Association; 2004:153-167.
526. Schmidt-Kassow M, Deusser, M., Thiel, C., Otterbein, S., Montag, C., Reuter, M., ... & Kaiser, J. . Physical exercise during encoding improves vocabulary learning in young female adults: a neuroendocrinological study. *PloS one.* 2013;8(5):e64172.
527. Labban JD, & Etnier, J.L. . Effects of acute exercise on long-term memory. *Research quarterly for exercise and sport.* 2011;82(4):712-721.
528. Basso JC, Shang, A., Elman, M., Karmouta, R., & Suzuki, W.A. Acute exercise improves prefrontal cortex but not hippocampal function in healthy adults. *Journal of the International Neuropsychological Society.* 2015;21(10):791-801.
529. Roig M, Nordbrandt, S., Geertsen, S.S., & Nielsen, J.B. The effects of cardiovascular exercise on human memory: A review with meta-analysis *Neuroscience and Biobehavioral Reviews.* 2013;37:1645–1666.
530. Travlos AK. High intensity physical education classes and cognitive performance in eighth-grade students: An applied study. *International Journal of Sport and Exercise Psychology.* 2010;8(3):302-311.
531. McNaughten D GC. Physical exertion and immediate mental performance of sixth-grade children. *Perceptual Motor Skills* 1993;77:1155–1159.
532. Gabbard C BJ. Effects of physical activity on mathematical computation among young children. *Journal of Psychology* 1979;103:287–288.
533. Cotman CW, & Berchtold, N.C. . Exercise: a behavioral intervention to enhance brain health and plasticity. *Trends in neurosciences.* 2002;25(6):295-301.
534. Snyder JS, Glover, L.R., Sanzone, K.M., Kamhi, J.F., & Cameron, H.A. . The effects of exercise and stress on the survival and maturation of adult-generated granule cells. *Hippocampus.* 2009;19 (10):898-906.
535. Fyhn M, Molden, S., Witter, M.P., Moser, E.I., & Moser, M.B. . Spatial representation in the entorhinal cortex. *Science.* 2004;305(5688):1258-1264.
536. Kirwan CB, & Stark, C.E. . Medial temporal lobe activation during encoding and retrieval of novel face-name pairs. *Hippocampus.* 2004;14(7):919-930.
537. Griffin ÉW, Mullally, S., Foley, C., Warmington, S.A., O'Mara, S.M., & Kelly, Á.M. Aerobic exercise improves hippocampal function and increases BDNF in the serum of young adult males. *Physiology & behavior.* 2011;104(5):934-941.
538. Reilly T, & Smith, D. . Effect of work intensity on performance in a psychomotor task during exercise. *Ergonomics.* 1986;29(601–606).
539. Chang YK, Labban, J.D., Gapin, J.I., & Etnier, J.L. . The effects of acute exercise on cognitive performance: a meta-analysis. *Brain research.* 2012;1453(87-101).
540. Sng E, Frith, E., & Loprinzi, P.D. . Temporal effects of acute walking exercise on learning and memory function. . *American Journal of Health Promotion.* 2017:0890117117749476.

541. Frith E, Sng, E., & Loprinzi, P.D. Randomized controlled trial evaluating the temporal effects of high-intensity exercise on learning, short-term and long-term memory, and prospective memory. *European Journal of Neuroscience.* 2017;46(10):2557-2564.
542. Chisholm DM, Collis, M.L., Kulak, L.L., Davenport, W., Gruber, N., & Stewart, G.W. . *PAR-Q validation report: the evaluation of a self-administered pre-exercise screening questionnaire for adults.* Victoria: Canada: BC Ministry of Health and Health and Welfare;1978.
543. To ML, Fisher, C.D., Ashkanasy, N.M., & Rowe, P.A. . Within-person relationships between mood and creativity. *Journal of Applied Psychology.* 2012;97(3):599.
544. Bledow R, Rosing, K., & Frese, M. . A dynamic perspective on affect and creativity. *Academy of Management Journal.* 2013;56(2):432-450.
545. Dow GT, & Mayer, R.E. . Teaching students to solve insight problems: Evidence for domain specificity in creativity training. *Creativity Research Journal.* 2004 16(4):389-398.
546. Duncker K, & Lees, L.S. On problem-solving. *Psychological monographs.* 1945;58(5):i.
547. Kleibeuker SW, De Dreu, C.K., & Crone, E.A. . The development of creative cognition across adolescence: distinct trajectories for insight and divergent thinking. *Developmental science.* 2013;16(1):2-12.
548. Shen W, Yuan, Y., Liu, C., & Luo, J. In search of the 'Aha!'experience: Elucidating the emotionality of insight problem-solving. *British Journal of Psychology.* 2016;107(2):281-298.
549. Miyake A. FNP, Emerson M.J., Witzki A.H., Howerter A., Wager T.D. . The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology.* 2000;41:49–100.
550. Barenberg J, Berse, T., & Dutke, S. Executive functions in learning processes: do they benefit from physical activity? *Educational Research Review.* 2011;6(3):208-222.
551. Hillman C.H. PMB, Raine L.B., Castelli D.M., Hall E.E., Kramer A.F. . The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience.* 2009;3:1044–1054.
552. Soga K, Shishido, T., & Nagatomi, R. . Executive function during and after acute moderate aerobic exercise in adolescents. *Psychology of Sport and Exercise.* 2015;6(7-17).
553. Best JR. Effects of physical activity on children's executive function: Contributions of experimental research on aerobic exercise. *Developmental Review.* 2010;30(4):331-351.
554. Atkinson G, & Batterham, A.M. . True and false interindividual differences in the physiological response to an intervention. *Experimental physiology.* 2015;100(6):577-588.
555. Mendelsohn GA, & Keppel, G. . An hypothesis approach to anagram solution. 14th Annual Meeting of the Psychonomic Society; 1974; Boston, Mass.
556. Mendelsohn GA, & O'Brien, A.T. . The solution of anagrams: A reexamination of the effects of transition letter probabilities, letter moves, and word frequency on anagram difficulty. *Memory and Cognition.* 1974;2:566-574.

