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Psychometric Evaluation of Memory and Concentration Sections in the Standardized Assessment of Concussion

Seungho Ryu
University of Mississippi

PSYCHOMETRIC EVALUATION OF MEMORY AND CONCENTRATION SECTIONS IN THE STANDARDIZED ASSESSMENT OF CONCUSSION

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Seungho Ryu

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ABSTRACT

The purpose of this study is to evaluate validate the memory and concentration sections of the Standardized Assessment of Concussion (SAC) from the SCAT5. Two studies were conducted. The first study examined item difficulty and discrimination using 10 new word lists of 3 versions in the immediate memory section using item analysis based on classical test theory and to equate scores earned on different versions of 10 word lists using test equating methods. The second evaluated the validity of digits backwards in the concentration section, and evaluated current and new scoring methods for the digit backwards.

Two hundred young adults with no previous history of a concussion or head injury in the previous 6 months were tested and a convenient sampling method was used for this study. Participants were tested on orientation, immediate memory, digits backwards, months in reverse order, and delayed memory sequentially. Participants visited a total of 3 times in this study for testing lists A, B, and C (counter-balanced design) of immediate memory, and testing list A and two of lists B-F (anchor-test design) of concentration. In order to minimize a potential learning and/or memory interference effect, 48 hours occurred between each assessment. The first study used item analysis to examine item difficulty and discrimination based on classical test theory on 10 new word-lists of 3 versions in the memory section and to connect scores earned on different versions of 10 word-list using test equating methods. The second study evaluated the validity of digits backwards in the concentration section and evaluated the current and new scoring methods for the digit backwards using item analysis.

Results of the first study were as follows: 1) the 3 lists of immediate and delayed memory had most items that obtained acceptable difficulty and discrimination. List A had 20 (100%), list B had 17 (85%), and list C contained 19 (95%) items that met both criteria; 2) to equate lists A and B, list A and C, smoothed equipercentile method and linear method were selected using root mean squared difference (RMDS) and mean signed difference (MSD). Based on the results of smooth equipercentile and linear equating, we developed a raw to raw rounded scores conversion table to equate list A and B / list A and C of immediate memory.

Results of the second study were as follows: 1) item determination indicated that 3, and the second row of 4 strings had an unacceptable item. However, 5 and 6 strings obtained acceptable both of item difficulty and discrimination; 2) We found that all 3 strings had unacceptable items using 3 scoring methods. In 4 strings, however, it was found that item determination was improved when using method 2 scoring. Therefore, it might be that method 2 scoring is a better scoring method than traditional and method 1 scoring.

Our study demonstrated the 3 versions in the memory sections had appropriate validity by an adequate amount of acceptable items. Furthermore, most items in each version have acceptable psychometric properties, enhancing the validity of baseline SAC score for assessing concussions' effects. In addition, we provided a scores conversion table of immediate memory for improving the validity of baseline SAC scores. However, the new 6 lists of digits backwards in the concentration section need to be modified to have adequate validity. In addition, it was found that the new scoring method proposed by SAC is different from the scoring method we tested. Therefore, clinicians and practitioners using SAC need to be careful when recognizing and interpreting SAC's problems when using SCAT5.

DEDICATION

This dissertation is wholeheartedly dedicated to my wife, Renee Lukas, who has been my source of inspiration and gave me strength when I thought of giving up, who continually provide her sacrifice, spiritual, emotional.

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CHAPTER I:

INTRODUCTION

Concussion is derived from the Latin *concutere*, which means "to shake violently"[1]. The definition of concussion in major sports and health organizations is as follows: 1) "a traumatic brain injury induced by biomechanical forces."[2]; 2) ''trauma induced alteration in mental status that may or may not involve loss of consciousness.''[3]; 3) "a traumatically induced transient disturbance of brain function and involves a complex pathophysiologic process."[4] Despite many attempts to define concussion, the term is still not well defined in clinical or research fields.[5-7] Therefore, to summarize the definition of concussion, it can be defined as a sudden, temporary change in consciousness caused by traumatic biomechanical forces that are transmitted directly or indirectly to the brain.[2-4,8] Also, concussions are manifested as mild traumatic brain injury (mTBI)[7,9]. Therefore, it is often used interchangeably with mTBI.[7,10]

Concussion has become an important topic of interest in the sports medicine and neurology community as well as sports participants, families, schools and organizations and the medical community are interested in comparing the incidence of concussions in school sports and whether the concussion rate increases or not.[11-13] One reason may be that concussion differs from many other sports injuries in that it is difficult to detect signs and to treat injury.[13] In the United States, it is noted that retired American football players have claimed to return to play too early after a collision in spite of the threat of concussion.[14] The number of people who have been hospitalized with more than one TBI worldwide is estimated at 57 million.[15,16] 1.7 million people experience a TBI annually in the United States, 80% of these are treated and discharged from the emergency room, 52,000 people pass away, and 275,000 people are hospitalized due to TBI.[17] Among TBI incident cases, about 70 to 90% are concussions.[18,19] According to another report, estimates of concussion range from 1.6 million to 3.8 million affected annually in the United States, with one in five children under 19 years of age having been treated for sports-related injuries.[14] To put this into perspective, about 460,000 athletes participate in college level sports annually and are at risk for a large portion of reported concussions.[20]

Various neurological symptoms can appear, which are significantly more functionally reflected than structural brain disorders from concussion.[21] Concussion causes symptoms that occur in physical, cognitive and emotional health.[10] Many studies report the following commonly reported symptoms and signs of injury: headache and dizziness in the physical health; difficulty in concentration and memory in the cognitive health; irritability and nervousness for emotional health; insomnia for sleep health.[22-25] Most (80% -90%) sports-related concussions resolve within 7-10 days, but for some athletes, complete recovery takes much longer and includes loss of consciousness, amnesia, sleep disorders, behavioral changes, and cognitive impairment.[10,26,27]

Repeated concussions are associated with long-term consequences and continue to affect people after years or even decades.[28] These results include mood and cognitive disorder, as well as pathological changes in the brain that include chronic traumatic encephalopathy (CTE).[29-32] Chronic traumatic encephalopathy was recently established on a consensus basis as a unique neuropathological disorder.[32] The relationship between concussion and CTE is still unclear, as the disease has been found in people who have been repeatedly exposed to head injuries through contact sports and other mechanisms. This notion represents another potential consequence of participating in contact or conflict sports.[32-34]

Concussions are 6 times more likely to occur in organized sports than in leisure physical activity.[35] It occurs in nearly all sports, however, the incidence of concussions in football is continually higher than in almost all other sports in high school and university athlete-related studies.[36] From 1999 to 2001, the original National Collegiate Athletic Association (NCAA) Concussion Report of 2,905 college football players yielded some important results.[25] Athletes with a history of concussion were more likely to have a potential concussion injury than patients with no history. One of 15 participants had a concussion sustained within the season, and almost all repeated concussions (92 %) occurred within 10 days of the initial concussion. The media also introduced the link between (repetitive) concussion injuries and bad psychosocial consequences through reports of famous athlete suicide or severe mood and behavioral disorders.[37] But until these risks become clear, there is a general consensus that competing players must have no residual effect of concussion before returning to competition [23] and the potential negative psychological consequences of sports-related concussions have been clearly considered within the post-concussion assessment tool.[38]

Many methods are developed for measuring concussion-related symptoms or impairment, including a simple "sideline" neurocognitive test [39,40], balance test[41], and a more extensive neuropsychological test[42,43] designed to detect changes in cognitive function by comparing the player's test score to their preseason baseline. The self-reported subjective symptom scales, such as symptom scale, concussion evaluation tools, Glasgow coma scale, Maddocks Questions, post-concussion symptom scales, and standardized assessment of concussion (SAC) have played an equal role in detecting diagnostic information on concussion and have been incontestable in several studies as being repeatedly sensitive to the consequences of concussion.[27,44,45] Because of the complex nature of concussions with a variety of signs and symptoms, it is best to use multidimensional testing with the agreement of experts.[24]

The Sport Concussion Assessment Tool (SCAT) was introduced following the 2nd International Conference on Concussion in Sport in Prague, Czech Republic in 2004.[12] The purpose was to 'create a standardised tool that could be used for patient education as well as for physician assessment of sports concussion'.[46] The SCAT2 and SCAT 3 were released, respectively, in 2008 and 2012. The latest version is the SCAT5 that was developed to improve on the previous versions of SCAT, consisting of the Red flags, Observable signs, Cervical spine assessment, Glasgow coma scale, Maddocks score, concussion symptom scales with 22 items, Standardized Assessment of Concussion (SAC), neurological screen, and Modified Balance Error Scoring System in 2017.[47] The Concussion in Sport Group (CISG) recommended to use the SCAT because it contains comprehensive instructions for the proper administration of subscales that must be carefully studied and executed before clinical use and represents the best established and rigorously developed instruments currently available for on-field or sideline evaluation.[2,10,48] SCAT can measure various signs and symptoms in different domains, therefore using SCAT can increase concussion assessment accuracy.[2,10,12,49]

The SAC test was developed to provide a standardized method for the assessment of a concussion on the sideline in sports settings [50,51] and has been widely used in the field.[52,53] The SAC test uses four domains to help identify cognitive dysfunctions, including orientation, immediate memory, concentration, and delayed memory.[50,51] Orientation is tested with 5 simple questions; for example, What month is it? and What is the date today? The participant receives 1 point for each correct answer (possible points = 5). The immediate memory is tested with a list of 5 words, and then having the participant repeat the list of 5 words in any order. This examination is repeated 3 times (possible points = 15). The concentration section consists of 2 parts: digits backwards and months in reverse order. Digits backwards is tested with a string of digits (numbers of digits: 3 to 6), and the participant repeats each string of digits backwards. For example, they were given the following digits, 4, 8, 5 and 7, and a correct response would be 7, 5, 8, and 4. Next, the participant is asked to list the months backwards. The participant receives 1 point for each correct answer in the concentration section (possible points = 5). For delayed memory, the participant is tested by recalling the list of 5 words from the immediate memory question (possible points = 5). The SAC is administered to obtain a baseline score before injury, and again, to classify a concussion after injury. The SAC has up to 30 possible points with each correct response corresponding to 1 point. If the SAC's pre- and post-total scores decrease by more than 3 points, it indicates a change in cognitive status has occurred.[51,54] The SAC test can be completed in less than 15 minutes.

It is easy to use, portable, and acceptably sensitive to concussions.[50,51,54] Recently, the SAC has been updated. In the memory section, 10 word lists have been added, so the SAC has two types of word lists in the memory section (both 5 and 10 word lists). In the concentration section, more string lists have been added to digits backwards and a new scoring method is introduced. The SAC has up to 50 possible points with each correct response corresponding to 1 point if the practitioner chooses the 10 word lists.

Several studies have identified potential problems with the memory sections of SAC.[55-57] According to a previous study by McElhiney et al.[56], the 5 word-list had a ceiling effect and the 10 word-list indicated acceptable psychometric properties that improved the validity of the memory section using item analysis. Norheim et al. concluded that the new 10 word-list eliminates the ceiling effect.[58] However, to ensure proper psychometric characteristics, such as reliability and validity, it is necessary to construct a valid and defensible test with acceptable item difficulty and discrimination; thus,an item analysis should be used to evaluate the new word list. Since there are 3 versions of 10 word-list in immediate memory of SAC, we cannot interchangeably use the SAC scores of each version because each version may have different difficulty levels. A problem such as this is of importance when diagnosing a concussion because, without proper adjustment for non-equivalence, the result could lead to a possible misdiagnosis.

In the concentration section, there are two types of measures: the digits backwards and months in reverse order. It is necessary to evaluate validity and item analysis of the digits backwards measure because we have limited information as to whether the digits backwards is an effective measure of concentration. According to a previous study, the item difficulty level of the 3 strings in digits backwards was unacceptable.[55] To our knowledge, no study has yet to examine the new 6 string lists of digits backwards psychometric properties, such as item difficulty. Also, the traditional digits backwards scoring method has potential problems, such as if both of the 3 strings (e.g., 4-9-2 and 6-3-9) fail, the test is automatically stopped (resulting in a score of zero for the remaining items) even if participants may be able to answer the rest of strings (4, 5, 6 strings) correctly. There have been no sutdies evaluated for concentration scoring. Therefore, it is necessary to study the validity of the item analysis and scoring method.

Purpose of Study

The purpose of this study was to evaluate validate the memory and concentration sections of the SAC from the SCAT5. Two studies were planned for the entire research purpose. The specific aims of this study are:

Study 1

1-1) to evaluate the validity of 10 new word lists of 3 versions in the memory section by performing item analysis (item difficulty and discrimination).

1-2) to equate 3 versions of 10 word lists in the memory section using test equating methods.

Study 2

2-1) to evaluate the validity of digits backwards in the concentration section by performing item analysis.

2-2) to evaluate current and new scoring methods for the digit backwards.

BIBLIOGRAPHY

1. Khurana VG, Kaye AHJJoCN. An overview of concussion in sport. 2012;19(1):1-11.
2. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. *British journal of sports medicine.* 2017;51(11):838-847.
3. Neurology AAo. Practice parameter: The management of concussion in sports (summary statement): Report of the Standards Subcommittee. *Neurology.* 1997;48:581-585.
4. Harmon KG, Drezner J, Gammons M, et al. American Medical Society for Sports Medicine position statement: concussion in sport. *Clinical Journal of Sport Medicine.* 2013;23(1):1-18.
5. Bodin D, Yeates KO, Klamar K. Definition and classification of concussion. In: *Pediatric and adolescent concussion.* Springer; 2012:9-19.
6. Scorza KA, Raleigh MF, O'Connor FG. Current concepts in concussion: evaluation and management. *American family physician.* 2012;85(2):123-132.
7. King D, Brughelli M, Hume P, Gissane C. Assessment, management and knowledge of sport-related concussion: systematic review. *Sports medicine.* 2014;44(4):449-471.
8. Ropper AH, Gorson KCJNEJoM. Concussion. 2007;356(2):166-172.

9. Herring SA, Bergfeld JA, Boland A, et al. Concussion (mild traumatic brain injury) and the team physician: a consensus statement. *Medicine and science in sports and exercise.* 2006;38(2):395-399.

10. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport—the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *PM&R.* 2013;5(4):255-279.

11. Aubry M, Cantu R, Dvorak J, et al. Summary and agreement statement of the first International Conference on Concussion in Sport, Vienna 2001. *The Physician and sportsmedicine.* 2002;30(2):57-63.

12. McCrory P, Johnston K, Meeuwisse W, et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *British journal of sports medicine.* 2005;39(4):196-204.

13. Lincoln AE, Caswell SV, Almquist JL, Dunn RE, Norris JB, Hinton RY. Trends in concussion incidence in high school sports: a prospective 11-year study. *The American journal of sports medicine.* 2011;39(5):958-963.

14. Maegele M. Traumatic brain injury in 2017: exploring the secrets of concussion. *The Lancet Neurology.* 2018;17(1):13-15.

15. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *The Journal of head trauma rehabilitation.* 2006;21(5):375-378.

16. Murray CJ, Lopez AD. *Global health statistics: a compendium of incidence, prevalence and mortality estimates for over 200 conditions.* Harvard University Press; 1996.

17. Faul M, Wald MM, Xu L, Coronado VG. Traumatic brain injury in the United States; emergency department visits, hospitalizations, and deaths, 2002-2006. 2010.

