DEVELOPMENT OF A CONCUSSION ASSESSMENT INSTRUMENT FOR THE SOUTH KOREAN SOLDIERS

by

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I dedicate this dissertation to my wife, Wonwoo Choi, for her endless love, sacrifice, and support.

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ABSTRACT

The purpose of this study was to develop and validate a practical concussion evaluation tool for the South Korean soldiers (SKS). This study was conducted in two phases. For phase 1, the English version of the current standardized assessment of concussion (SAC) was adapted for SKS by modifying and adding some items for resolving psychometric issues and considering cultural and linguistic equivalences, which led to develop the Korean version of the adapted SAC (K-SAC). The psychometric properties of the K-SAC were evaluated using an advanced measurement theory of Rasch model in a sample of healthy young adults without concussive injury. For phase 2, K-SAC was administered three times (i.e., baseline, time of injury, and after 48 hours) for the concussion and non-concussion groups, and the data collected was analyzed using a two-way repeated measured ANOVA to evaluate the validity of K-SAC in concussion assessment. The results of phase 1 indicated that the developed K-SAC has sound psychometric properties at baseline evaluation of cognitive function in the target population. All items of K-SAC were properly contributed to measure cognitive function level of the sample. There was no ceiling effect on the K-SAC scores. The item difficulties of K-SAC covered all range of participants' cognitive function levels, ranging from very easy to very difficult. The results of phase 2 demonstrated that the K-SAC also has a good validity for concussion assessment. There were significant mean differences in K-SAC scores between concussion and non-concussion groups at time of injury and no differences at baseline and after 48 hours. In concussion group, K-SAC score at time of concussion was significantly different when compared to the scores at baseline and after 48 hours. The findings of this study supports that the K-SAC can be a potential field concussion evaluation instrument for SKS. Further research will be required to validate K-SAC and improve generalizability of K-SAC in various settings and populations.

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CHAPTER 1

INTRODUCTION

Background

Concussion has been prevalent in the military setting. Concussion is a transient alteration in brain function induced by direct or indirect traumatic and biomechanical forces to the head.[4, 5, 6, 7, 8] Concussion represents the less severe end of the continuum of traumatic brain injury (TBI).[2, 8, 22] The concussion rate within the US military has been increased and increase in this rate of concussion accounts for most of the increase in overall TBI rate. According to Centers for Disease Control and Prevention (CDC), National Institutes of Health (NIH), Department of Defense (DOD), and Department of Veterans Affairs (VA) report to congress[21], about 4.2% of the total service members (SM) in the US military had TBI, and about 76.7% of them were classified as concussion from 2000 to 2010. More recently, Defense and Veterans Brain Injury Center (DVBIC) reported that 357,048 SMs who served in the US military were diagnosed with TBI from 2000 to 2016.[22] Of these, 82.3% were classified as concussion.[22] Due to the subtle nature of the injury characteristic, concussion is difficult to identify, assess, and manage.[56] Thus, the concussion rate can be potentially underestimated among SMs in the US military.[21, 56]

Subsequent concussion before full recovery from signs and symptoms induced by the previous concussion has profound effects on SMs' health. The subsequent concussion could occur with less direct or indirect force to head and can result in more severe and prolonged brain dysfunction than the previous concussion.[4, 5, 8, 37, 39] Accumulative or multiple concussions could increase the risk of second-impact syndrome (e.g., severe brain damage, coma, and death) and long-term cognitive health (e.g., chronic traumatic encephalopathy and late-life cognitive impairments such as depression and dementia).[7, 8, 44, 45, 46, 47] In addition, SMs who sustained a concussion during deployment are more likely to have physical and cognitive health problems, as well as post-traumatic stress disorder (PTSD) and depression as compared to their counterparts.[24] Those who had one or more concussions also reported poor general health, more missed workdays, and more medical visits in the past month than those who had no injury or other injuries.[24]

Besides impact of concussion on SMs' health, concussion is a critical concern for SMs in regarding combat performance. If SMs do not realize that they have a concussion, or if the SM returned to duty before they fully recovered from symptoms/signs of concussion, it could lead to devastating consequences for the SMs, as well as their units. Common acute effects of concussion involve headache, dizziness, confusion, disorientation, cognitive impairment (e.g., concentration, memory, etc.), poor balance performance, and sleep disturbance.[7, 58] The symptoms/signs caused by concussion influence negatively on physical performance and mental status, which can place individuals, teams, and/or units in danger at the battlefield or military training locations.[60, 61] In psychological perspectives, all critical decisions in wartime are made based on prompt and accurate evaluation of the given environment and enemy, which require sound psychological demand of SMs.[154] Even a small lapse of concentration and memory can bring about many deaths and mission failiures.[154, 155] In physical perspective, to conduct the given combat missions SMs are required to move quickly under fire, negotiate uneven or moving surfaces or terrain, shoot accurately, and multitask these three tasks in military operation settings. The poor physical performance of SMs induced by concussion may drastically reduce the possibility to survive and achieve combat missions.[60, 61, 63]

Early detection of concussed SMs is critical to prevent them from returning to hazardous duty with compromised mental status, as well as provide appropriate medical treatment at the right time.[21, 56, 60] In the current US military policy for concussions, all SMs who are involved in a potentially concussive event are required medical screening in a timely fashion to identify early concussed SMs, along with a 24-hour period of rest, even if they are not diagnosed with a concussion.[60, 62] SMs with a concussion should be immediately removed from duty and monitored with serial concussion assessments until their concussion symptoms are fully resolved to ensure their safe return to duty.[4, 5, 7, 8, 62] To initiate appropriate concussion management procedures, concussion evaluation should be made quickly and accurately at the location where the concussive event occured.[21, 62] Development of a practical assessment tool, which can screen a concussion immediately following a head injury event, have been requested for use in the frontline of military operational settings.[21, 60]

Unfortunately, no perception about concussion and risk of concussion, concussion assessment tools, and concussion management procedures have been established in the South Korean military. Despite the threat that concussions have on SMs in the military, there have been no studies investigating concussion incidences, its impact on SMs' health and combat performance, and valid concussion assessment tools for the South Korean soldiers (SKS). Furthermore, there are lacks of basic knowledge and perception for concussion as an important health concern in the South Korea.[29, 30] It is necessary to develop a practical and accurate concussion evaluation tool to protect SKS from the risk of concussion and initiate concussion research to develop well organized concussion management procedures.