557. Mendelsohn GA, Griswold, B.B., & Anderson, M.L. Individual differences in anagram-solving ability. *Psychological Reports.* 1966;19(3):799-809.
558. Mednick SA. The associative basis of the creative process. *Psychological Review.* 1962;69:220-232.
559. Sassenberg K, Moskowitz, G.B., Fetterman, A., & Kessler, T. Priming creativity as a strategy to increase creative performance by facilitating the activation and use of remote associations. *Journal of Experimental Social Psychology.* 2017;68:128-138.
560. Logue SF, & Gould, T. J. The neural and genetic basis of executive function: attention, cognitive flexibility, and response inhibition. *Pharmacology Biochemistry and Behavior.* 2014;123(45-54).
561. Safren MA. Associations, sets, and the solution of word problems. *Journal of Experimental Psychology.* 1962;64(1):40.
562. Campbell HL, Tivarus, M. E., Hillier, A., & Beversdorf, D.Q Increased task difficulty results in greater impact of noradrenergic modulation of cognitive flexibility. *Pharmacology Biochemistry and Behavior.* 2008;88(3):222-229.
563. Mendelsohn GA. Associative and attentional processes in creative performance *Journal of personality.* 1976;44(2):341-369.
564. Dominowski RL, & Ekstrand, B.R. . Direct and associative priming in anagram solving. *Journal of Experimental Psychology* 1967;74:84-86.
565. Safren MA. Associations, set, and the solution of word problems. *Journal of Experimental Psychology.* 1962;64:40-45.
566. Marsh RL, Bink, M.L., & Hicks, J.L. . Conceptual priming in a generative problem-solving task. *Memory & Cognition.* 1999a;27:355–363.
567. Ratcliff R, & McKoon, G. A retrieval theory of priming in memory. *Psychological Review.* 1988;95:385–408.
568. Higgins ET, & Brendl, C.M. Accessibility and applicability: Some "activation rules" influencing judgment. *Journal of Experimental Social Psychology.* 1995;31:218–243.
569. Inzlicht M, and Schmeichel, B.J. What is ego depletion? Toward a mechanistic revision of the resource model of self-control. *Perspect. Psychol. Sci.* 2012;7:450–463.
570. Dorris DC, Power, D.A., & Kenefick, E. . Investigating the effects of ego depletion on physical exercise routines of athletes. *Psychology of Sport and Exercise.* 2012;13(2):118-125.
571. Chang YK, Labban, J.D., Gapin, J.I., & Etnier, J.L. . The effects of acute exercise on cognitive performance: a meta-analysis. *Brain research.* 2012;1453:87-101.
572. Tomporowski PD. Effects of acute bouts of exercise on cognition. *Acta psychologica, .* 2003;112(3):297-324.
573. Yanagisawa H, Dan, I., Tsuzuki, D., Kato, M., Okamoto, M., Kyutoku, Y., & Soya, H. Acute moderate exercise elicits increased dorsolateral prefrontal activation and improves cognitive performance with Stroop test. *Neuroimage.* 2010;50(4):1702-1710.
574. Koppelstaetter F, Poeppel, T.D., Siedentopf, C.M., Ischebeck, A., Kolbitsch, C., Mottaghy, F.M., ... & Krause, B. J. Caffeine and cognition in functional magnetic resonance imaging. *Journal of Alzheimer's Disease* 2010;20(s1):S71-S84.