18. Control CfD, Prevention. Report to Congress on mild traumatic brain injury in the United States: steps to prevent a serious public health problem. *Atlanta, GA: Centers for Disease Control and Prevention.* 2003;45.

19. Cassidy JD, Carroll L, Peloso P, et al. Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. *Journal of rehabilitation medicine.* 2004;36(0):28-60.

20. Wasserman EB, Kerr ZY, Zuckerman SL, Covassin T. Epidemiology of sports-related concussions in National Collegiate Athletic Association athletes from 2009-2010 to 2013-2014: symptom prevalence, symptom resolution time, and return-to-play time. *The American journal of sports medicine.* 2016;44(1):226-233.

21. Dettwiler A, Murugavel M, Putukian M, Cubon V, Furtado J, Osherson D. Persistent differences in patterns of brain activation after sports-related concussion: a longitudinal functional magnetic resonance imaging study. *Journal of neurotrauma.* 2014;31(2):180-188.

22. Guskiewicz KM, Bruce SL, Cantu RC, et al. National Athletic Trainers' Association position statement: management of sport-related concussion. *Journal of athletic training.* 2004;39(3):280.

23. Randolph C, Millis S, Barr WB, et al. Concussion symptom inventory: an empirically derived scale for monitoring resolution of symptoms following sport-related concussion. *Archives of Clinical Neuropsychology.* 2009;24(3):219-229.

24. Graham R, Rivara FP, Ford MA, Spicer CM, Youth CoS-RCi, Council NR. *Sports-related concussions in youth: improving the science, changing the culture.* National Academies Press (US); 2014.

25. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *Jama.* 2003;290(19):2549-2555.

26. Echemendia RJ, Putukian M, Mackin RS, Julian L, Shoss N. Neuropsychological test performance prior to and following sports-related mild traumatic brain injury. *Clinical Journal of Sport Medicine.* 2001;11(1):23-31.

27. McCrea M, Guskiewicz KM, Marshall SW, et al. Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. *Jama.* 2003;290(19):2556-2563.

28. Baugh CM, Kroshus E, Kiernan PT, Mendel D, Meehan III WP. Football players' perceptions of future risk of concussion and concussion-related health outcomes. *Journal of neurotrauma.* 2017;34(4):790-797.

29. Guskiewicz KM, Marshall SW, Bailes J, et al. Association between recurrent concussion and late-life cognitive impairment in retired professional football players. *Neurosurgery.* 2005;57(4):719-726.

30. Guskiewicz KM, Marshall SW, Bailes J, et al. Recurrent concussion and risk of depression in retired professional football players. *Medicine & Science in Sports & Exercise.* 2007;39(6):903-909.

31. Stern RA, Daneshvar DH, Baugh CM, et al. Clinical presentation of chronic traumatic encephalopathy. *Neurology.* 2013;81(13):1122-1129.

32. McKee AC, Cairns NJ, Dickson DW, et al. The first NINDS/NIBIB consensus meeting to define neuropathological criteria for the diagnosis of chronic traumatic encephalopathy. *Acta neuropathologica.* 2016;131(1):75-86.

33. Gavett BE, Stern RA, McKee AC. Chronic traumatic encephalopathy: a potential late effect of sport-related concussive and subconcussive head trauma. *Clinics in sports medicine.* 2011;30(1):179-188.

34. Omalu BI, DeKosky ST, Hamilton RL, et al. Chronic traumatic encephalopathy in a national football league player: part II. *Neurosurgery.* 2006;59(5):1086-1093.

35. Browne GJ, Lam LT. Concussive head injury in children and adolescents related to sports and other leisure physical activities. *British journal of sports medicine.* 2006;40(2):163-168.

36. Kerr ZY, Thomas LC, Simon JE, McCrea M, Guskiewicz KM. Association between history of multiple concussions and health outcomes among former

college football players: 15-year follow-up from the NCAA Concussion Study (1999-2001). *The American journal of sports medicine.* 2018;46(7):1733-1741.

37. Kuhn AW, Yengo-Kahn AM, Kerr ZY, Zuckerman SL. Sports concussion research, chronic traumatic encephalopathy and the media: repairing the disconnect. In: BMJ Publishing Group Ltd and British Association of Sport and Exercise Medicine; 2017.

38. Alsalaheen B, Stockdale K, Pechumer D, Broglio SP. Validity of the immediate post concussion assessment and cognitive testing (ImPACT). *Sports medicine.* 2016;46(10):1487-1501.

39. McCrory P. Does second impact syndrome exist? *Clinical Journal of Sport Medicine.* 2001;11(3):144-149.

40. McCrea M, Kelly JP, Randolph C, Cisler R, Berger L. Immediate neurocognitive effects of concussion. *Neurosurgery.* 2002;50(5):1032-1042.

41. Guskiewicz KM. Assessment of postural stability following sport-related concussion. *Current Sports medicine reports.* 2003;2(1):24-30.

42. Echemendia RJ, Julian LJ. Mild traumatic brain injury in sports: neuropsychology's contribution to a developing field. *Neuropsychology review.* 2001;11(2):69-88.

43. Randolph C. Implementation of neuropsychological testing models for the high school, collegiate, and professional sport settings. *Journal of Athletic Training.* 2001;36(3):288.

44. Macciocchi SN, Barth JT, Alves W, Rimel RW, Jane JA. Neuropsychological functioning and recovery after mild head injury in collegiate athletes. *Neurosurgery.* 1996;39(3):510-514.

45. McCrory PR, Ariens M, Berkovic SF. The nature and duration of acute concussive symptoms in Australian football. *Clinical Journal of Sport Medicine.* 2000;10(4):235-238.

46. Davis GA, Purcell L, Schneider KJ, et al. The child sport concussion assessment tool 5th edition (child scat5): background and rationale. *Br J Sports Med.* 2017;51(11):859-861.

47. Sport concussion assessment tool - 5th edition. *British Journal of Sports Medicine.* 2017;51(11):851-858.

48. Echemendia RJ, Meeuwisse W, McCrory P, et al. The sport concussion assessment tool 5th edition (SCAT5): background and rationale. *Br J Sports Med.* 2017;51(11):848-850.

49. Guskiewicz KM, Register-Mihalik J, McCrory P, et al. Evidence-based approach to revising the SCAT2: introducing the SCAT3. *Br J Sports Med.* 2013;47(5):289-293.

50. McCrea M, Kelly JP, Randolph C, et al. Standardized assessment of concussion (SAC): on-site mental status evaluation of the athlete. *The Journal of head trauma rehabilitation.* 1998;13(2):27-35.

51. McCrea M. Standardized mental status testing on the sideline after sport-related concussion. *Journal of athletic training.* 2001;36(3):274.

52. Kelly KC, Jordan EM, Joyner AB, Burdette GT, Buckley TA. National Collegiate Athletic Association Division I athletic trainers' concussion-management practice patterns. *Journal of athletic training.* 2014;49(5):665-673.

53. Lynall RC, Laudner KG, Mihalik JP, Stanek JM. Concussion-assessment and-management techniques used by athletic trainers. *Journal of athletic training.* 2013;48(6):844-850.

54. Barr WB, McCrea M. Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. *Journal of the International neuropsychological Society.* 2001;7(6):693-702.

55. Ragan BG, Herrmann SD, Kang M, Mack MG. Psychometric Evaluation of the Standardized Assessment of ConcussionEvaluation of Baseline Score Validity Using Item Analysis. *Athletic training and sports health care.* 2009;1(4):180-187.

56. McElhiney D, Kang M, Starkey C, Ragan B. Improving the memory sections of the standardized assessment of concussion using item analysis. *Measurement in physical education and exercise science.* 2014;18(2):123-134.

57. Ragan BG, Kang M. Measurement issues in concussion testing. *Athletic Therapy Today.* 2007;12(5):2-6.

58. Norheim N, Kissinger-Knox A, Cheatham M, Webbe F. Performance of college athletes on the 10-item word list of SCAT5. *BMJ open sport & exercise medicine.* 2018;4(1):e000412.

CHAPTER II:

THE FIRST ARTICLE

Psychometric Evaluation of Memory Section in the Standardized Assessment of Concussion: Evaluation of Baseline Score Validity Using Item Analysis and Test Equating

INTRODUCTION

The term "concussion" is defined in various areas. For example, “the injury is caused by quantified direct or indirect force(s) to the brain” in biomechanics / “a defined physiological disruption of brain function” in physiology / “a range of evolving clinical symptoms and signs including an alteration in cognitive functioning or mental state (e.g. confusion, disorientation, slowed thinking) that may or may not involve transient loss of consciousness” in clinical.[1] Concussion is often used interchangeably as a diagnosis, with terms such as mild traumatic brain injury (mTBI), minor head injury, and mild closed head injury.[1-3] Concussion is more commonly used in the community of sports medicine, while mTBI is the preferred term in other medical specialties.[4] Several organizations have attempted to provide a definition for concussion or mTBI; however, no consensus has been reached. One of the first attempts at creating a definition was in 1966 by the Congress of Neurological Surgeons, where it was defined as “a clinical syndrome characterized by immediate and transient impairment of neural functions, such as alteration of consciousness, disturbance of vision, equilibrium, etc. due to mechanical forces.”[5] The International Symposia on Concussion in Sports provided the most recent consensus definition of concussion.[6] This definition, often called the Zurich definition, was “concussion is defined as a complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces” that emphasizes the functional changes that acutely follow concussion.

Concussion has become a major topic of interest within the community of sports medicine and neurology and has been recognized as a major public health concern.[7-11] It may be because concussions can be different from many other sports injuries in that it is difficult to detect the signs and treat injuries related to concussions and if people are properly trained to evaluate concussions the signs are not difficult to detect – but many of the signs are subjective and cannot be easily measured using standardized tests. Furthermore concussion rates have doubled over the past 2-3 decades.[12,13] Many sports such as football and basketball are linked to an increased risk of sports-related concussions.[14] In the United States, about 1.7 million people are concussed each year, which is associated with 1,365 million emergency room visits and 275,000 hospitalizations per year, which were estimated to reach $60 billion in the United States in 2000.[15,16] Also, the collegiate population is more clear-cut, with 121.5 cases per 10,000 students excluding varsity athletes and 132.4 cases per 10,000 with varsity athletes.[17]

Concussion causes physical, cognitive, and emotional health symptoms.[18] According to previous studies, they reported common symptoms and signs of concussion such as headache and dizziness, difficulty in concentration and memory, and irritability and nervousness.[19-22] The presence of physical, cognitive deficits, and other residual symptoms may not affect people’s lives in relation to sports participation and activities of daily living, but it can hinder their ability to socialize with friends, decrease work performance, and affect their health related quality of life.[23,24] Accordingly, it is crucial to measure the signs and symptoms of concussion accurately. Due to the complex nature of concussion with various signs and symptoms, it is best to use multidimensional tests with the consent of experts.[21]

The Sport Concussion Assessment Tool 5 (SCAT5), one of the widely used multidimensional test because it includes comprehensive guidelines for proper management of subscales that need to be carefully researched and implemented before clinical use and offers the best established and precisely developed on-field or sideline assessment instruments currently available.[18,25,26] The SCAT5 consists of multiple tests including the Red flags, Observable signs, Cervical spine assessment, Glasgow coma scale, Maddocks score, concussion symptom scales with 22 items, Standardized Assessment of Concussion (SAC), neurological screen, and Modified Balance Error Scoring System.[27]

The SAC test has four sections and identifies cognitive dysfunction including orientation, immediate memory, concentration, and delayed memory.[28,29] Orientation is tested with 5 simple questions. The participant receives 1 point for each correct answer (possible points = 5). In the immediate memory, there are 2 types of tests (6 versions of 5 word lists and 3 versions of 10 word lists). If the immediate memory is tested with a list of 5 words, the participant will repeat the list of 5 words in any order and when tested with a list of 10 words he or she repeats the list of 10 words in any order. This examination is repeated 3 times regardless the type of word list (possible points = 15 or 30). The concentration section is consisted of 2 parts; digits backwards and months in reverse order. Digits backwards is tested with a string of digits (numbers of digits: 3 to 6), and the participant repeats each string of digits backwards. Then, the participant is asked to list the months in reverse order. The participant receives 1 point for each correct answer in the concentration section (possible points = 5). For the delayed memory, the participant is tested on recalling the list of 5 or 10 words in the immediate memory section (possible points = 5 or 10). The SAC has a maximum of 30 or 50 possible points depending on the type of immediate memory.

Several studies have indicated potential problems of the memory section in SAC.[30,31] According to a previous study, the 5 word lists had a ceiling effect and the 10 word lists represented acceptable psychometric properties that improved the validity of the memory section using item analysis.[32] A new study also demonstrated that the ceiling effect was eliminated when using one of the 3 versions with the 10 word lists by comparing the descriptive statistics.[33] To ensure proper psychometric properties such as reliability and validity, valid and defensible tests must be constructed with acceptable item difficulty and discrimination. However, there is insufficient information on the new 10 word lists. Therefore, it is necessary to evaluate the new 3 versions of 10 word lists using item analysis. Furthermore, while the new 3 versions of 10 word lists are being used to measure the same immediate memory, test scores from these versions often are not exchangeable because they may be set on different difficulty and discrimination levels. In order to compare scores, or set equivalent criteria, across the 3 versions of 10 word lists, it is necessary to adjust for these difficulty differences, allowing the versions in the memory section to be used interchangeably using test equating. Test equating is a statistical method that is determined to make comparable scores, on different versions or forms of a test. Therefore, the purposes of this study are (1) to examine item difficulty and discrimination using 10 new word lists of 3 versions in the memory section using item analysis based on classical test theory and (2) to equate scores earned on different versions of 10 word-lists using test equating methods.

METHODS

Participants

In general, a sample size of 200 is recommended for reasonable statistical stability for conducting item analysis.[34,35] Therefore, 200 university students with no previous history of a concussion or head injury in the previous 6 months were tested. A convenient sampling method was used for this study. Investigators entered classrooms and recruited participants verbally. Only those who have met the Test of English as a Foreign Language (TOEFL) score required by the school participated, if the participants were international students. This study was approved by the university Institutional Review Board.

Instrument

The SAC in SCAT5 consists of 4 sections, including orientation, immediately memory, concentration, and delay memory. The immediate memory section is comprised of a set of 5-item word-lists and 10-item wordlists that is repeated three times. This study used the 10-item word lists that come from SAC. Three versions of 10-item word lists can be found in Table 1.

Table 1. 10-item word lists of 3 versions

List A	List B	List C
Finger	Baby	Jacket
Penney	Monkey	Arrow
Blanket	Perfume	Pepper
Lemon	Sunset	Cotton
Insect	Iron	Movie
Candle	Elbow	Dollar
Paper	Apple	Honey
Sugar	Carpet	Mirror
Sandwich	Saddle	Saddle
Wagon	Bubble	Anchor

Note. These word lists were used for the immediate and delayed memory sections.

