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DOES THE CONTRACTION HISTORY OF THE MUSCLE DICTATE CHANGES IN STRENGTH FOLLOWING RESISTANCE TRAINING?

A Dissertation
Presented in Partial Fulfillment of Requirements
For the Degree of Doctor of Philosophy
In the Department of Health, Exercise Science and Recreation Management
The University of Mississippi

by
Zachary Bell
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ABSTRACT

Within-subject training models, whereby researchers apply an exercise condition to one limb, and a separate exercise condition to the opposing limb, have become routine amongst the exercise literature. However, no study has directly tested whether exercising one limb with a high-load condition will influence strength adaptations within the opposing limb, even when the opposite limb is training. Furthermore, muscle post-activation performance enhancement (PAPE) is representing local level changes, however, more research is warranted to understand if this can be differentially impacted with different types (e.g. low load vs. high load) of resistance training. The purpose of this study was to determine if unilateral high-load training influences strength adaptations within the contralateral limb. A secondary purpose was to discern whether PAPE could be increased with resistance training. 116 participants were randomized to one of three intervention groups, and completed 18 training sessions involving isotonic elbow flexion exercise. Group 1 trained their dominant arm only, with a one-repetition maximum (1RM) test (maximum five attempts), followed by four sets of traditional exercise at an 8-12 RM. Group 2 completed the same training as Group 1 in their dominant arm, whilst the non-dominant arm completed four sets of low-load exercise (30-40 RM). Group 3 trained their non-dominant arm only, performing the same low-load exercise as Group 2. Participants were compared for changes in muscle thickness, isotonic elbow flexion 1RM, and postactivation performance enhancement (PAPE). Groups 1 (Δ 1.5 kg) and 2 (Δ1.1 kg) presented the greatest changes in non-dominant strength, as compared to Group 3 (Δ 0.3 kg). Only the arms being directly trained saw changes in muscle thickness, when compared to the untrained limbs. There were no differences amongst groups for changes in PAPE. Unilateral high-load training appears to influence strength changes in the contralateral arm, despite the contralateral arm training with a low-load exercise. Results of this study have broader implications for future research, and suggest that within-subject training models cannot be used when the primary outcome is strength changes.

ACKNOWLEDGEMENTS

“To all of my friends and family, without whom, none of this would have been possible.

I am eternally indebted to you all – thank you.”

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CHAPTER 1: INTRODUCTION

The American College of Sports Medicine (ACSM) recommends that healthy adults should engage in resistance exercise ≥2 days per week to confer health benefits along with reducing risks for morbidity and all-cause mortality (Westcott, 2009). With a suitable training regimen, exercising with a load corresponding to ≥70% of an individual's one-repetition maximum, the resultant muscle adaptations include increased muscle size and augmented strength (Hass et al., 2001). Despite this, regular engagement in exercise during the later years of life is dramatically reduced when it would be of the highest importance (Keadle et al., 2016). This inactivity precedes an eventual and progressive loss in muscle size, as well as function, which as been termed sarcopenia (Evans, 1995). Due to this sarcopenic response, frail individuals who have reduced strength and function are at a heightened risk for falls and injuries (Fukagawa et al., 1995). Such circumstances subsequently lead to hospitalization, and prolonged periods of immobilization that only further accelerates this reduction in muscle function, which has been referred to as the *catabolic crisis model* (English & Paddon-Jones, 2010). Thus, the correct application of resistance exercise, permitting an effective response among healthy and injurious populations, is necessary based on an ageing population and overall low adherence to exercise (Centers for Disease Control and Prevention (CDC), 2013a). Due to an overwhelming number of studies on this topic, there remains some incredulity surrounding the most suitably tailored exercise regimens that can result in an efficient increase for muscle strength and increased muscle size, thus allowing for greater functional capacity and independence.

As it relates to muscular adaptations, specifically following resistance training, a project completed by Moritani and deVries (1979) sought to build off previous work and attempted to clarify likely mechanisms leading towards augmentations in strength following resistance training (Moritani & deVries, 1979). This heavily cited intervention proclaimed that initial increases in strength can be attributed to neural enhancements, and after three to five weeks of continued training, any further increase will be driven by hypertrophy of muscle. In spite of this proclamation, in conjunction with a substantial number of studies frequently purporting that an increase in muscle size allots for a further increase in strength, these two responses to exercise, although occurring simultaneously, may be independent of one another (Loenneke, Dankel, Bell, Buckner, et al., 2019). For example, a study completed more recently by Dankel et al. (2017) found that when subjects exercised both limbs of the upper body with differing conditions, the arm exercising with a more traditional method (4 sets, ~70% 1RM) saw an increase in both muscle size and strength (Dankel et al., 2017a). However, the opposing limb that only completed strength tests saw increased strength without any significant changes in muscle size. This provides one example that would delineate between such muscle adaptations, and suggest that an increase in muscle size does not necessarily confer further augmentations in strength. As such, understanding how manipulations in resistance exercise will bring about specific adaptations would be of value when considering the applicability towards certain populations, and certainly offer greater transparency towards potential mechanisms for increased strength outside of increased muscle size.

The work completed by Dankel et al. (2017) involved a within-subject study design that had both limbs exercising, albeit with differing exercise loading patterns. In contrast, a common approach within other studies involves exercise that incorporates a unilateral design with comparisons being made towards the contralateral untrained limb, usually serving as an internal control. This would discern any adaptations that occur to be a result of the exercise intervention directly. However, a confounding aspect is the potential for a cross education of strength during resistance exercise. The earliest work to look at this phenomenon was by Scripture et al. (1894), who found that maximally squeezing a rubber bulb for a set of ten contractions, over eight sessions for a period of two weeks allowed for a more than 40% increase in strength into the non-training limb (Scripture et al., 1894). Subsequently, this topic has been heavily researched with a specific intent aimed towards rehabilitation amongst injured populations (Farthing & Zehr, 2014). In addition, another location that frequently discusses the cross education effect is the limitation section of published studies, when detailing the topic of muscular adaptations following resistance exercise. As such, there is the possibility of this physiologic neural spillover having an imposing effect on the opposing side of the body that may or may not also be engaging in some type of exercise.

Of note, the majority of studies that have demonstrated a cross education effect involve unilateral exercise on a single limb. Although repeatedly stated in the literature to be a limitation of within-subject designs (Mitchell et al. 2012a; Dankel et al. 2017), it has never been directly tested as to whether there is a cross education effect when the opposite limb is also trained. For example, the changes observed within unilateral training programs (Dankel et al., 2017a; Mitchell et al., 2012a) mirror that observed with designs that are not confounded by the possibility of a cross education effect (Morton et al., 2016; Schoenfeld et al., 2015). This suggests that the contraction history of the muscle may ultimately dictate any strength change during an exercise program, independent of the training completed by the opposite limb, and thus overriding any cross-education response that might occur. If true, this would be of immediate importance from a standpoint of exercise driven rehabilitation, as well as the study of skeletal muscle. However, as previously stated, to the best of the author's knowledge this idea has yet to be directly tested.

Purpose

The purpose of this study was to determine if the cross-education effect of strength is still present when both limbs are trained, or if the muscle primarily responds to its contraction history.

Research Questions

1. Does the contraction history of the muscle dictate strength adaptations and eliminate the cross education effect?
2. Is post-activation potentiation, a purported local level response, augmented with training?
3. Does post-activation potentiation differ based on the contraction history of the muscle?

Significance of Study

The utility of this work would be driven towards understanding the most effective training programs that can be implemented to maximize specific muscle adaptations, along with offering clarity towards study designs that incorporate a unilateral model. More specifically, if the cross education effect appears to be minimally impactful towards the contralateral side of the body, then this would eliminate an often-suggested confounder and would also likely lead to smaller sample sizes to answer skeletal muscle related research questions. Furthermore, this would specifically be beneficial amongst injurious and clinical populations who are seeking to accelerate recovery, either through increasing muscle strength and/or size during the rehabilitative process. However, if the contraction history of the muscle does impede the cross education effect from the opposing limb (injured or not), then this may provide rationale towards not using any load bearing exercise (i.e., the limb gains less strength by training with a very low load) if the intent is to maximize strength adaptations. Taken together, this study has important implications for both research design as well as clinical rehabilitation.

Assumptions

1. Participants answered questions pertaining to study inclusionary criteria truthfully.
2. Participants adhered to study restriction criteria for the duration of the exercise period.
3. Participants completed all measurements and training sessions with maximal effort.

Delimitations

1. Study results are reflective of adaptations amongst untrained individuals only.
2. Study results are applicable to individuals within the age range of 18-35 years only.
3. Study results are representative for upper body elbow flexion exercise only.

Limitations

1. Ultrasound was used for measurements of muscle size, despite MRI being the recognized gold-standard assessment of skeletal muscle. Although this is a limitation, we did not have

access to an MRI scanner, and ultrasound is a common measurement technique used for tracking changes in muscle size, and has been shown to track well with MRI (Franchi et al., 2018; Loenneke, Dankel, Bell, Spitz, et al., 2019).

2. The investigators were not blinded to the individual group assignments during strength testing. However, the investigators provided the exact same testing instructions to all individuals.
3. We only assessed the elbow flexors; however, we felt this to be the most appropriate muscle group to test in terms of limiting measurement error and random biological variability. We believe this to be true due to the elbow flexors being minimally involved in everyday life in comparison to other muscle groups, such as the muscles of the legs.

Operational Definitions

1. Muscle thickness – The distance between the muscle-fat interface and underlying bone will be measured via B-mode ultrasound.
2. One-repetition maximum (1RM) – the maximal load that could be lifted one time with proper form for the dumbbell unilateral elbow flexion exercise.
3. Isokinetic strength – The maximal amount of torque that could be produced against an object moving at a set speed.
4. Post-activation potentiation – a phenomenon by which the force exerted by a muscle is increased due to its previous contraction.

CHAPTER 2: LITERATURE REVIEW

Guidelines for increasing muscle strength and size

Engagement in exercise and general physical activity is encouraged around the globe by exercise science professionals, public health and medical experts throughout the lifespan, as a means for attenuating morbidity, risk of premature mortality, and the prevention and/or management of chronic diseases (Health & Services, 2008). Specific to resistance-training exercise, the current stance by the American College of Sports Medicine (ACSM) asserts that healthy adults should regularly engage in strengthening exercise at a moderate to vigorous intensity, involving all muscle groups, ≥2 per week (Westcott, 2009). In addition, it is recognized that favorable muscular adaptations (i.e., strength and muscle size), are augmented when performing resistance training at a load corresponding to ≥70% of an individual's one repetition maximum (1RM) (Westcott, 2009). Despite the known physical and mental health benefits associated with resistance training, recent data would indicate that only 30% of US adults are currently meeting the recommended ACSM strength guidelines (Centers for Disease Control and Prevention (CDC), 2013b). Furthermore, inactivity and a predominantly sedentary lifestyle leads to the progressive loss in muscle mass and function termed sarcopenia (English & Paddon-Jones, 2010), which also places a heightened risk on certain populations for falls and injuries (Landi et al., 2012). With prolonged hospitalization due to illness and injury, there is an even more exaggerated loss of muscle mass and function. Upon recovery and return to ambulation, such groups never completely return to baseline measures for muscle size and strength, prior to their hospital stay. This has been coined the catabolic crisis model (English & Paddon-Jones, 2010), and an obvious remedy for this issue is the periodic involvement with resistance training. Due to the recognized benefits of regular involvement with resistance training, clearer understanding for the most effective means of weight training, that will maximize muscle adaptations and promote exercise adherence, is warranted for both healthy as well as injurious populations across all age ranges.

Mechanisms behind changes in muscle size

Skeletal muscle plays equally important roles with both mobility and metabolism. More specifically, sufficient muscle mass is necessary for performing functional movements associated with activities of daily living, and the prolonged maintenance of baseline strength is associated with the prevention of premature all-cause mortality (Leong et al., 2015). In addition, skeletal muscle accounts for approximately 75% of insulin-stimulated glucose disposal, and thus plays an pivotal role in total body glycemic control (DeFronzo et al., 1985). Exercise, coupled with an adequate nutritional intake, results in an increase in muscle size, which is referred to as hypertrophy. This is the increase in muscle fiber size during postnatal development, and is typically found when muscle protein synthesis exceeds muscle protein breakdown. Such an increase is found following muscular contraction from resistance exercise. Here, it is understood that with a suitable resistance exercise regimen, there can be augmentations in skeletal muscle through a process known as mechanotransduction, which is the conversion of a mechanical signal (muscle contraction) to a chemical signal (translation initiation), also referenced as the signal transduction pathway within muscle (Toigo & Boutellier, 2006).

The key pathway at the core to this cascading effect is the mammalian target of rapamycin complex 1 (mTORC1) (Laplante & Sabatini, 2012; Saxton & Sabatini, 2017). This is a fundamental regulator for increased protein synthesis following muscle loading, as evidence provided for this pathway is shown through the administration of rapamycin, which is inhibitory towards mTORC1 and the subsequent accretion of muscle size (Bodine, 2006). This model dictates that activation of mTORC1 involves the specific recruitment of mTORC1 towards the lysosome, activating this kinase and followed subsequently with stimulation of protein translation. A more recent proposition instead suggests that a fundamental step with the interaction between mTORC1 and the lysosome is the translocation of this complex towards the sarcolemmal membrane (Hodson & Philp, 2019). This intracellular translocation, which places the mTORC1 complex in proximity to the membrane, is pivotal due to an abundance of upstream activators residing at this specific location. The translocation of the complex to the periphery is catalyzed through nutritional availability and resistance exercise. In effect, this would be indicative of more localized mechanisms that relate to muscle growth, as heightened protein synthesis and hypertrophy is represented by the contracting muscle. In addition, various loading patterns appear to be useful towards the signal transduction pathway, producing favorable muscular adaptations from resistance exercise. Hence, similar responses can be found at lower loads under conditions where exercise is completed to volitional fatigue. More specifically, exercising to failure permits much greater activation of surrounding fibers, even with low-load resistance exercise, offering comparable adaptations to more traditional loading patterns (Mitchell et al., 2012b; Ogasawara et al., 2013). Furthermore, previous work has considered the possibility for an exercise-induced elevation in systemic hormones to exaggerate this signaling cascade (West et al., 2010). However, there was no such difference found with an increase in circulating hormones towards an elevated hypertrophic response in skeletal muscle, and this would suggest that specific muscle adaptations are more localized to the muscle along with the demands placed upon it. This localized effect, as it relates to muscular adaptations, would be of importance among certain populations who are recovering from muscle site-specific injury and/or illnesses.

Mechanisms behind changes in muscle strength – trained limb

It is understood that there can be large changes in muscle strength following a resistance training program, specifically with those utilizing loads that are ≥70% of an individual's one repetition maximum (1RM). For the initial adaptations in strength, enhancements in neural drive mechanisms appear to be playing a distinct role towards developed strength from resistance exercise (Moritani & deVries, 1979). This specific enhancement in neural drive can be the result of an increase in central motor drive, elevated motor neuron excitability as well as reduced presynaptic inhibition (Per Aagaard et al., 2002). What has also been considered is the association with an increase in strength is the development of muscle hypertrophy, which some suggest to be additive towards strength gains following resistance training (Ikai & Fukunaga, 1970; Moritani & deVries, 1979). With these two variables, the narrative was put forward that the time course of strength adaptations can be accounted for primarily through neural mechanisms initially, and then followed subsequently by hypertrophy of muscle that results in further increases of strength (D. G. Sale, 1988). Despite this contention, increased muscle size and elevated strength, although occurring simultaneously are not necessarily synonymous, and correlations between the two adaptations remains unfounded (Buckner et al., 2016; Dankel et al., 2018; Loenneke, Dankel, Bell, Buckner, et al., 2019). Evidence for this has been presented from our laboratory showing that simply repeated performance of a one-repetition maximum test produces comparable increases in strength to traditional high load exercise (Mattocks et al., 2017). An additional study from our lab offers further delineation between muscle adaptations for increased strength and muscle hypertrophy, whereby participants exercised both limbs but with different training conditions (Dankel et al., 2017a). By design, both arms completed testing for a one-repetition maximum, but one arm also completed an additional three sets of elbow flexion at 70% 1RM. The arm with the greatest volume of work saw greater increases in muscle thickness but strength adaptations did not differ between limbs, suggesting that other mechanisms, outside of muscle growth are contributory towards increased strength in skeletal muscle. One example is the possibility of intrinsic properties that are specific to the muscle fibers. In a recent meta-analysis, there was a discussion towards increased specific fiber tension that might appear through shifts in fiber types, an increase in calcium sensitivity, and/or increased strength of myosin binding during cross bridge binding (Dankel et al., 2019). Once again, continued research on the topic of mechanisms involved with improved strength from resistance exercise is necessary for clarification as well as the justification towards suggested hypotheses.

Mechanisms behind changes in muscle strength – untrained limb

A more common design used for the determination of strength and muscle size adaptations are unilateral exercise regimes that allow for researchers to incorporate a within-subject design, and make comparisons to the contralateral untrained limb (serving as a control). What is often evident from such study designs is the increased strength found within the opposing untrained limb (Farthing et al., 2009; Lee & Carroll, 2007; Lepley & Palmieri-Smith, 2014; Magnus et al., 2013; Wilkinson et al., 2006).

With this, numerous terms such as cross transfer, inter-limb transfer, crossover effect, are often used to explain this physiological phenomenon (Cirer-Sastre et al., 2017). The initial terminology used when discussing this inter-limb transfer was by Walter W. Davis who referred to this increased strength in the non-trained limb as the cross education effect (Davis, 1899). Currently, the precise mechanisms that result in there being an increase in muscular strength of the contralateral limb, following unilateral exercise, are not known, however, a few plausible mechanisms driving an increase in force generating capacity within the untrained opposite limb have been presented. Firstly, this effect may be the result of a ‘neural spillover’, with the descending drive towards the contracting limb also inducing adaptations into the non-training limb (Carroll et al., 2006). A second possibility is neurophysiological adaptations located at cortical, subcortical or spinal levels, which occur from strength enhancements by the trained limb, and now accessible by the untrained limb. Similarly, a separate explanation would suggest that adaptations in the untrained limb could be explained through the bilateral access model that specifically indicates that the movement pattern executed in the trained arm can be reproduced within the untrained limb (Ruddy & Carson, 2013). Previous work on this idea suggests that changes in motor unit synchronization patterns and conduction of the homologous muscle in the non-trained limb can be similar to the trained limb (Carroll et al., 2006). If true, this would offer support to the concept of adaptations located at the peripheral level of the central nervous system. In addition, evidence has been presented to highlight the potential of a neural interaction between hemispheres of the brain (Farthing et al., 2011), which would relate to a cross activation mechanism at the sub-cortical level. More recently, emphasis has been directed towards the mirror neuron system that suggests that simply visualizing the exercise movement can be sufficient to induce strength and functional improvements within the untrained limb (Zult et al., 2014). Importantly, what appears clearer is that these neural adaptations are not independent of each other, and in most instances complimentary towards a cross education effect. In conjunction with this concept, any adaptations at the muscle level (vascular, fiber type, contractile protein composition, cross-sectional area) do not appear explain any such effect for improved strength, seemingly to occur only within the limb that is exercising (Houston et al., 1983; Moritani & deVries, 1979; Narici et al., 1989). However, the magnitude of contralateral strength improvements is typically small, and therefore physiological measurements need to be sensitive to identifying any (potential) changes as a result of a training intervention. Thus, changes in homologous muscles of the contralateral limb (hypertrophy, muscle enzymatic processes, contractile protein alterations) should not be disregarded, as these adaptations may in some instances be too small to be detected.

The 'how' of the cross education effect

The primary mechanisms that appear to be driving a cross education effect into the contralateral limb are neural mechanisms, with one such mechanism seemingly found within the cortical pathways (Farthing et al., 2011; Lee et al., 2010; Pearce et al., 2013). One of the earliest known studies to explore the cross education effect involved one participant squeezing a rubber bulb attached to a manometer with their left hand to assess grip strength (Scripture et al., 1894). During the following two weeks, the participant performed ten maximal contractions with their right hand, completing one set on each of the eight sessions. On the 13th day, it was found that strength had increased by 43% in the left hand. Despite having a number of limitations, this was a pioneering project that set in motion our understanding of the cross education effect, and paved the way for future researchers to consider the most suitable ways that amplify the cross education effect towards the contralateral untrained limb. The majority of work completed on the cross education effect considers the utility among injurious populations as means of therapy and rehabilitation (Hendy et al., 2012). If there can be improvements in the homologous muscles of the untrained limb when it is injured and unable to appropriately complete resistance training, this can be a valuable therapeutic technique to bolster the recovery process. However, despite there being considerably more research on this topic, there is large heterogeneity in the methods as well as training parameters (frequency, load, repetition scheme) to elicit these favorable adaptations. There appears to be a distinguishable cross education effect when engaging in unilateral exercise, but due to the differential approaches taken pertaining to study design, there is also large variability amongst the literature. For example, some researchers suggest that the magnitude of the cross education effect is dependent on limb dominancy (Farthing & Zehr, 2014). More specifically, it is the general view of several researchers specializing in the cross-education effect that the magnitude of a strength transfer is much larger when directly training the dominant limb, whilst the non-dominant limb remains untrained and receives a cross-education effect (Farthing et al., 2005). There are, however, some researchers who consider limb dominancy to not be a dictating factor for the magnitude of strength changes with the cross education effect (Coombs et al., 2016). From here it can be speculated that the manner in which training is being completed, as well as study design, which would offer the most compelling explanation for what (if any) role limb dominancy might play with the cross education effect.