575. Glynn LM. Giving birth to a new brain: hormone exposures of pregnancy influence human memory. *Psychoneuroendocrinology* 2010;35(1148–1155).
576. Buckwalter JG, Buckwalter, D.K., Bluestein, B.W. & Stanczyk, F.Z. Pregnancy and post partum: changes in cognition and mood. *Prog. Brain Res.* 2001;133(303–319).
577. Waisman Campos M, Serebrisky, D., & Mauricio Castaldelli-Maia, J. Smoking and cognition. *Current drug abuse reviews.* 2016;9(2):76-79.
578. Deary IJ, Corley, J., Gow, A.J., Harris, S.E., Houlihan, L.M., Marioni, R.E., ... & Starr, J.M Age-associated cognitive decline. *British medical bulletin.* 2009;92(1):135-152.
579. Martini DN, & Broglio, S.P. Long-term effects of sport concussion on cognitive and motor performance: a review. *International journal of psychophysiology.* 2018;132:25-30.
580. Warburton DE, Jamnik, V. K., Bredin, S.S., & Gledhill, N. The physical activity readiness questionnaire for everyone (PAR-Q+) and electronic physical activity readiness medical examination (ePARmed-X+). *The Health & Fitness Journal of Canada.* 2011;4(2):3-17.
581. Warburton DE, Bredin, S.S., Jamnik, V.K., & Gledhill, N. Validation of the PAR-Q+ and ePARmed-X+. *The Health & Fitness Journal of Canada.* 2011;4(2):38-46.
582. Kumar VK, Kemmler, D., & Holman, E.R The Creativity Styles Questionnaire--Revised. *Creativity Research Journal.* 1997;10(1):51-58.
583. Deese J. Influence of inter-item associative strength upon immediate free recall. *Psychological Reports.* 1959;5(3):305-312.
584. Maltzman I, & Morrisett Jr, L. Different strengths of set in the solution of anagrams. *Journal of Experimental Psychology* 1952;44(4):242.
585. Dominowski RL, & Ekstrand, B.R. Direct and associative priming in anagram solving. *Journal of Experimental Psychology.* 1967;74(1):84.
586. Ansburg PI, & Hill, K. Creative and analytic thinkers differ in their use of attentional resources. *Personality and Individual Differences.* 2003;34(7):1141-1152.
587. Schuberth RE, Spoehr, K.T., & Haertel, R.J. Solving anagrams: Category priming and the differential availability of category solutions. *The Quarterly Journal of Experimental Psychology.* 1979;31(4):599-607.
588. Bowden EM, & Jung-Beeman, M. Normative data for 144 compound remote associate problems. Behavior Research Methods, Instruments, & Computers. *35.* 2003;4(634-639).
589. Schooler JWM, J. The ineffability of insight. 1995.
590. Lee CS, Huggins, A.C., & Therriault, D.J. A measure of creativity or intelligence? Examining internal and external structure validity evidence of the Remote Associates Test. *Psychology of Aesthetics, Creativity, and the Arts.* 2014;8(4):446.
591. Garber CE, Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., ... & Swain, D.P. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine & Science in Sports & Exercise.* 2011;43(7):1334-1359.
592. *IBM SPSS Statistics for Windows* [computer program]. Version Version 25.0. . Armonk, NY: IBM Corp; 2017.

593. *JASP* [computer program]. Version (Version 0.9.1.0)2018.
594. Wagenmakers EJ, Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., ... & Matzke, D. Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic bulletin & review.* 2018;25(1):35-57.
595. Jeffreys H. *Theory of probability.* 3 ed. Oxford, UK: Oxford University Press; 1961.
596. Dennis AR, Minas, R.K., & Bhagwatwar, A.P. . Sparking creativity: Improving electronic brainstorming with individual cognitive priming. *Journal of Management Information Systems.* 2013;29(4):195-216.
597. Higgins ET, & Eitam, B. Priming… Shmiming: it's about knowing when and why stimulated memory representations become active. *Social Cognition.* 2014;32(Supplement):225-242.
598. Posner MI, & Snyder, C.R.R. . *Attention and cognitive control.* R. Solso (Ed.) ed. Hillsdale, NJ: Erlbaum1975.
599. Yap MJ, Hutchison, K.A., & Tan, L.C. INDIVIDUAL DIFFERENCES IN SEMANTIC PRIMING PERFORMANCE. *Big data in cognitive science.* 2016;203.
600. Ortells JJ, Kiefer, M., Castillo, A., Megías, M., & Morillas, A. . The semantic origin of unconscious priming: Behavioral and event-related potential evidence during category congruency priming from strongly and weakly related masked words. *Cognition, .* 2016;146:143-157.
601. Andrews S, Lo, S., & Xia, V. Individual differences in automatic semantic priming. *Journal of Experimental Psychology: Human Perception and Performance.* 2017;43(5).
602. Ferrand L, & New, B. . Semantic and associative priming in the mental lexicon. *Mental lexicon: Some words to talk about words.* 2003:25-43.
603. Lucchiari C, & Vanutelli, M.E. Promoting creativity through transcranial direct current stimulation (tDCS). A critical review. *Frontiers in behavioral neuroscience.* 2018;12:167.
604. Ball L, & Stevens, A. Evidence for a verbally-based analytic component to insight problem solving. Paper presented at: Proceedings of the Annual Meeting of the Cognitive Science Society2009.
605. Petrides M, Alivisatos, B., & Frey, S. Differential activation of the human orbital, mid-ventrolateral, and mid-dorsolateral prefrontal cortex during the processing of visual stimuli. *Proceedings of the National Academy of Sciences.* 2002;99(8):5649-5654.
606. Benedek M, Bergner, S., Könen, T., Fink, A., & Neubauer, A.C. EEG alpha synchronization is related to top-down processing in convergent and divergent thinking. *Neuropsychologia.* 2011;49(12):3505-3511.
607. Schacter DL, Wig, G.S., & Stevens, W.D. Reductions in cortical activity during priming. *Curr opin neurobiology.* 2007;17(2):171-176.
608. Henson R, Shallice, T., & Dolan, R. . Neuroimaging evidence for dissociable forms of repetition priming. *Science.* 2000;287(5456):1269-1272.
609. Wiggs C.L. MA. Properties and mechanisms of perceptual priming. *Curr Opin Neurobiology* 1998;8:227-233.
610. Barr N, Pennycook, G., Stolz, J.A., & Fugelsang, J.A. Reasoned connections: A dual-process perspective on creative thought. *Thinking & Reasoning.* 2015;21(1):61-75.