Procedures

Informed consent was obtained before participation in this study. Each participant completed a health history questionnaire to identify his or her age, sex, and possible history of head trauma. Participants were tested sequentially for orientation, immediate memory, digits backwards, months in reverse order, and delay memory. They visited a total of 3 times on Zoom in this study for testing list A, B, and C of immediate memory with a counter-balancing order. The delayed recall was performed after 5 minutes have passed by the end of the immediate recall section. In order to minimize a potential learning and/or memory interference effect, 48 hours occurred between each assessment. Data collection consisted of an oral interview via Zoom and it took approximately 15 minutes to complete. Before starting the experiment, researchers advised participants to remove tools that they could use to cheat, such as pens and paper, from where they were sitting. Also, the day before data collection, researchers contacted the participant in advance by email or message and requested the participants to participate only in a quiet place without any distractions. Participants were tested on list A, B, and C, respectively as demonstrated below in Table 2.

Table 2. Test order of 10-item word lists

Participant ID	1st visit	2nd visit	3rd visit
1	List A	List B	List C
2	List B	List C	List A
3	List C	List A	List B
4	List A	List C	List B
5	List B	List A	List C
6	List C	List B	List A
⋮	⋮	⋮	⋮
193	List A	List B	List C
194	List B	List C	List A
195	List C	List A	List B
196	List A	List C	List B
197	List B	List A	List C
198	List C	List B	List A
199	List A	List B	List C
200	List B	List C	List A

Data Analysis

Analysis method for the first purpose of study

Psychometric properties, item difficulty, and item discrimination were calculated for each item of all versions in immediate memory using Iteman software (v 3.5). In addition, to determine the similarity of meaning of words to each other in the memory section, latent semantic analysis was used.

Item difficulty (*P*)

Item difficulty represents the proportion of participants who answered an item correctly. There are two types (criterion-referenced standard and individual-centered or norm-referenced standards) of acceptable ranges of item difficulty recommended by the National Organization for Competency Assurance (NOCA) handbook. The acceptable range for a criterion-referenced standard is 0.33 to 0.92, whereas the acceptable range for an individual-centered method or norm-referenced standard is 0.10 to .92. Because the National Association of Athletic Trainers and the International Consensus Statement on Sports Concussion recommends the use of an individual-centered standard that compares post-injury scores to baseline scores, an acceptable *P* range was set between 0.10 and 0.92 to allow for wide range of item difficulties.[6,19,28,35] Each item below P = 0.10 was considered "too hard," and above P = 0.92 was regarded as "too easy."

Item discrimination

Item discrimination represents how well each item separates the upper group from the bottom group. Item discrimination was evaluated using point-biserial correlation (r_{pb}). Greater than or equal to 0.10 of the point-biserial correlation (r_{pb}) indicates item discrimination is acceptable[35], and less than 0.10 indicates unacceptable discrimination.

Item determination

Each item was classified as "acceptable" or "unacceptable" based on the results of both item difficulty and item discrimination. The criteria of "acceptable" is that the item must have both an item difficulty (P) of 0.10 to 0.92 and item discrimination (r_{pb}) of greater than 0.10. If one or both of these criteria is not met, the item will be considered unacceptable.[31]

Analysis method for the second purpose of the study

Test equating is "a statistical procedure to establish the relationships between scores from two or more tests, or simply to place two or more tests on a common scale." (Hambleton & Swaminathan, 1985). The purpose of test equating is to improve test score integrity by not having to administer the same test again and again, which ensures fairness of a test or eliminate a practice effect, multiple forms are often required in testing practice and to use test scores interchangeability. While multiple tests are being used to measure the same variable in practice, test scores from these tests often are not interchangeable because they are set on different scales.[36]

Test equating methods can be classified as linear and equipercentile (unsmoothed / smoothed) equating in traditional equating.[37,38] Traditional equating is suitable for single and equivalent-group designs. The linear equating method is used to calculate the slope and intercept using the mean and standard deviation of the two tests, and then predict the new test score using the linear equation. For example, the linear equating method is set as following:

$$\frac{X_1 - \overline{X}_1}{S_1} = \frac{X_2 - \overline{X}_2}{S_2} \rightarrow X_1 = \frac{S_1}{S_2} X_2 + \left[\overline{X}_1 - \frac{S_1}{S_2} \overline{X}_2 \right]$$

Where X_1 and X_2 are raw scores, $\overline{X}_1$ and $\overline{X}_2$ are means, and S_1 and S_2 are standard deviation of test 1 and test 2.

In equipercentile equating, score distributions are set the same so that the same percentile ranks from different tests are deemed to indicate the same level of performance. Therefore, determining the percentile rank for the score distribution of each of the two tests to be equated is the first stage in equipercentile equating for single and equivalence groups designs. Then a "rank-raw score curve" can be created after plotting the percentile rankings for the raw scores from each of the two tests. To determine the best equating method among traditional equating, we will utilize two indexes such as root mean squared difference (RMDS) and mean signed difference (MSD).[37] The RMDS indicates similarly to the standard error of estimate in a regression analysis in evaluating prediction accuracy, which is defined as:

$$RMSD = \sqrt{\frac{1}{N} \sum_{j=1}^{N} (O_j - E_j)^2}$$

Where O_j indicates to Examinee *j*'s observed score on list A, E_j indicates to Examinee *j*'s equivalent score on test based on the examinee's list B, and N indicates to the total number of examinees. The MSD indicates equating bias, which means the tendency is to generate equated scores that are systematically too high or low[39], which is defined as:

$$MSD = \frac{1}{N} \sum_{j=1}^{N} (O_j - E_j)$$

The smaller the RMSD and MSD indicate the more accurate the equating.

Test equating was calculated for each version of immediate memory using traditional methods (Linear and equipercentile equating). Linear and equipercentile equating were calculated by RAGE-RGEQUATE (v3.22).

We developed a raw score conversion table to compare the raw scores of three versions.

RESULTS

Demographic Characteristics

Demographic characteristics of the study variables are shown in Table 3. Participants, on average, were 22.42 (4.92) years of age, 62.5% female, 63% non-Hispanic white. Three-fourths (78%) of the sample were undergraduate students and one-fourth (22%) were graduate students.

Table 3. Demographic characteristics (N = 200)

Variable	Point Estimate
Age, *M* years (*SD*)	22.42 (4.92)
Gender, # (%)	
Male	75 (37.50)
Female	125 (62.50)
Race, # (%)	
Non-Hispanic White	126 (63)
Non-Hispanic Black	36 (18)
Other / Multirace	35 (17.5)
Mexican American	2 (1)
Other Hispanic	1 (0.5)
Education, # (%)	
Undergraduate	156 (78)
Freshman	15 (7.5)
Sophomore	40 (20)
Junior	66 (33)
Senior	35 (17.5)
Graduate	44 (22)

Note. *M* = mean; *SD* = standard deviation; # = numbers

Results for the first purpose of study

Item Difficulty

Out of a total possible score of 20, the means and standard deviations of item difficulty in each memory section were 0.61 ± 0.15 (List A), 0.64 ± 0.21 (List B), and 0.55 ± 0.18 (List C). Overall, the difficulty of C was higher than List A and B.

The item analysis indicated that most items in each version had appropriate item difficulty of immediate and delayed memory. However, some items were shown to be too easy (List A = 0, 0%; List B = 2, 10%; List C = 0, 0%). Word "Baby" in list B indicated too easy both in immediate and delayed memory. As indicated in Table 4, all versions of the immediate and delayed memory have a different range of mean difficulty, indicating that each version of immediate and delayed memory is different in item difficulty levels.

Table 4. Item difficulty based on List A, B, and C

		Item Difficulty (.1 ≤ *P* ≤ .92)			
	Item	List A	List B	List C	*M*
Immediate Memory	1	0.75	0.95	0.90	0.87
	2	0.71	0.90	0.56	0.72
	3	0.56	0.70	0.47	0.58
	4	0.48	0.48	0.31	0.42
	5	0.49	0.41	0.45	0.45
	6	0.31	0.36	0.24	0.30
	7	0.32	0.28	0.46	0.35
	8	0.44	0.37	0.31	0.37
	9	0.62	0.65	0.53	0.60
	10	0.56	0.30	0.37	0.41
	M	0.52	0.54	0.46	
Delayed Memory	1	0.81	0.93	0.85	0.86
	2	0.71	0.88	0.66	0.75
	3	0.79	0.75	0.68	0.74
	4	0.79	0.81	0.51	0.70
	5	0.66	0.77	0.63	0.69
	6	0.60	0.70	0.55	0.62
	7	0.55	0.64	0.76	0.65
	8	0.63	0.62	0.50	0.58
	9	0.69	0.70	0.68	0.69
	10	0.68	0.58	0.49	0.58
	M	0.69	0.74	0.63	
	Total M	0.61	0.64	0.55	

Item Discrimination

Out of the total possible score of 20, the means and standard deviations of item difficulty in each memory section were the following; List A = 0.29 ± 0.10, list B = 0.29 ± 0.11, and list C = 0.26 ± 0.08.

The results revealed that each version in the number of items had appropriate discrimination; List A had 20 items (100%), list B had 19 items (95%), and list C had 19 items (95%). The word “Saddle” in list B and “Jacket” in list C showed to be problematic in immediate memory and there were no problems with words in the delayed memory. Item discrimination results are presented in Table 5 based on point-biserial correlations, listed by SAC list.

Table 5. Item discrimination based on List A, B, and C

	Item Discrimination (.1 $\leq r_{pb}$)			
	Item	List A	List B	List C
Immediate Memory	1	0.17	0.10	0.01
	2	0.16	0.32	0.24
	3	0.25	0.12	0.25
	4	0.41	0.34	0.22
	5	0.26	0.40	0.16
	6	0.18	0.26	0.15
	7	0.23	0.29	0.21
	8	0.21	0.22	0.23
	9	0.19	0.08	0.22
	10	0.16	0.18	0.23
	M	0.22	0.23	0.19
Delayed Memory	1	0.38	0.30	0.33
	2	0.27	0.29	0.34
	3	0.33	0.31	0.29
	4	0.32	0.32	0.36
	5	0.29	0.42	0.30
	6	0.42	0.33	0.33
	7	0.48	0.39	0.28
	8	0.44	0.44	0.32
	9	0.37	0.30	0.33
	10	0.35	0.48	0.34
	M	0.37	0.36	0.32
	Total M	0.29	0.29	0.26

Item Determination

Item determination indicated, based on the results, that the 3 lists of immediate and delayed memory had most items that obtained acceptable difficulty and discrimination. List A had 20 (100%), list B had 17 (85%), and list C contained 19 (95%) items that met both criteria. Item determination results are presented in Table 6, listed by SAC list.

Table 6. Item determination based on both item difficulty and item discrimination

		List A			List B			List C		
	Item	P	r_{pb}	D	P	r_{pb}	D	P	r_{pb}	D
Immediate Memory	1	0.75	0.17	A	0.95	0.10	U	0.90	0.01	U
	2	0.71	0.16	A	0.90	0.32	A	0.56	0.24	A
	3	0.56	0.25	A	0.70	0.12	A	0.47	0.25	A
	4	0.48	0.41	A	0.48	0.34	A	0.31	0.22	A
	5	0.49	0.26	A	0.41	0.40	A	0.45	0.16	A
	6	0.31	0.18	A	0.36	0.26	A	0.24	0.15	A
	7	0.32	0.23	A	0.28	0.29	A	0.46	0.21	A
	8	0.44	0.21	A	0.37	0.22	A	0.31	0.23	A
	9	0.62	0.19	A	0.65	0.08	U	0.53	0.22	A
	10	0.56	0.16	A	0.30	0.18	A	0.37	0.23	A
Delayed Memory	1	0.81	0.38	A	0.93	0.30	U	0.85	0.33	A
	2	0.71	0.27	A	0.88	0.29	A	0.66	0.34	A
	3	0.79	0.33	A	0.75	0.31	A	0.68	0.29	A
	4	0.79	0.32	A	0.81	0.32	A	0.51	0.36	A
	5	0.66	0.29	A	0.77	0.42	A	0.63	0.30	A
	6	0.60	0.42	A	0.70	0.33	A	0.55	0.33	A
	7	0.55	0.48	A	0.64	0.39	A	0.76	0.28	A
	8	0.63	0.44	A	0.62	0.44	A	0.50	0.32	A
	9	0.69	0.37	A	0.70	0.30	A	0.68	0.33	A
	10	0.68	0.35	A	0.58	0.48	A	0.49	0.34	A

Note. P= Item difficulty; r_{pb} = Item discrimination; D = Item determination; U = Unacceptable; A = Acceptable

Results of latent semantic analysis

Figure 1A-C displays the correlation coefficients among words in each version of immediate memory. The highest correlation scores for each version were 0.36 (Candle-Lemon) in list A, 0.23 (Baby-Monkey) in version B, and 0.26 (Saddle-Arrow) in version C. The correlation was interpreted according to the criteria used by Safrit and Wood[40] as follows: 0. - 0.2 = no relationship, 0.2 – 0.39 = low, 0.4 – 0.59 = moderate, 0.6 – 0.79 = moderately high, and 0.8 - 1 = high. The highest correlation score for each version has a weak relationship, indicating no problem with measuring immediate memory.

Document	Finger	Penny	Blanket	Lemon	Insect	Candle	Paper	Sugar	Sandwich	Wagon
Finger	1	0.20	0.17	0.19	0.09	0.18	0.22	0.10	0.16	0.09
Penny	0.20	1	0.21	0.13	-0.00	0.06	0.11	0.09	0.20	0.13
Blanket	0.17	0.21	1	0.12	0.00	0.36	0.15	0.03	0.16	0.15
Lemon	0.19	0.13	0.12	1	0.02	0.09	0.16	0.30	0.28	0.07
Insect	0.09	-0.00	0.00	0.02	1	-0.01	0.03	0.02	0.05	-0.00
Candle	0.18	0.06	0.36	0.09	-0.01	1	0.10	0.09	0.09	0.06
Paper	0.22	0.11	0.15	0.16	0.03	0.10	1	0.03	0.18	0.04
Sugar	0.10	0.09	0.03	0.30	0.02	0.09	0.03	1	0.24	-0.00
Sandwich	0.16	0.20	0.16	0.28	0.05	0.09	0.18	0.24	1	0.08
Wagon	0.09	0.13	0.15	0.07	-0.00	0.06	0.04	-0.00	0.08	1

Figure 1A. Correlation coefficients among 10 word list in version A of immediate memory

Document	Baby	Monkey	Perfume	Sunset	Iron	Elbow	Apple	Carpet	Saddle	Bubble
Baby	1	0.23	0.05	0.11	0.04	0.15	0.14	0.09	0.01	0.12
Monkey	0.23	1	0.07	0.11	0.04	0.07	0.19	0.20	0.09	0.06
Perfume	0.05	0.07	1	0.15	0.02	0.05	0.15	0.18	0.00	0.10
Sunset	0.11	0.11	0.15	1	0.05	0.11	0.12	0.15	0.13	0.11
Iron	0.04	0.04	0.02	0.05	1	0.01	0.08	0.08	0.07	-0.01
Elbow	0.15	0.07	0.05	0.11	0.01	1	0.14	0.18	0.13	0.06
Apple	0.14	0.19	0.15	0.12	0.08	0.14	1	0.13	0.02	0.14
Carpet	0.09	0.20	0.18	0.15	0.08	0.18	0.13	1	0.12	0.13
Saddle	0.01	0.09	0.00	0.13	0.07	0.13	0.02	0.12	1	0.00
Bubble	0.12	0.06	0.10	0.11	-0.01	0.06	0.14	0.13	0.00	1

Figure 1B. Correlation coefficients among 10 word list in version B of immediate memory

Document	Jacket	Arrow	Pepper	Cotton	Movie	Dollar	Honey	Mirror	Saddle	Anchor
Jacket	1	0.11	0.19	0.19	0.16	0.12	0.20	0.05	0.11	0.13
Arrow	0.11	1	0.06	0.02	0.10	0.05	0.07	0.05	0.26	0.03
Pepper	0.19	0.06	1	0.10	0.12	0.06	0.17	-0.02	0.03	0.11
Cotton	0.19	0.02	0.10	1	0.03	0.08	0.03	-0.00	0.03	0.04
Movie	0.16	0.10	0.12	0.03	1	0.13	0.04	0.10	0.04	0.01
Dollar	0.12	0.05	0.06	0.08	0.13	1	0.03	0.03	0.07	0.04
Honey	0.20	0.07	0.17	0.03	0.04	0.03	1	0.10	0.06	-0.02
Mirror	0.05	0.05	-0.02	-0.00	0.10	0.03	0.10	1	0.00	0.01
Saddle	0.11	0.26	0.03	0.03	0.04	0.07	0.06	0.00	1	0.07
Anchor	0.13	0.03	0.11	0.04	0.01	0.04	-0.02	0.01	0.07	1

Figure 1C. Correlation coefficients among 10 word list in version C of immediate memory

Results for the second purpose of study

The results of equating accuracy are summarized by method in Table 7 and 8. The RMSD and MSD index were used to identify the best equating method. The smaller the RMSD and MSD indicate the more accurate the equating. Between list A and B of immediate and delayed memory, the smoothed equipercentile method had the smallest RMSD (1.199). The unsmoothed equipercentile method had the largest (1.445). This is also the same for MSD which was the one closest to zero and had an MSD value of -1.169 (s=1.00). Therefore, smoothed equipercentile method was selected to equate lists A and B of immediate and delayed memory. Between list A and C of immediate and delayed memory, the linear method had the smallest RMSD (2.470), and the unsmoothed equipercentile method had the largest (2.505). This is also true for MSD at a value of 2.425 (s=1.00), which was the one closest to zero. Hence, to equate lists A and C of immediate and delayed memory, the linear method was chosen.