Post-Activation Potentiation

Much like the cross education of strength, another physiological phenomenon is one that is referred to as post-activation potentiation. This is recognized as a muscle response through which the acute muscle force that can be produced is enhanced as a result of the contractile history of that specific muscle (Robbins, 2005). To be more detailed, this increased force output can be exploited through maximally contracting a limb for a very short duration (four to six seconds), pausing for a few minutes before completing another contraction, to which the muscle is now regarded as being *potentiated* and is now capable of producing an elevated force output over that if there had been no preceding maximal contraction (Digby G. Sale, 2002). This can be completed within isolated muscle fibers, whereby twitch force increases shortly following a high-intensity contraction of the same muscle (MacIntosh et al., 2008). This would instead be referred to as post-tetanic potentiation (Abbate et al., 2000). However, there has been greater emphasis placed on an *in vivo* model that involves a high-intensity voluntary conditioning contraction by the participant, and then a separate measurement of the subsequent contraction. More specifically, with a suitable conditioning contraction there can be an increase in muscle force, rate of force development or both, which is deemed to be a direct result of the post-activation potentiation or PAP. Evidence of this phenomenon is regarded as being more likely within more explosive type exercise and movements (Seitz & Haff, 2016). As an example, previous work completed within the lower body found that the completion of high-intensity squat exercise with resistance bands, prior to the performance of vertical jump movements, enhanced overall jumping performance (Mina et al., 2019). Thus, it appears that the loading contraction on the neuromuscular system conditions the muscle through excitement and through eliciting a more sensitive state to which there can be improvements in a particular movement or in performance (Guellich & Schmidtbleicher, 1996).

The suggested mechanisms involved with post-activation potentiation are considered to be the phosphorylation of myosin regulatory light chain. This has been purported to increase the number of attached cross bridges at a given Ca^{2+} concentration released from the sarcoplasmic reticulum within a muscle (Kamm & Stull, 2011). What appears to be key to facilitating this effect within the muscle is the manner in which the muscle is potentiated, and then the duration of time following this initial muscle contraction to where the muscle is able to recover and then a potentiated effect can be realized in an explosive movement. The conditioning stimulus is typically executed through a maximum isometric voluntary contraction (MVIC). In addition, it is reported that shorter duration contractions (MVIC ≤10 seconds) will result in a potentiated effect and that longer duration contractions (MVIC ≥60 seconds) will result in a combination of both muscle potentiation as well as muscle fatigue (Márquez et al., 2018). Therefore, it is necessary to consider both the duration of the conditioning contraction, along with the rest interval before realizing the effect of an enhanced contraction. Since muscle contractile activity produces both fatigue and a potentiating effect, the balance between these two determinants will enhance, reduce or bring about no change in the response of the muscle contraction (Vandenboom et al., 1993). If the following contraction is too soon, then fatigue appears to dominate over any potentiation effect. In contrast, if the rest interval is too long then the conditioning effect on the muscle is lost and any potentiated effect is dissipated, resulting in no enhanced contraction (Rassier & Macintosh, 2000).

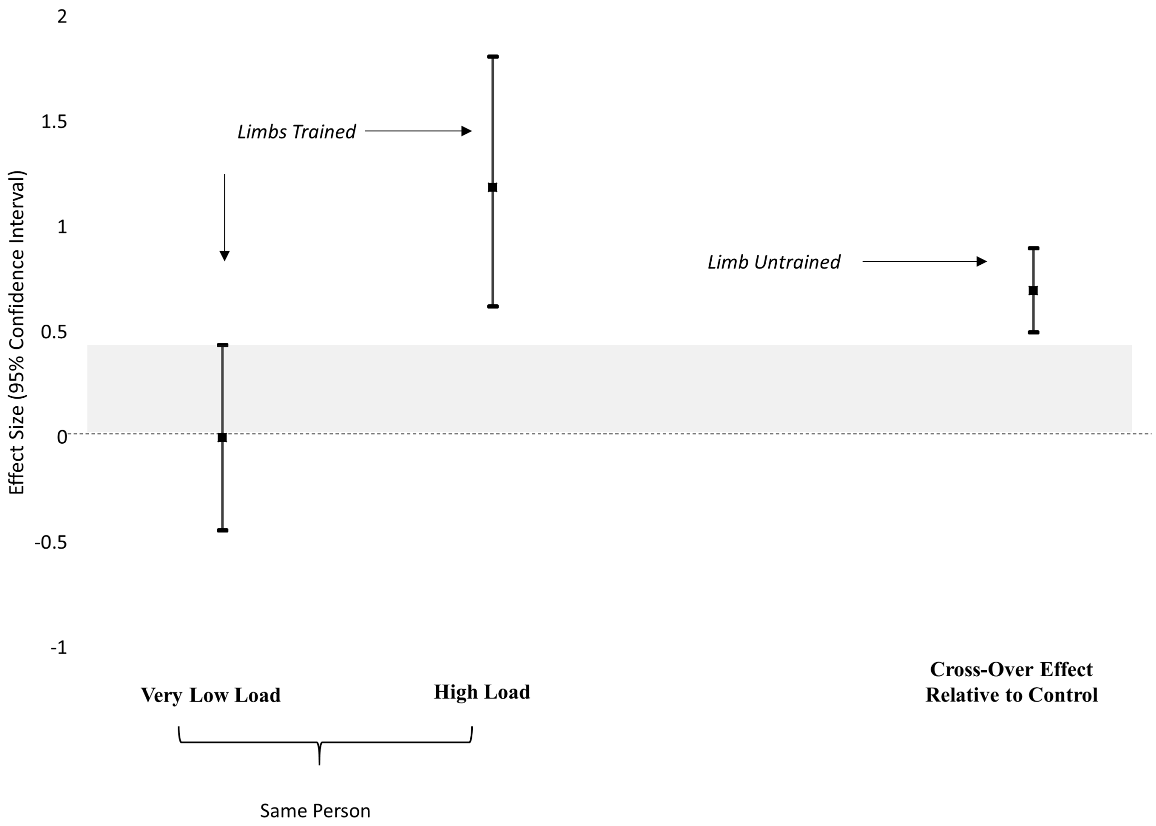
The majority of work completed deems the post-activation potentiation effect to be viewed as an acute response to exercise. In contrast, there is limited work directed towards a training response and the likely effects that are apparent following a regimented exercise program over a series of weeks or months. From the perspective of the contractile activity of the muscle, clarification on muscle properties that allow for a heightened force output would be useful towards understanding potential factors that are mediating strength enhancement following a resistance training intervention. Previous work on this topic would suggest that following a resistance training intervention, participants are able to exhibit a more pronounced post-activation potentiation effect (Miyamoto et al., 2013). Rationalization for this point are potentially explained by an accretion of larger percentage of type II muscle fibers (Maughan et al., 1983), and therefore greater phosphorylation of myosin light chain (P. Aagaard & Andersen, 1998). There is also the likelihood of trained individuals showing greater fatigue resistance at near maximal loads compared to their non-resistance trained counterparts (Chiu & Barnes, 2003). As such, future work might consider modulations in post-activation potentiation following a resistance-training program, to tease out the underpinnings for ameliorations in muscle strength as a more local response.

Study Design (Within vs. Between)

With any research involving human test subjects, the recruitment of a large, as well as heterogeneous sample size, which allows for the effective answering of a research question is of pivotal importance. More specifically, an adequate sample size is required for providing appropriate strength towards a project in order to have statistical power to answer the research question. With sample size estimation or calculation, a number of factors should be considered. Within experimental research, knowing the population standard deviation and setting an effect size (difference between the intervention and control groups) are typically required and often unique to each experimental study. Examples may include estimating the population standard deviation through the completion of pilot testing with a smaller sample of participants, based upon data from a previous experiment within the same laboratory, or through reviewing the literature and adopting a similar sample size. The power of the experiment is regarded as the probability that the effect will be detected and is often set arbitrarily at 0.8 or 0.9 (80 or 90% chance of finding statistical significance). With this, it can be noted that 1-power (sometimes referred to instead as β) is the chance of obtaining a false negative, where the researcher fails to reject an untrue null hypothesis (type I error). The probability of a positive finding being due to chance alone is denoted as α and usually set at 0.05. In other words, a *P*-value of 0.03 would be recognized as a statistically significant and is understood as being the probability of achieving a *t*-statistic of this value, or more extreme, with the sampled data given that the null hypothesis is true. Here, the researcher seeks the chance of mistakenly designating a difference (when there isn't a difference) to be no more than 5% (Fisher, 1956). Once the researcher has appropriately defined the effect size, the population standard deviation, power and significance level for the study, in addition to the statistical model to be employed for the data analysis, sample size can be computed. Due to the large increase in statistical software and programs available with the expansion of technology, there are numerous options for sample size estimation. Some of the more commonly used approaches include SPSS, G*Power, and ShinyApp (Lakens & Caldwell, 2021). Therefore, the effective calculation for a required sample size provides justification for not only being able to appropriately answer a specified research question but also for using only the necessary number of participants within a project that might be time sensitive and potentially placing undue stress on participants who are volunteering their time for the project. Additionally, although a larger sample size might allow for an increased chance for obtaining a more obvious difference between groups, this may also result in a greater financial burden on the primary investigator and the institution where the study is being conducted. Hence, this provides reasoning for sample size determination prior to the data collection portion of the study.

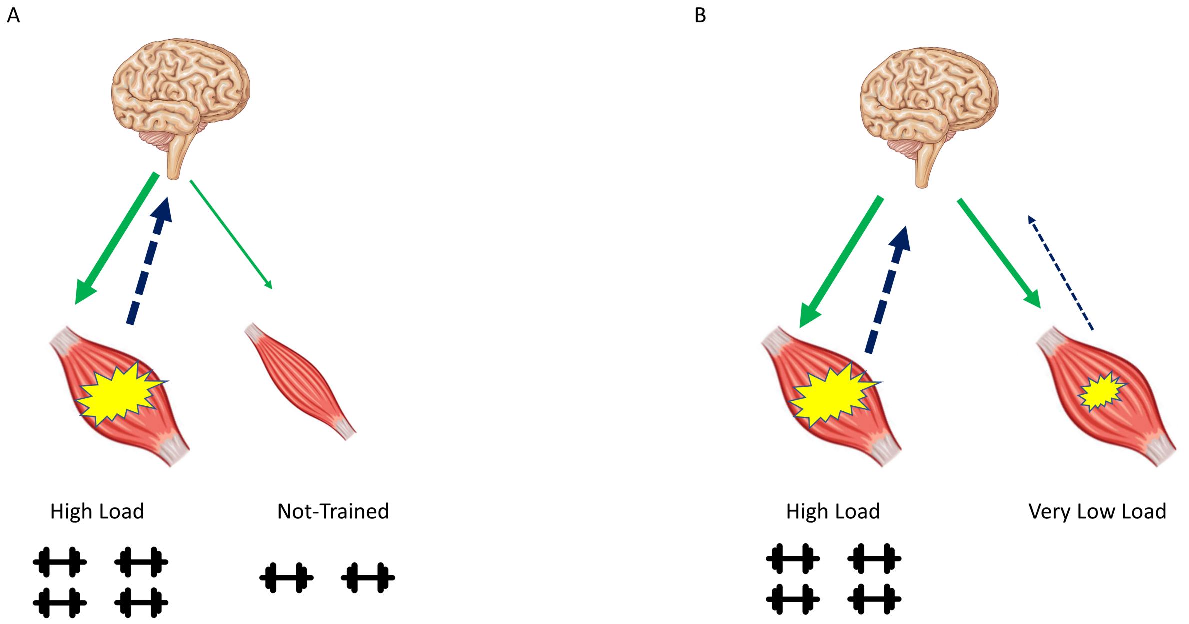
Relating to study design, the use of a unilateral exercise regimen allows for the within subject comparison to be made (exercising limb vs. control limb) and thus limits potential confounding biological variables that are more evident when utilizing a between subject approach. This would also be of use, as the project would not require the same quantity of participation to answer the same research question. More specifically, if training with a between group design, this would require 64 participants (total of 128) among each group (at a power of 0.8) in order to detect a moderate effect. In contrast, if executing the same research study but with the incorporation of a within subject design, then this would allow for the same comparison to be made with a total of only 34 participants with each limb completing a different training protocol. However, it is understood from the cross education literature that specific training in one limb can have an imposing effect towards the non-trained limb, as it relates to enhanced strength. This is certainly a limitation for the unilateral exercise model if the non-exercising limb is to be considered an internal control. However, there is the possibility of eliminating any cross education effect when both limbs are training, and as such, any adaptations produced are representative of the contraction history within that muscle and not the training from the contralateral limb. As an example, a previous study completed within the lower body involving eighteen male participants performing ten-weeks of unilateral knee extension exercise found that strength changes reflected the specific demands placed upon each limb (Mitchell et al., 2012b). Briefly, each participant had each leg randomized to one of three exercise conditions; 30% 1RM for three sets, 80% 1RM for one set and 80% 1RM for three sets, with each set of exercise completed to task failure. Post-intervention measurements were for muscle strength, as determined by 1RM, as well as whole muscle volume via MRI scan. Here, the researchers highlighted that despite all groups having similar increases for muscle volume, there were much larger increases in strength found for the high-load conditions (80% 1RM). In another example, Jessee and colleagues provide further insight to the concept of the muscle responding only to its contraction history (Jessee et al., 2018). For this study, each limb was randomized to one of a possible four exercising conditions. Three conditions involved exercise at 15% 1RM, with or without differing levels of blood flow restriction (moderate or high pressure) and fourth condition that involved a traditional high load resistance exercise. Following the eight-week intervention, only the condition that involved traditional high-load exercise saw an increase in strength, whereas the low-load conditions did not. Interestingly, the magnitude of the strength change found within a limb not undergoing any resistance exercise, and receiving a cross education effect from the contralateral limb that is engaging in a high load exercise condition, is much larger than what would be observed when compared to a limb training with a very low load (Figure 1). Once again, this implies that when both limbs are training that the resultant adaptations in strength are dependent upon the contraction history of that specific muscle. If the cross education effect is primarily neural, there is then the possibility of the afferent signals from the training limb inhibiting a cross education signal from the contralateral limb, even if the opposing arm is exercising with a much higher load (Figure 2). At this time, this is simply a theory and requires further investigation. If found to be true, this may provide support towards unilateral training models as a means for assessing any strength adaptations without the potential confounding effect from the opposing limb. As it relates to statistical power, this would also provide further rationale with the use of a within subject model that would require fewer participants, as opposed to a between subject that would require a larger sample size to detect a difference.

Figure 1. The Effects of Unilateral Exercise Programs



Following an 8-week training intervention (Jessee et al., 2018), individuals completing high-load exercise in one limb found a greater augmentation in strength measures within a limb that was not training, compared to a limb completing training with a very low load. The upper bound of the very low load limb (noted in grey) is less than that of the cross education effect (Carroll et al., 2006), indicating that this strength change in the untrained limb may exceed that of the limb training with a very low load.

Figure 2 Hypothetical figure depicting strength adaptations being reflective of muscle contraction history



When completing a high load exercise bout, there is afferent signaling driven towards the brain, followed by efferent signaling back towards the same exercising muscle with a potential neural spillover to the non-exercising limb, theorized to be influencing the cross education effect (Figure 2A). In contrast, when the opposing limb is completing a very low load exercise bout, the muscle response is dictated by the contraction history and local mechanisms are instead dictating any muscular adaptations and nullifying any cross education signal (Figure 2B).

CHAPTER 3: METHODS

Participants

A total of 128 participants were recruited for participation in this study. Inclusionary criteria were as follows: (1) must be between the ages of 18-35 years; (2) cannot have any orthopedic injuries preventing engaging with and performing elbow flexion exercise; (3) could not be regularly engaging in resistance exercise within the previous six months; and (4) could not be using tobacco products.

Study Design

Participants were allocated to one of a possible three training groups that included one pre-visit for completing baseline measurements, 18 training sessions (three times per week) for completing the group specific exercise, and one post-visit that was used to determine any changes in the dependent variables following the intervention period. The pre-visit consisted of determination of exclusionary criteria, general paperwork (study aims and purpose, PAR-Q, etc.), completion of anthropometric data (height and body mass), measuring muscle thickness on the anterior portion of the upper arm, measurements for maximal voluntary strength as determined by isokinetic dynamometry, and concluded with testing of one-repetition maximum (1RM) strength in both arms. The intervention period lasted six weeks. Arm dominancy was considered as the preferred arm for throwing a ball. For the training groups, Group 1 completed maximal strength testing [one repetition maximum (1RM)] in their dominant arm, and then completed an additional bout of exercise within the same limb, involving four sets of a traditional exercise loading pattern (8-12 repetitions). The non-dominant limb remained untrained for the entirety of the intervention period. Group 2 completed 1RM testing in their dominant arm, and then completed an additional bout of exercise within the same limb, involving four sets of a traditional exercise-loading pattern (8-12 repetitions). The non-dominant limb completed four sets of exercise at a low-loading pattern, aiming to complete between 30-40 repetitions. Group 3 performed exercise in their non-dominant arm only, whilst the dominant arm remained untrained for the entirety of the intervention period. The non-dominant arm completed four sets of exercise at a low-loading pattern, aiming to complete between 30-40 repetitions. Table 1 is provided for illustrative purposes for limb-specific training allocation during the intervention period. Procedures implemented during the pre-testing visit were replicated during the post-testing visit, commencing with muscle thickness measurements. Importantly, post-testing was no sooner than 48 hours following the completion of the final training session to account for any potential effects of the final training bout on post testing measurements and testing. Additionally, post-testing did not extend beyond five days following the final training session.

Table 1 Limb Specific Allocation for Training During 6-Week Intervention Period

Group	Dominant Limb	Non-Dominant Limb
1	High Load	*No Training*
2	High Load	Low Load
3	*No Training*	Low Load

Following randomization, participants were assigned to one of a possible three groups. Group 1 performed high-load exercise within their dominant limb and the non-dominant arm remained untrained for the same time period. Group 2 performed high-load exercise within their dominant limb and in addition completed low-load exercise within their non-dominant limb. Group 3 completed low-load exercise within their non-dominant limb, whilst the dominant limb remained untrained for the same duration of time.

Muscle Thickness

Ultrasound measurements (Logiq e, General Electric Fairfield, CT) of muscle thickness were made on the anterior portion of the participants' upper arms. The probe (Logiq e, L4-12t probe, General Electric, Fairfield, CT) was coated with a transmission gel and held lightly, in a transverse arrangement, against the participants' skin. Measurements were taken at 60% and 70% between the acromion process and lateral epicondyle of the arm. Two images were captured at each site, and were used for the subsequent analysis following the data collection portion of the study. Measurements for muscle thickness were completed following data collection. The same researcher (ZWB) performed all of the B-mode ultrasound measures on the participants, as well as the muscle thickness measurements on the device. Participants were coded at the onset of the study, and thus the researcher was blinded to specific group allocation when assessing muscle thickness measures with all images.

Post Activation Potentiation Protocol

Post-activation potentiation measurements were completed initially during the pre-visit, and once more following the intervention during the post-visit. Participants were seated on a dynamometer (Biodex Medical Systems, Shirley, New York, USA) with the seat and lever arm adjusted appropriately and tailored for each individual. Dynamometry settings were recorded to allow for standardization with all future testing. After weighing the arm to correct for gravity, participants performed three consecutive isokinetic maximal contractions at 210°/s. This was incorporated specifically as a warm prior to exercise testing, and then participants rested for a period of five minutes. After a five-minute rest interval, participants completed the same three consecutive isokinetic (210°/s) contractions, and recorded values were used for the baseline measurements. Following the completion of the third contraction, participants relaxed for another period of five minutes, after which they completed a maximal isometric contraction with the lever arm situation at 60°. This was a maximal contraction, lasting for a period of six seconds. Participants then relaxed for a period of three minutes, and then completed the same three consecutive isokinetic contractions that were completed five minutes prior to the six-second isometric contraction. The order of testing completed during the pre-visit was replicated for each participant during the post-visit.