611. Evans JSB, & Stanovich, K.E. Dual-process theories of higher cognition: Advancing the debate. *Perspectives on psychological science.* 2013;8(3):223-241.
612. Hillman CH, Snook, E.M., & Jerome, G.J. Acute cardiovascular exercise and executive control function. *International Journal of Psychophysiology.* 2003;48(3):307-314.
613. Colzato LS, Szapora Ozturk, A., Pannekoek, J.N., & Hommel, B. The impact of physical exercise on convergent and divergent thinking. *Frontiers in human neuroscience.* 2013;7(824).
614. Frith E, & Loprinzi, P.D. Experimental effects of acute exercise and music listening on cognitive creativity. *Physiology & behavior.* 2018;191:21-28.
615. Roediger HL, III, & McDermott, K.B. Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition.* 1995;21:803-814.
616. Deese J. On the prediction of occurrence of particular verbal intrusions in immediate recall. *Journal of Experimental Psychology.* 1959;58:17-22.
617. Roediger HL, III, Watson, J.M., McDermott, K.B., & Gallo, D.A. Factors that determine false recall: a multiple regression analysis. *Psychonomic Bulletin and Review.* 2001;8:385-407.
618. Reyna VF, & Brainerd, C.J. Fuzzy-trace theory and false memory: New frontiers. *Journal of Experimental Child Psychology.* 1998;71(194-209).
619. Siddiqui A, & Loprinzi, P. Experimental investigation of the time course effects of acute exercise on false episodic memory. *Journal of clinical medicine.* 2018;7(7):157.

VITA

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RESEARCH EMPHASIS

My research focuses on the effects of health behavior on psychological parameters, primarily creativity-related cognitions.

EDUCATION

Bellarmine University: Louisville, KY

Date of Degree: May 9, 2015

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AWARDS

-Graduate Achievement Award in Health and Kinesiology (University of Mississippi, School of Applied Sciences, April 2018)

-H. Leon Garrett Health Promotion Award (University of Mississippi Health, Exercise Science and Recreation Management Department, April 2018)

-Spring 2019 Dissertation Fellowship Award (University of Mississippi)

TEACHING EXPERIENCE

-Cardiac Rehabilitation Graduate Assistant- Baptist Memorial Hospital Oxford, MS (Fall, 2016)

-Exercise Science Undergraduate Practicum/Internship Advisor (Spring, 2017, Fall 2018)

-ES 440: Behavioral Aspects of Exercise (Spring, 2018, Fall 2018)
-HP 203: CPR (Summer Intersession, 2017)
-HP 203: CPR (Summer 2, 2017)
-HP 203: CPR (Fall, 2017)
-EL 158: Aerobics (Fall, 2017)
-EL 129: Body Contouring and Conditioning (Spring, 2018)

RESEARCH MENTORSHIP

Name of Student	**Education**	**Project**
Ali Siddiqui	Undergraduate	Temporal Effects of Acute Exercise on Insight Creativity Performance
Dylan Delancey	Undergraduate	Long-Term Memory Effects of Acute Exercise During the Memory Consolidation Stage of Memory Formation
Pamela Ponce	Undergraduate	Effects of Acute Exercise on Stress-Induced Memory Function
Caitlin Rowan	Undergraduate	Physical Activity and Affective Responses to Static versus Dynamic Facebook Content
Anna Holt Shaw (current mentee)	Undergraduate	Embodied Creativity: Flex your Imagination
Lauren Frazier (current mentee)	Undergraduate	Embodied Creativity: Flex your Imagination
Simmy Vig (current mentee)	Undergraduate Honors Student	Embodied Creativity: Flex your Imagination Effects of Example Modalities on Generative Creativity (if funded)
Kasside Floyd (current mentee)	Undergraduate	Do Spatial Frames of Reference Impact Embodied Creativity?

RESEARCH GRANTS

ACSM research grant submission: “Biopsychosituational Responses to Exercise” January 2017 ($2700-not funded)

Graduate Student Council research grant submission: “Effects of Example Modalities on Generative Creativity” February 2019 ($1000-pending)

PUBLICATIONS

Book Chapters

1. **Frith, E.** & Loprinzi, P.D. (2018). Exercise, cognitive creativity, and dementia. In Martin & Preedy (Eds.), *The Neuroscience of Dementia: Diagnosis and Management*. Elsevier. St. Louis, Missouri.