Table 7. Summary of equating accuracy by method between lists A and B

Equating Method	RMSD	MSD
Unsmoothed Euqipercentile	1.445	-1.335
Smoothed Equipercentile		
s=0.01	1.438	-1.336
s=0.05	1.425	-1.327
s=0.10	1.407	-1.319
s=0.20	1.378	-1.305
s=0.30	1.345	-1.282
s=0.40	1.307	-1.254
s=0.50	1.274	-1.229
s=0.75	1.216	-1.183
s=1.00	1.199	-1.169
Linear	1.343	-1.330

Note, RMSD = root mean squared difference; MSD = mean signed difference

Table 8. Summary of equating accuracy by method between lists A and C

Equating Method	RMSD	MSD
Unsmoothed Euqipercentile	2.505	2.443
Smoothed Equipercentile		
s=0.01	2.482	2.425
s=0.05	2.476	2.427
s=0.10	2.477	2.434
s=0.20	2.483	2.447
s=0.30	2.490	2.458
s=0.40	2.494	2.464
s=0.50	2.490	2.461
s=0.75	2.490	2.461
s=1.00	2.490	2.461
Linear	2.470	2.440

Note, RMSD = root mean squared difference; MSD = mean signed difference

Based on the results of smooth equipercentile and linear equating, both a raw to raw conversion table and a raw to raw rounded scores conversion table to equate list A and B / list A and C of immediate and delayed memory were developed, as summarized in Table 9. Based on this conversion table, an examinee's score on list A can easily be transferred to an equivalent score of list B and C, or vice versa. For example, if an examinee scores 4 in list A, the equivalent score will be obtained on list B, according to the table, is 5.

Table 9. Raw to raw conversion table and raw to raw rounded scores conversion table

List A	List B	List C
0	0.057	-0.265
1	1.171	0.655
2	2.284	1.575
3	3.398	2.495
4	4.512	3.415
5	5.626	4.335
6	6.739	5.256
7	7.853	6.176
8	8.967	7.096
9	10.081	8.016
10	11.194	8.936
11	12.308	9.856
12	14.536	10.776
13	14.536	11.697
14	15.649	12.617
15	16.732	13.537
16	17.781	14.457
17	18.727	15.377
18	19.673	16.297
19	20.618	17.218
20	21.564	18.138
21	22.510	19.058
22	23.455	19.978
23	24.401	20.898
24	25.347	21.818
25	26.293	22.738
26	27.238	23.659
27	28.184	24.579
28	29.13	25.499
29	30.075	26.419
30	31.021	27.339
31	31.967	28.259
32	32.913	29.180
33	33.858	30.100
34	34.804	31.020
35	35.750	31.940
36	36.695	32.860
37	37.641	33.780
38	38.492	34.700
39	39.295	35.621
40	40.098	36.541

⇨

List A	List B	List C
0	0	0
1	1	1
2	2	2
3	3	2
4	5	3
5	6	4
6	7	5
7	8	6
8	9	7
9	10	8
10	11	9
11	12	10
12	13	11
13	15	12
14	16	13
15	17	14
16	18	14
17	19	15
18	20	16
19	21	17
20	22	18
21	23	19
22	23	20
23	24	21
24	25	22
25	26	23
26	27	24
27	28	25
28	29	25
29	30	26
30	31	27
31	32	28
32	33	29
33	34	30
34	35	31
35	36	32
36	37	33
37	38	34
38	38	35
39	39	36
40	40	37

DISCUSSION

Previous work has demonstrated the 5 word lists had a ceiling effect and the 10 word lists represented acceptable psychometric properties that improved the validity of the memory section using item analysis.[26,31,32] A new study also demonstrated that by comparing the descriptive statistics, the ceiling effect was removed when utilizing one of the 3 versions with the 10 word lists.[33] No study has looked at the new 3 versions of the 10 word list of immediate memory using item analysis and test equating.

Our findings demonstrated 3 versions of 10 word list of immediate memory (list A = 100%, list B = 80%, and list C = 90%) and delayed memory (list A = 100%, list B = 90%, and list C = 100%) are psychometrically acceptable. All words in the immediate and delayed memory sections were acceptable in version A. However, two words ("Baby" / "Saddle") in the immediate memory and a word ("Baby") in the delayed memory were unacceptable in list B. In list C of immediate memory, in addition, only the word "Jacket" could not be an acceptable item, and all words in delayed memory were acceptable.

Our results are consistent with a previous study about the memory section. According to McElhiney et. al., results using a self-developed 10-word list, 80% (8 out of 10) of items in immediate memory and 90% (9 out of 10) of items in delayed memory were acceptable.[31] Also, we found that the beginning and end words in the lists were not acceptable in immediate memory. The reason why the words “Baby,” “Jacket,” and “Saddle” were unacceptable might be explained as follows. Immediate memory is fixed when the researcher reads a list of words so that participants can remember the beginning and end of the word list relatively easily. For example, the average of item difficulty of items tends to have a U-shape in the three lists in Table 4. In other words, words near the beginning and the end tend to be high item difficulty (easily remembered), but words near the center tend to be low item difficult (hard to remember) for participants. Considering the fact that the word “Saddle” was an acceptable item in a 5 word-list in a previous study,[31] this may be a matter of the position of the word.

As for the word “Saddle”, there might be another reason for the unacceptable item, which is the word relationship with the following word "Bubble." We confirmed that there is no similarity of meaning of words, saddle and bubble, in the memory section using the latent semantic analysis. However, it can be assumed that the participant could remember the word relatively easily due to the similarity of the pronunciation of “Saddle” and “Bubble”. We found that our results are consistent with previous studies, but it is still determined that the word lists in lists B (“Baby” and “Saddle”) and C (“Jacket”) need to be modified. In addition, when practitioners use the immediate memory section, we recommend using list A because lists B and C require modification and result in better validity.

Another result we observed indicated that each version of 10 word lists in immediate memory has different item difficulty levels. The average item difficulty levels indicated list C (immediate and delayed memory = 0.46 and 0.63, respectively) had the most difficult items among the 3 versions of 10 word lists, and list B (immediate and delayed memory = 0.54 and 0.74, respectively) had the easiest in both immediate and delayed memory sections.

Our study confirmed that the 3 versions in the memory section exhibited different item difficulties. Using versions with a different difficulty level may cause a serious problem with the interpretation of results from the SAC memory section. To offset different levels of item difficulty across 3 versions, we used the test equating method. We examined RMSD / MSD accuracy index to select the best test equating model. We provided a concordance table built in the current study that links lists A and B with lists A and C in the immediate & delay memory, allowing scores to be exchanged between versions. Therefore, scores from different versions of immediate & delay memory can be compared.

Test equating could provide many other benefits to help evaluating concussions such as SAC. Test equating, in other words, is beneficial for interpreting new tests when test validity is unsure.[39] For example, to measure baseline scores for SAC, existing SAC items may have appropriate psychometric properties, such as item difficulty, demonstrated in previous studies. However, we cannot compare the latest version in SAC with the current version score in SAC because we don't know if the new version has the appropriate item difficulty and item discrimination. This dilemma is quickly solved utilizing test equating.

There were few limitations to this study. The participants were only college students and we did not take into account variables such as intelligence or learning disability. In addition, the testing equating method applied in this study is linear and equipercentile methods in classical test theory, where score distributions are assumed to be same. The same percentile ranks from different tests are deemed to indicate the same level of performance. Unfortunately, one of the weaknesses of the classical test theory is sample dependent. Classical test theory primarily focuses on total test scores. In other words, the total number of items answered correctly means total test scores indicate examinees' ability.[41] Therefore, the problem with sample dependent is that the results may be different if the same study subjects are changed. Finally, the SAC was designed to be administered in a face-to-face setting, but due to COVID-19, it was administered as a Zoom-based in this study. The results may differ slightly from those of a face-to-face due to this process modification.

Future studies of the SAC might examine as follows: 1) to make a more valid test of immediate and delay memory by studying the word order effect and by replacing the word "Saddle" with another word; 2) it is necessary to apply an equalization method by item response theory because test equating based on classical test theory is sample dependent. Item response theory primarily concentrates on the pattern of examinees' responses to each item, which means because the item and person parameters are in the same logit unit, they may be combined and compared. Therefore, estimated person ability is not test-dependent and estimated item parameters are not sample-dependent in item response theory.[42,43]

CONCLUSION

Our study demonstrated the 3 versions in the memory sections had appropriate validity by an adequate amount of acceptable items. The majority of items in each version have acceptable psychometric properties, enhancing the validity of baseline SAC score for assessing concussions' effects. In addition, our study confirmed the 3 lists in memory section seem to have differing difficulties; therefore, we provided a scores conversion table of immediate memory to improve the validity of baseline SAC scores.

BIBLIOGRAPHY

1. Bodin D, Yeates KO, Klamar K. Definition and classification of concussion. In: *Pediatric and adolescent concussion.* Springer; 2012:9-19.
2. Sussman ES, Pendharkar AV, Ho AL, Ghajar J. Mild traumatic brain injury and concussion: terminology and classification. In: *Handbook of clinical neurology.* Vol 158. Elsevier; 2018:21-24.
3. Thiessen ML, Woolridge DP. Pediatric minor closed head injury. *Pediatric Clinics.* 2006;53(1):1-26.
4. Tator CH. Let's standardize the definition of concussion and get reliable incidence data. In:2009.
5. Cook A, Hunt W, Mosberg W. Glossary of Head injury, including some definitions of injury to the cervical spine. *Clin Neurosurg.* 1966;12:386-394.
6. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on Concussion in Sport–the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. *South African Journal of sports medicine.* 2009;21(2).
7. Aubry M, Cantu R, Dvorak J, et al. Summary and agreement statement of the first International Conference on Concussion in Sport, Vienna 2001. *The Physician and sportsmedicine.* 2002;30(2):57-63.

8. McCrory P, Johnston K, Meeuwisse W, et al. Summary and agreement statement of the 2nd International Conference on Concussion in Sport, Prague 2004. *British journal of sports medicine.* 2005;39(4):196-204.

9. Guskiewicz KM, Mihalik JP, Shankar V, et al. Measurement of head impacts in collegiate football players: relationship between head impact biomechanics and acute clinical outcome after concussion. *Neurosurgery.* 2007;61(6):1244-1253.

10. Kelly JP. Traumatic brain injury and concussion in sports. *JAMA.* 1999;282(10):989-991.

11. Thurman DJ, Branche CM, Sniezek JE. The epidemiology of sports-related traumatic brain injuries in the United States: recent developments. *The Journal of head trauma rehabilitation.* 1998;13(2):1-8.

12. Lincoln AE, Caswell SV, Almquist JL, Dunn RE, Norris JB, Hinton RY. Trends in concussion incidence in high school sports: a prospective 11-year study. *The American journal of sports medicine.* 2011;39(5):958-963.

13. Bakhos LL, Lockhart GR, Myers R, Linakis JG. Emergency department visits for concussion in young child athletes. *Pediatrics.* 2010;126(3):e550-e556.

14. Daneshvar DH, Nowinski CJ, McKee AC, Cantu RC. The epidemiology of sport-related concussion. *Clinics in sports medicine.* 2011;30(1):1-17.

15. Faul M, Wald MM, Xu L, Coronado VG. Traumatic brain injury in the United States; emergency department visits, hospitalizations, and deaths, 2002-2006. 2010.

16. Finkelstein E, Corso PS, Miller TR. *The incidence and economic burden of injuries in the United States.* Oxford University Press, USA; 2006.

17. Breck J, Bohr A, Poddar S, McQueen MB, Casault T. Characteristics and Incidence of Concussion Among a US Collegiate Undergraduate Population. *JAMA Network Open.* 2019;2(12):e1917626-e1917626.

18. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport—the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *PM&R.* 2013;5(4):255-279.

19. Guskiewicz KM, Bruce SL, Cantu RC, et al. National Athletic Trainers' Association position statement: management of sport-related concussion. *Journal of athletic training.* 2004;39(3):280.

20. Randolph C, Millis S, Barr WB, et al. Concussion symptom inventory: an empirically derived scale for monitoring resolution of symptoms following sport-related concussion. *Archives of Clinical Neuropsychology.* 2009;24(3):219-229.

21. Graham R, Rivara FP, Ford MA, Spicer CM, Youth CoS-RCi, Council NR. *Sports-related concussions in youth: improving the science, changing the culture.* National Academies Press (US); 2014.

22. Guskiewicz KM, McCrea M, Marshall SW, et al. Cumulative effects associated with recurrent concussion in collegiate football players: the NCAA Concussion Study. *Jama.* 2003;290(19):2549-2555.

23. Yang C-C, Tu Y-K, Hua M-S, Huang S-J. The association between the postconcussion symptoms and clinical outcomes for patients with mild traumatic brain injury. *Journal of Trauma and Acute Care Surgery.* 2007;62(3):657-663.

24. Kuehl MD, Snyder AR, Erickson SE, McLeod TCV. Impact of prior concussions on health-related quality of life in collegiate athletes. *Clinical Journal of Sport Medicine.* 2010;20(2):86-91.

25. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. *British journal of sports medicine.* 2017;51(11):838-847.

26. Echemendia RJ, Meeuwisse W, McCrory P, et al. The sport concussion assessment tool 5th edition (SCAT5): background and rationale. *Br J Sports Med.* 2017;51(11):848-850.