A useful and practical concussion assessment tool for SM's in the military should be objective, quick, and non-invasive. It should also not require administration by medical or psychology experts for concussion screenings of SKS on the battlefield.[21, 60, 62] Among currently available practical concussion assessment tools, the Standardized Assessment of Concussion (SAC) is a good alternative concussion assessment tool that can be adapted and used for SKS in the field during peacetime and wartime.[21, 126, 127, 131] The SAC is quick (i.e., about 3-5 minutes) and easy to use, portable, inexpensive, and acceptably sensitive to concussion.[6, 76, 85, 86, 87, 91, 93] The SAC is one of the most widely used assessment tools; both as an individual assessment tool and as a main component of the Sport Concussion Assessment Tool 3 (SCAT 3) and Military Acute Concussion Evaluation (MACE) in sports and military-related settings.[81, 82] In addition, SAC is an objective assessment tool for cognitive impairments induced by concussion[76, 85, 86], and no learning/practice effects are identified in multiple assessments using SAC.[101, 112]

However, SAC also has an important issue that should be addressed for accurate assessments of concussions. In the current SAC, there is a discrepancy between item construction and interpretation method.[132, 134] Individual-centered standard is recommended to interpret SAC score. In other words, post-injury score is compared with the baseline score, and having more than a 3 point reduction in SAC score indicates that a patient has concussion. Accurate concussion evaluation using individual-centered standard requires assumptions that SAC items discriminate well at all levels of cognitive function, and scores from SAC are normally distributed.[132, 134] SAC does not satisfy these assumptions well. A ceiling effect (i.e., negatively skewed distribution of scores) and poor construction of items (i.e., absence of items for person with high cognitive function) were reported from several previous studies.[87, 91, 92, 132, 135] The SAC needs more difficult items than the current items used by the SAC to solve these problems.[132, 135]

There have been three commonly used methods to examine if a scale has desired psychometric properties, which are the classical test theory (CTT), item response theory (IRT), and Rasch model. The Rasch model has several advantages over CTT and IRT. The Rasch model can provide very useful and accurate information like invariant and independent parameter estimates (i.e., item difficulty and person ability) and item-person distribution map on a unidimensional common scale when comparing with CTT.[139, 146] The information produced by Rasch can be used to evaluate if a developed concussion evaluation scale has a wide range of item difficulty to discriminate well at all levels of cognitive function.[139, 146] In general, the Rasch model requires a smaller sample size for accurate parameter estimates than IRT.[138, 156, 157]

Appropriate translation requires a balance between the linguistic and cultural equivalence.[147, 149, 150] Adoption, adaption, and assembly are commonly used methods to translate from an original language to the target language in translation practices.[147, 148, 149] To maintain the balance when conducting translation, the three methods can be flexibly applied in accordance with the characteristics of each item in an instrument and culture of the target population.[147, 149] Another important consideration is the main purpose of translation.[147, 149] If the purpose of translation is to accurately measure the same construct in the target population, not to compare the scores between original and target populations, cultural equivalence could be weighted more than linguistic equivalence.[147, 149] For this purpose, adaptation and assembly may be more appropriate methods than adoption in translation.

In summary, concussion is a significant health concern in the military that can lead to disastrous consequences in peacetime and wartime. Early detection of concussions is critically important to prevent further complications of a concussion on SMs' health and reduction of combat performance, as well as to treat concussions in a timely fashion for SM's in the military. Therefore, it desperately needs a practical and accurate concussion assessment tool that can be administrated on the field right after a concussive event. There are no concussion assessment tools for the SKS. The SAC is a good alternative method to assess concussions that can be adapted for the SKS. The SAC has been most widely recognized as a practical and acceptably accurate concussion assessment tool in the US military and sport settings. However, the SAC needs to be improved in item difficulty for accurate assessment of concussions at all levels of cognitive function. In addition, translation from English to Korean is required, and cultural equivalence should be considered for appropriate translation. Process of improvement and adaptation of the SAC will involve substantial changes that can lead to the development of a new concussion assessment tool and psychometric evaluation using a Rasch measurement model.

Purpose of This Study

The purpose of this study was to develop and validate a practical concussion assessment instrument, Korean version of the adapted standardized assessment of concussion (K-SAC), for the South Korean soldiers (SKS). The specific aims of this study were: 1) to develop K-SAC for SKS based on SAC; 2) evaluate and confirm if the K-SAC has sound psychometric properties when measures baseline cognitive function in a target population using the Rasch measurement model; and 3) examine if the K-SAC can detect changes of cognitive function induced by concussions in a target population.

Research Hypotheses

The following hypotheses will be tested: 1) the K-SAC has a wide range of item difficulty that can measure accurately at all levels of cognitive function in a target population; 2) the K-SAC can detect changes in cognitive function induced by concussion in the target population.

Significance of This Study

This is the first study to develop and provide a useful concussion assessment instrument for SKS who are at high risk of concussion. Currently, there is no available concussion assessment instrument for SKS. In addition, there is lack of perception about concussion and its gravity associated with soldiers' health and combat performance in the South Korean Military. The developed instrument will contribute to protect SMs from concussion and its severe impacts on health and combat performance. It could help provide a way for SMs in the South Korea that are evaluated for concussions by providing more useful information immediately post-injury. The populations who will benefit from this research include; field leaders/commanders, military training leaders, allied medical professionals, and most importantly the South Korean soldiers. In addition, the academic community will gain useful information about the validity of the K-SAC in this population. Lastly, we expect that this study will be a turning point for the change of perception about concussion and its risk, and for an establishment of concussion management guidelines or policies in the South Korean military and civil society.

Limitations

This study includes the following limitations. 1) Most of the participants in this study were highly educated and intelligent compared to general the South Korean soldiers. This means that the sample used in this study may not be a representative of the South Korean soldiers. The caution should be necessary to interpret the results of this study for generalization. When considering the main purpose of this study, the sample of this study is appropriate to attain the goal of this study that confirms the increase in item difficulty of the K-SAC to assess accurately at a high level of cognitive function in baseline measurement. 2) Due to the improvement in item difficulty and adaptation of SAC in Korean, there were substantial changes of items in the current SAC. These changes may significantly restrict comparability of the scores from the current SAC and the K-SAC.

CHAPTER 2

LITERATURE REVIEW

This chapter is devoted to the review of literature related to the importance of concussion assessment and needs to develop a practical concussion assessment instrument. This review of literature contains the following sections: concussion; concussion assessment tools; measurement issues in concussion evaluation; methods to evaluate psychometric properties; and translation.

Concussion

Definition of Concussion

Despite many attempts to establish a definition of concussion, there is still no universally accepted definition in clinical and research settings.[1, 2, 3, 17] The recently proposed definitions[4, 5, 6, 7, 8] by major sports and health related organizations are present on Table 1. When synthesizes the most commonly accepted definitions of concussion, concussion can be defined as a transient alteration in brain function induced by direct or indirect traumatic and biomechanical forces to the head.[4, 5, 6, 7, 8] Thus, concussion can be occurred by direct or indirect force transmitted to the brain through any part of the body (e.g., head, face, neck, etc.).[2, 4, 32]

There have been some debates for the distinction between a concussion and mild traumatic brain injury (MTBI).[31] The term of concussion has been used interchangeably with MTBI in the literature.[8, 9, 16, 17, 22, 31] Both concussion and MTBI represent a less severe end of the continuum of traumatic brain injury (mild, moderate, and severe) as well as the definitions of both terms overlapped.[2, 8, 22] Some researchers, however, suggest that concussion is a subset of MTBI and is a less severe traumatic brain injury than MTBI.[3, 4, 7] The definition of concussion is still evolving, and many people still use the terms of concussion and MTBI interchangeably.[8, 9, 16, 17, 22, 31] Therefore, in this literature review, the terms of concussion and MTBI will be considered interchangeable to be consistent with previous literature (hereafter called concussion).