One Repetition Maximum

Testing of one repetition maximum strength was completed initially during the pre-visit and once more following the intervention during the post-visit. Maximum concentric strength (the heaviest weight that can be lifted one time) of the participants' arms, using unilateral elbow flexion exercise, completed with free weights (dumbbells), was tested. The maximum weight lifted was used to set the workload for the exercise bouts. In addition, this was used to assess baseline strength measurements to post-intervention measurements for changes in strength. Participants completed the same protocol in both arms. The order of testing completed during the pre-visit was replicated for each participant during the post-visit. All 1RM attempts were separated by 90 seconds of rest, and performed such that the participants completed the elbow flexion movement with their heels, back and shoulders against the wall, as means to standardize and the maintenance of strict form during testing. All 1RMs were measured to the nearest 0.2 kg, and were typically obtained within six to eight attempts. In a randomized fashion, the 1RM measurements were obtained in one arm, before continuing to test 1RM strength within the contralateral opposing arm.

Training Protocol

Training sessions occurred three times per week, on non-consecutive days, and were separated by a minimum of 24 hours. For Groups 1 and 2, each session consisted of testing maximal elbow flexion strength in the dominant arm, coupled with a traditional loading pattern of four sets of 8-12 repetitions within the same dominant arm. Following this, only Group 2 completed exercise in the non-dominant arm, performing a low-load exercise pattern that involved four sets of between 30-40 repetitions. Group 3 completed exercise within the non-dominant arm only, with the dominant arm remaining untrained for the entire intervention period. The non-dominant arm performed a low-load exercise pattern that involved four sets of between 30-40 repetitions. There was a 90 second rest period between exercise sets. When performing maximal strength testing within the dominant limb, Groups 1 and 2 completed up to five attempts, commencing with a load corresponding to ~85% of the individuals' 1RM. The load was then progressively increased until the participants' either failed on one of the attempts, or they were successful with each of the five attempts. The goal was to try and match their previous 1RM on the fourth attempt, and then exceed this value with their fifth attempt. Each of the attempts was separated by 90 seconds of rest. The dominant arm was chosen to be trained in this manner, in order to observe a cross education effect, which has been proposed to occur to a much greater magnitude towards the non-dominant arm (Farthing, 2009)

Statistical Analysis

Changes in muscle strength, size, and post-activation potentiation (Post Test- Pre Test) of the non-dominant arm were determined using Bayes Factors for Informative Hypotheses (BAIN, version 0.2.1) in R Studio Version 1.2.1335. Specifically, the "ancov" function of BAIN was utilized with the pre value serving as a covariate. Specific hypotheses were evaluated by comparing Bayes Factors and the posterior probabilities between models. This R function utilizes a fraction of the information in the data to specify the variance of the prior distribution (Hoijtink et al., 2019). Hypotheses tested are found in Table 2.

Table 2 Description of the hypotheses (H) compared for each variable. H1 is hypothesis 1; H2: hypothesis 2; H3: hypothesis 3. Data that cannot be accounted for by any of the preset hypotheses is incorporated within the unconstrained model.

Variables		**Hypotheses Compared**
Muscle Strength (Non-Dominant)		
	H1	Group 1 > Group 2 = Group 3
	H2	Group 1 = Group 2 > Group 3
	H3	Group 1 = Group 2 = Group 3
Muscle Strength (Dominant)		
	H1	Group 1 = Group 2 > Group 3
	H2	Group 1 = Group 2 = Group 3
Post-Activation Potentiation (Non-Dominant)		
	H1	Group 1 = Group 2 = Group 3
	H2	Group 2 = Group 3 > Group 1
	H3	Group 1 > Group 2 = Group 3
Post-Activation Potentiation (Dominant)		
	H1	Group 1 = Group 2 = Group 3
	H2	Group 1 = Group 2 > Group 3
Muscle Thickness (Non-Dominant)		
	H1	Group 2 = Group 3 > Group 1
	H2	Group 1 = Group 2 = Group 3
Muscle Thickness (Dominant)		
	H1	Group 1 = Group 2 > Group 3
	H2	Group 1 = Group 2 = Group 3

CHAPTER 4: RESULTS

Demographics

128 individuals were recruited for this study, however, 12 participants were excluded for various reasons (e.g., three were excluded due to university closure as a result of the COVID-19 global pandemic, six were excluded due to personal reasons unrelated to the study, two were excluded as they later revealed they were engaging in resistance training, and one participant was unable to complete training due to contracting COVID-19), leaving a remaining sample of 116 (66 females, 50 males). The mean age of the participants was (*mean* ± *SD*) 21 ± 2 years, the mean height was 169.4 ± 8.4 centimeters, and the mean body mass was 72.6 ± 21.2 kilograms. Of this sample, 7 participants indicated they were left-hand dominant (5 females, 2 males), with 109 participants indicating they were right-hand dominant (61 females, 48 males). There were 40 participants randomized to Group 1, 39 participants randomized to Group 2, and 37 participants randomized to Group 3.

TABLE 3 Age, height, and body mass for Group 1, Group 2, and Group 3 (mean±SD)

	Age (*yrs.*)	Height (*cm.*)	Body Mass (*kg.*)
Group 1 (*n=40*)	21 (2)	168.6 (8.1)	74.2 (18.3)
Group 2 (*n=39*)	21 (3)	170.1 (7.7)	75.6 (23.0)
Group 3 (*n=37*)	22 (2)	169.6 (9.6)	67.9 (22.1)

Muscle Strength (Non-Dominant)

For the BAIN Analysis, the following three hypotheses were compared:

(H1): Group 1 > Group 2 = Group 3, i.e. “The change in muscle strength of the non-dominant arm is greatest in Group 1, with no differences in strength between Group 2 and Group 3”;

(H2): Group 1 = Group 2 > Group 3, i.e. “The change in muscle strength of the non-dominant arm is greatest in Group 1 and Group 2, when compared to Group 3, with no differences between Group 1 and Group 2”; and,

(H3): Group 1 = Group 2 = Group 3, i.e. “The change in muscle strength of the non-dominant arm is not different amongst Group 1, Group 2 and Group 3”.

The analysis demonstrated that of the hypotheses compared (Figure 3), the posterior probability favors the second hypothesis (H2), which indicates that changes in 1RM strength of the non-dominant were greatest in Group 1 (1.54, kg) and Group 2 (1.07, kg), when compared to Group 3 (0.36, kg), without differences between Groups 1 and 2 (Table 4). The posterior probabilities for each hypothesis (including the unconstrained model) are as follows: H1: 0.127; H2: 0.695; H3: 0.002; HU: 0.176. Changes in 1RM strength of the non-dominant arm are presented in Figure 4, and comparisons among hypotheses are shown in Table 5. Taken together, these findings indicate that unilateral high-load training does confer a cross-education effect. This was apparent even when the contralateral side, receiving the cross-education effect, is simultaneously completing low-load exercise (Group 2).

FIGURE 3 Pie chart showing probability distribution amongst hypotheses (including unconstrained model) for muscle strength of the non-dominant arm. (H1) The change in muscle strength of the non-dominant arm is greatest in Group 1, with no differences in strength between Group and Group 3; (H2) The change in muscle strength of the non-dominant arm is greatest in Group 1 and Group 2, when compared to Group 3, with no differences between Group 1 and Group 2; and, (H3) The change in muscle strength of the non-dominant arm is not different amongst Group 1, Group 2 and Group 3.

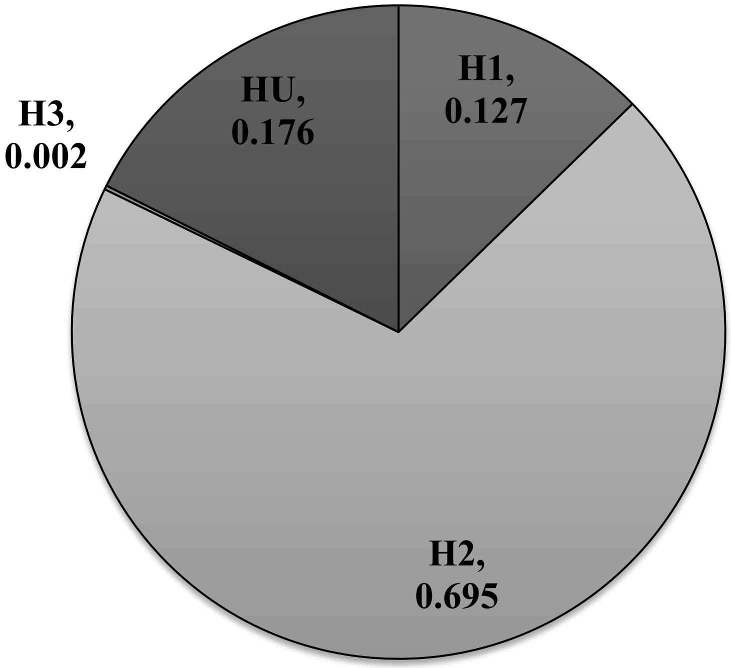


TABLE 4 Data presented in the table below represents mean values for 1RM strength of the non-dominant arm at Pre and Post. The difference (adjusted for baseline strength) is presented in the far-right column. N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

	Pre (*kg*)	Post (*kg*)	Difference (*kg* (*95% credible interval*))
Group 1 (No training)	11.71	13.23	1.54 (1.1, 1.9)
Group 2 (Low Load)	11.64	12.70	1.07 (0.6, 1.4)
Group 3 (Low-Load)	10.94	11.34	0.36 (-0.1, 0.76)

FIGURE 4 Data presented in the figure below represents the change in 1RM strength of the non-dominant arm (adjusted for baseline strength). N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

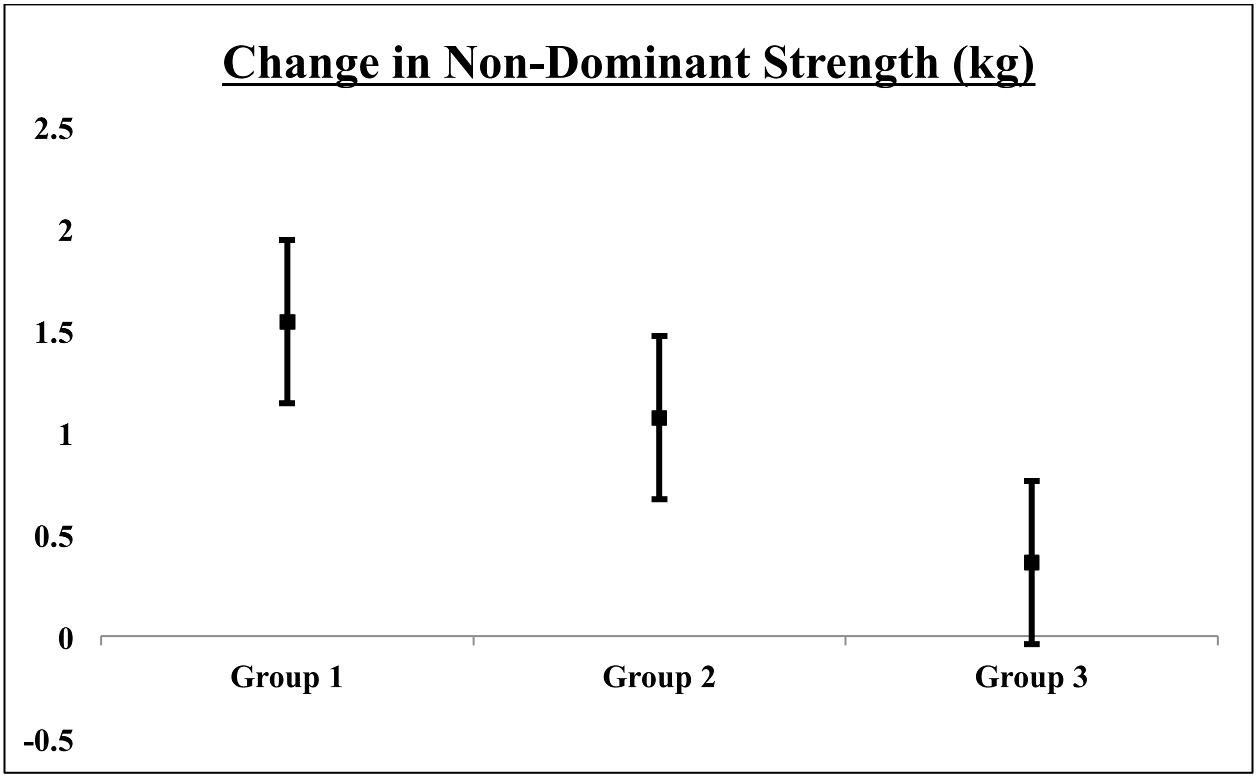


Table 5 Data presented below provides a Bayes Factor Matrix for comparing likelihood evidence amongst the three separate hypotheses (H1, H2 and H3). (H1) The change in muscle strength of the non-dominant arm is greatest in Group 1, with no differences in strength between Group 2 and Group 3; (H2) The change in muscle strength of the non-dominant arm is greatest in Group 1 and Group 2, when compared to Group 3, with no differences between Group 1 and Group 2; and, (H3) The change in muscle strength of the non-dominant arm is not different amongst Group 1, Group 2 and Group 3.

	H1	**H2**	**H3**
H1	1.000	0.183	61.357
H2	5.497	1.000	336.196
H3	0.016	0.003	1.000

Muscle Strength (Dominant)

For the BAIN Analysis, the following hypotheses were compared:

(H1): Group 1 = Group 2 > Group 3, i.e. The change in muscle strength of the dominant arm is greatest in Group 1 and Group 2, when compared with Group 3, with no differences between Group 1 and Group 2; and,

(H2): Group 1 = Group 2 = Group 3, i.e. "The change in muscle strength of the dominant arm is not different amongst Group 1, Group 2 and Group 3".

The analysis demonstrated that of the hypotheses compared (Figure 5), the posterior probability favors the first hypothesis (H1), which indicates that changes in 1RM strength of the dominant arm were greatest in Group 1 (2.24, kg) and Group 2 (2.22, kg), when compared to Group 3 (0.36, kg), without differences between Group 1 and Group 2 (Table 6). The posterior probabilities for each hypothesis (including the unconstrained model) are as follows: H1: 0.939; H2: 0.001; HU: 0.061. Changes in 1RM strength of the dominant arm are presented in Figure 6, and comparisons among hypotheses are shown in Table 7. Taken together, these findings indicate that high-load training does result in improved muscle strength

FIGURE 5 Pie chart showing probability distribution amongst hypotheses (including unconstrained model). (H1) The change in muscle strength of the dominant arm is greatest in Group 1 and Group 2, when compared with Group 3, with no differences between Group 1 and Group 2; and, (H2) The change in muscle strength of the dominant arm is not different amongst Group 1, Group 2 and Group 3.

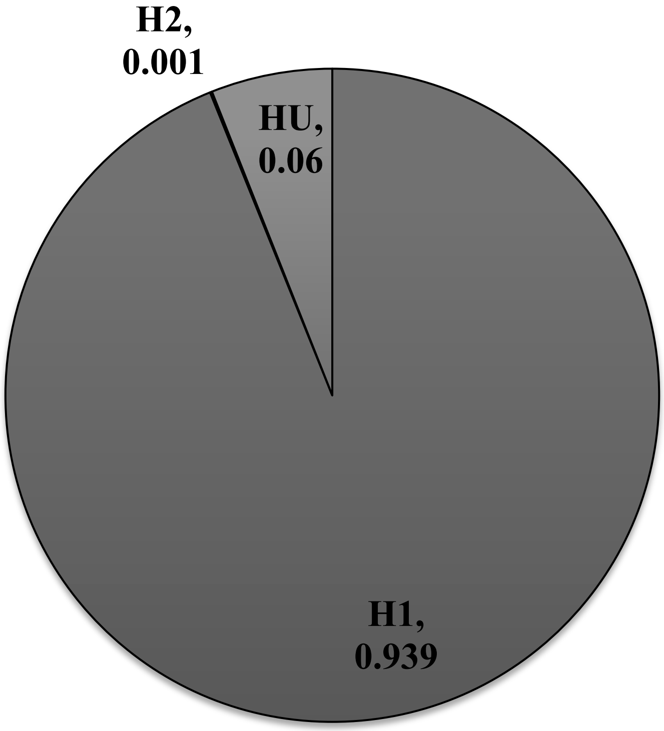


TABLE 6 Data presented in the table below represents mean values for 1RM strength of the dominant arm at Pre and Post. The difference (adjusted for baseline strength) is presented in the far-right column. N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

	Pre (*kg*)	Post (*kg*)	Difference (*kg* (*95% credible interval*))
Group 1 (High-Load)	13.08	15.30	2.24 (1.9, 2.6)
Group 2 (High-Load)	12.90	15.11	2.21 (1.9, 2.6)
Group 3 (No training)	12.00	12.41	0.36 (0.1, 0.7)

FIGURE 6 Data presented in the figure below represents the change in 1RM strength of the dominant arm (adjusted for baseline strength). N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

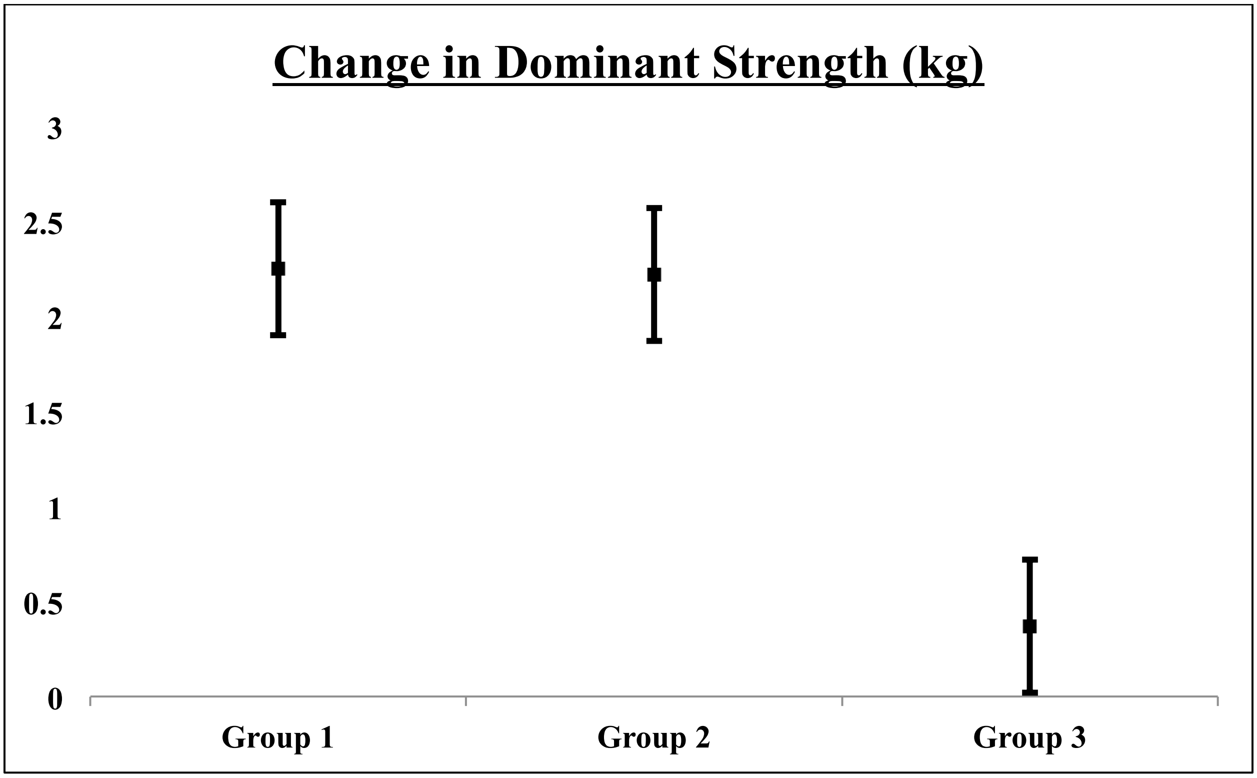


TABLE 7 Data presented below provides a Bayes Factor Matrix for comparing likelihood evidence between the two separate hypotheses (H1 and, H2). (H1) The change in muscle strength of the dominant arm is greatest in Group 1 and Group 2, when compared with Group 3, with no differences between Group 1 and Group 2; and, (H2) The change in muscle strength of the dominant arm is not different amongst Group 1, Group 2 and Group 3.

	H1	**H2**
H1	1.000	3.991e + 15
H2	2.506e – 16	1.000

Post-Activation Potentiation (Non-Dominant)

For the BAIN Analysis, the following three hypotheses were compared:

(H1): Group 1 = Group 2 = Group 3, i.e. “The change in post-activation potentiation of the non-dominant arm is not different amongst Group 1, Group 2, and Group 3”;

(H2): Group 2 = Group 3 > Group 1, i.e. “The change in post-activation potentiation of the non-dominant arm is greatest in Group 2 and Group 3, when compared to Group 1, with no differences between Group 2 and Group 3”; and,

(H3): Group 1 > Group 2 = Group 3, i.e. “The change in post-activation potentiation of the non-dominant arm is greatest in Group 1, when compared to Group 2 and Group 3, with no differences between Group 2 and Group 3”.