27. Sport concussion assessment tool - 5th edition. *British Journal of Sports Medicine.* 2017;51(11):851-858.

28. McCrea M, Kelly JP, Randolph C, et al. Standardized assessment of concussion (SAC): on-site mental status evaluation of the athlete. *The Journal of head trauma rehabilitation.* 1998;13(2):27-35.

29. McCrea M. Standardized mental status testing on the sideline after sport-related concussion. *Journal of athletic training.* 2001;36(3):274.

30. Ragan BG, Kang M. Measurement issues in concussion testing. *Athletic Therapy Today.* 2007;12(5):2-6.

31. Ragan BG, Herrmann SD, Kang M, Mack MG. Psychometric Evaluation of the Standardized Assessment of ConcussionEvaluation of Baseline Score Validity Using Item Analysis. *Athletic training and sports health care.* 2009;1(4):180-187.

32. McElhiney D, Kang M, Starkey C, Ragan B. Improving the memory sections of the standardized assessment of concussion using item analysis. *Measurement in physical education and exercise science.* 2014;18(2):123-134.

33. Norheim N, Kissinger-Knox A, Cheatham M, Webbe F. Performance of college athletes on the 10-item word list of SCAT5. *BMJ open sport & exercise medicine.* 2018;4(1):e000412.

34. Spector PE. *Summated rating scale construction: An introduction.* Vol 82: Sage; 1992.

35. Crocker L, Algina J. *Introduction to classical and modern test theory.* ERIC; 1986.

36. Dungan L. Examination development. *Certification: A NOCA Handbook Washington, DC: National Organization for Competency Assurance.* 1996:1-40.

37. Kolen MJ, Brennan RL. *Test equating: Methods and practices.* Springer Science & Business Media; 2013.

38. Cook LL, Eignor DR. IRT equating methods. *Educational measurement: Issues and practice.* 1991;10(3):37-45.

39. Zhu W. Test equating: What, why, how? *Research quarterly for exercise and sport.* 1998;69(1):11-23.

40. Safrit MJ, Wood TM. *Introduction to measurement in physical education and exercise science.* William C. Brown; 1995.

41. Hambleton RK, Jones RW. Comparison of classical test theory and item response theory and their applications to test development. *Educational measurement: issues and practice.* 1993;12(3):38-47.

42. Bond T. *Applying the Rasch model: Fundamental measurement in the human sciences.* Routledge; 2015.

43. Lord FM. *Applications of item response theory to practical testing problems.* Routledge; 2012.

CHAPTER III

THE SECOND ARTICLE

Psychometric Evaluation of Concentration Section in the Standardized Assessment of Concussion: Evaluation of Baseline Score Validity Using Rasch model

INTRODUCTION

The definition of concussion is diverse and includes mechanical, pathophysiological and clinical features.[1] Concussion is often defined as presenting immediate and temporary symptoms of mild traumatic brain injury (mTBI). Concussion is widely used in the community of sports medicine, whereas mTBI is the favored term in other medical specialties.[2] Concussion / mTBI is a common neurological trauma in the general population[3] and is increasingly seen in athletic[4] and military[5] settings. Therefore, it is a common concern for public health, which influences millions of people each year.[6]

According to the Centers for Disease Control and Prevention (CDC), the 2010 estimate of TBI-caused mortality, hospital admissions, and emergency room visits totaled 2.5 million cases in the USA, however, this may be underestimated because it only includes those who have had clinical treatment and have received the relevant diagnostic code.[7,8] The TBI caused $60 billion in lifetime injury costs, and most of these traumas have been classified as mild in the United States.[3,9]

The defining diagnostic clinical features of concussion include physical signs, somatic symptoms, and cognitive and behavioral changes.[10,11] Previous studies indicate the following commonly reported symptoms and signs of concussion: weakness, blurred vision, and impaired balance in physical signs; headache, dizziness, and nausea in somatic symptoms; slow reaction time, fatigue, concentration, anxiety, sleep disturbance, impaired attention, and sadness in cognitive and behavioral changes.[10,11] Due to the complex nature of concussion with various signs and symptoms, it is best to use multidimensional tests with the consent of experts.[12]

Many methods for measuring concussion-related symptoms or impairment have been introduced, including a simple neurocognitive "sideline" test[13,14], balance test[15], and a more extensive neuropsychological test[16,17] designed to identify changes in cognitive function by comparing the players with their pre-season baseline. The use of the Sports Concussion Assessment Tool 5 (SCAT5) is recommended by the Concussion in Sport Group (CISG) because it contains comprehensive guidelines for the appropriate management of subscales that must be carefully studied and executed prior to clinical use and indicates the best established and rigorously developed instruments currently available for on-field or sideline assessment.[1,10,11] The SCAT5 is comprised of multiple tests that include the Red flags, Observable signs, Cervical spine assessment, Glasgow coma scale, Maddocks score, concussion symptom scales, Standardized Assessment of Concussion (SAC), neurological screen, and Modified Balance Error Scoring System.[18]

The SAC test consists of four domains and distinguishes cognitive dysfunction with orientation, immediate memory, concentration, and delayed memory.[19,20] Advantages of the SAC in SCAT5 is ease of use, portability, available to anyone and sensitive to concussions.[19-21] The current version of the concentration section has two parts with 6 lists including the “digits backwards” and “months in reverse order”. If proper psychometric properties like reliability and validity are to be ensured, valid and defensible tests must be constructed. According to a previous study, item difficulty level of 3 strings in digits backwards was unacceptable.[22] The item difficulty levels of 3 strings digits backwards items in all 3 versions were 0.95, 0.99, and 0.97, respectively, which was too easy.

Not only is there insufficient information, such as item difficulty on new items added in digits backwards, and to our knowledge, no research has yet investigated the new 6 lists of digits backwards psychometric properties, such as item difficulty. Thus, in the digits backwards section, it is necessary to evaluate item difficulty of new 6 lists of digits backwards using item analysis.

In addition, in scoring the digits backwards, the traditional scoring method has potential problems because if both of the 3 strings (e.g., 4-9-2 and 6-3-9) fail, the test is automatically stopped (that is, receiving a score of zero for the remaining items) even if participants may be able to answer the rest of the strings (4, 5, 6 strings) correctly. However, there has been no evaluation of digits backwards scoring. For this reason, it is necessary to study the validity of the scoring method.

Therefore, the purposes of this study are 1) to evaluate the validity of digits backwards in the concentration section by examining item analysis (item difficulty) and 2) to compare the current and new scoring methods for the digit backwards.

METHODS

Participants

200 young adults who have no history of a concussion or head injury in the previous 6 months participated in this study. The investigator entered classrooms and recruit participants via word-of-mouth (e.g., academic classes or Zoom) from the author's university. When participants are international students, Only those who have met the Test of English as a Foreign Language (TOEFL) score required by the school participated. This study was approved by the university Institutional Review Board.

Instrument

The concentration section is originally comprised of 6 lists of digits backwards and months in reverse order. Examples of the concentration section can be found in Table 10, 11.

Table 10. 6 lists of digits backwards

List A	List B	List C	List D	List E	List F
4-9-3	5-2-6	1-4-2	7-8-2	3-8-2	2-7-1
6-2-9	4-1-5	6-5-8	9-2-6	5-1-8	4-7-9
3-8-1-4	1-7-9-5	6-8-3-1	4-1-8-3	2-7-9-3	1-6-8-3
3-2-7-9	4-9-6-8	3-4-8-1	9-7-2-3	2-1-6-9	3-9-2-4
6-2-9-7-1	4-8-5-2-7	4-9-1-5-3	1-7-9-2-6	4-1-8-6-9	2-4-7-5-8
1-5-2-8-6	6-1-8-4-3	6-8-2-5-1	4-1-7-5-2	9-4-1-7-5	8-3-9-6-4
7-1-8-4-6-2	8-3-1-9-6-4	3-7-6-5-1-9	2-6-4-8-1-7	6-9-7-3-8-2	5-8-6-2-4-9
5-3-9-1-4-8	7-2-4-8-5-6	9-2-6-5-1-4	8-4-1-9-3-5	4-2-7-9-3-8	3-1-7-8-2-6

Table 11. Months in reverse order

Dec - Nov - Oct - Sept - Aug - Jul - Jun - May - Apr - Mar - Feb - Jan

Procedures

All participants completed a consent form (indicating approval by corresponding to the author's institutional review board). A health history questionnaire was completed for each participant to identify his or her age, sex and possible history of head trauma. Participants were tested on orientation, immediate memory, digits backwards, months in reverse order, and delay memory sequentially. The delayed recall was performed after 5 minutes have passed by the end of the immediate recall section. Participants completed 3 Zoom meetings for this study. When using Zoom, to avoid limitations such as cheating and location, on the day before the data collection researchers contacted the participant by email or message in advance and requested participants only take the SAC in a quiet place without distractions. Before beginning the experiment, researchers advised the participants to remove devices that may be used to cheat from where they are seated, such as pens and paper. In the immediate memory and digit backwards, all study participants were tested in the same order as Tables 12 and 13. For example, a person, ID #2, was tested on list B of immediate memory and list A of digits backwards on the first visit. If a person, ID #5, is visiting for the second time, he or she was tested on list A of immediate memory and list E of digits backwards (see Tables 12 and 13). Not all participants were tested on all six lists. Instead, all participants were measured on list A and two of lists B-F. This method is called anchor-test design and is used as a method to collect data in the field of educational psychology effectively. The numbers of participants tested on certain sets can be found in Table 14.

Table 12. Test order of 10-item word lists

Participant ID	1st visit	2nd visit	3rd visit
1	List A	List B	List C
2	List B	List C	List A
3	List C	List A	List B
4	List A	List C	List B
5	List B	List A	List C
6	List C	List B	List A
⁞	⁞	⁞	⁞
193	List A	List B	List C
194	List B	List C	List A
195	List C	List A	List B
196	List A	List C	List B
197	List B	List A	List C
198	List C	List B	List A
199	List A	List B	List C
200	List B	List C	List A

Table 13. Test order of digits backwards

Participant ID	1st visit	2nd visit	3rd visit
1	List A	List B	List C
2	List A	List D	List E
3	List A	List F	List B
4	List A	List C	List D
5	List A	List E	List F
⁞	⁞	⁞	⁞
196	List A	List B	List C
197	List A	List D	List E
198	List A	List F	List B
199	List A	List C	List D
200	List A	List E	List F

Table 14. Numbers of participants tested on certain sets

Test order of Digit Backward	Number
List A – B – C	40
List A – D – E	40
List A – F – B	40
List A – C – D	40
List A – E – F	40

The traditional scoring method in the concentration section is to determine if the participant reports the string in reverse order correctly, and if so, they get a point. The participant can get the maximum score of 4 (see Table 15). We also propose new scoring methods for digit backwards (two methods). First, if the participant reports the string in the reverse order correctly, they get the point. If they do not, they then read the next string of the same length. If they get both strings wrong, they receive a score of zero for that row, but the concentration section does not end and the test keeps going (Table 15). Second, all of the questions are given 1 point if answered correctly (Table 16). The scoring calculations for each method asked participants to read every string and then adjusted their scores accordingly.

The test interval of each version was at least 48 hours to include a wash out period. Data collection consisted of an oral interview via Zoom with the participant and the examiner, which took approximately less than 15 minutes to complete.

Table 15. Scoring of Traditional Method and New Method 1

<table>
<tr><th>List A</th><th></th><th></th><th>Score</th><th>Scoring Method</th></tr>
<tr><td>4 — 9 — 3</td><td>Y</td><td>N</td><td>0</td><td rowspan="8">1. Traditional way
If the participant misses both strings (4 – 9 – 3 and 6 – 2 – 9), they receive 0 points and the concentration section ends automatically. That means participant will not be tested on the next strings (3 – 8 – 1 – 4 to 7 – 1 – 8 – 4 – 6 – 2).
2. Method 1
1) If the participant correctly answers the first string (4 – 9 – 3), the second string will be ignored and they will move on to the next string (3 – 8 – 1 – 4).
2) If one of the two strings (4 – 9 – 3 and 6 – 2 – 9) matches the correct answer, the participant will be given 1 point.
3) If the participant misses both strings (4 – 9 – 3 and 6 – 3 – 9), they receive zero points, but it is not the end of the section and they will then move on to the next string (3 — 8 — 1 — 4) in the concentration section.</td></tr>
<tr><td>6 — 2 — 9</td><td>Y</td><td>N</td><td>1</td></tr>
<tr><td>3 — 8 — 1 — 4</td><td>Y</td><td>N</td><td>0</td></tr>
<tr><td>3 — 2 — 7 — 9</td><td>Y</td><td>N</td><td>1</td></tr>
<tr><td>6 — 2 — 9 — 7 — 1</td><td>Y</td><td>N</td><td>0</td></tr>
<tr><td>1 — 5 — 2 — 8 — 6</td><td>Y</td><td>N</td><td>1</td></tr>
<tr><td>7 — 1 — 8 — 4 — 6 — 0</td><td>Y</td><td>N</td><td>0</td></tr>
<tr><td>5 — 3 — 9 — 1 — 4 — 8</td><td>Y</td><td>N</td><td>1</td></tr>
</table>

Table 16. Scoring of New Method 2

<table>
<tr><th>List A</th><th></th><th></th><th>Score</th><th>Scoring Method</th></tr>
<tr><td>4 — 9 — 3</td><td>Y</td><td>N</td><td>0.5</td><td rowspan="8">3. Method 2
Test all strings and score only the correct answers to the questions.</td></tr>
<tr><td>6 — 2 — 9</td><td>Y</td><td>N</td><td>0.5</td></tr>
<tr><td>3 — 8 — 1 — 4</td><td>Y</td><td>N</td><td>0.5</td></tr>
<tr><td>3 — 2 — 7 — 9</td><td>Y</td><td>N</td><td>0.5</td></tr>
<tr><td>6 — 2 — 9 — 7 — 1</td><td>Y</td><td>N</td><td>0.5</td></tr>
<tr><td>1 — 5 — 2 — 8 — 6</td><td>Y</td><td>N</td><td>0.5</td></tr>
<tr><td>7 — 1 — 8 — 4 — 6 — 0</td><td>Y</td><td>N</td><td>0.5</td></tr>
<tr><td>5 — 3 — 9 — 1 — 4 — 8</td><td>Y</td><td>N</td><td>0.5</td></tr>
</table>

Data Analysis

For the first purpose of this study, item psychometric properties, item difficulty, and item discrimination were calculated for each item of all lists of digits backwards by using Iteman software (v 3.5).

Item difficulty (*P*)

The proportion of participants who correctly answered an item is referred to as item difficulty. The National Organization for Competency Assurance (NOCA) handbook recommends two types (criterion-referenced standard and individual-centered or norm-referenced standard) of acceptable ranges of item difficulty. A criterion-referenced standard has an acceptable range of 0.33 to 0.92, while an individual-centered approach or norm-referenced standard has an acceptable range of 0.10 to 0.92. Since the National Association of Athletic Trainers and the International Consensus Statement on Sports Concussion propose using an individual-centered standard that contrasts post-injury scores to baseline scores, a P range of 0.10 to 0.92 was chosen to account for a broad range of item difficulties.[19,23-25] Each item below P = 0.10 was deemed "too hard," and above P = 0.92 was regarded as "too easy."