Characteristics of Concussion

There are some common characteristics that may be used to define the nature of concussive head injury.[4, 32] Concussion may or may not involve the loss of consciousness.[4, 7, 32] Typically, concussion brings about immediately short-lived impairment of neurologic function, and approximately 80%-90% of concussions resolve spontaneously within 7-10 days.[2, 4, 7, 32] Majority of concussions may be resolved progressively, but symptoms may last in some cases.[4, 32] Although most concussion symptoms and signs disappear within 7 to 10 days, about 10 to 15% of these are persistent for more than 10 days.[3, 4] The impairment of neurologic function caused by concussion may be primarily associated with a functional disturbance rather than structure injury so that standard structural neuroimaging may not detect the impairment.[4, 7, 32] Due to the subtle nature of concussion, identification and assessment of concussion may be difficult.

Table 1. Definitions of Concussion

Source	Definitions
● Consensus statement on concussion in sport: The 4th International Conference on concussion in sport held in Zurich, November 2012[4]	● Concussion is a brain injury and is defined as a complex pathophysiology process affecting the brain, induced by biomechanical forces.
● National Athletic Trainers' Association position statement of sport concussion[5]	● Concussion is defined as a trauma induced alteration in mental status that may or may not involve loss of consciousness.
● American Academy of Neurology summary of evidence-based guideline update: Evaluation and management of concussion in sports[6]	● Concussion is recognized as a clinical syndrome of biomechanically induced alteration of brain function, typically affecting memory and orientation, which may involve loss of consciousness.
● American Medical Society for Sports Medicine position statement: Concussion in sport[7]	● Concussion is defined as a traumatically induced transient disturbance of brain function and involves a complex pathophysiologic process.
● Concussion (Mild traumatic brain injury) and Team Physician: A consensus statement-2011 update[8]	● Concussion or mild traumatic brain injury (MTBI) is a pathophysiological process affecting the brain induced by direct or indirect biomechanical forces.

Prevalence of Concussion

Traumatic brain injury (TBI) is a leading cause of death or disability. An estimated number of people worldwide who have been hospitalized with one or more TBI were 57 million.[9, 10] In the US, an estimated 1.7 million people suffer from TBI annually,[11] and approximately 3.2-5.3 million people are living with a TBI-related disability[12, 13, 14]. It is estimated that approximately 1.36 million people visit emergency departments; 270,000 people are hospitalized; and 52,000 people die annually due to TBI in US.[11] TBI is associated with about 31% of all injury-related deaths[11] and an estimated direct medical costs and indirect costs was about $60 billion in 2000[15]. About 70-90% of annual TBI incident cases are mild TBI, which is a concussion.[16, 17] An estimated cost of concussions is approximately 17 billion.[16, 18]

The incidence of TBI can be potentially underestimated because most of the data from previous studies do not include patients who received medical care from other facilities (e.g., outpatient clinics and federal facilities) or people who did not receive medical care.[16, 17, 19] For example, those who have less severe TBI (i.e., concussion) are more likely to use non-hospital settings and emergency department for treatment instead of a hospital[16, 23], and about 25-42% of people with a TBI did not receive medical care[20, 23]. Therefore, the actual incidence of TBI, especially concussion, could be much higher than the figures that were reported.[16, 17, 19]

TBI has also been prevalent in military personnel during peacetime and wartime. Post-deployment surveys regarding TBI and/or concussion indicated that about 15-23% of service members (SM) deployed to Iraq and Afghanistan have experienced a TBI, and a majority of them had a concussion.[24, 25, 26] The concussion rate in the US military increased, and the increase in the rate of concussions accounted for most of the increase in overall TBI rate. From 2000 to 2011, 4.2% (i.e., 235,046) of the total SMs in the US military had a TBI, and 76.7% of them were classified as concussion.[21] More recently, the Defense and Veterans Brain Injury Center (DVBIC) reported that 357,048 SMs who served in the US military were diagnosed with a TBI from 2000 to 2016.[22] Of these, 82.3% (i.e., 294,010) were classified as a concussion.[22] These figures can be potentially underestimated due to limitations in the existing surveillance system, and it is especially fact for the incidence rate of concussions among SMs.[21]

The epidemiology of concussions is little known among Korean civilian and military populations. Very few studies have examined the incidence rate of concussions in several sports, with small sample sizes such as Judo[27] and Snowboarding[28]. The reported incidence rates of sports-related concussions were 3.64-114.40 per 1,000 athlete-exposures.[27, 28] There is no TBI and/or concussion surveillance system for both civilian and military populations. In addition, there are lacks of basic knowledge and recognition for concussions as an important health concern in the South Korea.[29, 30] However, it may be presumed based on other countries' data[9, 10, 21, 22, 24, 25, 26] that concussions are spread out across Korean civilian and military populations even though there are very little epidemiological studies in this population.

Consequences of Concussion

The symptoms and signs of an acute concussion are typically categorized into physical, cognitive, emotional, and sleep domains.[7] There are several commonly reported symptoms and signs at the time of injury such as: headaches and dizziness for physical domain; difficulty in concentration and memory for cognitive domain; irritability and nervousness for emotional domain; and insomnia for sleep domain (see Table 2 for detailed information).[7, 33, 34, 35, 36, 37] Patients with concussive head injuries will sustain one or more symptoms and/or signs from one or more of these domains.[4, 32, 36] When a patient shows any one or more of these symptoms and signs, a concussion should be suspected.[4, 32, 36]

Table 2. Acute Symptoms and Signs of Concussion

Domains	Symptoms and signs[7, 33, 34, 35, 36]
● Physical	● Headache, Nausea, Vomiting, Balance problems, Dizziness, Visual problems, Fatigue, Sensitivity to light, Sensitivity to noise, Numbness/tingling, Dazed, Stunned, Loss consciousness (even briefly)
● Cognitive	● Feeling mentally "foggy", Feeling slowed down, Difficulty concentrating, Difficulty remembering, Forgetful of recent information and conversations, Confused about recent events, Answers questions slowly, Repeats questions
● Emotional	● Irritability, Sadness, More emotional, Nervousness
● Sleep	● Drowsiness, Sleeping more than usual, Sleeping less than usual, Difficulty falling asleep