The analysis demonstrated that of the hypotheses compared (Figure 7), the posterior probability favors the first hypothesis (H1), which indicates that changes in post-activation potentiation of the non-dominant arm were not different amongst Group 1 (-0.19, Nm), Group 2 (0.47, Nm) and Group 3 (-0.06, Nm) (Table 8). The posterior probabilities for each hypothesis (including the unconstrained model) are as follows: H1: 0.699; H2: 0.222; H3: 0.050; HU: 0.029. Changes in post-activation potentiation of the non-dominant arm are presented in Figure 8, and comparisons among hypotheses are shown in Table 9. Taken together, these findings indicate that six-weeks of unilateral bicep curl training (low-load) does not alter PAP responses.

FIGURE 7 Pie chart showing probability distribution amongst hypotheses (including unconstrained model) for post-activation potentiation of the non-dominant arm. (H1) The change in post-activation within the non-dominant arm is not different amongst Group 1, Group 2, and Group 3; (H2) The change in post-activation potentiation of the non-dominant arm is greatest in Group 2 and Group 3, when compared to Group 1, with no differences between Group 2 and Group 3; and, (H3) The change in post activation potentiation is greatest in Group 1, when compared with Group 2 and Group 3, with no differences between Group 2 and Group 3

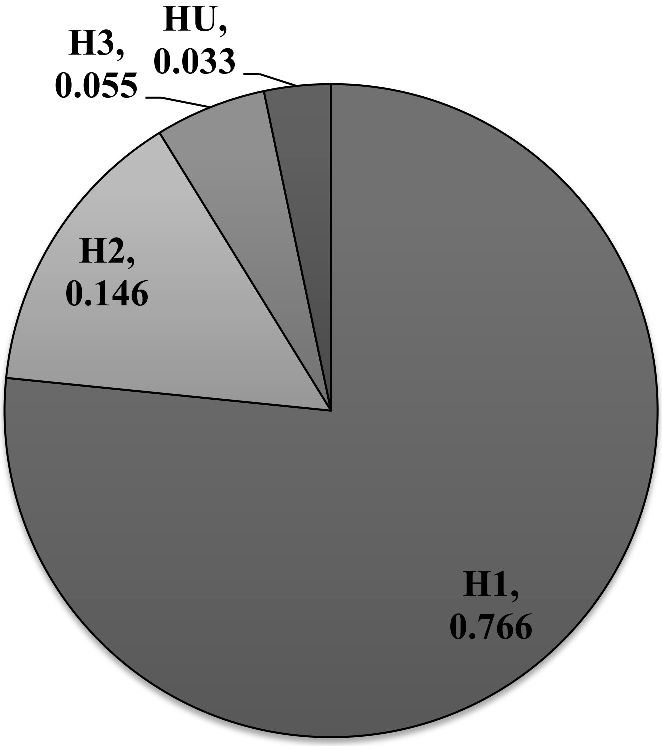


TABLE 8 Data presented in the table below represent mean values for post activation potentiation of the non-dominant arm at Pre and Post. The difference (adjusted for baseline force) is presented in the far-right column. N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

	Pre (*Nm*)	Post (*Nm*)	Difference (*Nm* (*95% credible interval*))
Group 1 (No training)	-0.47	-0.60	-0.19 (-0.91, 0.53)
Group 2 (Low-Load)	-0.30	0.09	0.47 (-0.26, 1.20)
Group 3 (Low-Load)	-0.42	-0.45	-0.06 (-0.80, 0.69)

FIGURE 8 Data presented in the figure below represents the change in post-activation potentiation of the non-dominant arm (adjusted for baseline force). N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

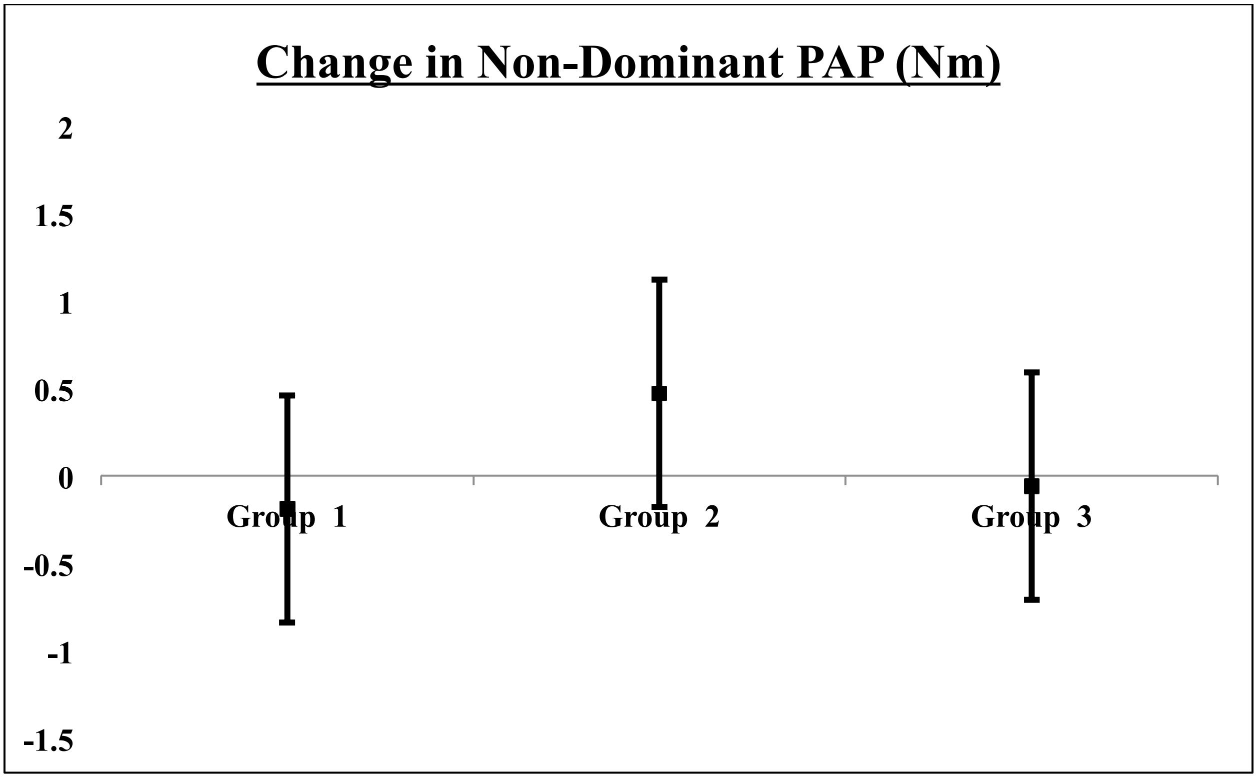


Table 9 Data presented below provides a Bayes Factor Matrix for comparing likelihood evidence amongst the three separate hypotheses (H1, H2 and H3). (H1) The change in post-activation potentiation of the non-dominant arm is not different amongst Group 1, Group 2 and Group 3; (H2) The change in post-activation potentiation of the non-dominant arm is greatest in Group 2 and Group 3, when compared to Group 1, with no differences between Group 2 and Group 3; and, (H3) The change in post-activation potentiation of the non-dominant arm is greatest in Group 1 when compared to Group 2 and Group 3, with no differences between Group 2 and Group 3.

	H1	**H2**	**H3**
H1	1.000	3.152	13.887
H2	0.317	1.000	4.406
H3	0.072	0.227	1.000

Post-Activation Potentiation (Dominant)

For the BAIN Analysis, the following hypotheses were compared:

(H1): Group 1 = Group 2 = Group 3, i.e. “The change in post-activation potentiation of the dominant arm is not different amongst Group 1, Group 2, and Group 3”; and,

(H2): Group 1 = Group 2 > Group 3, i.e. “The change in post-activation potentiation of the dominant arm is greatest in Group 1 and Group 2, when compared to Group 3, with no differences between Group 1 and Group 2”.

The analysis demonstrated that of the hypotheses compared (Figure 9), the posterior probability favors the first hypothesis (H1), which indicates that changes in post-activation potentiation of the dominant were not different between Group 1 (0.14, Nm), Group 2 (-0.72, Nm) and Group 3 (-0.46, Nm) (Table 10). The posterior probabilities for each hypothesis (including the unconstrained model) are as follows: H1: 0.811; H2: 0.145; HU: 0.044. Changes in post-activation potentiation of the dominant arm are presented in Figure 10, and comparisons among hypotheses are shown in Table 11. Taken together, these findings indicate that six-weeks of unilateral bicep curl training (high-load) does not alter PAP responses.

FIGURE 9 Pie chart showing probability distribution amongst hypotheses (including unconstrained model) for post-activation potentiation of the dominant arm. (H1) The change in post-activation within the dominant arm is not different amongst Group 1, Group 2, and Group 3; and, (H2) The change in post-activation potentiation of the dominant arm is greatest in Group 1 and Group 2, when compared to Group 3, with no differences between Group 1 and Group 2

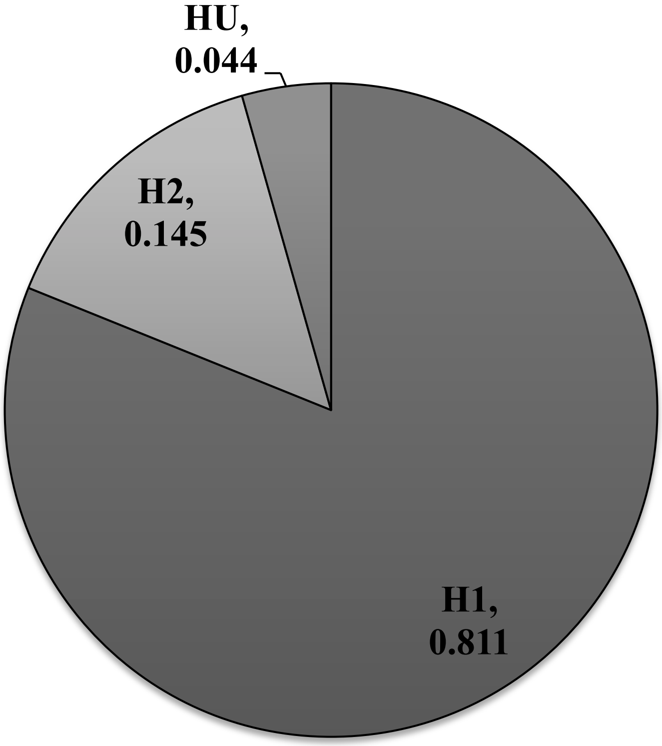


TABLE 10 Data presented in the table below represent mean values for post-activation potentiation of the dominant arm at Pre and Post. The difference (adjusted for baseline force) is presented in the far-right column. N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

	Pre (*Nm*)	Post (*Nm*)	Difference (*Nm* (*95% credible interval*))
Group 1 (High-Load)	0.23	0.71	0.14 (-0.66, 0.95)
Group 2 (High-Load)	0.98	-0.09	-0.72 (-1.53, 0.09)
Group 3 (No training)	0.59	0.14	-0.46 (-1.29, 0.37)

FIGURE 10 Data presented in the figure below represents the change in post-activation potentiation of the dominant arm (adjusted for baseline force). N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

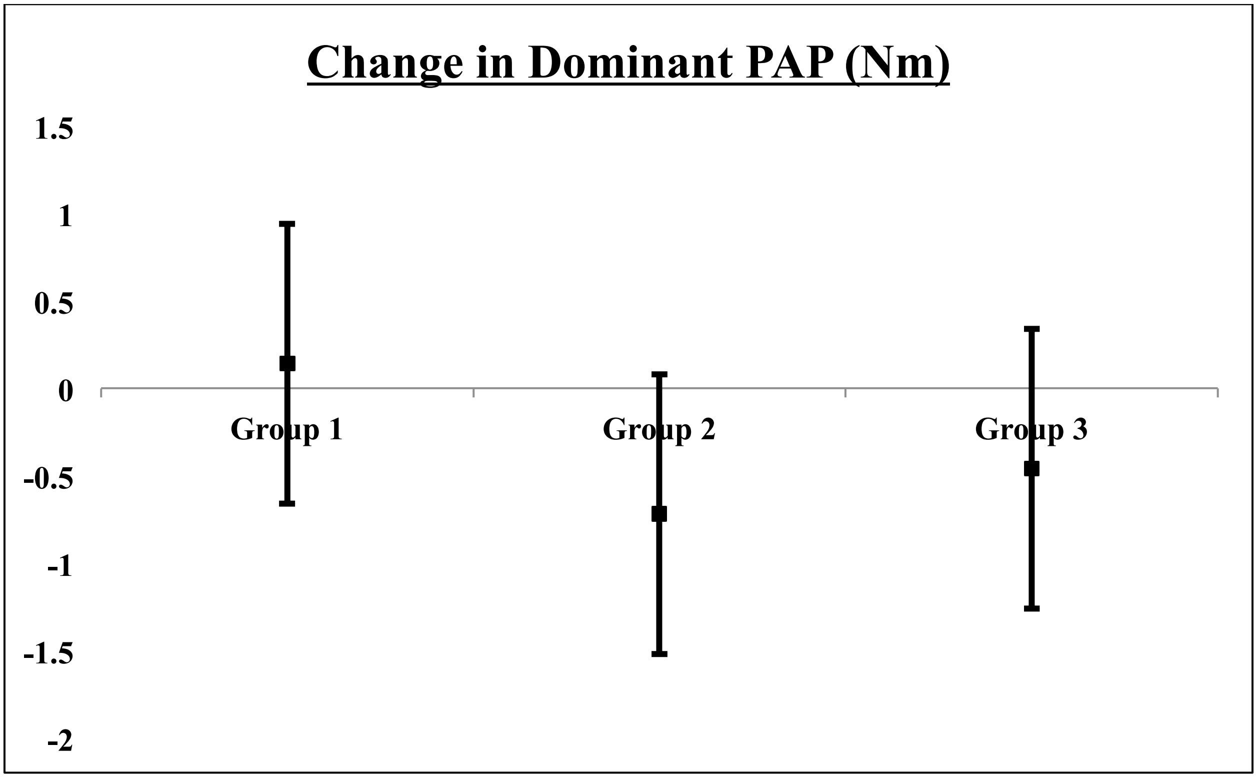


Table 11 Data presented below provides a Bayes Factor Matrix for comparing likelihood evidence between the two hypotheses (H1 and H2). (H1) The change in post-activation potentiation of the dominant arm is not different amongst Group 1, Group 2 and Group 3; (H2) The change in post-activation potentiation of the dominant arm is greatest in Group 1 and Group 2, when compared to Group 3, with no differences between Group 1 and Group 2

	H1	**H2**
H1	1.000	5.609
H2	0.178	1.000

Muscle Growth (Non-Dominant) 60% site

For the BAIN Analysis, the following hypotheses were compared:

(H1): Group 2 = Group 3 > Group 1, i.e. “The change in muscle thickness at the 60% site of the non-dominant arm is greatest in Group 2 and Group 3, when compared to Group 1, with no differences between Group 2 and Group 3”; and,

(H2): Group 1 = Group 2 = Group 3, i.e. “The change in muscle thickness at the 60% site of the non-dominant arm is not different amongst Group 1, Group 2 and Group 3”.

The analysis demonstrated that of the hypotheses compared (Figure 11), the posterior probability favors the first hypothesis (H1), which indicates that changes in muscle thickness at the 60% site of the non-dominant were greatest in Group 2 (0.13, cm) and Group 3 (0.11, cm), when compared to Group 1 (-0.08, cm), with no differences between Group 2 and Group 3 (Table 12). The posterior probabilities for each hypothesis (including the unconstrained model) are as follows: H1: 0.933; H2: 0.001; HU: 0.066. Changes in muscle thickness at the 60% site of the non-dominant arm are presented in Figure 12, and comparisons among hypotheses are shown in Table 13. Taken together, these findings indicate that low-load unilateral bicep curl training for six-weeks results in increased muscle thickness at the 60% site on the anterior portion of the biceps brachii.

FIGURE 11 Pie chart showing probability distribution amongst hypotheses (including unconstrained model) for muscle thickness at the 60% site of the non-dominant arm. (H1) The change in muscle thickness of the non-dominant arm is greatest in Group 2 and Group 3, when compared to Group 1, with no differences between Group 2 and Group 3; and, (H2) The change in muscle thickness at the 60% site of the non-dominant arm is not different amongst Group 1, Group 2, and Group 3

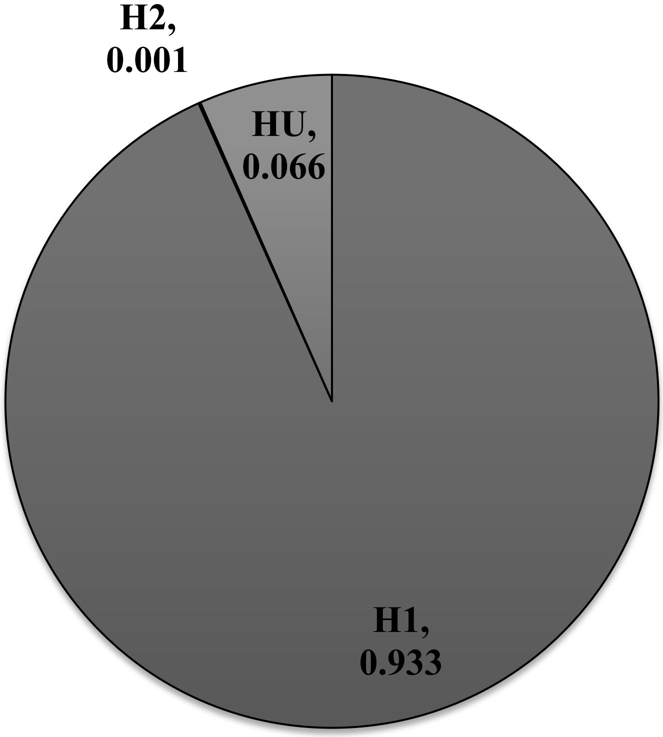


TABLE 12 Data presented in the table below represents mean values for muscle thickness at the 60% site of the non-dominant arm at Pre and Post. The difference (adjusted for baseline muscle thickness) is presented in the far-right column. N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

	Pre (*cm*)	Post (*cm*)	Difference (*cm* (*95% credible interval*))
Group 1 (No training)	3.36	3.27	-0.08 (-0.15, -0.01)
Group 2 (Low-Load)	3.31	3.44	0.13 (0.06, 0.20)
Group 3 (Low-Load)	3.25	3.37	0.11 (0.03, 0.18)

FIGURE 12 Data presented in the figure below represents the change in muscle thickness at the 60% site of the non-dominant arm (adjusted for baseline muscle thickness). N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

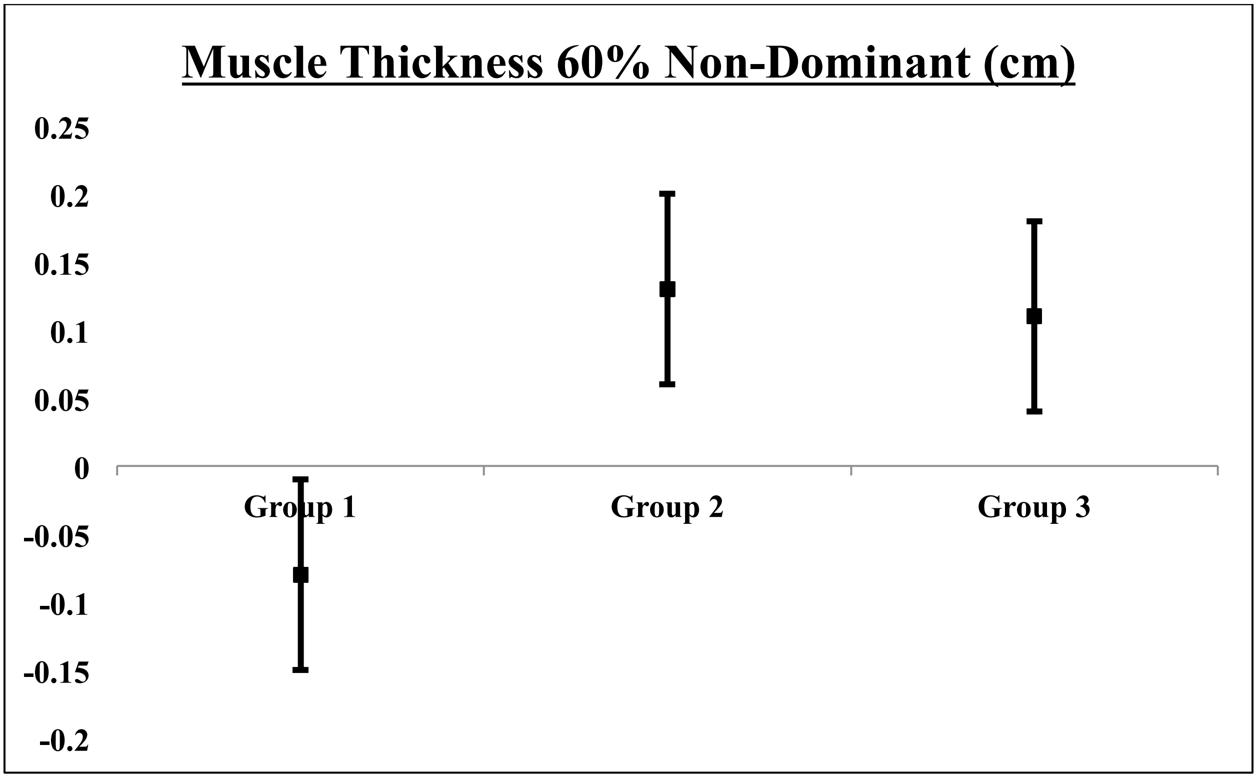


Table 13 Data presented below provides a Bayes Factor Matrix for comparing likelihood evidence between the two separate hypotheses (H1 and H2). (H1) The change in muscle thickness at the 60% site of the non-dominant arm is greatest in Group 2 and Group 3 when compared to Group 1; and, (H2) The change in muscle thickness at the 60% site of the non-dominant arm is not different amongst Group 1, Group 2, and Group 3.