Item discrimination

Item discrimination refers to how well each item distinguishes the upper and bottom groups. Point-biserial correlation (r_{pb}) was used to assess item discrimination. Item discrimination that is greater than or equal to 0.10 of the point-biserial correlation (r_{pb}) indicates item discrimination is permissible[25], whereas less than 0.10 indicates unacceptable discrimination.

Item Determination

Based on the results of item difficulty and item discrimination, each item was classified as “acceptable” or “unacceptable”. The criteria of “acceptable” was the item must have both an item difficulty (*P*) of 0.10 to 0.92 and item discrimination (r_{pb}) of greater than 0.10. If one or both of these criteria is not met, the item will be considered unacceptable.[22]

To evaluate the second purpose of this study, item psychometric properties, item difficulty, and item discrimination from item analysis was examined for each scoring methods to validate the digit backwards scores. In addition, one-way ANOVA was used to compare scores among scoring methods. The point-biserial correlation will also be computed to examine convergent validity evidence of digit backwards scores, comparing to months in reverse order items.

RESULTS

Demographic Characteristics

Table 3 indicates demographic characteristics of the study variables. Participants on average were 22.42 (4.92) years of age, 62.5% female, 63% non-Hispanic white. Three-fourths (78%) of the sample were undergraduate students and one-fourth (22%) were graduate students.

Table 3. Demographic characteristics (N = 200)

Variable	Point Estimate
Age, *M* years (*SD*)	22.42 (4.92)
Gender, # (%)	
Male	75 (37.50)
Female	125 (62.50)
Race, # (%)	
Non-Hispanic White	126 (63)
Non-Hispanic Black	36 (18)
Other / Multirace	35 (17.5)
Mexican American	2 (1)
Other Hispanic	1 (0.5)
Education, # (%)	
Undergraduate	156 (78)
Freshman	15 (7.5)
Sophomore	40 (20)
Junior	66 (33)
Senior	35 (17.5)
Graduate	44 (22)

Note. *M* = mean; *SD* = standard deviation; # = numbers

Results for the first purpose of study

Item Difficulty

In 3 strings, 4 of the 6 items (67%) in first row / 0 of the 6 items (0%) in second row of digits backwards were acceptable item difficulty (Table 17). In 4 strings, the first / second row had 6 of the 6 items (100%) and 2 of the 6 items (33%) had acceptable item difficulty. In 5 and 6 strings, all items had acceptable item difficulty, however all of the second row of 3 strings was too easy.

Table 17. Item difficulty based on digits backwards (List A- F)

	Item Difficulty ($.1 \leq P \leq .92$)					
Item	List A	List B	List C	List D	List E	List F
3 strings	**0.94**	0.92	0.92	**0.99**	0.92	0.92
	0.99	**0.99**	**0.99**	**1**	**0.99**	**0.99**
4 strings	0.78	0.70	0.82	0.86	0.82	0.90
	0.92	0.92	**0.94**	**0.98**	**0.96**	**0.96**
5 strings	0.47	0.60	0.52	0.56	0.72	0.60
	0.59	0.65	0.74	0.80	0.78	0.72
6 strings	0.22	0.26	0.29	0.31	0.32	0.19
	0.29	0.32	0.41	0.45	0.44	0.42

Note. Bold indicates that the item is not acceptable.

Item Discrimination

The results revealed that most numbers of the items in the lists had appropriate discrimination; 4, 5, and 6 strings had 6 items (100%) in both the first and second row. However, both 3 strings (7-8-2 / 9-2-6) indicated problematic item discrimination results, which are presented in Table 18 based on point-biserial correlations.

Table 18. Item discrimination based on digits backwards (List A- F)

	Item Discrimination (.1 ≤ r_{pb})					
Item	List A	List B	List C	List D	List E	List F
3 strings	0.17	0.27	0.29	**0**	0.20	0.41
	0.22	0.26	0.10	**NA**	0.32	0.31
4 strings	0.42	0.31	0.22	0.27	0.30	0.35
	0.47	0.43	0.32	0.31	0.42	0.33
5 strings	0.62	0.65	0.57	0.50	0.69	0.53
	0.67	0.62	0.61	0.60	0.69	0.65
6 strings	0.53	0.61	0.53	0.51	0.53	0.42
	0.61	0.67	0.61	0.63	0.61	0.59

Note. Bold indicates that the item is not acceptable.

Item Determination

Based on the results, item determination indicated that 67% in the first row / 0% in the second row of 3 strings, 100% in the first row / 33% in the second row of 4 strings, and 100% in both rows of 5 & 6 strings of digits backwards obtained acceptable difficulty and discrimination. The lists had a minimum of 0 items (0%) and a maximum of 6 items (100%) that met both criteria.

Results for the second purpose of study

Item Difficulty

In the traditional scoring method, 4 of the 6 items (67%) of the first row / 0 of the 6 items (0%) of the second row in 3 strings of digits backwards had appropriate item difficulty (Table 19 and 20). However, the second question of the 3 strings question was too easy in the traditional scoring method. In 4 strings, 6 of the 6 items (100%) of the first row / 2 of the 6 items (33%) of the second row were acceptable item difficulty. All items (100%) in 5 and 6 strings had appropriate item difficulty. Method 1 scoring indicated having the same results in item difficulty as the traditional scoring method (Table 19 and 20).

In method 2 scoring, 4 of the 6 items (67%) of the first row / 0 of the 6 items (0%) of the second row in 3 strings had appropriate item difficulty; 6 of the 6 items (100%) of the first row / 5 of the 6 items (83%) of the second row in 4 strings had acceptable item difficulty; 5 and 6 strings had 100% acceptable items and all of the second row in 3 strings were too easy (Table 19 and 20).

Item Discrimination

In the digits backwards, most items had acceptable discrimination. To explain in more detail, item discrimination was problematic in 3 stings (7-8-2 / 9-2-6) in the traditional scoring; 3 strings (7-8-2 in first row and 6-2-9, 9-2-6, 4-7-9 in second row) in Method 1 scoring and 3 strings (7-8-2 and 3-8-2 in first row / 4-7-9 in second row) in Method 2 scoring.

Item Determination

In the traditional scoring method and method 1 scoring, 4 of the 6 items (67%) of the first row / 0 of the 6 items (0%) of the second row in 3 strings, and 6 of the 6 items (100%) of first row / 2 of the 6 items (33%) of second row in 4 strings of digits backwards met both criteria (item difficulty and item discrimination). In 5 and 6 strings, all items had acceptable item determination. However, method 2 scoring indicated 4 of the 6 items (67%) of the first row / 0 of the 6 items (0%) of the second row in 3 strings, and 6 of the 6 items (100%) of the first row / 2 of the 6 items (83%) of the second row in 4 strings of digits backwards met both criteria (item difficulty and item discrimination). All items had acceptable item determination in 5 and 6 strings. In summary, the entire second row in 3 strings had unacceptable items using 3 different scoring methods. In 4 strings, however, it was found that item determination improved when using method 2 scoring instead of traditional method and method 1 (Table 19). Therefore, it might be concluded that method 2 scoring is a better scoring method than traditional and method 1.

Table 19. Acceptable percentage of item determination based on digits backwards (strings) by scoring methods

	Item Determination ($.1 \leq P \leq .92$ / $.1 \leq r_{pb}$)		
Item	Traditional	Method 1	Method 2
3 strings	67%	67%	67%
	0%	0%	0%
4 strings	100%	100%	100%
	33%	33%	83%
5 strings	100%	100%	100%
	100%	100%	100%
6 strings	100%	100%	100%
	100%	100%	100%

Table 20. Item determination based on both item difficulty and item discrimination based on digits backwards (List A- F) by scoring methods

		Traditional Scoring			Method 1 Scoring			Method 2 Scoring		
	Item	*P*	r_{pb}	D	*P*	r_{pb}	D	*P*	r_{pb}	D
List A	4-9-3	**0.94**	0.17	U	**0.94**	0.14	U	**0.94**	0.10	U
	6-2-9	**0.99**	0.22	U	**0.99**	**0.08**	U	**0.94**	0.22	U
	3-8-1-4	0.78	0.42	A	0.78	0.31	A	0.78	0.30	A
	3-2-7-9	0.92	0.47	A	0.92	0.29	A	0.80	0.35	A
	6-2-9-7-1	0.47	0.62	A	0.50	0.53	A	0.50	0.46	A
	1-5-2-8-6	0.59	0.67	A	0.64	0.58	A	0.48	0.52	A
	7-1-8-4-6-2	0.22	0.53	A	0.23	0.50	A	0.26	0.42	A
	5-3-9-1-4-8	0.29	0.61	A	0.35	0.56	A	0.24	0.42	A
List B	5-2-6	0.92	0.27	A	0.92	0.29	A	0.92	0.28	A
	4-1-5	**0.99**	0.26	U	**0.99**	0.22	U	**0.99**	0.20	U
	1-7-9-5	0.70	0.31	A	0.70	0.29	A	0.70	0.29	A
	4-9-6-8	0.92	0.43	A	0.92	0.34	A	0.84	0.28	A
	4-8-5-2-7	0.60	0.65	A	0.61	0.58	A	0.61	0.49	A
	6-1-8-4-3	0.65	0.62	A	0.71	0.50	A	0.54	0.46	A
	8-3-1-9-6-4	0.26	0.61	A	0.30	0.58	A	0.30	0.53	A
	7-2-4-8-5-6	0.32	0.67	A	0.38	0.61	A	0.22	0.48	A
List C	1-4-2	0.92	0.29	A	0.92	0.30	A	0.92	0.27	A
	6-5-8	**0.99**	0.10	U	**0.99**	0.11	U	**0.95**	0.15	U
	6-8-3-1	0.82	0.22	A	0.82	0.24	A	0.82	0.20	A
	3-4-8-1	**0.94**	0.32	U	**0.96**	0.36	U	0.86	0.22	A
	4-9-1-5-3	0.52	0.57	A	0.52	0.54	A	0.52	0.47	A
	6-8-2-5-1	0.74	0.61	A	0.74	0.58	A	0.64	0.56	A
	3-7-6-5-1-9	0.29	0.53	A	0.30	0.51	A	0.30	0.42	A
	9-2-6-5-1-4	0.41	0.61	A	0.42	0.61	A	0.29	0.44	A
List D	7-8-2	**0.99**	**0**	U	**0.99**	**0**	U	**0.99**	**-0.04**	U
	9-2-6	**1**	**NA**	U	**1**	**NA**	U	**0.96**	0.28	U
	4-1-8-3	0.86	0.27	A	0.86	0.25	A	0.86	0.21	A
	9-7-2-3	**0.98**	0.31	U	**0.98**	0.31	U	0.88	0.34	A
	1-7-9-2-6	0.56	0.50	A	0.56	0.47	A	0.56	0.36	A
	4-1-7-5-2	0.80	0.60	A	0.79	0.55	A	0.60	0.38	A
	2-6-4-8-1-7	0.31	0.51	A	0.32	0.50	A	0.32	0.40	A
	8-4-1-9-3-5	0.45	0.63	A	0.46	0.60	A	0.30	0.40	A
List E	3-8-2	0.92	0.20	A	0.92	0.12	A	0.92	**0.09**	U
	5-1-8	**0.99**	0.32	U	**0.99**	0.22	U	**0.99**	0.20	U
	2-7-9-3	0.80	0.30	A	0.84	0.17	A	0.84	0.18	A
	2-1-6-9	**0.96**	0.42	U	**0.98**	0.17	U	**0.94**	0.22	U
	4-1-8-6-9	0.72	0.69	A	0.74	0.60	A	0.74	0.44	A
	9-4-1-7-5	0.89	0.69	A	0.79	0.58	A	0.48	0.38	A
	6-9-7-3-8-2	0.32	0.53	A	0.35	0.50	A	0.35	0.36	A
	4-2-7-9-3-8	0.44	0.61	A	0.50	0.48	A	0.32	0.30	A
List F	2-7-1	0.92	0.41	A	0.92	0.34	A	0.92	0.31	A
	4-7-9	**0.99**	0.31	U	**0.99**	**0.07**	U	**0.98**	**0.06**	U
	1-6-8-3	0.90	0.35	A	0.91	0.22	A	0.91	0.22	A
	3-9-2-4	**0.96**	0.33	U	**0.99**	0.22	U	0.90	0.29	A
	2-4-7-5-8	0.60	0.53	A	0.61	0.46	A	0.61	0.27	A
	8-3-9-6-4	0.70	0.65	A	0.79	0.39	A	0.55	0.32	A
	5-8-6-2-4-9	0.19	0.42	A	0.24	0.34	A	0.24	0.30	A
	3-1-7-8-2-6	0.42	0.59	A	0.48	0.53	A	0.40	0.50	A

Note. *P*= Item difficulty; r_{pb} = Item discrimination; D = Item determination; U = Unacceptable; A = Acceptable

The result of one-way ANOVA examining the difference in digits backwards score between three scoring methods (traditional, method 1, and method 2) is presented in Table 21. Using an alpha level of .05, there is a significant group effect on the digits backwards score, $F(2, 597) = 12.45$, $MSE = 0.86$, $p < .001$, partial $\eta^2 = .04$. The Tukey's HSD post hoc test indicated that method 2 scoring ($M = 2.47$; $SD = 0.89$) has significantly lower score when comparing to traditional scoring method ($M = 2.82$; $SD = 0.99$) and method 1 scoring ($M = 0.91$; $SD = 0.90$).

Table 21. Results of one-way ANOVA

Scoring Method	n	*Mean* (*SD*)	*F*-value	*p*-value	*Partial* η^2
Traditional	200	2.82 (0.99)	12.45	<.001	.04
Method 1	200	2.91 (0.90)			
Method 2	200	2.47 (0.89)*			

Note. Levene's $F = 2.45$, $p = .09$; $MSE = 0.86$
* significantly different from traditional and method 1 scoring using Tukey's *HSD* post hoc test

The result of point-biserial correlation examining convergent validity evidence of digits backwards scores, comparing to months in reverse order items is shown in Table 22. There were positive correlations between digits backwards and months in reverse order by scoring method, traditional method ($r = 0.15$), method 1 ($r = 0.15$), and method 2 ($r = 0.19$).

Table 22. Correlation between digits backwards and months in reverse order by scoring methods

	Months in Reverse Order		
	Traditional Scoring	Method 1 Scoring	Method 2 Scoring
Digits Backwards	0.15*	0.15*	0.19*

Note. * = *p* less than .05

DISCUSSION

For the measurement of concentration, the recently released SCAT5 includes a new item to add on each string of digits backwards in previous versions of the SAC. As discussed by the authors of the SCAT5, it suggested that when they use alternate sets for digits backwards their administration should be randomized at baseline and serially postinjury. The rationale for adding a new item to each string was to prevent memorizing and practicing digits.[11] In addition, previous study demonstrated digit backwards has unacceptable psychometric properties such as item difficulty[22,26] and insufficient information, such as item difficulty on new items added in digits backwards. Therefore, it is necessary to evaluate item difficulty of the new 6 lists of digits backwards using item analysis.