In addition to these acute symptoms and signs, there have been reported further complications associated with multiple or repeated concussions within a short interval. Concussion is considered as a strong predictor of subsequent concussion incidence. People who have a history of one or more concussions have a higher risk for subsequent concussions than those with no concussion history.[4, 5, 7, 8] Several studies reported that athletes who have experienced a concussion before are 1.2-3.5 times more likely to have subsequent concussion incidences as compared to athletes who have no concussive injury history.[37, 38] The subsequent concussion may occur with less direct or indirect force to head than the previous concussion, and the recovery time after a subsequent concussion may be longer than the previous concussion.[37, 39] Having a subsequent concussion before fully recovering from a previous concussion could result in more severe and prolonged brain dysfunction than the previous concussion.[4, 5, 8, 40, 41, 42, 43]

Although the associations of concussion with second-impact syndrome (SIS) and long-term cognitive health (e.g., chronic traumatic encephalopathy [CTE] and late-life cognitive impairments) have not been well established, many studies have speculated that accumulative or multiple concussive head injuries may lead to these disorders.[4, 5, 7, 8] SIS has been considered as a catastrophic consequence of repeated concussions.[50, 51, 52, 55] SIS is characterized by the diffuse cerebral swelling involving catastrophic deterioration.[50, 51, 52, 53, 54, 55] It is believed that this condition could occur when a patient with a prior concussion sustains a second concussive head injury before the symptoms and signs related with the previous one have fully resolved.[50, 51, 52, 55] This condition rarely occurs, but the outcome of SIS is extremely critical such as severe brain damage, coma, and death.[7, 8]

CTE is a neurodegenerative disease that appears years or decades after the recovery of a head injury.[46] The symptoms of CTE include; disordered memory, speech and gait abnormalities, behavior and emotional changes, and parkinsonian signs.[46, 47] Although the relationship between a concussion and CTE still remains unclear, a majority of researchers have believed CTE to be a result of repetitive head injuries.[46, 47, 48, 49] In addition to CTE, several studies reported that repeated or accumulative concussions may lead to late-life cognitive impairments such as depression[44] and dementia[45].

The Importance of Concussion Assessment in Military

Concussion has been a significant health concern because of the possible mid and long-term effects in military.[4, 5, 7, 8, 24, 64, 65, 66] In the Iraq and Afghanistan wars, concussive head injury was recognized as one of the most major injuries.[21, 65, 66] Many service members (SM) after deployment at the theater of operations showed concussion-related symptoms such as headache, memory and concentration disturbances, and balance problems.[24, 67] A study[24] examined SMs in 3 to 4 months after their deployment in the Iraq war to examine the relationship between concussions and physical and mental health problems. SMs who sustained concussions during deployment are more likely to have physical and cognitive health problems, as well as post-traumatic stress disorder (PTSD) and depression as compared to their counterparts.[24] Those who had one or more concussions also reported poor general health, more missed workdays, and more medical visits in the past month than those who had no injury or other injuries.[24]

Beside mid and long-term effects of concussion after deployment, concussions can also have a negative effect on combat-related physical and cognitive functions during deployment for military operations following as: difficulty in moving and performing quickly under time pressure, negotiating uneven or moving surfaces or terrain, multitasking; decrease in marksmanship performance, situational awareness, self-esteem and confidence; and a feeling of fear in military operation settings.[63] Common acute effects of concussions involve mainly physical symptoms (e.g., headache and dizziness), cognitive impairment (e.g., concentration and memory), and poor balance performance.[58, 59] These symptoms caused by concussion may directly influence physical performance and mental status, which can lead to place individuals, teams, and/or units in danger at the theater of operations.[60, 61] Because most SMs conduct missions and tasks in extremely stressful environments in terms of psychological and physical stress, they should be sturdy physically and psychologically for successfully conducting their duties under these stressors.[57] SMs also have to perform wartime missions under extreme fear related to the possibility of death for themselves, as well as their colleagues. If one member of the team or unit sustains a concussion or multiple concussions, it can be very dangerous in military operation settings. The fighting efficiency of the SMs with concussive head injuries could be reduced drastically due to the physical symptoms and cognitive impairments. It can increase the risk for another injury or death in wartime, which can subsequently lead to the probability of mission failure. In peacetime, some lasted symptoms may result in a decrease of work performance, behavioral or emotional problems, and relationship problems with other team members.[63]

Due to these reasons, the Department of Defense (DoD) and the Department of Veterans Affairs (DVA) introduced new screening and management procedures for concussions.[62, 68] The SMs in the US military who are involved in a potentially concussive event are mandatorily required medical screening in a timely fashion, along with a 24-hour period of rest.[62] In addition, to avoid further complications associated with multiple or repeated concussions, major sports and military-related research groups and associations recommend that patients suspected of having a concussion should not return to duty on the day of injury and must have a minimum 24 hours for recovery.[4, 5, 6, 7, 8, 62] After all symptoms are fully resolved, returning to duty is highly recommended.[4, 5, 6, 7, 8, 62] Concussions, therefore, influence directly or indirectly the level of combat readiness and troop retention rate in peacetime and wartime.[61]

Summary

As mentioned above, concussions occur frequently in the military. The acute and chronic consequences caused by a concussion have a profound effect on SMs' capability to perform combat operations, as well as their physical and psychological health. Accurate evaluation of a concussion is important for appropriate treatment and prevention of multiple or repeated concussions. Early identification of concussions lead to early treatment that maximizes the probability of recovery, as well as the prevention of further complications and long-term effects from multiple or repeated concussions.[62, 69]

In the current practice for concussion, SMs who are diagnosed with a concussion should be immediately removed from duty and monitored with a serial concussion assessment until their concussion symptoms and signs are fully resolved to ensure their safe return to hazardous duty.[4, 5, 6, 7, 8, 62] To do this, when a concussive event occurs, a trained SM or health provider is required to proficiently evaluate the patient to determine if the patient requires immediate removal or return to duty.[4, 5, 6, 7, 8, 62, 69] The decision should be made quickly and accurately at the place where the concussive event occurs. Therefore, development of a practical and accurate assessment instrument for concussions is very important for accurate and quick concussion diagnosis.

Concussion Assessment Tools

By practicableness on the sideline or field, concussion assessment tools can be categorized into sideline assessment of concussion and post-sideline assessment of concussion tools. Commonly used sideline assessment tools of concussion in sports and military-related settings includes the Glasgow coma scale, post-concussion symptom scales, standardized assessment of concussion (SAC), balance error scoring system (BESS), sport concussion assessment tool (SCAT) 3, and military acute concussion evaluation (MACE).[2, 7, 36, 69] Post-sideline assessment tools of concussions include neuroimaging (e.g., computed tomography [CT], magnetic resonance imaging [MRI], functional MRI, magnetic resonance spectroscopy, diffusion tensor imaging, and high-definition fiber tracking) and neuropsychological assessments (e.g., Immediate Post-Concussion Assessment and Cognitive Testing [ImPACT], CogSport, Concussion Resolution Index [CRI], and Automated Neuropsychological Assessment Metrics [ANAM]).[4, 5, 7, 36]

The sideline assessment tools of concussion are more effective in time- and availability-wise than post-sideline assessment tools because of their quickness, simplicity, and inexpensive nature to use, even if they may not identify comprehensive concussion symptoms and signs.[4, 5, 6, 36, 69] The post-sideline assessment tools for concussion are a more in-depth battery of tests compared to sideline assessment tools. However, they require more time, equipment, and highly trained personnel for administration and interpretation of a score from them.[4, 5, 6, 36] Considering the purpose of this study, this literature review will focus on sideline assessment tools of concussion. The following sections discuss commonly used sideline concussion assessment tools for concussion.