	H1	**H2**
H1	1.000	5154.290
H2	1.940e -4	1.000

Muscle Growth (Non-Dominant) 70% site

For the BAIN Analysis, the following hypotheses were compared:

(H1): Group 2 = Group 3 > Group 1, i.e. "The change in muscle thickness at the 70% site of the non-dominant arm is greatest in Group 2 and Group 3, when compared to Group 1, with no differences between Group 2 and Group 3"; and,

(H2): Group 1 = Group 2 = Group 3, i.e. "The change in muscle thickness at the 70% site of the non-dominant arm is not different amongst Group 1, Group 2 and Group 3".

The analysis demonstrated that of the hypotheses compared (Figure 13), the posterior probability favors the first hypothesis (H1), which indicates that changes in muscle thickness at the 70% site of the non-dominant were greatest in Group 2 (0.29, cm) and Group 3 (0.27, cm), when compared to Group 1 (0.08, cm), with no differences between Group 2 and Group 3 (Table 14). The posterior probabilities for each hypothesis (including the unconstrained model) are as follows: H1: 0.935; H2: 0.001; HU: 0.064. Changes in muscle thickness at the 70% site of the non-dominant arm are presented in Figure 14, and comparisons among hypotheses are shown in Table 15. Taken together, these findings indicate that low-load unilateral bicep curl training for six-weeks results in increased muscle thickness at the 70% site on the anterior portion of the biceps brachii, when compared to an arm not performing any training.

FIGURE 13 Pie chart showing probability distribution amongst hypotheses (including unconstrained model) for muscle thickness at the 70% site of the non-dominant arm. (H1) The change in muscle thickness of the non-dominant arm is greatest in Group 2 and Group 3, when compared to Group 1, with no differences between Group 2 and Group 3; and, (H2) The change in muscle thickness at the 70% site of the non-dominant arm is not different amongst Group 1, Group 2, and Group 3

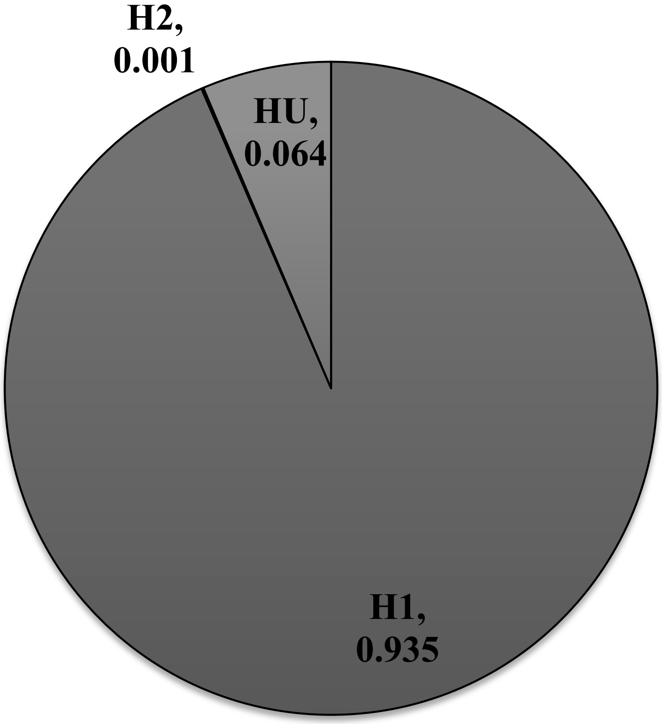


TABLE 14 Data presented in the table below represents mean values for muscle thickness at the 70% site of the non-dominant arm at Pre and Post. The difference (adjusted for baseline muscle thickness) is presented in the far-right column. N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

	Pre (*cm*)	Post (*cm*)	Difference (*cm* (*95% credible interval*))
Group 1 (No training)	3.49	3.57	0.08 (0.03, 0.14)
Group 2 (Low-Load)	3.48	3.76	0.29 (0.23, 0.34)
Group 3 (Low-Load)	3.39	3.66	0.27 (0.22, 0.33)

FIGURE 14 Data presented in the figure below represents the change in muscle thickness at the 70% site of the non-dominant arm (adjusted for baseline muscle thickness). N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

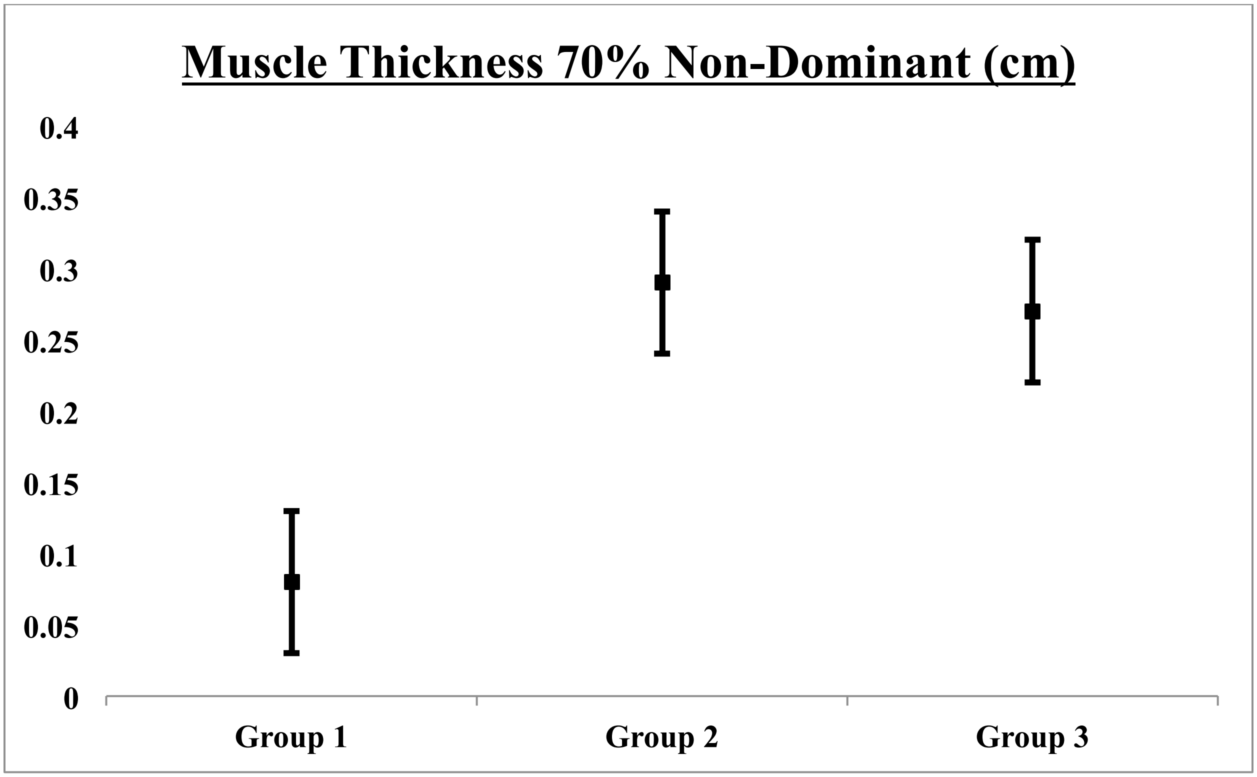


Table 15 Data presented below provides a Bayes Factor Matrix for comparing likelihood evidence between the two separate hypotheses (H1 and H2). (H1) The change in muscle thickness at the 70% site of the non-dominant arm is greatest in Group 2 and Group 3, when compared to Group 1, with no differences between Group 2 and Group 3; and, (H2) The change in muscle thickness at the 70% site of the non-dominant arm is not different amongst Group 1, Group 2, and Group 3.

	H1	H2
H1	1.000	3.295e +6
H2	3.035e -7	1.000

Muscle Growth (Dominant) 60% site

For the BAIN Analysis, the following hypotheses were compared:

(H1): Group 1 = Group 2 > Group 3, i.e. “The change in muscle thickness at the 60% site of the dominant arm is greatest in Group 1 and Group 2, when compared to Group 3, with no differences between Group 1 and Group 2”; and,

(H2): Group 1 = Group 2 = Group 3, i.e. “The change in muscle thickness at the 60% site of the dominant arm is not different amongst Group 1, Group 2 and Group 3”.

The analysis demonstrated that of the hypotheses compared (Figure 15), the posterior probability favors the first hypothesis (H1), which indicates that changes in muscle thickness at the 60% site of the dominant were greatest in Group 1 (0.26, cm) and Group 2 (0.29, cm), when compared to Group 3 (0.03, cm), with no differences between Group 1 and Group 2 (Table 16). The posterior probabilities for each hypothesis (including the unconstrained model) are as follows: H1: 0.924; H2: 0.001; HU: 0.075. Changes in muscle thickness at the 60% site of the dominant arm are presented in Figure 16, and comparisons among hypotheses are shown in Table 17. Taken together, these findings indicate that high-load unilateral bicep curl training for six-weeks results in increased muscle thickness at the 60% site on the anterior portion of the biceps brachii, when compared to an arm not performing any training.

FIGURE 15 Pie chart showing probability distribution amongst hypotheses (including unconstrained model) for muscle thickness at the 60% site of the dominant arm. (H1) The change in muscle thickness of the dominant arm is greatest in Group 1 and Group 2, when compared to Group 3, with no differences between Group 1 and Group 2; and, (H2) The change in muscle thickness at the 60% site of the dominant arm is not different amongst Group 1, Group 2, and Group 3

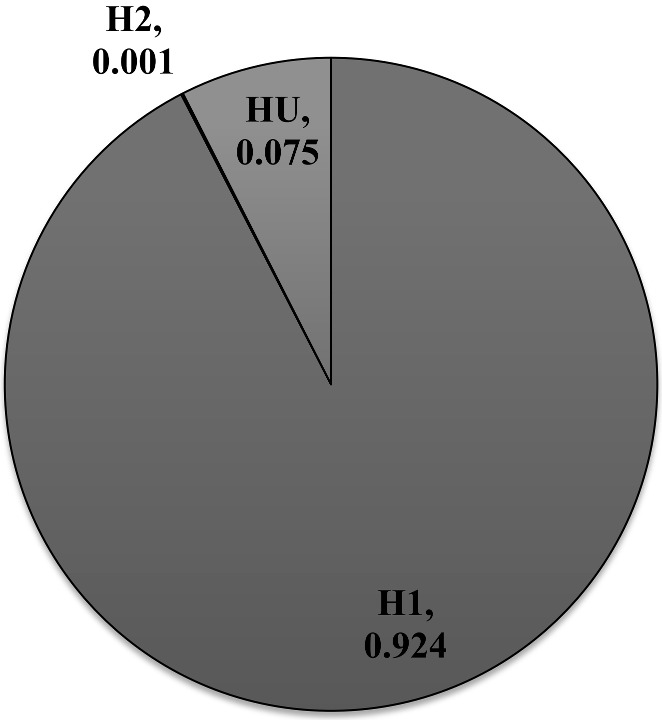


TABLE 16 Data presented in the table below represents mean values for muscle thickness at the 60% site of the dominant arm at Pre and Post. The difference (adjusted for baseline muscle thickness) is presented in the far-right column. N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

	Pre (*cm*)	Post (*cm*)	Difference (*cm* (*95% credible interval*))
Group 1 (High-Load)	3.37	3.62	0.26 (0.20, 0.32)
Group 2 (High-Load)	3.30	3.59	0.29 (0.23, 0.35)
Group 3 (No training)	3.25	3.29	0.03 (-0.03, 0.10)

FIGURE 16 Data presented in the figure below represents the change in muscle thickness at the 60% site of the dominant arm (adjusted for baseline muscle thickness). N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

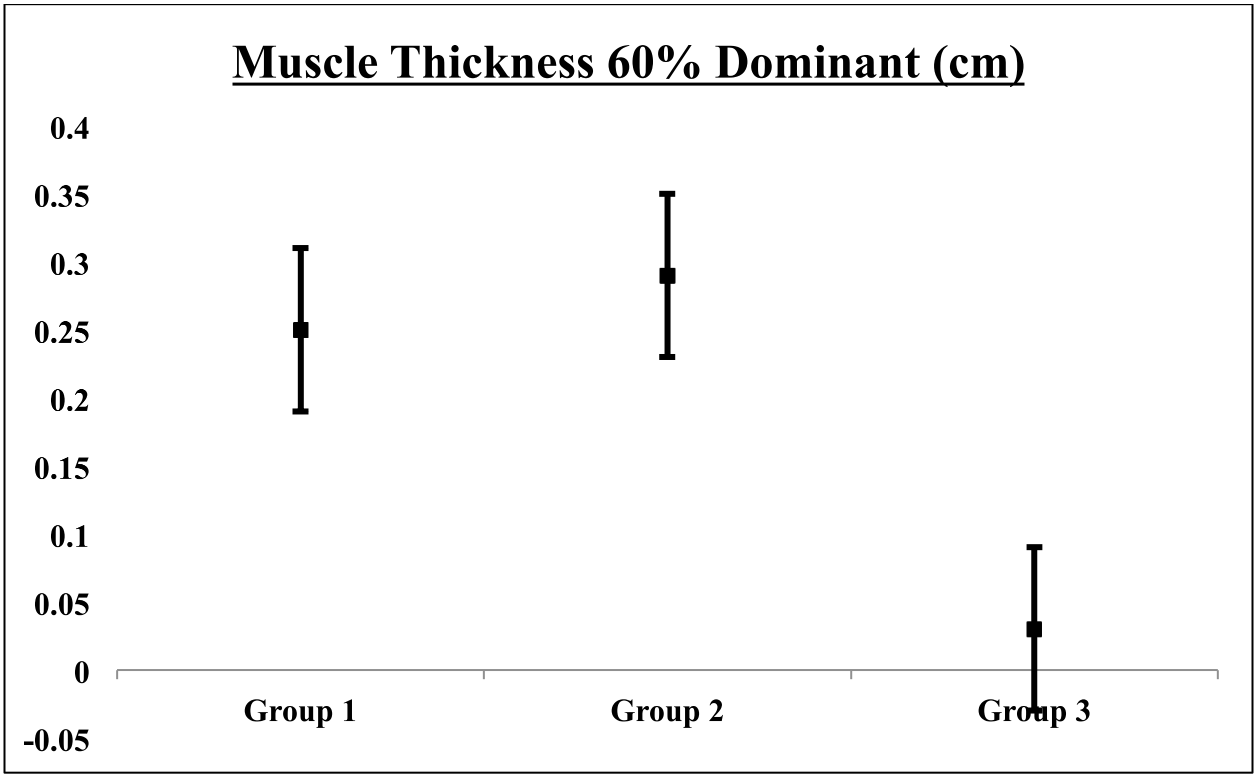


Table 17 Data presented below provides a Bayes Factor Matrix for comparing likelihood evidence between the two separate hypotheses (H1 and H2). (H1) The change in muscle thickness at the 60% site of the dominant arm is greatest in Group 1 and Group 2 when compared to Group 3; and, (H2) The change in muscle thickness at the 60% site of the dominant arm is not different amongst Group 1, Group 2, and Group 3

	H1	**H2**
H1	1.000	2.543e +7
H2	3.932e -8	1.000

Muscle Growth (Dominant) 70% site

For the BAIN Analysis, the following hypotheses were compared:

(H1): Group 1 = Group 2 > Group 3, i.e. "The change in muscle thickness at the 70% site of the dominant arm is greatest in Group 1 and Group 2, when compared to Group 3, with no differences between Group 1 and Group 2"; and,

(H2): Group 1 = Group 2 = Group 3, i.e. "The change in muscle thickness at the 70% site of the dominant arm is not different amongst Group 1, Group 2 and Group 3".

The analysis demonstrated that of the hypotheses compared (Figure 17), the posterior probability favors the first hypothesis (H1), which indicates that changes in muscle thickness at the 70% site of the non-dominant were greatest in Group 1 (0.25, cm) and Group 2 (0.26, cm) when compared to Group 3 (0.01, cm), with no differences between Group 1 and Group 2 (Table 18). The posterior probabilities for each hypothesis (including the unconstrained model) are as follows: H1: 0.935; H2: 0.001; HU: 0.064. Changes in muscle thickness at the 70% site of the dominant arm are presented in Figure 18, and comparisons among hypotheses are shown in Table 19. Taken together, these findings indicate that high-load unilateral bicep curl training for six-weeks results in increased muscle thickness at the 70% site on the anterior portion of the biceps brachii, when compared to an arm not performing any training.

FIGURE 17 Data presented in the figure below represents the change in muscle thickness at the 70% site of the dominant arm (adjusted for baseline muscle thickness). N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

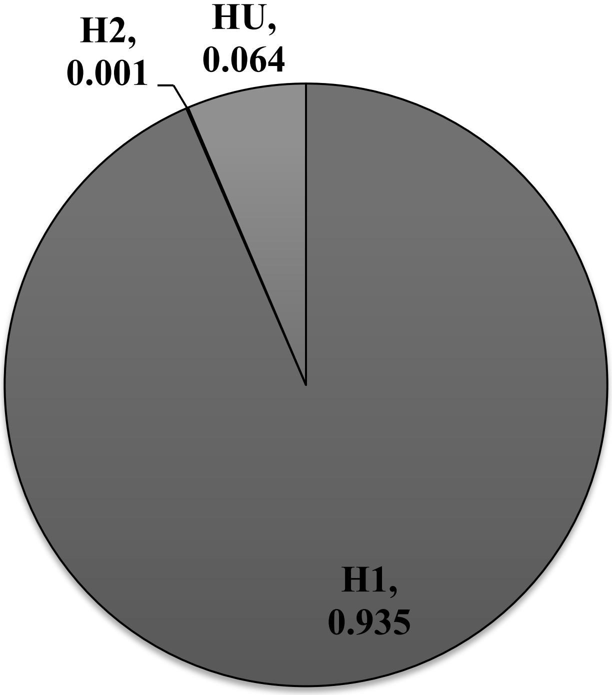


TABLE 18 Data presented in the table below represents mean values for muscle thickness at the 70% site of the dominant arm at Pre and Post. The difference (adjusted for baseline muscle thickness) is presented in the far-right column. N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

	Pre (*cm*)	Post (*cm*)	Difference (*cm* (*95% credible interval*))
Group 1 (High-Load)	3.67	3.92	0.25 (0.20, 0.30)
Group 2 (High-Load)	3.63	3.89	0.26 (0.21, 0.31)
Group 3 (No training)	3.55	3.56	0.01 (-0.04, 0.06)

FIGURE 18 Data presented in the figure below represents the change in muscle thickness at the 70% site of the dominant arm (adjusted for baseline muscle thickness). N=116 (Group 1, 40; Group 2, 39; Group 3, 37)