Published Peer-Reviewed Journal Articles:

1. Loprinzi, P.D. & **Frith, E**. (2016). Physical activity, mortality and prostate disease. *Journal of Molecular Pathophysiology, 5,* 81-84.
2. Mahoney, S.E., Carnes, A.D., Wójcicki, T.R., **Frith, E**., & Ferry, K. (2016). Habitual Dietary Intake among Recreational Ultra-Marathon Runners: Role of Macronutrients on Performance. *Journal of Food and Nutrition Research*, *4*(4), 205-209.
3. Loprinzi, P.D. & **Frith, E**. (2017). Motor skills and free-living physical activity showed no association among preschoolers in 2012 U.S. National Youth Fitness Survey. *Perceptual and Motor Skills*, *124*, 321-328.
4. **Frith, E**., Addoh, O., Mann, J.R., Windham, B. Gwen, & Loprinzi, P.D. (2017). Individual and combined associations of cognitive and mobility limitations on mortality risk among older adults. *Mayo Clinic Proceedings, 92,* 1494-1501.
5. **Frith, E**. & Loprinzi, P.D. (2017). The protective effects of a novel fitness-fatness index on all-cause mortality among adults with cardiovascular disease. *Clinical Cardiology*, *40,* 469-473.
6. **Frith, E**. & Loprinzi, P.D. (2017). Physical activity and cognitive function among older adults with hypertension. *Journal of Hypertension*, *35,* 1271-1275.
7. **Frith, E**. & Loprinzi, P.D. (2017). Social support and cognitive function in older adults. *Best Practices in Mental Health,* 13(2), 41-49.
8. **Frith, E**. & Loprinzi, P.D. (2017). Predictive validity of a fitness fatness index in predicting cancer-specific mortality. *Journal of Behavioral Health*, *6,* 189-191.
9. **Frith, E**. & Loprinzi, P.D. (2017). Fitness fatness index and Alzheimer-specific mortality. *European Journal of Internal Medicine, 42,* 51-53.
10. Loprinzi, P.D. & **Frith, E**. (2017). Cardiometabolic healthy obesity paradigm and all-cause mortality risk. *European Journal of Internal Medicine, 43,* 42-45.
11. **Frith, E**. & Loprinzi, P.D. (2017). Free-living physical activity, executive function and chronic kidney disease. *Journal of Molecular Pathophysiology*, *6,* 42-45.
12. **Frith, E**. & Loprinzi, P.D. (2017). Exercise facilitates smoking cessation indirectly via intention to quit smoking: Prospective cohort study among a national sample of young smokers. *American Journal of Health Promotion*. doi: 10.1177/0890117117717372
13. **Frith, E**. & Loprinzi, P.D. (2017). Muscle strengthening activities and retinopathy. *Journal of Molecular Pathophysiology, 6, 38-41.*

14. **Frith, E**. & Loprinzi, P.D. (2017). The association between physical activity and
15. **Frith, E**. & Loprinzi, P.D. (2017). Food insecurity and cognitive function in older adults: Brief report. *Clinical Nutrition*, *46,* 2067-2077.
16. **Frith, E**. & Loprinzi, P.D. (2018). Retinopathy and mortality. *Diabetes Spectrum*, Diabetes Spectrum, *31*, 184-188.
17. Loprinzi, P.D., Edwards, M.K., & **Frith, E**. (2017). Potential avenues for exercise to activate episodic memory-related pathways: A narrative review. *European Journal of Neuroscience*, *46*, 2067-2077.
18. Loprinzi, P.D. & **Frith, E**. (2018). Accelerometer-assessed physical activity and school absenteeism due to illness or injury among children and adolescents: NHANES 2003-2006. *American Journal of Health Promotion*. *32*(3):571-577
19. **Frith, E**. & Loprinzi, P.D. (2017). The association between physical activity and cognitive function with considerations by social risk status. *Europe's Journal of Psychology*, *13*, 767-775.
20. **Frith, E**. & Loprinzi, P.D. (2017). Can Facebook reduce perceived anxiety among college students? A randomized controlled pilot exercise trial using the Transtheoretical Model of behavior change. *JMIR Mental Health, 4*(4): e50.
21. Loprinzi, P.D., **Frith, E**., Edwards, M.K., Sng, E., & Ashpole, N. (2017). The effects of exercise on memory function among young- to middle-age adults: Systematic review and recommendations for future research. *American Journal of Health Promotion*. doi: 10.1177/0890117117737409.
22. **Frith, E**., Sng, E., & Loprinzi, P.D. (2017). Randomized controlled trial evaluating the temporal effects of high-intensity exercise on learning, short-term and long-term memory, and prospective memory. *European Journal of Neuroscience, 46,* 2557-2564.
23. Sng, E., **Frith, E**., & Loprinzi, P.D. (2017). Temporal effects of acute walking exercise on learning and memory function. *American Journal of Health Promotion, 32, 1518-1525. doi: 10.1177/0890117117749476*
24. **Frith, E**. & Loprinzi, P.D. (2018). The association between bouted and non-bouted physical activity on retinopathy prevalence. *European Journal of Internal Medicine*, 47, 32-35.
25. **Frith, E**. & Loprinzi, P.D. (2018). Accelerometer-assessed light-intensity physical activity and mortality among those with mobility limitations. *Disability and Health Journal*. 11, 298-300.
26. Loprinzi, P.D., Sng, E., & **Frith, E**. (2018). "Memorcise": Implications for patient compliance and medication adherence. *The Physician and Sportsmedicine*, 46, 21-23.
27. Loprinzi, P.D., Edwards, M.K. & **Frith, E**. (2018). Review of the literature examining the association between physical activity and retinopathy. *The Physician and Sportsmedicine*, 46, 123-128.
28. **Frith, E**. & Loprinzi, P.D. (2018). Physical activity is associated with higher cognitive
29. **Frith, E.** & Loprinzi, P.D. (2018). Leukocyte telomere length and cognitive function in older adults. *Journal of Cognitive-Behavioral Psychotherapy and Research, 7(1), 14-18.*