Glasgow Coma Scale

In the 1970s, Glasgow Coma Scale was developed for assessment of the level of consciousness for patients with head injury.[70, 71, 77] This scale consists of a series of questions that assess motor responsiveness, verbal performance, and eye opening to determine the level of consciousness immediately after the injury. Best eye, motor responses, and verbal are graded from 1 to 4, 1 to 6 and 1 to 5, respectively, and the 3 scores are added up to make up the final score. The combined total score can range from 3 to 15. The severity of TBI is categorized into three grades: severe = equal to or less than 8; moderate = 9 to 12; and mild = 13-15 of total scores.[71] The GSC has been widely accepted in clinical settings as an objective and valid assessment tool for TBI.[72, 73] The GSC is useful for assessing relatively severe head injuries[74, 75, 76] Gomez and colleagues[78] reported that 95% of 2484 patients who sustained mild head injuries scored 15, 4% of them scored 14, and 1% of them scored 13 from GSC. Most of the patients with mild head injuries scored 14-15 out of 15 points so that the GSC could help identify more severe TBI rather than concussion. In the sports-related setting, patients that scored less than 15 GSC were removed from play and went through emergency management.[4]

Maddocks Questions

Maddocks et al[79] examined the sensitivity of traditional orientation questions and recent memory questions from concussed athletes and non-concussed athletes. They reported that the questions related with recently acquired information were more sensitive in concussion assessment and gave important clinical information at the time of injury than traditional orientation questions. It includes 5 recall questions of recently acquired information of the current and past play.[79] The questions are as follows: 1) What venue are we at today? 2) Which half is it now? 3) Who scored last in this match? 4) What team did you play last week/game? 5) Did your team win the last game? The Maddocks score is composed of these 5 questions, and 1 point is obtained for each correct answer. The use of these questions is recommended for only sideline diagnosis of concussion. There is no clear criterion of concussion on Maddock score.[4]

Post-Concussion Symptom Scale

Right after a concussive head injury, typically one or more concussion symptoms or signs are reported, and the largest degree of change immediately post-concussion was identified on concussion symptom scales.[85] As a result, concussion symptom scales have been used most commonly to assess concussion in the athletic training practices.[80, 81, 82, 83] There have been many different forms of concussion symptom scales/checklist published from 1995 to 2009.[2, 84] These concussion symptom scales include the Pittsburgh Steelers Post-Concussion Scale, Post-Concussion Scale (PCS), Post-Concussion Symptom Assessment Questionnaire (PCSQ), Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) Post-Concussion Symptom Scale (ImPACT-PCSS), Concussion Resolution Index–Post Concussion Questionnaire (CRI), Vienna Post-Concussion Symptom Scale, Graded Symptom Checklist/Scale (GSC/GSS), Head Injury Scale (HIS), CogState-Sport Symptom Checklist, Signs and Symptoms Checklist (SSC), Sport Concussion Assessment Tool–Post Concussion Symptom Scale (SCAT-PCSS), and Concussion Symptom Inventory (CSI).[2, 84] These symptom scales/checklists contain a slightly different list of symptoms associated with concussions between 9 to 34, but the listed symptoms are very similar among them.[2, 84] The responses of these scales/checklists are typically a Likert scale type for response categories, and summated to provide a total score.[2, 84, 76] There, however, is still no gold standard symptom scale.[76]

Among these, ImPACT-PCSS have been widely used on the sideline or field.[69, 76, 86, 85] The ImPACT-PCSS contains a list of 22 different concussive symptoms such as headache, pressure in the head, neck pain, nausea or vomiting, dizziness, blurred vision, balance problems, sensitivity to light, sensitivity to noise, feeling slowed down, feeling like "in a fog", "don't feel right", difficulty concentrating, difficulty remembering, fatigue or low energy, confusion, drowsiness, trouble falling asleep, more emotional, irritability, sadness, and nervousness or anxiousness. Patients with concussive head injuries require determining the severity of each of the 22 symptoms based on a 7-point Likert scale ranging from 0 (not present) to 6 (severe).The total score is the sum of the number of symptoms endorsed (maximum possible = 22) or the severity scores of each symptom (maximum possible = 132) rated by the patient. Lower scores on the symptom scale indicate less impairment while larger scores represent more severe impairment. Concussion can be suspected when the patient reports 3-5 times the number of baseline symptoms at injury time and/or 6-8 points higher on severity scale as compared to baseline points on the severity scale. This symptom scale has shown a reliability of 0.55-0.94 and sensitivity of 0.41-0.89 and specificity of 0.79-0.99 in previous studies.[6, 86, 95, 96, 97, 98, 99]

The symptom scale can be quickly administered and can identify a variety of symptoms related with concussions.[76] However, it is heavily subjective and has the risk of being under-reported due to the patient's desire to return to play or duty early.[87, 88] A study reported that 26% of the athletes with a symptom-free score on a symptom checklist still presented impairments in standardized cognitive and balance testing.[87] Another study found the reasons why concussions are not reported by high school football players.[88] The most common reasons why concussions were not reported were as follows: 1) they thought that it was not a serious enough injury to get medical care (66.4% of respondents); 2) they wanted to stay in the game (41.0%); 3) they did not know that it was a concussion (36.1%); 4) and they did not want to let down their teammates (22.1%).[88] Therefore, use of the symptom scales/checklists may be not recommended for sideline assessments of concussions due to the tendency of patients to under-report their symptoms.[76, 87, 88]

Standardized Assessment of Concussion (SAC)

In the 1990's, a specific need was raised from the Colorado Medical Society (CMS) and the American Academy of Neurology (AAN) for the development of a valid, standardized, and systematic evaluation tool for concussions which could be administrated by either athletic trainers or similar personnel on the sideline right after a concussive head injury.[89, 90] The CMS and ANN suggested that the sideline evaluation tool should include testing of orientation, attention, concentration, and memory.[89, 90, 91] To comply in accordance with these suggestions, the SAC was developed by McCrea and his colleagues.[91]