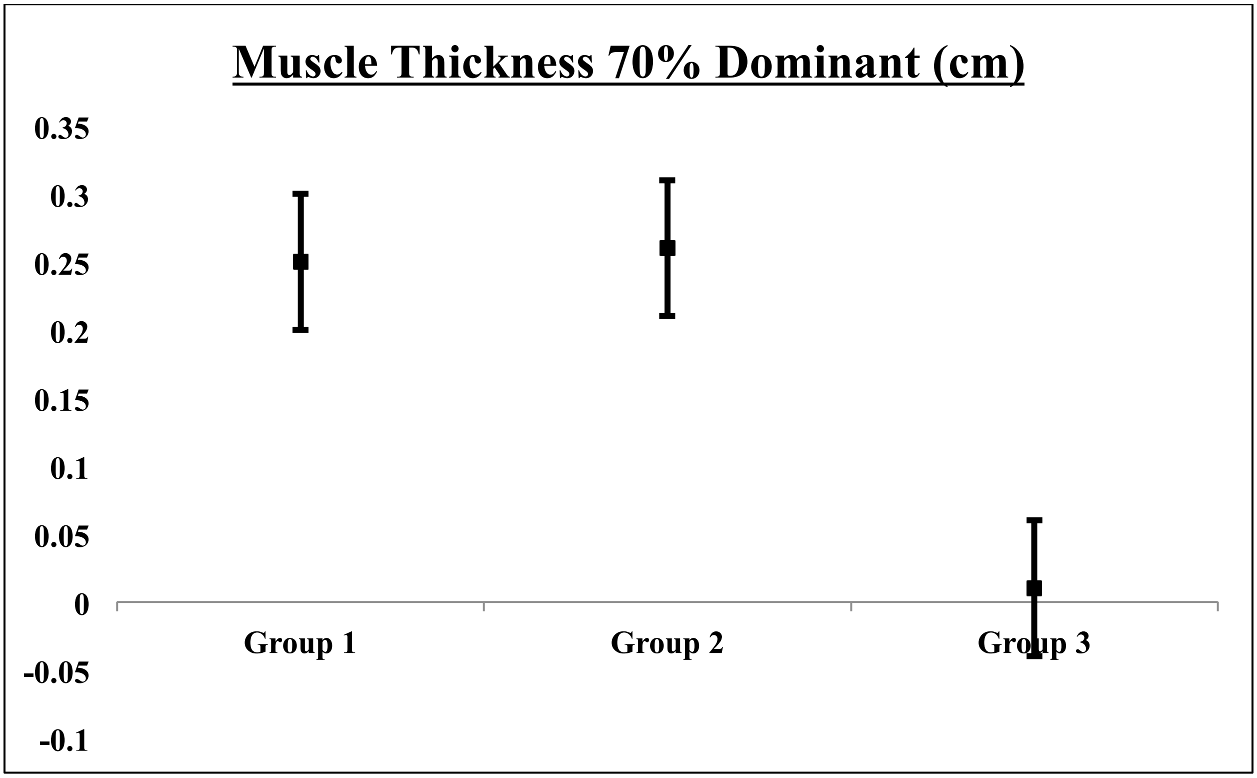


Table 19 Data presented below provides a Bayes Factor Matrix for comparing likelihood evidence between the two separate hypotheses (H1 and H2). (H1) The change in muscle thickness at the 70% site of the dominant arm is greatest in Group 1 and Group 2, when compared to Group 3; and, (H2) The change in muscle thickness at the 70% site of the dominant arm is not different amongst Group 1, Group 2, and Group 3

	H1	H2
H1	1.000	2.696e +13
H2	3.709e -14	1.000

CHAPTER 5: DISCUSSION

Main Findings

The main findings from the present study include: (1) strength changes of the non-dominant arm were greatest for Group 1 (high-load training in the dominant arm only) and Group 2 (high-load training in the dominant arm, low load training non-dominant), when compared to that of Group 3 (low-load training in the non-dominant arm only); (2) strength changes of the dominant arm were greatest for Group 1 (high-load training in the dominant arm only) and Group 2 (high-load training in the dominant arm, low load training non-dominant), when compared to that of Group 3 (low-load training in the non-dominant arm only); (3) There was no evidence of improved post-activation performance enhancement (PAPE) following the six-week training intervention for any of the groups; (4) changes in muscle thickness at both measured sites (60% and 70%) within the non-dominant arm were greatest for Group 2 (high-load training in the dominant arm, low load training non-dominant) and Group 3 (low-load training in the non-dominant arm only), when compared to that of Group 1 (high-load training in the dominant arm only); and, (5) changes in muscle thickness at both measured sites (60% and 70%) within the dominant arm were greatest for Group 1 (high-load training in the dominant arm only) and Group 2 (high-load training in the dominant arm, low load training non-dominant), when compared to Group 3 (low-load training in the non-dominant arm only). Simply stated, unlike strength, changes in muscle size were evident only within the arms that exercised, and did not appear to be influenced by exercise (specifically high-load) in the opposing side of the body.

Changes in Muscle Strength of the Non-Dominant Arm

Based upon a conceptual model that was conceived from previously published work (Bell et al., 2020), it was considered that high-load unilateral training in the dominant limb would result in a cross-education effect towards the contralateral, non-dominant untrained limb (Group 1). However, if the contralateral limb were to be engaging in a low-load training intervention simultaneously (Group 2), then there would be no evidence showing a cross-education effect. More specifically, it was thought that the muscle would be respondent to its own contraction history, and not influenced by a cross-education effect from the other side of the body that was engaging in high-load exercise. As such, despite our original hypothesis (changes in muscle strength of the non-dominant arm would be greatest for Group 1, when compared to Group 2 and Group 3), the greatest changes in strength of the non-dominant arm were found for both Group 1 and Group 2, over that of Group 3. More specifically, results of this study show that the potency of the cross-education effect was so great, that it dictated strength changes within the non-dominant arm, overriding the muscle contraction history. This is highlighted by Group 2, which presented an increase in muscle strength in the non-dominant arm following the six-week intervention, understood to be a result of the cross-education effect, and not the low-load training. This can be accounted by Group 3, who completed the same low-load intervention in the non-dominant arm as Group 2, but did not have an increase in muscle strength. Thus, the high-load training seemingly drove strength augmentations towards the non-dominant limb, highlighting the cross-education effect influencing strength adaptations compared to directly training the limb.

Despite study results not matching what was originally hypothesized, findings from this project, certainly strength adaptations, are important for the purpose of clarifying potential dangers of researchers opting for the unilateral training model for a study design. In addition, the use of a within subject study design, whereby both limbs in the upper body are engaging in resistance training, but with separate conditions (high-load vs. low-load) carries the potential limitation of one limb influencing strength adaptations within the other. Although this notion of inter-limb strength transfer is referred to within the limitations section of most studies, it is never been directly assessed, highlighting the novelty of this project. When considering the cross education effect, it is generally considered that strength adaptations are localized to the homologous muscles of the contralateral limb, and muscle adaptations are detected when strength is assessed in the same manner to which the training occurred (Lee & Carroll, 2007). Furthermore, it is important for the muscle(s) that are training to be maximally stimulated to bring about this potential neurological spillover, and that lighter loads are less likely to influence any cross education response. As such, a recent study assessed differential training loads (25% vs. 75% 1RM), along with training to a set volume or until failure, to understand likely muscular adaptations within the trained and untrained limbs (Colomer-Poveda et al., 2021). This study assigned participants to one of a possible four groups. One group performed three sets of low-load (25% 1RM) exercise until failure. A second group performed three sets of high-load (75% 1RM) exercise until failure. A third group completed six sets of five repetitions, high-load (75% 1RM) exercise. The fourth group was a time-matched non-exercise control. The training groups performed unilateral knee extension exercise four times per week, over the course of four weeks, with measurements for maximal voluntary isometric contraction, corticospinal excitability, and 1RM, which were completed prior to and following the intervention period. Notable outcomes from this study showed that strength augmentations in the contralateral (untrained) leg were evident for the high-load training groups only. The authors concluded that high-load, but not low-load, training results in strength improvements for the untrained leg, and further suggested that fatigue does not further enhance this response. This would once again speak to the potency with the cross education effect, in that performing high-load exercise alone produces a cross-education effect, whether it is performed to concentric failure or not. Although not statistically compared, this would also support findings from the current study, showing how the high-load conditions produced an increase in strength within the contralateral limb, but there was no change in strength for either limb with the group that performed low-load exercise alone (Group 3). Further still, the cross education effect was also found in a limb that was training with an exercise regimen that does not result in muscular strength improvements.

For the current study, there were two separate groups performing four sets of progressive high-load (~75% 1RM) unilateral elbow flexion exercise. Thus, based upon previous research, it was likely that a cross-education effect would be shown within the contralateral limb untrained arm. However, what was unclear was whether the cross-education effect would still be found, even when the contralateral arm was directly trained with a loading pattern that would not result in an increase in muscle strength (Group 2). The eventuality of the training intervention was that the cross-education effect was presented amongst Group 2, even though the arm receiving the cross-education effect was training during that same time period. This finding is remarkable for a variety of reasons, but a key one being that of study design. Ultimately, this would indicate that use of a within subject model, whereby both limbs are training but with separate conditions (e.g. high-load vs. low-load), is not a suitable method when the outcome variable of interest is specific to changes in muscle strength. The current findings highlight that the muscle contraction history of a low-load training paradigm is not resistant to the cross-education effect. Alternatively, if both limbs are to be training, whereby one arm trains with a high-load condition, and then the opposing arm trains with the same exact same high-load condition, it is the author's view that strength adaptations will be similar between limbs, and unlikely influenced by one another. It is thought that if the muscle is to be maximally contracting, this will be dictating any adaptations and therefore the muscle contraction history will be the pivotal factor for any changes likely to be found within the muscle, specifically muscle strength.

Changes in Post-Activation Potentiation

Post-activation potentiation, although small, is understood to be representative of local level changes to the muscle. Previous research considered whether performing a unilateral maximal voluntary contraction would potentiate the contralateral limb, and also if there was a relationship with muscle size (Wong et al., 2020). The aforementioned study noted that post-activation performance enhancement was specific to the arm that was being conditioned, and that conditioning one side of the body does not bring about a response to the contralateral side. Furthermore, it was indicated that post-activation potentiation was unrelated to muscle size. However, approximately one third of this sample was reported as being trained (i.e. performed resistance training in the arms at least two times per week in the previous 3 months), and it was this specific cohort that had evidence for post-activation potentiation, with no evidence for changes in post-activation potentiation amongst the untrained cohort. A limitation of this study is that although a sample of the participants (32 out of 107) were deemed 'trained' in the upper body, this should be interpreted with caution as there is likely to be considerable variation in training amongst those individuals. To the best of our knowledge, only one study has provided evidence as to whether post-activation potentiation can be increased through training (Miyamoto et al., 2013), with the outcome indicating that post-activation potentiation can be slightly improved with resistance training. However, findings from the current study indicate that post-activation potentiation cannot be augmented with training, as there was no evidence for an increase for any condition, amongst any of the groups. This was in spite of strength being improved for both arms in the two groups that completed high-load training (Groups 1 and 2).

Evidence for post-activation potentiation has been provided in previous studies, by way of vertical jump (Gossen & Sale, 2000), sprint running (Yetter & Moir, 2008), cycling exercise (Munro et al., 2017), swimming performance (Hancock et al., 2015), and elbow flexion exercise (Wong et al., 2020). Although the aforementioned studies are not a comprehensive listing, they share a common factor of incorporating participants who range from being moderately trained, to highly trained collegiate level athletes. It is thought by some researchers that potentiation of muscle is more likely amongst participants of higher relative strength, as well as those considered to be regularly training (Chiu et al., 2003; Rixon et al., 2007). The latter was previously highlighted in the study by Wong and colleagues (Wong et al., 2020), who used a large sample size (n=107), but only those who self-reported being resistance-trained (n=32) presented evidence of post-activation potentiation. However, owing to the fact that post-activation potentiation is typically quite small, researchers investigating this response should seek to be very detailed, and avoid variability with testing, if they wish to understand more on this physiological response. This would also suggest there needs to be great reliability, as well as low error amongst measurements, and likely a very large sample size, in order to effectively detect whether or not an increase in post-activation potentiation occurred. It is also purported that researchers should not only incorporate highly-trained individuals as participants, but also consider those who train with a specialized skill component within their exercise regimen, e.g. sprint cyclists (Munro et al., 2017). Therefore, it is perhaps not too surprising that the current study did not provide evidence for post-activation potentiation at baseline or following the intervention, despite certain conditions showing an increase in muscle strength and/or muscle hypertrophy. In contrast, what is surprising is that Miyamoto at al. (2013) did find that resistance training in the lower body resulted in an increase in muscle potentiation, despite using previously untrained individuals. This only study to the best of the author's knowledge, that shows training specific enhancement in post-activation potentiation (Miyamoto et al., 2013).

It is not clear as to why there were enhancements in muscle potentiation for Miyamoto and colleagues (2013), and not for the current study. Although speculative, one argument is the vast majority of research that considers post-activation potentiation uses a model that assesses muscles within the lower body, which was the case for Miyamoto et al. (2013) (knee extensors), but not for this study (biceps brachii). Additionally, it has been argued that training duration could be a dictating factor, such that adaptations specific to enhancing muscle potentiation might require longer training interventions, and thus offer reasoning as to why Miyamoto et al. (2013) found augmentations, since they used a 12-week training regimen, and that the current study might have produced changes, had the training intervention extended beyond 6-weeks. What is also important to mention is how there was evidence for muscle potentiation at baseline (prior to any resistance training), and may highlight to future researchers that any likely change in muscle potentiation is dependent upon whether there is evidence for PAPE at baseline.

Nonetheless, a change in post-activation potentiation was not the primary aim for the current study. This was used as a secondary aim as a means for understanding how a muscle (or a group of muscles) might become stronger with resistance training, outside of changes in muscle hypertrophy. More specifically, post-activation potentiation is understood to be representing a local level response (Wong et al., 2020), and owing to this theory, a change in this variable might also provide clarity as to internal properties, within a muscle, that are contributing to increases in muscle strength when there are no changes in the size of the muscle (Dankel et al., 2019), as is typically the case for strength increases via the cross education effect. However, there were no changes in measures for post-activation performance enhancements, despite evidence being provided for improvements in muscle strength after the 6-week training intervention. Nevertheless, future research on post-activation potentiation responses should be targeted in a way that is very specific, as it pertains to the study design, the exercise movement and whether this necessitates some level of skill acquisition, the length of the training intervention, and also the training status of the participants. It is the authors' belief that muscle potentiation does exist, but should not be approached with the goal of achieving a competitive edge with sports performance, owing to the variable nature of this response, in addition to how small muscle potentiation is when it does appear, and thus unlikely to complement athletic performance when training status among such athletes is already so high. Instead, exploring the manner in which muscle potentiation does occur, along with the most likely mechanisms, is a research venture that would be contributory towards the muscle physiology literature, and once again might permit clarity as to both how and why muscles adapt with resistance training.

Changes in Muscle Thickness

Following the six-week training intervention, each arm that was engaging in some manner of training, whether this was the high-load or the low-load exercise condition, presented an increase in muscle thickness when compared to the untrained arms (non-dominant for Group 1; dominant for Group 3), which did not see any changes in muscle thickness. This finding coincided with what was initially hypothesized, owing to the exercise conditions being completed until failure (deemed as volitional task failure or the inability to maintain the metronome cadence (1 s concentric; 1 s eccentric)), which although not deemed a critical determinant for producing muscle hypertrophy (Sampson & Groeller, 2016), would maximize the likelihood for changes to be similar across exercising conditions. Furthermore, changes in muscle thickness were similar to previous research from our laboratory (Dankel et al., 2020; Jessee et al., 2018). Of note, there was no evidence for changes in muscle thickness for the non-dominant arm of Group 1, which did not perform any exercise but did present evidence for an increase in muscle strength. This can be accounted for by the cross education effect, since the dominant arm was engaging in high-load training. This result would also coincide with previous research that has measured the cross education effect of strength, where there is an increase in muscle strength for the untrained limb, but without any morphological changes to the muscle (Carroll et al., 2006). Due to the specifics of these adaptations (increased strength; no changes in muscle size), the candidate mechanisms that explain why a cross education effect occurs are thought to be mediated by neural pathways at the cortical and/or subcortical level (Ruddy & Carson, 2013). This is one of the reasons as to why there has been some hesitancy to offer the cross education training as a form of rehabilitation to clinical/injurious populations, if there is to be no tangible change in the size of the muscle. During a muscular contraction, the mechanotransduction pathway is one that propagates a chemical signal, through that of muscle mechanosensors, which in turn heightens the muscle protein synthetic response and allows for building of muscle tissue as a result of exercise. This of course is not what occurs with a cross education effect, and offers reasoning why the muscle does not see any distinct muscle growth, as there is no localized muscular contraction to the muscle area. However, it is conceivable that the muscle, specific to the arm receiving a cross education effect, may instead have some form of muscle preservation, if it is that certain neural pathways spilling towards the contralateral limb are also activating signaling cascades that promote activation of the mTOR pathway.

Within the cross education literature, there is a general consensus that although the increase in strength is small, and will occur without changes in muscle size, that this can be applied to injurious/clinical populations as a form of rehabilitation. As such, there is research available to show that unilateral training is effective in attenuating the loss in in both muscle strength and size within the contralateral limb, whilst immobilized during the same time period (Andrushko et al., 2018). More specifically, when a limb is immobilized, there is a gradual but evidential attenuation in muscle mass. This is thought to be a result of a large reductions in the protein synthetic response (Phillips & McGlory, 2014). And, despite theories related to potential mechanisms explaining why there are reductions in muscle being somewhat contentious (Reid et al., 2014), is it collectively found that limb immobilization can result in muscle mass declines within as little as three to four weeks of immobilization (Booth, 1982). However, if the individual is to be performing unilateral exercise in the contralateral limb, the rate at which muscle mass is lost slows dramatically, and has been referred to as cross education muscle sparing (Andrushko et al., 2018). This is a remarkable finding, as the vast majority of research on the cross education effect indicates that there will unlikely be any change/improvement in the musculature, but when using an immobilization model, there is the possibility for muscle sparing effects. This, once again, is considered to be specific to the homologous muscles opposing the training limb, and might brings about the question as to whether the muscle itself might be playing a role with the cross education effect, as well as neural-driven pathways. A potential idea is to couple the cross education effect with blood flow restriction, and attempting to determine whether creating a heightened metabolic environment in the muscle may result in small, but notable, increases in muscle size, coinciding with likely increases in muscle strength.

Limitations

This study is not without limitations. Firstly, we opted for a Bayesian Informative Hypothesis Evaluations (BAIN) statistical model, which assumes equal probabilities for each of the separately generated hypotheses. Although all hypotheses tested were deemed physiologically plausible, it also understood that the prior odds for each were not the same. For example, it is physiologically plausible that changes in strength for the dominant arm could be similar for each group. However, it is much more likely that strength would be augmented to a greater extent for the two groups completing high-load training exercise, three times a week for six-weeks, compared to a group that did not perform any training. Nonetheless, this method was used in order to specify hypotheses we were more concerned with, and wished to compare head to head. One hypothesis that was not tested, specific to strength of the non-dominant arm, was Group 1 > Group 2 > Group 3. When choosing hypotheses, it was hypothesized that strength of Group 2 would respond like Group 3 or Group 1, but it was not considered that they would be between these two groups. Given the probability that remained for the unconstrained model, the hypothesis Group 1 > Group 2 > Group 3 should be examined in future research. Secondly, changes in muscle thickness were evaluated by B-mode ultrasound, and although both a reliable and valid measurement tool (Cartwright et al., 2013), is not considered to be the gold standard for detecting changes in muscle size. However, previous work suggests that muscular adaptations, by way of resistance training, will lead to similar conclusions, whether assessments are carried out with ultrasonography or with MRI (Franchi et al., 2018; Loenneke, Dankel, Bell, Spitz, et al., 2019). Lastly, data collection for this study began November 2019, and was paused March 2020 due to the COVID-19 global pandemic, and then resumed January 2021. When resuming data collection, participants were required to wear facemasks during all testing procedures, as well as during training sessions. There is the possibility that facemasks may impose upon exercise performance, and create a heightened demand with the level of exertion performed by the participants. However, data is available to show that facemasks do not heavily impact exercise time to exhaustion, when completed by overtly healthy young adults, which was the primary demographic for this study (Epstein et al., 2020).

CHAPTER 6: CONCLUSION

Main Findings

The main findings from the present study include: (1) strength changes of the non-dominant arm were greatest for Group 1 (high-load training in the dominant arm only) and Group 2 (high-load training in the dominant arm, low load training non-dominant), when compared to that of Group 3 (low-load training in the non-dominant arm only); (2) strength changes of the dominant arm were greatest for Group 1 (high-load training in the dominant arm only) and Group 2 (high-load training in the dominant arm, low load training non-dominant), when compared to that of Group 3 (low-load training in the non-dominant arm only); (3) There was no evidence of improved post-activation performance enhancement (PAPE) following the six-week training intervention for any of the groups; (4) changes in muscle thickness at both measured sites (60% and 70%) within the non-dominant arm were greatest for Group 2 (high-load training in the dominant arm, low load training non-dominant) and Group 3 (low-load training in the non-dominant arm only), when compared to that of Group 1 (high-load training in the dominant arm only); and, (5) changes in muscle thickness at both measured sites (60% and 70%) within the dominant arm were greatest for Group 1 (high-load training in the dominant arm only) and Group 2 (high-load training in the dominant arm, low load training non-dominant), when compared to Group 3 (low-load training in the non-dominant arm only).

Research Questions

1. We questioned whether or not the contraction history of the muscle would dictate strength adaptations and would eliminate the cross education effect? A remarkable finding from our study was that the low-load training in the non-dominant arm of Group 2 did not dictate changes in strength, and was instead influenced by the cross education effect, brought about by the high-load training of the dominant arm. This finding speaks to the potency of the cross education effect, such that Group 3 also performed the same low-load training within the non-dominant arm, without the high-load training in the dominant arm, but did not see strength enhancements following low-load training. This would indicate that strength adaptations of the non-dominant arm are largely a result of the high-load training within the dominant arm.
2. We questioned whether post-activation performance enhancement, a purported local level response, would be augmented with resistance training? Following the training intervention, there were no changes for post-activation performance enhancement in either arm (dominant or non-dominant), amongst any of the groups. Although speculative, it might be suggested that the training intervention was too short (6-weeks) to promote specific adaptations directing muscle potentiation.
3. We questioned whether or not post-activation performance enhancement would differ based on the contraction history of the muscle? Since there was no evidence for changes in post-activation performance enhancement for any of the groups, it is not possible to discern whether or not there are differences in muscle potentiation based on the muscle contraction history. It can simply be stated that neither high-load, or low-load, unilateral elbow flexion

training three times a week for six weeks was insufficient to produce adaptations specific to post-activation performance enhancement.