30. Loprinzi, P.D. & **Frith, E**. (2018). The association between perceived physical activity and cognitive function in older adults. *Psychological Reports*. doi: 10.1177/0033294117750632
31. **Frith, E**., Shivappa, N., Mann, J.R., Hebert, J.R., Wirth, M., & Loprinzi, P.D. (2018). Dietary inflammatory index and memory function: Population-based national sample of elderly Americans. *British Journal of Nutrition*, 119, 552-558.
32. **Frith, E**. & Loprinzi, P.D. (2018). Fitness fatness index and residual-specific mortality. *Cardiopulmonary Physical Therapy Journal*, *29,* 106-109. doi:10.1097/CPT.0000000000000079
33. **Frith, E**. & Loprinzi, P.D. (2018). Experimental evaluation of exercise-related hedonic responses to preferred versus imposed media content. *Health Promotion Perspectives, 8,* 109-119.
34. Crush, E., **Frith, E**., & Loprinzi, P.D. (2018). Experimental effects of acute exercise duration and exercise recovery on mood state. *Journal of Affective Disorders*, *229,* 282-287.
35. Loprinzi, P.D., **Frith, E**., & Edwards, M.K. (2018). Resistance exercise and episodic memory function: A systematic review. *Clinical Physiology and Functional Imaging*, *38,* 923-929. doi: 10.1111/cpf.12507
36. Loprinzi, P.D. & **Frith, E**. (2018). Effects of sedentary behavior, physical activity, frequency of protein consumption, lower extremity strength and lean mass on all-cause mortality. *Journal of Lifestyle Medicine, 8, 8-15.*
37. Sng, E., **Frith, E**., & Loprinzi, P.D. (2018). Experimental effects of acute exercise on episodic memory acquisition: Decomposition of multi-trial gains and losses. *Physiology & Behavior, 186,* 82-84.
38. Loprinzi, P.D. & **Frith, E.** (2018). Obesity and episodic memory function. Journal of Physiological Sciences, *64*(4)*,* 321-331.
39. **Frith, E.**, & Loprinzi, P. D. (2018). Experimental effects of acute exercise and music listening on cognitive creativity. *Physiology & behavior*.
40. Loprinzi, P.D. & **Frith, E.** (2018). Memorcise in the context of Parkinson's disease. Journal of Cognitive Enhancement, *2*(2), 208-216.
41. Loprinzi, P.D. & **Frith, E.** (2018). A brief primer on the mediational role of BDNF in the exercise-memory link. *Clinical Physiology & Functional Imaging*.
42. Delancey, D., **Frith, E.,** Sng, E. & Loprinzi, P.D. (in press). Randomized controlled trial examining the long-term memory effects of acute exercise during the memory consolidation stage of memory formation. *Journal of Cognitive Enhancement*.
43. **Frith, E.** & Loprinzi, P.D. (in press). Physical activity and cognitive function among older adults with an elevated gamma gap. *Medical Principles and Practice*.
44. Loprinzi, P.D. & **Frith, E.** (in press). Protective and therapeutic effects of exercise on stress-induced memory impairment. *Journal of Physiological Sciences*.
45. **Frith, E.,** Shivappa, N., Mann, J.R., Hebert, J., Wirth, M. & Loprinzi, P.D. (in press). Letter to Editor in response to: Potential confounding in a study of dietary inflammatory index and cognitive function. *British Journal of Nutrition*.