Our findings demonstrated the 6 lists of digits backwards in the concentration section are problematic (3 strings = 67 in first row and 0% in second row / second of 4 strings = 33%). Unacceptable items were found in the same questions such as second item of 3 strings (item difficulty range = 0.99 - 1) in all lists, and the second item of 4 strings (item difficulty range = 0.94 – 0.98) in List C-F. The unacceptability of 3 strings in each list might be explained by the following reasons; 1) participants' ability to recall the first 3 strings in the list, regardless of other strings in the list used and, 2) 3 strings are too easy to participants. As a result, these deficits in concentration section have an impact on the validity and usefulness of the baseline concentration measurement.

Interestingly, it can be seen that the item difficulty of the second item in each string is higher (more easy) than that of the first item. In the recently released SCAT5, a new item was added to each string in previous versions of digits backwards and a new scoring method was introduced. For this phenomenon, our research team thinks it is due to the result of the scoring method. The new scoring method is a system that moves to the following string if only one of the two items in each string is answered correctly. If a participant answered the first item (4-9-3) correctly, the second item (6-3-9) is assumed to be answered correctly and moves to the next string without testing it. Therefore, it is concluded that item difficulty in both 3 and 4 strings might appear too easy because the frequency of the second item answered correctly increases.

We suggested different methods with the score in the digits backwards and confirmed the results. The method proposed by the existing SCAT5 states that if the participant misses both strings, no points are awarded and the concentration section ends without being tested on the next set of strings. We suggested two new methods. In method 1, even if both strings are missed and no points are given, they are able to move on to the next set of strings. In method 2, all questions would be measured and each correct answer would be awarded a point. As a result, when Method 2 was applied, the most items met both criteria of item difficulty and item discrimination.

In addition, when we compared the averages of the 3 scoring methods there was no difference between the traditional scoring method and method 1, but there was a difference between method 2 and both traditional scoring and method 1. Moreover, when checking the normality distribution for the three scoring methods, method 2 showed a curve close to the normal distribution, and traditional scoring and method 1 showed a slightly negative skew. It indicates that using our proposed method, method 2 scoring, might provide more accurate results.

Finally, the convergent validity was checked by using each scoring method of digits backwards and months in reverse order, which is another question of measuring the concentration area of SAC. Due to both tests measuring the same concentration, we expected a high correlation. As a result, each convergent validity value was statistically significant, but the correlation coefficients were weak and it did not get the results we expected. The months in reverse order had a negatively skewed distribution, which means almost all examinees got the answer correct. Based on the item analysis results of the months in reverse order, the item was unacceptable (item difficulty and discrimination index were 0.94 and 1, respectively). This implied that the months in reverse order failed to measure all of the ability levels of participant's concentration.

Another reason may be that these two tasks may vary considerably on the demands of working memory. The reverse month task involves recalling 12 words (not digits) that need to be retrieved from semantic memory, whereas the digit task involves fewer digits that are retrieved from working memory. Therefore, the main similarity between these tasks is the "reverse" component, but many other aspects are different, which could explain the low correlation coefficients. Further investigation is needed to evaluate the use of the months in reverse order item.

There are several limitations in this study. To begin with, the samples used in this study are unlikely to be representative of the general population. The samples were voluntarily collected from college students and we did not take into account similar characteristics with intelligence, learning ability, language, memory, and reasoning traits. In addition, because classical test theory is descriptive and sample dependent, the parameters of a person and an item from item analysis are significantly reliant on each other. Therefore, generalizing the findings of this study to the general population may be difficult. Lastly, The SAC was designed to be administered in a face-to-face setting, but due to COVID-19, it was administered as a Zoom-based intervention in this study. Based on this procedure change, the results may differ slightly than a study conducted face-to-face. However, in the clinical field, telemedicine, which uses high-speed communication systems and software application technologies to provide, manage, and monitor healthcare services, allows numerous clinical assessment tests to be done at a distance.[27,29] These telemedicine counterparts have similar performance characteristics as a traditional in-person clinical examination.[28-31] Therefore, although using Zoom was not an ideal choice, it was the second-best option for our research to avoid COVID-19 exposure.

Future studies of the concentration section in the SAC might benefit from the following: 1) additional test development procedures are suggested by the classical item analysis technique employed in this study. Advanced measurement models, such as Item Response Theory and Rasch modeling may be needed.[32,33] This offers for a better understanding of the test's measuring capabilities by looking at the distribution of the items, the placement, redundancy, and gapping.[34,35]; 2) In the digits backwards, random order rather than 3-4-5-6 string order is necessary to study whether 3 strings items are unacceptable by order or inappropriate because the difficulty is too easy.; 3) We need to engage a broader range of participants to increase the likelihood of generalizability of our future studies.

CONCLUSION

Our study demonstrated the new 6 lists of digits backwards in the concentration section needs to be modified in order to have adequate validity. In addition, it was found that the new scoring method proposed by SAC is different from the scoring method we tested. Therefore, clinicians and practitioners using SAC need to be careful when recognizing and interpreting the problems that SAC has when using SCAT5. Further research will be required to verify and improve the accuracy and generalizability of the concentration section.

BIBLIOGRAPHY

1. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport—the 4th International Conference on Concussion in Sport held in Zurich, November 2012. PM&R. 2013;5(4):255-279.

2. Tator CH. Let's standardize the definition of concussion and get reliable incidence data. In:2009.

3. Cassidy JD, Carroll L, Peloso P, et al. Incidence, risk factors and prevention of mild traumatic brain injury: results of the WHO Collaborating Centre Task Force on Mild Traumatic Brain Injury. Journal of rehabilitation medicine. 2004;36(0):28-60.

4. Coronado VG, McGuire LC, Faul M, Sugerman DE, Pearson WS. Traumatic brain injury epidemiology and public health issues. Brain injury medicine: Principles and practice. 2012;84.

5. Iverson GL, Langlois JA, McCrea MA, Kelly JP. Challenges associated with post-deployment screening for mild traumatic brain injury in military personnel. The Clinical Neuropsychologist. 2009;23(8):1299-1314.

6. Laker SR. Epidemiology of concussion and mild traumatic brain injury. PM&R. 2011;3:S354-S358.

7. The Centers for Disease Control and Prevention. Traumatic brain injury. http://www.cdc.gov/traumaticbraininjury/. Accessed May 25th, 2020.

8. Voss JD, Connolly J, Schwab KA, Scher AI. Update on the epidemiology of concussion/mild traumatic brain injury. Current pain and headache reports. 2015;19(7):32.

9. Finkelstein E, Corso PS, Miller TR. The incidence and economic burden of injuries in the United States. Oxford University Press, USA; 2006.

10. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. British journal of sports medicine. 2017;51(11):838-847.

11. Echemendia RJ, Meeuwisse W, McCrory P, et al. The sport concussion assessment tool 5th edition (SCAT5): background and rationale. Br J Sports Med. 2017;51(11):848-850.

12. Graham R, Rivara FP, Ford MA, Spicer CM, Youth CoS-RCi, Council NR. Sports-related concussions in youth: improving the science, changing the culture. National Academies Press (US); 2014.

13. McCrory P. Does second impact syndrome exist? Clinical Journal of Sport Medicine. 2001;11(3):144-149.

14. McCrea M, Kelly JP, Randolph C, Cisler R, Berger L. Immediate neurocognitive effects of concussion. Neurosurgery. 2002;50(5):1032-1042.

15. Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports medicine reports. 2003;2(1):24-30.

16. Randolph C. Implementation of neuropsychological testing models for the high school, collegiate, and professional sport settings. Journal of Athletic Training. 2001;36(3):288.

17. Echemendia RJ, Julian LJ. Mild traumatic brain injury in sports: neuropsychology's contribution to a developing field. Neuropsychology review. 2001;11(2):69-88.

18. Sport concussion assessment tool - 5th edition. British Journal of Sports Medicine. 2017;51(11):851-858.

19. McCrea M, Kelly JP, Randolph C, et al. Standardized assessment of concussion (SAC): on-site mental status evaluation of the athlete. The Journal of head trauma rehabilitation. 1998;13(2):27-35.

20. McCrea M. Standardized mental status testing on the sideline after sport-related concussion. Journal of athletic training. 2001;36(3):274.

21. Barr WB, McCrea M. Sensitivity and specificity of standardized neurocognitive testing immediately following sports concussion. Journal of the International neuropsychological Society. 2001;7(6):693-702.

22. Ragan BG, Herrmann SD, Kang M, Mack MG. Psychometric Evaluation of the Standardized Assessment of ConcussionEvaluation of Baseline Score Validity Using Item Analysis. Athletic training and sports health care. 2009;1(4):180-187.

23. McCrory P, Meeuwisse W, Johnston K, et al. Consensus statement on Concussion in Sport–the 3rd International Conference on Concussion in Sport held in Zurich, November 2008. South African Journal of sports medicine. 2009;21(2).

24. Guskiewicz KM, Bruce SL, Cantu RC, et al. National Athletic Trainers' Association position statement: management of sport-related concussion. Journal of athletic training. 2004;39(3):280.

25. Crocker L, Algina J. Introduction to classical and modern test theory. ERIC; 1986.

26. McElhiney D, Kang M, Starkey C, Ragan B. Improving the memory sections of the standardized assessment of concussion using item analysis. Measurement in physical education and exercise science. 2014;18(2):123-134.

27. Okereafor K, Adebola O, Djehaiche R. Exploring the potentials of telemedicine and other noncontact electronic health technologies in controling the spread of the novel coronavirus disease (covid-19). 2020.

28. Wootton R. Twenty years of telemedicine in chronic disease management–an evidence synthesis. Journal of telemedicine and telecare. 2012;18(4):211-220.

29. Weinstein RS, Lopez AM, Joseph BA, et al. Telemedicine, telehealth, and mobile health applications that work: opportunities and barriers. The American journal of medicine. 2014;127(3):183-187.

30. Yager PH, Clark ME, Dapul HR, Murphy S, Zheng H, Noviski N. Reliability of circulatory and neurologic examination by telemedicine in a pediatric intensive care unit. The Journal of pediatrics. 2014;165(5):962-966. e965.

31. Siew L, Hsiao A, McCarthy P, Agarwal A, Lee E, Chen L. Reliability of telemedicine in the assessment of seriously ill children. Pediatrics. 2016;137(3).

32. Lord FM. Applications of item response theory to practical testing problems. Routledge; 2012.

33. Rasch G. Probabilistic models for some intelligence and achievement tests (Expanded edition, 1980. Chicago, IL. In: University of Chicago Press). Copenhagen, Denmark: Danish Institute for …; 1960.

34. Zhu W, Timm G, Ainsworth B. Rasch calibration and optimal categorization of an instrument measuring women's exercise perseverance and barriers. Research Quarterly for Exercise and Sport. 2001;72(2):104-116.

35. Jette AM. Assessing disability in studies on physical activity. American Journal of Preventive Medicine. 2003;25(3):122-128.

LIST OF APPENDICES

APPENDIX A

Original Version of Standardized Assessment of Concussion

ORIENTATION (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1
Orientation score		**of 5**

IMMEDIATE MEMORY (1 point for each correct answer)

The Immediate Memory component can be completed using the traditional 5-word per trial list or optionally using 10-words per trial to minimize any ceiling effect. All 3 trials must be administered irrespective of the number correct on the first trial. Administer at the rate of one word per second.

Please choose EITHER the 5 or 10 word list groups and circle the specific word list chosen for this test.

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. For Trials 2 & 3: I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.

List	Alternate 5 word lists					Score (of 5) Trial 1	Trial 2	Trial 3
A	Finger	Penny	Blanket	Lemon	Insect			
B	Candle	Paper	Sugar	Sandwich	Wagon			
C	Baby	Monkey	Perfume	Sunset	Iron			
D	Elbow	Apple	Carpet	Saddle	Bubble			
E	Jacket	Arrow	Pepper	Cotton	Movie			
F	Dollar	Honey	Mirror	Saddle	Anchor			
Immediate Memory Score								**of 15**

List	Alternate 10 word lists					Score (of 10) Trial 1	Trial 2	Trial 3
G	Finger Candle	Penny Paper	Blanket Sugar	Lemon Sandwich	Insect Wagon			
H	Baby Elbow	Monkey Apple	Perfume Carpet	Sunset Saddle	Iron Bubble			
I	Jacket Dollar	Arrow Honey	Pepper Mirror	Cotton Saddle	Movie Anchor			
Immediate Memory Score								**of 30**

CONCENTRATION

Digits Backwards (1 point for each correct answer)

Please circle the Digit list chosen (A, B, C, D, E, F). Administer at the rate of one digit per second reading DOWN the selected column.

I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.

Concentration Number Lists (circle one)					
List A	List B	List C			
4-9-3	5-2-6	1-4-2	Y	N	0
6-2-9	4-1-5	6-5-8	Y	N	1
3-8-1-4	1-7-9-5	6-8-3-1	Y	N	0
3-2-7-9	4-9-6-8	3-4-8-1	Y	N	1
6-2-9-7-1	4-8-5-2-7	4-9-1-5-3	Y	N	0
1-5-2-8-6	6-1-8-4-3	6-8-2-5-1	Y	N	1
7-1-8-4-6-2	8-3-1-9-6-4	3-7-6-5-1-9	Y	N	0
5-3-9-1-4-8	7-2-4-8-5-6	9-2-6-5-1-4	Y	N	1
List D	List E	List F			
7-8-2	3-8-2	2-7-1	Y	N	0
9-2-6	5-1-8	4-7-9	Y	N	1

4-1-8-3	2-7-9-3	1-6-8-3	Y	N	0
9-7-2-3	2-1-6-9	3-9-2-4	Y	N	1
1-7-9-2-6	4-1-8-6-9	2-4-7-5-8	Y	N	0
4-1-7-5-2	9-4-1-7-5	8-3-9-6-4	Y	N	1
2-6-4-8-1-7	6-9-7-3-8-2	5-8-6-2-4-9	Y	N	0
8-4-1-9-3-5	4-2-7-9-3-8	3-1-7-8-2-6	Y	N	1
Digits Score					of 4

Month in Reverse Order (1 point for correct answer)

Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November. Go ahead.

Dec-Nov-Oct-Sep-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan	0	1
Months Score		of 1
Concentration Total Score (Digits + Months)		of 5

DELAYED RECALL (1 point for each correct answer)

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section. Score 1 pt. for each correct response.

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.

Time Started	

Please record each word correctly recalled. Total score equals number of words recalled.

Total number of words recalled accurately:	of 5 or	of 10

APPENDIX B

Version of Standardized Assessment of Concussion for This Study

ORIENTATION (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1
Orientation score		**of 5**

IMMEDIATE MEMORY (1 point for each correct answer)

The Immediate Memory component can be completed using 10-words per trial. All 3 trials must be administered irrespective of the number correct on the first trial. Administer at the rate of one word per second.

Please circle the specific word list chosen for this test.

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. For Trials 2 & 3: I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.

List	Alternate 10 word lists					Score (of 10) Trial 1	Trial 2	Trial 3
A	Finger	Penny	Blanket	Lemon	Insect			
	Candle	Paper	Sugar	Sandwich	Wagon			
B	Baby	Monkey	Perfume	Sunset	Iron			
	Elbow	Apple	Carpet	Saddle	Bubble			
C	Jacket	Arrow	Pepper	Cotton	Movie			
	Dollar	Honey	Mirror	Saddle	Anchor			
Immediate Memory Score								**of 30**

CONCENTRATION

Digits Backwards (1 point for each correct answer)

Please circle the Digit list chosen (A, B, C, D, E, F). Administer at the rate of one digit per second reading DOWN the selected column.

I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.