Significance of Study Findings

Results of this study indicate that high-load unilateral elbow flexion training alone does present a cross education effect towards the homologous muscles of the contralateral arm, and this adaptation is maintained, even when the contralateral arm is also training with a low-load condition during the same time period. As such, it can be inferred that the potency of the cross education effect is so great that this will still be apparent, even though that same arm is performing a training intervention, which does not result in augmentations in muscle strength, despite there being hypertrophy of muscle. This latter point would provide additional weight to the notion that changes in muscle strength are not mediated by hypertrophy, since an increase in muscle size did not always result in improved muscle strength, along with improved strength not always presenting hypertrophy of muscle. Stated another way, an increase in muscle strength is not necessarily dependent upon an increase in muscle size. Furthermore, post-activation performance enhancement was not augmented following six-weeks of elbow flexion training. Post-activation performance enhancement is recognized as a local-level response, and it was considered that a change in muscle potentiation might reveal more about the intrinsic properties of the muscle dictating strength augmentations following resistance training. However, there were no changes in post-activation performance enhancement measures, for any condition, following the intervention. It is not clear as to why there wasn't evidence for muscle potentiation within the current study, but one suggestion is that this responsiveness is more likely found among athletic populations, who perform exercise at higher intensities and with specific movement, e.g. sprint cyclists. Additionally, to the best of the author's knowledge, only one other study has questioned whether resistance training can produce increases in muscle potentiation. The researchers did see an increase for muscle potentiation, and this might be as a result of using a training intervention of a longer duration (i.e. 12-weeks).

Future Research

Future directions on the topic of cross education effect are primarily driven towards understanding candidate mechanism(s) that might explain its occurrence. The most commonly used explanation is one highlighting neurally driven pathways, owing largely to the adaptations being that of improved muscle strength without changes in muscle size. However, what remains less definitive are the specific sites that produce this response. It is the supposition amongst various research groups that the cross education effect is a result of adaptations at the cortical, subcortical, spinal or directly at the neuromuscular junction, with adaptations found intrinsically to the muscle outside of muscle hypertrophy. Clarifying which of these sites plays the biggest role with changes in strength requires suitable manipulations of the training protocol. For example, certain studies have activated the muscle by way of electrical stimulation, which considers locally driven changes, and would be in contrast to the current study that used voluntary muscle activation. If the muscle is being stemmed, and there is evidence for a cross education effect, this might provide a technique for determining intrinsic muscle properties that are dictating strength changes, outside of adaptations that are centrally located (e.g. cortical, subcortical, spinal cord). Nonetheless, there is also a collective understanding that adaptations that bring about the cross education effect are unlikely to be occurring through one site, but rather a myriad of locations that are working together to produce an increase in strength within the untrained homologous muscles. Additionally, one prospective idea is to consider how when training both limbs, each with a high load condition, may produce even greater changes in strength among both limbs compared to training only one limb unilaterally. Thus, if strength adaptations can be further increased in one limb, when the opposing limb is also engaging in the same high-load exercise, it might be inferred that this increase was the result of the cross education effect. More specifically, if unilateral strength adaptations are greater when training both sides of the body, versus only training that one limb independent of the other, this might present a novel approach with the cross education literature, as well as potentially highlighting alternative mechanisms and/or approaches towards training. However, this idea is only speculative at this time and requires further investigation.

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Zult, T., Howatson, G., Kádár, E. E., Farthing, J. P., & Hortobágyi, T. (2014). Role of the mirror-neuron system in cross-education. *Sports Medicine (Auckland, N.Z.)*, *44*(2), 159–178. https://doi.org/10.1007/s40279-013-0105-2

VITA

EDUCATION

May 2022 Ph.D. Health and Kinesiology
The University of Mississippi

May 2017 M.S. Exercise Science
Eastern Kentucky University

May 2014 B.A. Exercise Science
The University of the Cumberlands

PROFESSIONAL EXPERIENCE

2017-Present Graduate Teaching Assistant at The University of Mississippi;
Oxford, MS

2015-17 Graduate Research Assistant at Eastern Kentucky University;
Richmond, KY

RESEARCH PRESENTATIONS

1. Data-Blitz (9th Annual University of Mississippi Research Symposium) – 03/26/2019
   The Perceived Tightness Scale Does Not Provide Reliable Estimates of Blood Flow Restriction Pressure – Received Travel Funds ($300)

2. Trainology Conference III – 07/12/2019
   Changes in Muscle Strength Occur in the Trained and Untrained Arm Independent of Changes in Muscle Size – 3rd Place ($200)

3. Trainology Conference IV – 07/10/2020
   Conditioning Participants to a Relative Pressure: Implications for Practical Blood Flow Restriction – 1st Place ($200)

4. Trainology Conference V – 07/9/2021
   Comparing Two Conditioning Methods: Implications for Practical Blood Flow Restriction – 2nd Place ($300)

GRANT WORK

1. Loenneke JP. Principal Investigator (2018). Are there individual responses to two distinct resistance exercise protocols: Or is it all just measurement error?" American College of Sports Medicine $10,000 (Not Funded)
    - Scott J. Dankel, **Zachary W. Bell** (Doctoral Students) intellectually contributed to this grant.

2. Loenneke JP. Principal Investigator (2019). "Does inter-repetition rest augment adaptation when effort is matched?" American College of Sports Medicine $10,000 (not funded)
    - Robert W. Spitz, Vickie Wong, **Zachary W. Bell**, and Scott J. Dankel (Doctoral Students) intellectually contributed to this grant.

3. Loenneke JP. Principal Investigator (2019). "The cognitive effects of acute exercise with and without blood flow restriction and full body cooling (VASPER^{TM} exercise)." VASPER $30,953 (**Awarded**)
    - **Zachary W. Bell**, Vickie Wong, Robert W. Spitz, and Yujiro Yamada intellectually contributed to this grant.

4. Loenneke JP. Principal Investigator (2020). "The role of lactate in the cognitive inhibitory response to acute exercise." American College of Sports Medicine $5,400 (Under Review)
    - **Zachary W. Bell**, Vickie Wong, Robert W. Spitz, and Yujiro Yamada intellectually contributed to this grant.

5. Loenneke JP. Principal Investigator (2020). "The effect of blood flow restriction on preventing orthostatic intolerance." Mississippi Space Grant Consortium $12,000 (**Awarded**)
    - Vickie Wong **Zachary W. Bell**, Robert W. Spitz, Yujiro Yamada, and Jun Seob Song intellectually contributed to this grant.

6. Loenneke JP. Principal Investigator (2021). "The influence of Blood Flow Restriction Training on Resting Blood Pressure in Women: Adaptive or Maladaptive?" Foundation for Women's Wellness $25,000 (Under Review).
    - Robert W. Spitz, **Zachary W. Bell**, Vickie Wong, Yujiro Yamada, and Jun Seob Song intellectually contributed to this grant.

7. Loenneke JP. (Principal Investigator); Jessee MB (Co-Investigator); Dankel SJ (Co-Investigator); Owens J (Co-Investigator); and JG Mouser (Consultant). (2021). "The Impact of Blood Flow Restriction Training on Vascular Function and Blood Pressure: Does the Effect Depend on Race and Sex?" Department of Defense (PRMRP Clinical Trial) $1,205,862 (Not Funded).
    - **Zachary W. Bell**, Robert W. Spitz, Vickie Wong, Yujiro Yamada, and Jun Seob Song intellectually contributed to this grant.

8. Loenneke JP. (Principal Investigator); Jessee MB (Co-Investigator); Loprinzi, PD (Consultant) (2021). “A Novel Strategy for Improving Anxiety and Blood Pressure Simultaneously” National Institutes of Mental Health $275,000 (Under Review).
    - **Zachary W. Bell**, Robert W. Spitz, Vickie Wong, Ryo Kataoka, Jun Seob Song, and Yujiro Yamada intellectually contributed to this grant.
9. Loenneke JP. Principal Investigator (2022). “An efficient and effective way to mitigate the rise in anxiety.” John W. Brick Mental Health Foundation. $438,328 (Pre-Application, Under Review).
    - Co-Investigator (Dr. Matthew Jessee)
    - Consultant (Dr. Paul Loprinzi)
    - **Zachary W. Bell**, Robert W. Spitz, Vickie Wong, Ryo Kataoka, Jun Seob Song and Yujiro Yamada intellectually contributed to this grant.

PEER-REVIEWED PUBLICATIONS

TOTAL: 65
FIRST-AUTHOR: 8
H-INDEX: 15
TOTAL CITATIONS: 676

1) Dankel SJ, Mouser JG, Mattocks KT, Jessee MB, Buckner SL, **Bell ZW**, Abe T, Loenneke JP. Changes in Muscle Size via MRI and Ultrasound: Are they Equivalent? Scandinavian Journal of Medicine and Science in Sports (2018) Apr;28(4):1467-146
    ⇒ Role: Project design, data analysis, manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 3.531

2) Mattocks KT, Jessee MB, Mouser JG, Dankel SJ, Buckner SL, **Bell ZW**, Owens J, Abe T, Loenneke JP. The Application of Blood Flow Restriction: Lessons from the Laboratory. Current Sports Medicine Reports (2018) Apr;17(4):129-134.
    ⇒ Role: Project design and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 1.24

3) Abe T, Dankel SJ, Buckner SL, Jessee MB, Mattocks KT, Mouser JG, **Bell ZW**, Loenneke JP. Differences in 100-m sprint performance and skeletal muscle mass between elite male and female sprinters. The Journal of Sports Medicine and Physical Fitness (2018) Feb;59(2):304-309.
    ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 1.49

4) Mouser JG, Jessee MB, Mattocks KT, **Bell ZW**, Buckner SL, Dankel SJ, Abe T, Loenneke JP. Blood Flow Restriction: Methods Matter. Experimental Gerontology (2018) Apr;104:7-8.
    ⇒ Role: Project design and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 3.376

5) **Bell ZW**, Buckner SL, Jessee MB, Mouser JG, Mattocks KT, Dankel SJ, Abe T, Loenneke JP. Moderately Heavy Exercise Produces Lower Cardiovascular, RPE, and Discomfort compared to Lower Load Exercise with and without Blood Flow Restriction. European Journal of Applied Physiology (2018) Jul;118(7):1473-1480.
   - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 45%. Journal impact factor: 3.078

6) Dankel SJ, Jessee MB, Mattocks KT, Buckner SL, Mouser JG, **Bell ZW**, Abe T, Loenneke JP. Perceptual and arterial occlusion responses to very low-load blood flow restricted exercise performed to volitional failure. Clinical Physiology and Functional Imaging (2018) Jan;39(1):29-34.
   - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 35%. Journal impact factor: 2.273

7) Mouser JG, Mattocks KT, Dankel SJ, Buckner SL, Jessee MB, **Bell ZW**, Abe T, and Loenneke JP. Very Low Load Resistance Exercise in the Upper Body with and without Blood Flow Restriction: Cardiovascular Outcomes. Applied Physiology, Nutrition, and Metabolism (2018) Mar;44(3):288-292
   - ⇒ Role: Data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.665

8) Abe T, Dankel SJ, Buckner SL, Jessee MB, Mattocks KT, Mouser JG, **Bell ZW**, Loenneke JP. Magnetic resonance imaging-measured skeletal muscle mass to fat-free mass ratio increases with increasing levels of fat-free mass. The Journal of Sports Medicine and Physical Fitness (2018) Apr;59(4):619-623.
   - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 1.49

9) Buckner SL, Dankel SJ, **Bell ZW**, Abe T, Loenneke JP. The association of hand grip strength and mortality: What does it tell us and what can we do with it? Rejuvenation Research (2018) Jun;22(3):230-234.
   - ⇒ Role: Project design and manuscript revisions. Estimated percent contribution to the team effort: 25%. Journal impact factor: 4.663

10) **Bell ZW**, Dankel SJ, Mattocks KT, Buckner SL, Jessee MB, Mouser JG, Abe T, Loenneke JP. An Investigation Into Setting the Blood Flow Restriction Pressure based on Perception of Tightness. Physiological Measurement. (2018) Oct 19;39(10):105006.
   - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 45%. Journal impact factor: 2.866

11) Jessee MB, Buckner SL, Mouser JG, Mattocks KT, Dankel SJ, Abe T, **Bell ZW**, JP Bentley, Loenneke JP. Muscle adaptations to high-load training and very low-load training with and without blood flow restriction. Frontiers in Physiology (2018) Oct 16;9:1448.
   - ⇒ Role: Data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 4.134

12) Hornsby WG, Gentles JA, Haff GG, Stone MH, Buckner SL, Dankel SJ, **Bell ZW**, Abe T, Loenneke JP. What is the impact of muscle hypertrophy on strength and sport performance? Strength and Conditioning Journal (2018) Dec 1;40(6):99-111.
   - ⇒ Role: Manuscript revisions. Estimated percent contribution to the team effort: 15%. Journal impact factor: 1.654

13) Jessee MB, Buckner SL, Dankel SJ, Mattocks KT, **Bell ZW**, Abe T, Loenneke JP. Arterial occlusion pressure as a method to quantify cardiovascular responses to exercise. Biomedical Physics & Engineering Express (2018) 29;4(6):065034.
   - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 1.391

14) Dankel SJ, Abe T, **Bell ZW**, Jessee MB, Buckner SL, Mouser JG, Mattocks KT, Loenneke JP. The impact of ultrasound probe tilt on muscle thickness and echo-intensity: A cross-sectional study. Journal of Clinical Densitometry (2018) Oct-Dec;23(4):630-638.
   - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.617

15) Buckner SL, Jessee MB, Dankel SJ, Mattocks KT, Mouser JG, **Bell ZW**, Abe T, Bentley JP, Loenneke JP. Acute skeletal muscle responses to very low load resistance exercise with and without the application of blood flow restriction in the upper body. Clinical Physiology and Functional Imaging (2018) May;39(3):201-208.
   - ⇒ Role: Data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.273

16) Mattocks KT, Mouser JG, Jessee MB, Dankel SJ, Buckner SL, **Bell ZW**, Abe T, Loenneke JP. Acute hemodynamic changes following high load and very low load lower body resistance exercise with and without the restriction of blood flow. Physiological Measurement (2018) Dec 21;39(12):125007.
   - ⇒ Role: Data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.866

17) Hornsby GW, Gentles JA, Haff GG, Stone MH, Buckner SL, Dankel SJ, **Bell ZW**, Abe T, Loenneke JP. Brief Examination of Hypertrophy and Performance with a Discussion of Recent Claims. Strength & Conditioning Journal (2018) Dec 1; 40(6):99-111.
    - ⇒ Role: Manuscript revisions. Estimated percent contribution to the team effort: 15%. Journal impact factor: 1.654

18) Abe T, Mouser JG, Dankel SJ, **Bell ZW**, Buckner SL, Mattocks KT, Jessee MB, Loenneke JP. A method to standardize the blood flow restriction pressure by an elastic cuff. Scandinavian Journal of Medicine and Science in Sports (2018) Mar;29(3):329-335.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.617

19) Abe T, **Bell ZW**, Dankel SJ, Wong V, Spitz RW, Loenneke JP. The Water-Fat Separation Method for Determining the Fat-free Component of Subcutaneous Adipose Tissue in Humans: A Brief Review. Journal of Clinical Densitometry (2018) Jul-Sep;23(3):390-394.
    - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.617

20) Abe T, Dankel SJ, Buckner SL, Jessee MB, Mattocks KT, Mouser JG, **Bell ZW**, Loenneke JP. Short-term (24 hours) and Long-term (1 year) Assessments of Reliability in Older Adults: Can One Replace the Other? The Journal of Aging Research and Clinical Practice (2018) May 17;18:82-4
    - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 1.49

21) Mattocks KT, Mouser JG, Matthew B. Jessee MB, Buckner SL, Dankel SJ, **Bell ZW**, Abe T, Bentley JP, Loenneke JP. Perceptual changes to progressive exercise with and without blood flow restriction. Journal of Sports Sciences (2019) Aug;37(16):1857-1864.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 3.337

22) Loenneke JL, **Bell ZW**, Abe T, Buckner SL, Jessee MB, Dankel SJ, Mattocks KT. Is Muscle Growth a Mechanism for Increasing Strength. Medical Hypotheses (2019) Apr;125:51-56.
    - ⇒ Role: Manuscript revisions. Estimated percent contribution to the team effort: 15%. Journal impact factor: 1.538

23) Dankel SJ, Abe T, Spitz RW, Viana R, **Bell ZW**, Wong V, Chatakondi RN, Loenneke, JP. Impact of Acute Fluid Retention on Ultrasound Echo Intensity. Journal of Clinical Densitometry (2019) Jan-Mar;23(1):149-150.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.617

24) Lane MT, Byrd MT, **Bell ZW**, Hurley T. Effects of Supplementation of a Pre-workout on Power Maintenance in Lower Body and Upper Body Tasks in Women. Journal of Functional Morphology and Kinesiology (2019) Apr 5;4(2):18.
    - ⇒ Role: Project design, manuscript revisions, recruitment, paperwork and data collection. Estimated percent contribution to the team effort: 35%. Journal impact factor: 1.30

25) Spitz RW, Chatakondi RN, **Bell ZW**, Wong V, Dankel SJ, Abe T, Loenneke, JP. The impact of cuff width and biological sex on cuff preference and the perceived discomfort to blood flow restricted arm exercise. Physiological Measurement (2019) Jun 4;40(5):055001.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.866

26) Wong V, Abe T, Chatakondi, RN, **Bell ZW**, Spitz RW, Dankel SJ, Loenneke JP. The influence of biological sex and cuff width on muscle swelling, echo intensity, and the fatigue response to blood flow restricted exercise. Journal of Sports Sciences (2019) Aug;37(16):1865-1873.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 3.337

27) Jessee MB, Buckner SL, KT Mattocks, Dankel SJ, Mouser JG, **Bell ZW**, Abe T, and Loenneke JL. Blood flow restriction augments the skeletal muscle response during very low-load resistance exercise to volitional failure. Physiology International (2019) Jun 1;106(2):180-193.
    - ⇒ Role: Data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 25%. Journal impact factor: 2.09

28) Abe T, Loenneke JL, Dankel SJ, Viana R, **Bell ZW**. Impact of gastric bypass surgery on fat-free mass and fat mass ratio of adipose tissue: a brief review. European Radiology (2019) Mar 1;15(1):11-4.
    - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 4.017

29) **Bell ZW**, Dankel SJ, Spitz RW, Chatakondi RN, Abe T, Loenneke JP. The Perceived Tightness Scale Does Not Provide Reliable Estimates of Blood Flow Restriction Pressure. Journal of Sport Rehabilitation (2019) Sep 24;29(4):516-518.
    - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 50%. Journal impact factor: 1.931

30) Abe T, Dankel SJ, **<u>Bell ZW</u>**, Fujita E, Akamine T, Yaginuma Y, Spitz RW, Wong V, Viana R, Loenneke J. Impact of fat-free adipose tissue on the prevalence of low muscle mass estimated using calf circumference in middle-aged and older adults. <u>Journal of Frailty and Ageing</u> (2019); 9(2):90-93.
    - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.74

31) Buckner SL, Jessee MB, Dankel SJ, Mattocks KT, Mouser GM, **<u>Bell ZW</u>**, Abe T, Bentley JP, Loenneke JP. Blood flow restriction does not augment low force contractions taken to or near task failure. <u>European Journal of Applied Physiology</u> (2020). Jun;20(5):650-659.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 3.078

32) Abe T, Wong V, Dankel SJ, **<u>Bell ZW</u>**, Spitz RW, Viana R, Loenneke JP. Skeletal muscle mass in female athletes: The average and the extremes. <u>The American Journal of Human Biology</u> (2020). Mar;32(2):e23333.
    - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 1.928

33) Dankel SJ, **<u>Bell ZW</u>**, Spitz RW, Wong V, Chatakondi RN, Buckner SL, MB Jessee, Mattocks KT, mouser GM, Abe T, Loenneke JP. Assessing differential responders and mean changes in muscle size, strength, and the cross-over effect to two distinct resistance training protocols. <u>Applied Physiology, Nutrition, and Metabolism</u> (2020). May;45(5):463-470.
    - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 35%. Journal impact factor: 2.665

34) Loenneke JP, Dankel SJ, **<u>Bell ZW</u>**, Spitz RW, Abe T, Yasuda T. Ultrasound and MRI measured changes in muscle mass gives different but similar conclusions: a Bayesian approach. <u>European Journal of Clinical Nutrition</u> (2019). Aug;73(8):1203-1205.
    - ⇒ Role: Manuscript revisions and data analysis. Estimated percent contribution to the team effort: 20%. Journal impact factor: 4.016