46. Loprinzi, P.D. & **Frith, E.** (in press). Interhemispheric activation and memory function: Considerations and recommendations in the context of cardiovascular exercise research. *Psychological Reports.*
47. Loprinzi, P.D., **Frith, E.**, & Edwards, M.K. (2018). Exercise and emotional memory: A systematic review. *Journal of Cognitive Enhancement*. 48. **Frith, E.** & Loprinzi, P.D. (in press). The association between lower extremity muscular strength and cognitive function in a national sample of older adults. *Journal of Lifestyle Medicine.*
49. Loprinzi, P.D., Edwards, M.K., & **Frith, E.** (in press). Exercise and prospective memory. *Journal of Lifestyle Medicine.*
50. **Frith, E.,** Ramulu, P.Y., Ashar, B., & Loprinzi, P.D. (in press). Association of single and multiple medical conditions with work status among adults in the United States. *Journal of Lifestyle Medicine.*
51. Loprinzi, P.D. & **Frith, E.** (2018). The role of sex in memory function: Considerations and recommendations in the context of exercise. *Journal of Clinical Medicine, 7*(6). *132.*
52. Patterson, R., **Frith, E.** & Loprinzi, P.D. (2018). The experimental effects of acute walking on cognitive creativity performance. *Journal of Behavioral Health, 7,* 113-119.
53. Haynes IV, J.T., **Frith, E.,** Sng, E. & Loprinzi, P.D. (2018). The experimental effects of acute exercise on episodic memory function: Considerations for the timing of exercise. *Psychological Reports*.
54. **Frith, E.,** Sng, E., & Loprinzi, P.D. (2018). Randomized controlled trial considering varied exercises for reducing proactive memory interference. *Journal of Clinical Medicine. 7*(6), 147.
55. **Frith, E.** & Loprinzi, P.D. (2018). Physical activity and individual cognitive function parameters: Unique exercise-induced mechanisms. *Journal of Cognitive-Behavioral Psychotherapy and Research, 7,* 92-106.
56. **Frith, E.** & Loprinzi, P.D. (2018). Physical activity, muscle strengthening activities and systemic inflammation among retinopathy patients. *Diabetes Spectrum.*
57. Loprinzi, P.D., Ponce, P. & **Frith, E.** (in press). Hypothesized mechanisms through which acute exercise influences episodic memory. Physiology International.
58. Edwards, M.K., Wade, B., **Frith, E**., & Loprinzi, P.D. (in press). Mindfulness-based walking vs. seated meditation on anxiety, affect, fatigue and cognition. *Journal of Behavioral Health.*
59. Ikuta, T., **Frith, E**., Ponce, P. & Loprinzi, P.D. (in press). Association of physical activity on the functional connectivity of the hippocampal-orbitofrontal pathway. *Physician and Sportsmedicine*.
60. Wingate, S., Crawford, L., **Frith, E.** & Loprinzi, P.D. (2018). Experimental investigation of the effects of acute exercise on memory interference. Health Promotion Perspectives, *8,* 208-214.
61. Yanes, D., **Frith, E**., & Loprinzi, P.D. (in press). Memory-related encoding-specificity paradigm: experimental application to the exercise domain. Europe’s Journal of Psychology.

62. Ryu, S., **Frith, E.,** Pedisic, Z., Kang, M., & Loprinzi, P.D. (in press). Secular trends in the association between obesity and hypertension among adults in the United States, 1999-2014. European Journal of Internal Medicine.
63. **Frith, E.,** Miller, S., & Loprinzi, P.D. (in press). A review of experimental research on embodied creativity: Revisiting the mind-body connection. Journal of Creative Behavior.

RESEARCH POSTER SUBMISSIONS AND PRESENTATIONS

1. Mahoney, S. E., Carnes, A. J., **Frith, E.,** & Ferry, K. (2015). Southeast ACSM Abstract Submission (May 2015): "Associations Between Dietary Intake And 161-km Race Performance, Fatigue, And Muscle Soreness." (Accepted)
2. Mahoney, S. E., Carnes, A. J., **Frith, E.,** & Ferry, K. (2015). ACSM National Conference Abstract Submission: "Associations Between Dietary Intake And 161-km Race Performance, Fatigue, And Muscle Soreness." (Accepted)
3. Lane, M.T., Byrd, T., Bell, Z., **Frith. E.** Lane, L.M.C. (2016) Effects of a pre-workout supplement on peak power and power maintenance during lower and upper body testing. "Proceedings of the Thirteenth International Society of Sports Nutrition (ISSN) Conference and Expo." Journal of the International Society of Sports Nutrition 13.1 (2016): 33. Abstract Presentation.
4. Lane, M.T., **Frith. E.** (2016) Supplementation Practices Among Young Athletes. Department of Physical Health Education, College of Health Sciences, Eastern Kentucky University Graduate Scholar Day (March 2016) Abstract Presentation.
5. **Frith, E.,** Crush, E., & Loprinzi, P. (2014). Association of physical education frequency, duration, and school sports participation with U.S. adolescent physical activity, muscular fitness, and exercise-related beliefs. Bellarmine University Undergraduate Research Fair
6. **Frith, E.** and Loprinzi, P.D. (2018) ACSM National Conference Research Abstract Submission: "Experimental Investigation of Exercise-Related, Perceived Hedonic Responses to Preferred versus Imposed Media Content.
7. Ponce, P., **Frith, E.,** and Loprinzi, P.D. (2018) Southeast ACSM Abstract Submission: "Effects of Acute Exercise on Stress-Induced Memory Function." (Accepted)
8. **Frith, E.** and Loprinzi, P.D. (2018) Southeast ACSM Abstract Submission: "Experimental Investigation of Exercise-Related, Perceived Hedonic Responses to Preferred versus Imposed Media Content." (Accepted)
9. **Frith, E.,** Sng, E., Loprinzi, P.D. (2018) NASPSPA Conference Abstract Submission. "Examining the Impact of Acute Exercise on Prospective, Immediate and Delayed-Memory Performance."
10. **Frith, E.** TEDx University of Mississippi Speaking Presentation. February 3, 2018. "Exercise for Creativity."
11. **Frith, E.** and Loprinzi, P.D. (2018) National ACSM Abstract Submission: "Experimental Investigation of Exercise-Related, Perceived Hedonic Responses to Preferred versus Imposed Media Content." (Accepted)
12. Ponce, P., **Frith, E.,** and Loprinzi, P.D. (2018) National ACSM Abstract Submission: "Effects of Acute Exercise on Stress-Induced Memory Function." (Accepted)