The SAC consists of questions associated with orientation, concentration, and immediate and delayed memory for immediate sideline mental status evaluation of patients with a concussive head injury.[91, 92] The orientation is examined by asking a simple 5 questions: what is the month?; what is the date today?; what is the day of the week?; what year is it?; and what time is it right now? The patient scores 1 point for each correct answer (possible points = 5). The immediate memory is examined by reading a list of 5 words, and then having the patient repeat the list of 5 words in any order. The patient scores 1 point for each correct word. This examination is repeated 3 times (possible points = 15). The concentration is examined by reading a string of digits (numbers of the digits: 3 to 6), and the patient repeats each string of digits in backwards. Then, the patient is asked to list the months of the year backwards. The patient scores 1 point for each correct answer (possible points = 5). For the delayed memory, the patient is asked to recall the list of 5 words in the immediate memory examination. The patient scores 1 point for each correct answer (possible points = 5). The SAC has maximum 30 possible points with each correct response worth 1 point. The SAC is administered before injury to obtain a baseline score and again after injury to identify a concussion. People with concussions have scored significantly lower points in immediate memory, concentration, and the delayed memory sections of the SAC versus individuals without a concussive head injury.[91, 92, 93, 94, 104] A decrease of ≥ 3 points in the SAC's total score indicates a concussion.[93, 94]

The SAC is an easy, practical, objective, and sensitive instrument to evaluate impairment in the most sensitive cognitive domains to concussion.[6, 76, 86] The SAC examination is administered orally by a tester to measure 4 different domains of cognitive function such as orientation, immediate memory, concentration, and delayed memory.[91] It has been designed to be administered by any individual without previous experience with neuropsychological testing on the sideline or field[6, 91] and takes about 3-5 minutes to complete.[6, 87, 93] The reliability and validity of the SAC has been established well in many previous studies.[87, 93, 94, 100, 102, 104] The reliability of SAC ranged from 0.42 to 0.71.[86, 94] It found a significant decrease in the SAC scores immediately after a concussion when comparing the concussed athletes to the uninjured athletes, with a sensitivity of 0.72-0.94 and specificity of 0.76-0.91.[6, 87, 93, 94] Broglio et al[85] conducted a meta-analysis related to the effect of concussions on cognitive function, signs/symptoms, and postural control. They reported that the largest effect was found in cognitive function as measured by the SAC when evaluated immediately after a concussive event. In the concussion assessment and management practices, serial administrations of concussion evaluation should be needed, and practice effects are a typical concern in the practices.[4, 5, 6, 7, 8] SAC has no learning/practice effects on the total SAC scores in multiple concussion evaulations.[101, 112]

However, the patients presented a significant increase in scores of an SAC examination after 48 hours of injury, up to baseline SAC scores, so the SAC may only be effective in diagnosing concussions within 2 days.[87, 91, 93, 104] These results would suggest that the SAC may provide the sports medicine clinician with the greatest amount of information pertaining to neurocognitive status immediately following injury.[85, 87, 93, 94] In addition, the SAC is not a comprehensive cognitive examination.[69, 76] The SAC is not a substitute for formal and in-depth neurologic or neuropsychological examinations of patients, but it is intended to detect the concussed patients immediately so that further evaluation and proper management techniques could be implemented.[5, 7, 69, 76]

Balance Error Scoring System

The Balance Error Scoring System (BESS) was developed by modifying the Romberg test for balance to provide an assessable balance method on the sideline.[106, 107] The BESS is a tool popularly used by athletic trainers and clinicians when evaluating balance and postural deficits as a result of a concussion.[80, 81, 82, 105] The BESS includes 6 stance examinations made up of three stances(i.e., single with non-dominant leg, double with shoulder width apart, and tandem stance) on a foam and firm surfaces. The examinations begin by assessing the stances on a firm surface, then following up with the same postures on a foam surface.[106, 107] Patients are tested by placing their hands on their hips and closing their eyes for 20 seconds, while any errors made by the patient are counted for scoring. The errors include opening eyes, hands taken off the hip, stepping, stumbling, and falling. Each error is recorded with a maximum of 10 errors possible for each stance. The maximum possible total score is 60 points. Higher scores indicate poorer balance and postural performance.

Although BESS requires small equipment (i.e., foam), it is easy to use on the sideline with only a 3-5 minute of administration time.[76, 108] To obtain the best information from BESS, the score after injury should be compared with the baseline score of BESS.[108] The BESS is administered before injury to obtain a baseline score, and administered again after injury to identify balance and postural impairments. The score of the BESS typically elevated 3-6 points from baseline at the time of injury.[86, 109] The BESS score for a healthy population is typically 6-9 points lower than in concussed patients.[86, 100, 105, 112] The BESS has presented a moderate level of reliability and validity for measuring balance impairments.[86, 105, 106, 107, 108] The BESS has a modest reliability, ranged from 0.57 to 0.96, depending on the type of reliability assessed.[107, 109, 111] The accuracy of BESS seems to be low to moderate for detecting concussion. Sensitivity of the BESS was ranged from 0.34 to 0.64 while specificity was 0.91-0.96.[6, 87] The BESS may be useful within 2 days after concussion occurs, however it is highly recommended to use BESS with other concussion assessment tools because not every patient with a concussion presents balance and postural dificits.[6, 87, 100, 106] There were significant learning/practice effects with the BESS when administered repeatedly[101, 111, 112], as well as a significant decrease in scores due to functional ankle instability and fatigue after high intensity exercise.[114, 115, 116, 117]

Sport Concussion Assessment Tool 3

Due to the complex nature of concussions having a variety of symptoms and signs, the Concussions in Sport Group (CISG)[4, 32] recommends that a single test battery is insufficient when making a clinical decision for concussion diagnosis, therefore a combination of measures should be implemented for more accurate concussion diagnosis. To reflect this recommendation for diagnosis of concussions, the sport concussion assessment tool (SCAT) was developed, a modified tool based on reliability and validity evidences from concussion literature.[4, 32, 86] The SCAT3 is the latest version of SCAT.[4] The SCAT3 is a combination of multiple tests including the Glasgow coma scale, Maddocks score, concussion symptom scales with 22 items, SAC, BESS, physical sign and coordination examinations (e.g., neck examination and finger to nose task).[4] The SCAT2 provided a total score (ranged from 0 to 100 points) for concussion assessment with a lower total score indicating poor performance.[86] Although several components of SCAT2 have presented scientific evidences related to psychometric properties for reliability (0.54-0.94), sensitivity (0.34-0.94), and specificity (0.76-1.0), there is no evidence to support the use of a total score.[86] There have also been little available normative data and clear cut-points to diagnose a concussion, as well as scientific evidences to support the use of SCAT3.[86] Currently, it has been recommended that those with any signs/ symptoms identified from any subscales of SCAT3 after concussive head injury should be immediately removed from activity and referred to a certified health professional.[4, 32]

The CISG recommended the use of SCAT3 for on-field or sideline evaluation of an acute concussion.[4, 32, 86] The SCAT3 can measure many different signs and symptoms in different domains so that the use of SCAT3 may increase the accuracy of a concussion assessment.[6, 85, 87] For example, McCrea and his colleagues[87] reported that the combined examinations of GCS, BESS, and SAC provided the highest accuracy of concussion diagnosis (sensitivity: 0.94; specificity: 0.93) as compared to a single concussion test. Despite this advantage, the SCAT3 has not been used widely in the field. Only 31% of athletic trainers have used SCAT2 when they assessed and diagnosed a concussion.[82] The SCAT3 takes 15 to 20 minutes to administer. It is recommended to be conducted after a minimum 15-minute rest period on the sideline to avoid the impact of fatigue on the performance of the patient.[4, 86] The SCAT3 requires much more additional time to complete on the sideline as compared to the other sideline evaluation tools of concussion such as GCS, BESS, and SAC.[76] In addition, SCAT3 was designed to be administered and interpreted by medical professionals.[4, 32, 86] These limitations may make SCAT3 impractical for everyday sideline assessment purposes. In addition, as addressed in PCSS and BESS paragraphs, some sub-tests of SCAT3 had poor to moderate psychometric properties and learning/practice effects.