35) Abe T, Spitz RW, Wong V, Viana RB, Yamada Y, **<u>Bell ZW</u>**, Chatakondi RN, Loenneke JP. Assessment of Facial Muscle Thickness by Ultrasound in Younger Adults: Absolute and Relative Reliability. <u>Journal of Cosmetics</u> (2019). Dec;6(4):65.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 35%. Journal impact factor: 2.93

36) **Bell ZW**, Wong V, Spitz RW, Chatakondi RN, Viana RB, Abe T, Loenneke JP. The contraction history of the muscle and strength change: lessons learned from unilateral training models. Physiological Measurement (2019). Feb 5;41(1):01TR01.
    - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, paperwork, recruitment, data collection. Estimated percent contribution to the team effort: 50%. Journal impact factor: 2.866

37) Spitz RW, **Bell ZW**, Viana RB, Chatakondi RN, Abe T, Loenneke JP. Blood Flow Restricted Exercise and Discomfort: A Review. The Journal of Strength and Conditioning Research (2019). Mar 1;36(3):871-879.
    - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 20%. Journal impact factor: 2.06

38) Spitz RW, **Bell ZW**, Wong V, Viana RB, Chatakondi RN, Abe T, Loenneke JP. The Position of the Cuff Bladder Has A Large Impact On The Pressure Needed For Blood Flow Restriction. Physiological Measurement (2019) Jan 30;41(1):01NT01.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.866

39) Abe T, Wong V, Spits RW, Viana RB, **Bell ZW**, Yamada Y, Chatakondi RN, Loenneke JP. Influence of sex and resistance training status on orofacial muscle strength and morphology in healthy adults between the ages of 18 and 40: A cross-sectional study. American Journal of Human Biology (2020) Nov;32(6):e23401.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 1.928

40) Wong V, Spitz RW, **Bell ZW**, Viana RB, Chatakondi RN, Abe T, Loenneke JP. Exercise Induced Changes in Echo Intensity within the Muscle: A Brief Review. Journal of Ultrasound (2020) Dec;23(4):457-472.
    - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 20%. Journal impact factor: 2.75

41) Abe T, **Bell ZW**, Wong V, Spitz RW, Viana RB, Yamada Y, Chatakondi RN, Loenneke JP. A practical method for assessing lip compression strength in healthy adults. Journal of Cosmetics (2020) Mar;7(1):5.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.93

42) Abe T, **Bell ZW**, Wong V, Spitz RW, Loenneke JP. Why is low body fat rarely seen in large-sized male athletes? American Journal of Human Biology (2020) Nov;32(6):e23399.
   - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 1.928

43) **Bell ZW**, Jessee MB, Mattocks KT, Buckner SL, Dankel SJ, Mouser JG, Abe T, Loenneke JP. Limb occlusion pressure: a method to assess changes in systolic blood pressure. International Journal of Exercise Science (2020);13(2):366.
   - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, paperwork, recruitment, data collection. Estimated percent contribution to the team effort: 50%. Journal impact factor: 0.00

44) Wong V, Abe T, Spitz RW, **Bell ZW**, Yamada Y, Chatakondi RN, Loenneke JP. Effects of Age, Sex, Disease, and Exercise Training on Lip Muscle Strength. Journal of Cosmetics (2020) Mar;7(1):18.
   - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.93

45) **Bell ZW**, Abe T, Wong V, Spitz RW, Viana RB, Chatakondi RN, Dankel SJ, Yamada Y, Loenneke JP. Muscle swelling following blood flow restricted exercise does not differ between cuff widths in the proximal or distal portions of the upper leg. Clinical Physiology and Functional Imaging (2020) Jul;40(4):269-276.
   - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, paperwork, recruitment, data collection. Estimated percent contribution to the team effort: 50%. Journal impact factor: 2.273

46) Abe T, Viana RB, Wong V, **Bell ZW**, Spitz RW, Yamada Y, Thiebaud RS, Loenneke JP. The influence of training variables on lingual strength and swallowing in adults with and without dysphagia. The Journal of Cachexia, Sarcopenia and Muscle (2020) Apr;5(2):29-41.
   - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 12.51

47) Wong V, Dankel SJ, Spitz RW, **Bell ZW**, Viana RB, Chatakondi RN, Abe T, Loenneke JP. The effect of blood flow restriction therapy on recovery following experimentally induced muscle weakness and pain. The Journal of Strength and Conditioning Research (2020) Apr 1;36(4):1147-1152.
   - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.06

48) Abe T, Kawamoto K, Dankel SJ, **Bell ZW**, Spitz RW, Wong V, Loenneke JP. Longitudinal associations between changes in body composition and changes in sprint performance in elite female sprinters. European Journal of Sport Science (2020) Feb;20(1):100-105.
    - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 4.05

49) Abe T, Dankel SJ, Spitz RW, Buckner SL, Wong V, Viana RB, **Bell ZW**, Loenneke JP. Does resistance training increase aponeurosis width? The current results and future tasks. European Journal of Applied Physiology (2020) Jul;120(7):1489-1494.
    - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 30%. Journal impact factor: 3.078

50) Buckner SL, Jessee MB, Mouser JG, Dankel SJ, Mattocks KT, **Bell ZW**, Abe T, Loenneke JP. The basics of training for muscle size and strength: A brief review on the theory. Medicine and Science in Sports and Exercise (2020) Mar;52(3):645-653.
    - ⇒ Role: Manuscript revisions. Estimated percent contribution to the team effort: 20%. Journal impact factor: 5.411

51) Spitz RW, Chatakondi RN, **Bell ZW**, Wong V, Viana RB, Dankel SJ, Abe T, Yamada Y, Loenneke JP. Blood Flow Restriction Exercise: Effects of Sex, Cuff width, and Cuff Pressure on Perceived Lower Body Discomfort. Perceptual and Motor Skills (2020) Feb;128(1):353-374.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 1.62

52) **Bell ZW**, Spitz RW, Wong V, Yamada Y, Chatakondi RN, Abe T, Dankel SJ, Loenneke JP. Conditioning Participants to a Relative Pressure: Implications for Practical Blood Flow Restriction. Physiological Measurement (2020) Sep 4;41(8):08NT01.
    - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, recruitment, data collection. Estimated percent contribution to the team effort: 50%. Journal impact factor: 2.866

53) Wong V, Yamada Y, **Bell ZW**, Spitz RW, Viana RB, Chatakondi RN, Abe T, Loenneke JP. Post-Activation Performance Enhancement: Does conditioning one arm augment performance in the other? Journal of Clinical Physiology and Functional Imaging (2020) Nov;40(6):407-14.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.273

54) Song JS, Abe T, **Bell ZW**, Wong V, Spitz RW, Yamada Y, Loenneke JP. The relationship between muscle size and strength does not depend on echo intensity in healthy young adults. Journal of Clinical Densitometry (2020) Jul-Sep;24(3):406-413.
   - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.617

55) Yamada Y, Frith E, Wong V, Spitz RW, **Bell ZW**, Chatakondi RN, Abe T, Loenneke JP. Acute Exercise and Cognition: A Review with Testable Questions for Future Research into Cognitive Enhancement with Blood Flow Restriction. Medical Hypotheses (2021) Jun;151:110586.
   - ⇒ Role: Manuscript revisions and data analysis. Estimated percent contribution to the team effort: 20%. Journal impact factor: 1.538

56) Song JS, Spitz RW, Yamada Y, **Bell ZW**, Wong V, Abe T, Loenneke JP. Exercise-induced hypoalgesia and pain reduction following blood flow restriction: a brief review. Physical Therapy in Sport (2021) Jul;50:89-96.
   - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 20%. Journal impact factor: 3.839

57) Abe T, Song JS, **Bell ZW**, Wong V, Spitz RW, Yamada Y, Loenneke JP. Comparisons of Calorie Restriction and Structured Exercise on Reductions in Visceral and Abdominal Subcutaneous Adipose Tissue: A Systematic Review. European Journal of Clinical Nutrition (2021) Feb;76(2):184-195.
   - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 20%. Journal impact factor: 4.016

58) Wong V, Song JS, **Bell ZW**, Yamada Y, Spits RW, Abe T, Loenneke JP. Blood Flow Restriction on Resting Blood Pressure and Heart rate: A Meta-Analysis of the Available Literature. Journal of Human Hypertension (2021) Jun 17:1-6.
   - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 20%. Journal impact factor: 3.012

59) Abe T, Wong V, **Bell ZW**, Spitz RW, Dankel SJ, Loenneke JP. Subcutaneous Adipose Tissue Distribution and Serum Lipid/Lipoprotein in Unmedicated Postmenopausal Women: A B-Mode Ultrasound Study. Akademiai Kiado Journals (2021) Dec 20;13(2):119-23.
   - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 20%. Journal impact factor: 0.00

60) Spitz RW, Dankel SJ, **Bell ZW**, Wong V, Abe T, Kang M, Loenneke JP. Blocking the Activin IIB Receptor with Bimagrumab (BYM33) Increases Walking Performance: A Meta-Analysis. Geriatrics & Gerontology International (2021) Oct;21(10):939-943.
   - ⇒ Role: Project design, data analysis and manuscript revisions. Estimated percent contribution to the team effort: 20%. Journal impact factor: 2.05

61) Yamada Y, Song JS, **Bell ZW**, Wong V, Spitz RW, Abe T, Loenneke JP. Effects of Isometric Handgrip Exercise with or without Blood Flow Restriction on Interference Control and Feelings. Journal of Clinical Physiology and Functional Imaging (2021) Nov;41(6):480-487.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.04

62) **Bell ZW**, Spitz RW, Wong V, Yamada Y, Song JS, Abe T, Loenneke JP. Can Individuals Be Taught to Sense the Degree of Vascular Occlusion? A comparison of Methods and Implications for Practical Blood Flow Restriction. The Journal of Strength and Conditioning Research (2021) Mar 1.
    - ⇒ Role: Project design, data analysis, statistical analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 50%. Journal impact factor: 2.06

63) Song JS, Yamada Y, Wong V, **Bell ZW**, Spitz RW, Abe T, Loenneke JP. Hypoalgesia Following Isometric Handgrip Exercise With and Without Blood Flow Restriction is Not Mediated by Discomfort Nor Changes in Systolic Blood Pressure. Journal of Sports Sciences (2021) Mar;40(5):518-526.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 3.04

64) Wong V, Bell ZW, Spitz RW, Song JS, Yamada Y, Abe T, Loenneke JP. Blood Flow Restriction Maintains Blood Pressure Upon Head-Up Tilt. Physiology International (2022) Mar 3.
    - ⇒ Role: Project design, data analysis, manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 30%. Journal impact factor: 2.09

65) Wong V, Song JS, Abe T, Spitz RW, Yamada Y, Bell ZW, Kataoka R, Kang M, Loenneke JP. Muscle Thickness Assessment of the Forearm via Ultrasonography: Is experience level important? Biomedical Physics & Engineering Express (2022) Feb 1;8(2).
    - ⇒ Role: Manuscript revisions, recruitment, paperwork, data collection. Estimated percent contribution to the team effort: 15%. Journal impact factor: 1.391

SCIENTIFIC ABSTRACTS/ORAL PRESENTATIONS

1) **Bell ZW**, Lane MT, Byrd T, Hurley T, Isfort K. Relationships Between Body Composition and Sports Performance In Collegiate Baseball. ACSM National Conference, May 2017 Denver, Colorado.
2) Mouser JG, Mattocks KT, Dankel, SJ, Buckner SL, Jessee MB, **Bell ZW**, Abe T, Loenneke JP. Cardiovascular Responses to Blood Flow Restriction and Very Low Load Resistance Exercise in the Upper Body. ACSM National Conference, May 2018, Minneapolis, Minnesota.
3) Jessee MB, Buckner SL, Mattocks KT, Mouser JG, Dankel SJ, **Bell ZW**, Abe T, Loenneke JP. Very Low Load Resistance Exercise Is Augmented By Blood Flow Restriction In The Lower Body. ACSM National Conference, May 2018, Minneapolis, Minnesota.
4) Mattocks KT, Mouser JG, Jessee MB, Dankel SJ, Buckner SL, **Bell ZW**, Abe T, Loenneke JP. Acute Hemodynamic Response to Very Low Load Resistance Exercise With or Without Blood Flow Restriction. ACSM National Conference, May 2018, Minneapolis, Minnesota.
5) Buckner SL, Jessee MB, Dankel SJ, Mouser JG, Mattocks KT, **Bell ZW**, Abe T, Loenneke JP. Muscular responses to very low load resistance exercise with blood flow restriction in the upper body. ACSM National Conference, May 2018, Minneapolis, Minnesota.
6) **Bell ZW**, Buckner SL, Jessee MB, Mouser JG, Mattocks KT, Dankel SJ, Abe T, Loenneke JP. Perceptual And Cardiovascular Responses to Very Low Load Exercise With And Without Blood Flow Restriction. ACSM National Conference, May 2018, Minneapolis, Minnesota.
7) Buckner SL, Jessee MB, Dankel SJ, Mattocks KT, Mouser JG, **Bell ZW**, Abe T, Loenneke JP. Blood Flow Restriction Does Not Augment Low Force Contractions Taken to or Near Task Failure. ACSM National Conference, May 2019, Orlando, Florida.
8) Jessee MB, Buckner SL, Mouser JG, Mattocks KT, Dankel SJ, Abe T, **Bell ZW**, Bentley JP, Loenneke JP. Endurance is Augmented by Greater Blood Flow Restriction Pressures. Muscle Size and Strength Are Not. ACSM National Conference, May 2019, Orlando, Florida.
9) Wong V, Chatakondi RN, Abe T, **Bell ZW**, Spitz RW, Dankel SJ, Loenneke, JP. The Acute Muscle Response: The Influence of Sex and Cuff Size. ACSM National Conference, May 2019, Orlando, Florida.
10) **Bell ZW**, Dankel SJ, Spitz RW, Chatakondi RN, Abe T, Loenneke JP. The Perceived Tightness Scale Does Not Provide Reliable Estimates of Blood Flow Restriction Pressure. ACSM National Conference, May 2019, Orlando, Florida.
11) Spitz RW, Chatakondi RN, **Bell ZW**, Wong V, Dankel SJ, Abe T, Loenneke JP. Narrow Cuffs Decrease the Perception of Discomfort with Blood Flow Restricted Exercise. ACSM National Conference, May 2019, Orlando, Florida.
12) Dankel SJ, Mouser JG, Abe T, **Bell ZW**, Buckner SL, Mattocks KM, Jessee MB, Loenneke JP. Arm Circumference as a Method to Standardize the Practical Blood Flow Restriction Pressure. Thematic Presentation at the ACSM National Conference, May 2019, Orlando, Florida.
13) Mattocks KM, Mouser JG, Jessee MB, Dankel SJ, Buckner SL, **Bell ZW**, Abe T, Bentley JP, Loenneke JP. High Blood Flow Restriction Pressure is Necessary to Induce Vascular Adaptations with Very Low-Load Training. ACSM National Conference, May 2019, Orlando, Florida.

14) Mouser JG, Mattocks KM, Jessee MB, Buckner SL, Dankel SJ, **Bell ZW**, Abe T, Bentley JP, Loenneke JP. High Pressure Blood Flow Restriction is Necessary for the Peripheral Vascular Adaptations with Very Low Loads. ACSM National Conference, May 2019, Orlando, Florida.
15) **Bell ZW** – Co-Chair with Loenneke JP. Thematic Posters, Physical Activity Interventions in the Modern Age. ACSM National Conference, May 2019, Orlando Florida.
16) **Bell ZW**, Abe T, Wong V, Spitz RW, Viana RB, Chatakondi RN, Dankel SJ, Yamada Y, Loenneke JP. Muscle Swelling Following Low Load Blood Flow Restriction Exercise Does Not Differ Between Cuff Widths In The Lower Body. ACSM National Conference, May 2020, Web-Based.
17) Spitz RW, Chatakondi RN, **Bell ZW**, Wong V, Viana RB, Dankel SJ, Abe T, Yamada Y, Loenneke JP. The Influence Of Sex And Cuff Width On Discomfort To Blood Flow Restriction In The Lower Body. ACSM National Conference, May 2020, Web-Based.
18) Wong V, Yamada Y, **Bell ZW**, Spitz RW, Viana RB, Chatakondi RN, Abe T, Loenneke JP. Is There A Cross Over Effect In Post Activation Potentiation? ACSM National Conference, May 2020, Web-Based.
19) Yamada Y, **Bell ZW**, Wong V, Spitz RW, Abe T, Loenneke JP. Impact Of Isometric Handgrip Exercise With Blood Flow Restriction On Interference Control And Affect. ACSM National Conference, May 2021, Web-Based.
20) **Bell ZW**, Spitz RW, Wong V, Yamada Y, Song JS, Abe T, Loenneke JP. Comparing Conditioning Methods: Implications For Practical Blood Flow Restriction. ACSM National Conference, May 2021, Web-Based.
21) Spitz RW, Song JS, Wong V, **Bell ZW**, Yuji Yamada, Abe T, Loenneke JP. The Effect Of Blood Flow Restricted Isometric Forearm Exercise On Discomfort And Force Production. ACSM National Conference, May 2021, Web-Based.
22) Song JS, **Bell ZW**, Wong V, Spitz RW, Yamada Y, Abe T, Loenneke JP. Effect Of Blood Flow Restricted Handgrip Exercise On Exercise-induced Hypoalgesia At Local And Non-local Muscles. ACSM National Conference, May 2021, Web-Based.
23) Wong V, Jessee MB, **ZW Bell**, Yamada Y, Song JS, Spitz RW, Abe T, Loenneke JP. The Influence Of Limb Blood Flow On Muscle Growth With Different Resistance Training Protocols. ACSM National Conference, May 2021, Web-Based.

JOURNALS REVIEWED FOR

1. European Journal of Applied Physiology
2. International Journal of Sports Medicine
3. Journal of Applied Physiology, Nutrition and Metabolism
4. Journal of Exercise Science and Fitness
5. Journal of Physical Activity and Health
6. Journal of Trainology

SERVICE

2015 Kentucky Adapted Physical Education Program
2016 Kentucky Adapted Physical Education Program (Student Coordinator)
2017 Kentucky Adapted Physical Education Program (Student Coordinator)
2018 Faculty Hiring Committee Student Member
2018 Mississippi Region VII Science Fair Judge – 1st - 6th Grade
2018 Rebel Man Sprint Triathlon volunteer: Supervisor/First Aid and CPR
2019 Rebel Man Sprint Triathlon volunteer: Supervisor/First Aid and CPR
2019 Mississippi Region VII Science Fair Judge – 1st - 6th Grade

AWARDS

- EKU Outstanding Graduate Student Award in Exercise Science – 2015/16
- University of Mississippi Trainology Conference – 2019 (3rd Place)
- University of Mississippi Trainology Conference – 2020 (1st Place)
- University of Mississippi Trainology Conference – 2021 (2nd Place)
- Exercise Science Graduate Student Blackburn Award – 2021

TEACHING EXPERIENCE

Fall 2017
ES 349 Exercise Physiology Lab (x2 sections)
EL 151 Weight Lifting (x2 sections)

Spring 2018
ES 349 Exercise Physiology Lab (x2 sections)
ES 457 Exercise Testing and Prescription (x2 sections)

Summer 2018
ES 456 Exercise Testing and Prescription Lecture
ES 457 Exercise Testing and Prescription Lab (x2 sections)

Fall 2018
HP 312 Behavioral Aspects of Weight Management Lecture
HP 312 Behavioral Aspects of Weight Management Web-Based Course

Spring 2019
HP 312 Behavioral Aspects of Weight Management Lecture
HP 312 Behavioral Aspects of Weight Management Web-Based Course

Summer 2019
ES 456 Exercise Testing and Prescription Lecture
ES 457 Exercise Testing and Prescription Lab

Fall 2019
HP 312 Behavioral Aspects of Weight Management Lecture
HP 312 Behavioral Aspects of Weight Management Web-Based Course

Spring 2020
HP 312 Behavioral Aspects of Weight Management Lecture
HP 312 Behavioral Aspects of Weight Management Web-Based Course

Summer 2020
ES 456 Exercise Testing and Prescription Lecture
ES 457 Exercise Testing and Prescription Lab

Fall 2020
HP 312 Behavioral Aspects of Weight Management Lecture
HP 312 Behavioral Aspects of Weight Management Web-Based Course

Spring 2021
HP 312 Behavioral Aspects of Weight Management Lecture
HP 312 Behavioral Aspects of Weight Management Web-Based Course

Summer 2021
ES 391 Trends and Topics in Exercise Science

Fall 2021
HP 312 Behavioral Aspects of Weight Management Lecture
HP 312 Behavioral Aspects of Weight Management Web-Based Course

Spring 2022
HP 191 Personal and Community Health
HP 312 Behavioral Aspects of Weight Management Lecture