13. Frith, E. Avila, B.N. and Miller, S.E (2019) SRCD Abstract Submission "An Evaluation of Age-Associated Trends in Divergent Thinking"

INVITED LECTURES AND PUBLIC SPEAKING

1. **Frith, E.**, Sng, E. "Exercise and Memory" (November 4, 2016) University of Mississippi HESRM Graduate Seminar Presentation.
2. **Frith, E**., "Exercise and Memory" Guest Speaker- Lafayette High School April 2017
3. **Frith, E**., "Exercises the Mind: Creative Thinking and Health Promotion" Seminar Guest Speaker: Department of Nutrition and Hospitality Management: November 6, 2017
4. **Frith, E**., "How to Define Cognitive Creativity" Guest Lecturer ES 440: Behavioral Aspects of Exercise: October 11, 2017 and October 12, 2017
5. **Frith, E**., "Resiliency to Stress" Guest Lecturer Exercise Science 440: Behavioral Aspects of Exercise. February 15, 2017 and February 17, 2017
6. **Frith, E**., "Exercise, Music and Creativity" (November 28, 2017) University of Mississippi HESRM Graduate Seminar Presentation.
7. **Frith, E**., "Exercise and Creativity" (October 10, 2017) University of Mississippi HESRM Graduate Seminar Presentation.
8. **Frith, E**., "Hedonic Responses to Self-Selected Versus Researcher-Imposed Media" (March 2017) University of Mississippi HESRM Graduate Seminar Presentation.
9. **Frith, E**., "Embodied Creativity" (November 2018) University of Mississippi HESRM Graduate Seminar Presentation.

ACHIEVEMENTS

Acceptance into the University of Mississippi's Experimental Psychology Doctoral Program (May 2018)
Graduate Achievement Award in Health and Kinesiology (University of Mississippi, School of Applied Sciences, April 2018)
2018 H. Leon Garrett Health Promotion Award (University of Mississippi Health, Exercise Science and Recreation Management Department, April 2018)
GLVC Cross Country Freshman of the Year (October 2011)
Bellarmine 5k Cross Country Record (October 2013)
Bellarmine 6k Cross Country Record (November 2014)
Bellarmine 5k Indoor Track Record (January 2014)
Bellarmine 3k Indoor Track Record (February 2014)
Bellarmine 5k Outdoor Track Record (May 2013)
Bellarmine 10k Outdoor Track Record (May 2012)
National Catholic Cross Country Invitational Champion (September 2013, 2014)
GLVC Conference Runner-Up (October 2012)
GLVC Conference Champion (Runner of the Year-October 2013, November 2014)
GLVC Scholar-Athlete of the Year (Fall Season 2013)
GLVC Outdoor Track Athlete of the Year (Spring Season 2013)
GLVC Runner of the Week (2011-2015: ten weekly awards)

ECAC Runner of the Week (2014 season: three weekly awards)
Bellarmine Cross Country MVP (2013, 2014)
NCAA Division 2 Athlete of the Week (October (first week) 2013)
NCAA Division 2 Cross Country All-American (November 2012-31st, December 2014-4th)
NCAA All-Midwest Regional Athlete (2011-15th, 2012-11th, 2014-2nd)
NCAA Division 2 National Championship Competitor (2012-2015)
The Knights Way Children's Camp Counselor: Center for Courageous Kids Oncology Week (April 12-14, 2013)
Bluegrass 10,000m Champion (July 4th, 2013)
A Midsummer Night's Run Champion (August 8th, 2015)
Who's Who Among Students in American Universities & Colleges Recipient (2014-2015)
Knight of Honor Court Nominee (2014-2015)
Omicron Delta Kappa National Leadership Honors Society (2014-2015)
Athletes in Action service trip to the Canary Islands (June 1-17, 2015)
Bellarmine University's Exercise Science Department's Most Outstanding Junior (May 2014)
Bellarmine University's Exercise Science Department's Most Outstanding Senior (May 2015)
Bellarmine University's Silver Knight Award for Academic and Athletic Excellence (May 2015)
Graduated Summa Cum Laude (May 9th, 2015)
Graduated Summa Cum Laude (August 15th, 2016)

PROFESSIONAL MEMBERSHIPS AND CERTIFICATIONS
ACSM Student Member 2015-Present
NASPSPA Student Member 2016-Present