Military Acute Concussion Evaluation

To provide the best medical care and prevent multiple concussions within short intervals, a concussion evaluation right after a head injury has been sustained is required in the combat theater.[21, 62] The military acute concussion evaluation (MACE) was developed by Defense and Veterans Brain Injury Center (DVBIC) in 2006 for concussion evaluations in the deployment settings.[60, 62] MACE consists of checking injury history and cognition evaluation sections.[127] The history section is designed to check if there were any past injuries or alterations of mental status related to having a concussion.[60] The cognition evaluation section adopted SAC to measure cognitive impairments in four cognitive domains (i.e., orientation, immediate memory, concentration, delayed memory).[60] In 2012, the original MACE was modified and updated substantially to reflect the latest knowledge from scientific research.[127] The modified version of MACE included an additional neurological examination section that consisted of a pupil response to light test, speech fluency test, grip strength and pronator drift tests, and balance test.[127] MACE can be administered by corpsmen and medics.

A patient would need further evaluation for brain injury if the patient has a concussive event and scores less than 25 points on the SAC, or has any symptoms during the neurological examinations.[60, 62, 127] The military has recommended to use MACE for initial evaluation and screening of a concussion in theater.[21, 60, 62, 125, 126, 127] Although the MACE has been widely used in deployment settings, validity and definitive cut points of MACE to detect concussion have not been established thoroughly for service members in military operations or combat settings.[21, 60] Coldren et al[128] examined the validity of the original MACE's capability to diagnose concussions in US Army soldiers from Operation Iraqi Freedom-deployed units. They reported that MACE provided insufficient sensitivity and specificity for diagnosis of concussion. Kennedy et al[129] examined the utility of the modified MACE as a primary evaluation tool for concussions in a combat operations setting. The results of their study indicated that the MACE presented an insignificant relationship with recovery time. These results may be because the SAC is a main portion of MACE, and administration of MACE was delayed after concussive events.[4, 87, 91, 93, 104] The modified version of MACE may not be useful to assess concussions in the field or frontline because it takes 15-20 minutes to administer the test.[118]

Potential Concussion Assessment Tools for Sideline Use

There are several potential concussion evaluation tools for sideline use such as the King-Devick test and clinical reaction time test, but neither have been used widely in the field.[2, 36, 69, 76, 80, 81, 82, 83] These tests are simple and easy to administer, and the administration of the tests and interpretation of results can be conducted by non-medical personnel, or a psychologist.[118, 119, 121, 122] However, there has been little reported evidence of the psychometric properties of these tests because they are relatively new.[36, 69, 120] In addition, these tests require additional equipment, which make them impractical for sideline evaluation of a concussion.[86]

King-Devick Test. The King-Devick (K-D) test is designed to detect impairments of eye movements, attention, language, and other areas associated with suboptimal brain function.[118, 119] This test measures the deficits in brain function based on the speed (i.e., seconds) of rapid number naming as well as errors made by patients.[118, 119] The K-D test includes four test cards, consisting of one demonstration card and three test cards. The patients are required to read the numbers on the cards from left to right without making any errors as quickly as possible. Each error made naming a number accounts for a -0.5 second penalty. The tester records the total time to complete the three test cards, along with the errors. Low speed represents suboptimal brain function. Typically, the test result is compared with a baseline result to detect a concussion. This test takes less than 2 minutes to administer. The K-D can be a strong potential rapid sideline concussion evaluation tool, but there is insufficient scientific evidence to see if the K-D test is valid enough to diagnose a concussion.[118, 120]

Clinical Reaction Time. The Clinical reaction time (CRT) test measures impaired reaction time caused by a concussive head injury.[121, 122, 123] It is simple and easy to use for sideline concussion evaluations. The patient is asked to sit with their forearm resting on a horizontal table surface with their hand mounted at the edge of the surface. The tester suspends a measuring stick within the patient's open hand, which is 1.3m long and marked in 0.5cm increments, then releases the stick at randomly assigned time intervals between 2 to 5 seconds to minimize anticipating the time of its release.[121, 122] This test is repeated 8 times after 2 practice trials, then the mean of the 8 measurements is recorded as a final score.[121, 122] The CRT is calculated using a formula ($d = \frac{1}{2} gt^2$), where *d* is distance, *g* is acceleration of gravity, and *t* is time in seconds. This test measures the reaction time post-concussion, and the score after concussive injury is compared with the baseline score to detect.[121, 122] If there is an increase in the reaction time, the patient may be considered of having a concussion with a sensitivity of 0.75 and specificity of 0.68.[124] Although several studies supported the use of CRT as a part of a multifaceted concussion assessment battery, further validation study may be needed to support the use of CRT.[120, 121, 122, 123, 124]

Summary

Many assessment tools for concussions are currently available, but there is no criterion method to evaluate concussions.[76, 85, 87, 130] The main reasons may be due to the nature of concussions including complexity and subtleness of signs and symptoms.[3, 4, 32, 56, 85] Concussions involve various signs and symptoms that are presented and last in various and irregular patterns.[3, 4 ,32, 85, 130] The consequences of a concussion are associated with brain functional disturbance instead of brain structural impairments, so the currently available concussion evaluation tools heavily rely on subjective and objective responses from patients with a concussive event for a diagnosis, instead of traditional neuroimaging techniques such as CT and MRI.[4, 7, 32, 69, 76] The latest knowledge of concussions have suggested the use of multifaceted assessment batteries for sideline or frontline assessment tools for concussion, such as SCAT3 and the updated version of MACE.[4, 85, 95, 130]

Unfortunately, the psychometric properties of the individual assessment tools in the multifaceted assessment battery are still not well-known.[36, 76, 84, 130] No scientific evidence has been established for an optimal combination of multiple assessments for accurate evaluations of concussions.[85, 86, 120] In addition, the suggested multifaceted assessment tools sacrifice efficiency and practicality for more comprehensive evaluations. In other words, they require more time and special training or certified qualification to use on the sideline or combat theater.[4, 76, 130]