Concentration Number Lists (circle one)					
List A	List B	List C			
4-9-3	5-2-6	1-4-2	Y	N	0
6-2-9	4-1-5	6-5-8	Y	N	1
3-8-1-4	1-7-9-5	6-8-3-1	Y	N	0
3-2-7-9	4-9-6-8	3-4-8-1	Y	N	1
6-2-9-7-1	4-8-5-2-7	4-9-1-5-3	Y	N	0
1-5-2-8-6	6-1-8-4-3	6-8-2-5-1	Y	N	1
7-1-8-4-6-2	8-3-1-9-6-4	3-7-6-5-1-9	Y	N	0
5-3-9-1-4-8	7-2-4-8-5-6	9-2-6-5-1-4	Y	N	1
List D	List E	List F			
7-8-2	3-8-2	2-7-1	Y	N	0
9-2-6	5-1-8	4-7-9	Y	N	1
4-1-8-3	2-7-9-3	1-6-8-3	Y	N	0
9-7-2-3	2-1-6-9	3-9-2-4	Y	N	1
1-7-9-2-6	4-1-8-6-9	2-4-7-5-8	Y	N	0
4-1-7-5-2	9-4-1-7-5	8-3-9-6-4	Y	N	1
2-6-4-8-1-7	6-9-7-3-8-2	5-8-6-2-4-9	Y	N	0
8-4-1-9-3-5	4-2-7-9-3-8	3-1-7-8-2-6	Y	N	1
Digits Score					of 4

Month in Reverse Order (1 point for correct answer)

Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November. Go ahead.

Dec-Nov-Oct-Sep-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan	0	1
Months Score		of 1
Concentration Total Score (Digits + Months)		of 5

DELAYED RECALL (1 point for each correct answer)

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section. Score 1 pt. for each correct response.

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.

Time Started	

Please record each word correctly recalled. Total score equals number of words recalled.

Total number of words recalled accurately:	of 10

VITA

Seungho Ryu, PhD

Department of Health, Exercise Science, and Recreation Management

University of Mississippi

I. EDUCATION AND EXPERIENCE

A. Educational Background

2017-2021 University of Mississippi – Oxford, MS
PhD: Health and Kinegiology
Specialization: Health Behavior and Promotion
Minor: Interdisciplinary Graduate Minor in Applied Statistics
Advisor: Minsoo Kang, PhD, FACSM

2015-2016 Middle Tennessee State University – Murfreesboro, TN
PhD: Human Performance
Specialization: Kinesmetrics (Measurement and Evaluation)
Advisor: Minsoo Kang, PhD, FACSM

2011-2013 Seoul National University – Seoul, South Korea
MS: Physical Education
Advisor: Yeonsoo Kim, MD, PhD
Thesis title: *The effect of combined exercise on phsical fitness and depression symptom in patients with schizophrenia*

2003-2009 Kyungsung University – Busan, South Korea
BA: Physical Education
Advisor: Jongjin Park, PhD

B. Academic Positions

2017-2021 Graduate Teaching Assistant – Department of Health, Exercise Science, and Recreation Management, University of Mississippi

2016-2017 Measurement and Statistical Consultant

; Kinesmetrics Consulting Lab, Department of Health and Human Performance, Middle Tennessee State University

- Provided statistical consulting services for faculty, students, and staff.
- Provided tutoring services involving statistical measures for doctoral, masters, and undergraduate students.

2015-2017 Graduate Teaching Assistant – Department of Health and Human Performance,
Middle Tennessee State University

C. Awards/Honors

2020 Measurement & Evaluation Graduate Student of the Year Award, SHAPE America

2017 1st Place in Scholar's Week Graduate Poster Competition, College of Behavioral and Health Sciences, Middle Tennessee State University
: Cross-validation of the developed obesity cut-off points for Korean adults

II. RESEARCH: PUBLICATIONS

A. Thesis/Dissertation Title

Ryu, S. (2021). Psychometric Evaluation of Memory and Concentration Sections in the Standardized Assessment of Concussion. The University of Mississippi, Oxford, USA.

Ryu, S. (2013). The effect of combined exercise on physical fitness and depression symptom in patients with schizophrenia, Seoul National University, Seoul, Korea.

B. Refereed Journal Articles Published

1. Jung, M., Kim, H., **Ryu, S.**, & Kang, M. (2021). Secular Trends in Physical Activity among Immigrants in the United States, 2009 to 2018. *Journal of Physical Activity & Health*. Doi: 10.1123/jpah.2020-0812.

2. Moore, D.C., **Ryu, S.**, Loprinzi, P.D. Experimental Effects of Acute Exercise on Forgetting (2020). *Physiology International*. Doi: 10.1556/2060.2020.00033

3. **Ryu, S.**, Loprinzi, P.D., Kim, H., Kang, M. (2020). Sedentary Behavior and Obesity in Youth According to Meeting Physical Activity Guidelines: National Health and Nutrition Examination Survey, 2003-2006. *Childhood Obesity*. Doi: 10.1089/chi.2019.0213.

4. **Ryu, S.**, Loprinzi, P.D., Kim, H., Kang, M. (2020). Temporal Trends in the Association between Participation in Physical Education and Physical Activity among U.S. High School Students, 2011-2017. *International Journal of Environmental Research and Public Health*, *17*(7), 2357. Doi: 10.3390/ijerph17072357

5. Jung, M., Zou, L., Yu, J. J., **Ryu, S.**, Kong, Z., Yang, L., ... & Loprinzi, P. D. (2020). Does Exercise Have a Protective Effect on Cognitive Function under Hypoxia? A Systematic Review with Meta-Analysis. *Journal of Sport and Health Science*. Doi: 10.1016/j.jshs.2020.04.004

6. Papini, N.M., Kang, M., **Ryu, S.**, Griese, E., Wingert, T., & Herrmann, S.D (2020). Rasch calibration of the 25-item Connor-Davidson Resilience Scale. *Journal of Health Psychology*. Doi: 10.1177/1359105320904769

7. Loprinzi, P.D., Franklin, J., Farris, A., & **Ryu, S.** (2019). Handedness, grip strength, and memory function: considerations by biological sex. *Medicina, 55*(8), 444. Doi: 10.3390/medicina55080444

8. Kim, K. M., Kim, J. S., Cruz-Díaz, D., **Ryu, S.**, Kang, M., & Taube, W. (2019). Changes in spinal and corticospinal excitability in patients with chronic ankle instability: A systematic review with meta-analysis. *Journal of Clinical Medicine, 8*(7), 1037. Doi: 10.3390/jcm8071037

9. **Ryu, S.**, Kim, H., Kang, M., Pedisic, Z., & Loprinzi, P.D. (2019). Secular trends in sedentary behavior among high school students in the United States, 2003-2015. *American Journal of Health Promotion*, 1-8. Doi: 10.1177/0890117119854043

10. Loprinzi, P.D., Blough, J., Crawford, L., **Ryu, S.**, Zou, L., & Li, H. (2019). The temporal effects of acute exercise on episodic memory function: Systematic review with meta-analysis. *Brain Sciences, 9*(4), 87. Doi: 10.3390/brainsci9040087

11. Frith, E., **Ryu, S.**, Kang, M., & Loprinzi, P.D. (2019). Systematic review of the proposed associations between physical exercise and creative thinking. *Europe's Journal of Psychology, 15*(4). 858-877. Doi: 10.5964/ejop.v15i4.1773

12. **Ryu, S.**, Frith, E., Pedisic, Z., Kang, M., & Loprinzi, P.D. (2019). Secular trends in the association between obesity and hypertension among adults in the United States, 1999-2014. *European Journal of Internal Medicine*. Doi: 10.1016/j.ejim.2019.02.012

13. Loprinzi, P.D., Blough, J., **Ryu, S.** & Kang, M. (2019). Experimental effects of exercise on memory function among mild cognitive impairment: Systematic review and meta-analysis. *The Physician and Sportsmedicine, 47*(1), 21-26. Doi: 10.1080/00913847.2018.1527647

14. **Ryu, S.**, Shivappa, N., Veronese, N., Kang, M., Mann, J.R., Hebert, J.R., Wirth, M.D., & Loprinzi, P.D. (2018). Secular trends in dietary inflammatory index among adults in the United States, 1999-2014. *European Journal of Clinical Nutrition, 73*, 1343-1351. Doi: 10.1038/s41430-018-0378-5

15. Williams, C., Stone, R., & **Ryu, S.** (2018). Source of Stress in sport: A Rasch Calibration. *Journal of Public Health Issues and Practices, 2*(121), 1-6.

16. Kim, H, Mun, J., **Ryu, S.**, & Kang, M. (2017). Validation of Korean of International Physical Activity Questionnaire: construct-related validity. *The Korean Journal of Physical Education, 56*(2), 605-616. Doi: 10.23949/kjpe.2017.03.56.2.44

17. Mun, J., Kim, H**.**, **Ryu, S.**, & Kang, M. (2016). Development of a model to estimate body fat percentage using decision-tree analysis. *The Korean Journal of Physical Education, 55*(5), 675-685.

18. **Ryu, S.**, Song, B., Kim, Y., & Kwon, H. (2015). The Effect of combined exercise on physical fitness and depression symptom in patients with schizophrenia. *Korean Journal of Adapted Physical Activity, 49*(4), 39-48.

III. RESEARCH: PRESENTATIONS

1. **Ryu, S.,** Jung, M., & Kang, M. (2021, May). Psychometric Evaluation of Memory Section in the Standardized Assessment of Concussion from the SCAT5. To be presented at the ACSM national conference.

2. Jung, M., Kim, H., **Ryu, S.**, & Kang, M. (2021, May). Secular Trends in Physical Activity among Immigrants in the United States, 2009 To 2018. To be presented at the ACSM national conference.

3. Kang, M., Kim, H., **Ryu, S.**, & Jung, M. (2021, April). Scale Adaption in Exercise and Sport Sciences. To be presented at the SHAPE America virtual national conference.

4. **Ryu, S.**, Kim, H., Loprinzi, P., & Kang, M. (2020, May). The Mediating effect of Physical Activity on Relationship between Sleep and Weight Status. Online presented at the ACSM national conference because of COVID-19.

5. Kim, H., **Ryu, S.**, & Kang, M. (2020, May). Identifying Threshold of Daily Sedentary Behavior Time For Prevention of Obesity. Online presented at the ACSM national conference because of COVID-19.

6. **Ryu, S.**, Kim, H., Loprinzi, P., & Kang, M. (2020, April). Temporal Trends in the Association between Participation in Physical Education and Physical Activity Among High School Students in the United States, 2011-2017. Online because of COVID-19 at the SHAPE America national conference

7. **Ryu, S.**, Kim, H., Loprinzi, P., & Kang, M. (2019, May). Temporal trends of physical activity in high school students in the United States, 2011-2017. Paper presented at the ACSM national conference, Orlando, FL.

8. **Ryu, S.**, Kim, H., Loprinzi, P., & Kang, M. (2019, April). Trends of sedentary behavior in high school students in the United States, 2003-2015. Paper presented at the SHAPE America national conference, Tampa, FL.

9. Papini, N, Kang, M, **Ryu, S**, Griese, E, Wingert, T, Herrmann, SD. (March, 2019). Rasch calibration of the 25-item Connor-Davidson Resilience Scale. Society of Behavioral Medicine Annual Meeting Abstracts. Washington, D.C. Annals of Behavioral Medicine, 53(S1):S277.

10. **Ryu, S.**, Kim, H., & Kang, M. (2018, May). Effect of Warm-up intervention on physical performance: a meta-analysis. Paper presented at the ACSM national conference, Minneapolis, MN.

11. Kim, H., Mun, J., **Ryu, S.**, & Kang, M. (2018, March). Sedentary behavior and metabolic syndrome in physically active adults. Paper presented at the SHAPE America national conference, Nashville, TN.

12. **Ryu, S.**, Mun, J., Kim, H., & Kang, M. (2018, March). Trend analysis of measurement and evaluation in RQES using text mining. Paper presented at the SHAPE America national conference, Nashville, TN.

13. **Ryu, S.**, Kim, H., Mun, J., & Kang, M. (2018, March). Association between sedentary behavior and obesity in adolescent according to meeting of physical activity guideline. Paper presented at the SHAPE America national conference, Nashville, TN.

14. **Ryu, S.**, Kim, H., Mun, J., & Kang, M. (2017, May). Validity of sedentary behavior guideline for youth. Paper presented at the ACSM national conference, Denver, CO.

15. Kim, H., **Ryu, S.**, Ragan, B. G., & Kang, M. (2016, June). Compositional data analysis of Sedentary Behavior Patterns in Overweight and Non-Overweight Adults. Paper presented at the ACSM national conference, Boston, MA.

16. **Ryu, S.**, Kim, H., Mun, J., Ragan, B. G., & Kang, M. (2016, June). Compositional data analysis of total activity patterns by sex and obesity status. Paper presented at the ACSM national conference, Boston, MA.

17. Kim, H., Farnsworth, J. L., **Ryu, S.**, & Kang, M. (2015, October). Convergent validity evidence for the Sedentary Behavior Record. Paper presented at the Sedentary Behavior & Health Conference. Urbana-Champaign, IL.

IV. TEACHING

A. Years at Colleges/Universities

2017-2021 Teaching Assistant – Department of Health, Exercise, and Recreation Management, University of Mississippi

Primary Instructor

ES 351 Measurement & statistics in Exercise Science (3 credits)
HP 191 Personal and community Health (3 credits)
EL 147 Tennis (1 credit)

Guest Lectures

ES 620 Selected Topics in Exercise Science (Meta-Analysis) (Lecture – Comprehensive Meta-Analysis Software); **Grad level**

2015-2016 Teaching Assistant – Department of Health and Human Performance, MTSU

Teaching Assistant

PHED 1080 Beginning Bowling (1 credit)
PHED 1040 Beginning Tennis (1 credit)
HHP 6700 Data Analysis and Organization for Human Performance; **Grad level**

Guest Lectures

HHP 6700 Data Analysis and Organization for Human Performance (Lecture – Analysis of Variance); **Grad level**
HHP 7300 Current Measurement Issues in Health and Human Performance; (Lecture – Validity Generalization); **Grad level**
HHP 7740 Meta-Analysis (Lecture – Comprehensive Meta-Analysis Software); **Grad level**

V. SERVICE

A. Statistics consulting

2019- 2021 Statistical Consultant
; Research & Analytics Lab, School of Applied Sciences, University of Mississippi

- Provided statistical consulting services for faculty, students, and staff.
- Provided tutoring services involving statistical measures for doctoral, masters, and undergraduate students.

B. Journal Reviewer

2019-present Journal of Physical Activity & Health

C. Annual Workshop Presentation

A professional lecture provided to the graduate student and faculty members at UM and MTSU.

1. **Ryu, S.** (2021, March). Nonparametric statistics: Spearman rho correlation. Presented at the *1st Annual School of Applied Sciences Workshop.* University, MS.

2. **Ryu, S.** (2017, February). Nonparametric statistics: Wilcoxon Signed Rank test, Mann-Whitney U-test. To be presented at the *5th Annual Kinesmetrics Statistical Consulting Workshop.* Murfreesboro, TN.

3. **Ryu, S.** (2016, March). Data mining techniques: Association Rule. Presented at the *4th Annual Kinesmetrics Statistical Consulting Workshop.* Murfreesboro, TN.