The main purpose of sideline or field assessment tools for a concussion is early identification of the place where the concussion occurs, to implement appropriate concussion management procedures such as removal from play or duty to prevent a second injury, treatment in a timely manner, and return to play or duty after full recovery from concussion signs/symptoms.[3, 4, 69, 130] There are several practical concussion assessment tools (see Table 3), but a useful sideline or field assessment tool for concussions should be quick and easy to use, portable, inexpensive, usable by anyone, and acceptably sensitive to concussion. Most of these conditions are satisfied by SAC[6, 76, 85, 86, 87, 91, 93], which is one of the most widely used assessment tools, both as an individual assessment tool and a main component of SCAT3 and MACE in sports and military-related settings.[81, 82] In addition, SAC is an objective assessment tool for cognitive impairments induced by concussion[76, 85, 86], and no practice/learning effects are identified in multiple assessments using SAC.[101, 112] Therefore, SAC could be a very strong field measurement instrument as a practical concussion assessment tool to use for military personnel in peacetime and wartime.[21, 126, 127, 131]

Table 3. Sideline/field Assessment Tools of Concussion

Tests	Domain(s) evaluated	Characteristics
● Glasgow Coma Scale	● Brain impairment	● 1-2 minutes to administer ● Effective for evaluation of severe head injury
● Maddocks questions	● Short & intermediate term memory	● Quick & simple to administer ● Measures only memory
● Post-Concussion Symptom Scales	● Signs/ symptoms	● Quick to administer ● Measures various common sings & symptoms of concussion ● Tendency to under-report by patient
● Standardized Assessment of Concussion	● Orientation, immediate & delayed memory, & concentration	● 3-5 minutes to administer ● Easy & simple to use ● Measures various domains of cognitive function ● Acceptable sensitivity & specificity
● Balance Error Scoring System	● Balance impairment	● 3-5 minutes to administer ● High specificity & low sensitivity ● Practice/learning effect
● King-Devick Test	● Saccadic eye movement & attention	● 1-2 minutes to administer ● Practice/learning effect ● Limited evidence to support use
● Clinical Reaction Time	● Reaction time	● Quick to administer ● Limited evidence to support use
● Sport Concussion Assessment Tool 3	● Comprehensive concussion domains including cognitive & balance impairment, & signs/symptoms	● 15-20 minutes to administer ● Requires a certified health provider ● Measures various domains ● Unestablished criteria to interpret test results
● Military Acute Concussion Evaluation	● Concussion event, cognitive & neurological impairment, & signs/symptoms	● 15-20 minutes to administer ● Limited evidence to support use ● Recommends to use by the US military

Measurement Issues in Concussion Evaluation

Although many concussion tests have been developed and widely used in sports and military settings, psychometric properties of those tests have not been examined thoroughly. Especially, this is very true for neuropsychological (NP) tests, which measure cognitive or behavioral impairments induced by concussion.[102, 131, 132, 134] Randolph et al[131] examined the usefulness of existing NP tests including traditional pencil-and paper NP tests and computerized neurocognitive tests. The criteria to determine the usefulness were reliability, validity, and clinical utility. The authors concluded that there were no existing conventional and computerized NP tests meeting these criteria. The usefulness of NP tests remains unanswered due to poor psychometric properties[132] and insufficient empirical evidence[131].

Lack of Rationale about Construction of NP Tests

According to Ragan et al[132], the main reason for the poor performance of NP tests may result from the discrepancy between design and interpretation of the NP tests. The theoretical rationale for the use of NP tests is well established[131], while theoretical rationale for the tests construction, including design of the concussion tests and interpretation of the tests' scores, are not well addressed in the literature of concussion measurement.[132] It may imply that test developers of NP tests heavily relied on the clinical knowledge and expertise.[132] For this reason, it has been questioned if the test design matches appropriately with the standard of the test score interpretation.[132, 134] Many of the NP tests adopted and/or adapted from pre-developed items or instruments to assess cognitive function that were not originally developed for healthy adults, but developed for a different population such as patients with severe TBI and the elderly. Some of them, however, are adopted and used for assessment of concussions in young and healthy adults and a serial assessment of concussion in sports and military settings without considering the originally intended item construction of the tests.[132] These issues are found in other concussion assessment tools such as sign/symptom scales, balance impairment measures, and cognitive status measures.[132]

These issues should also be addressed for accurate measurement of cognitive function using SAC. There are two widely used measurement tools of mental status in clinical and sport settings, respectively, which are mini-mental status examination (MMSE) and SAC. The two instruments measure similarly orientation, memory (immediate and delayed), and attention/concentration domains for an evaluation of overall mental status. Although the items between MMSE and SAC are not exactly the same, they include some of the same items or similar pattern/type of items to measure the same construct. However, the target population, interpretation of test scores, and administration manner are different. In the medical field, MMSE was developed to examine cognitive mental status for the elderly and patients with cognitive impairment including dementia and depression in 1975.[133] MMSE has criterion-referenced standard (i.e., cut-point) and does not require repeated administrations to interpret the test score. On the other hand, in the field of sports, SAC was developed to evaluate cognitive mental status for athletes and patients with concussions in 1997.[91]

Individual-centered standard (i.e., baseline measurement of each individual) and a serial administration are required to interpret the test score of SAC. There is no clear rationale for the test design and recommended interpretation methods in SAC.[132]

Discrepancy of Test Design with Interpretation Method

It seems to match up the test design of MMSE with interpretation of the scores from MMSE. The items of MMSE are easy for normal elderly, but not easy for old patients with cognitive impairment.[133] MMSE adopts a well-established criterion-referenced standard (i.e., < 24 out of 30 for abnormal) to discriminate patients and normal elderly.[133] Unlike the MMSE, the test design of SAC does not seem to match up with the interpretation of the scores from SAC. The items of SAC are very easy for athletes or healthy young adults, while not easy for patients with concussion. SAC adopts individual-centered standard to discriminate concussed athletes and non-concussed athletes. In other words, the SAC score after sustaining a concussed injury is compared with the individual’s baseline SAC score to diagnose concussion. To ensure accurate interpretation with individual-centered standard, the SAC should have items with a wide range of difficulties (i.e., from very easy to very difficult), but most items of SAC are easy for healthy young adults. This can cause critical problems in concussion evaluation with SAC and individual-centered standard.

In order to improve understanding about measurement problems in use of SAC with individual-centered standard, Figure 1 and 2 demonstrate an important measurement concept of the individual-centered standard. When considering the current test practice and interpretation of SAC, there have to be assumptions that the SAC can discriminate well at all levels of cognitive function, and the scores from SAC should be normally distributed.[132, 134] These assumptions have to be met in both baseline and post-injury measurement for an accurate evaluation of a concussion. Figure 1 illustrates a case of meeting assumptions for the use of individual-centered standard.[132, 134] As Figure 1 demonstrates, SAC can measure accurately at all levels of cognitive function, which means that items of SAC discriminate or cover all ranges of true ability, and the test score reflect well true ability (i.e., a person’s cognitive function). According to the current concussion measurement practice, more than 2 points reduction in score of SAC indicates that the athlete has a concussion and needs to initiate appropriate concussion management. In this case, person A with 2 points reduction does not have a concussion, while person B with 6 points reductions has a concussion. SAC provides valid measurement values and the diagnosis of concussion is correct for the both participants.[132, 134]

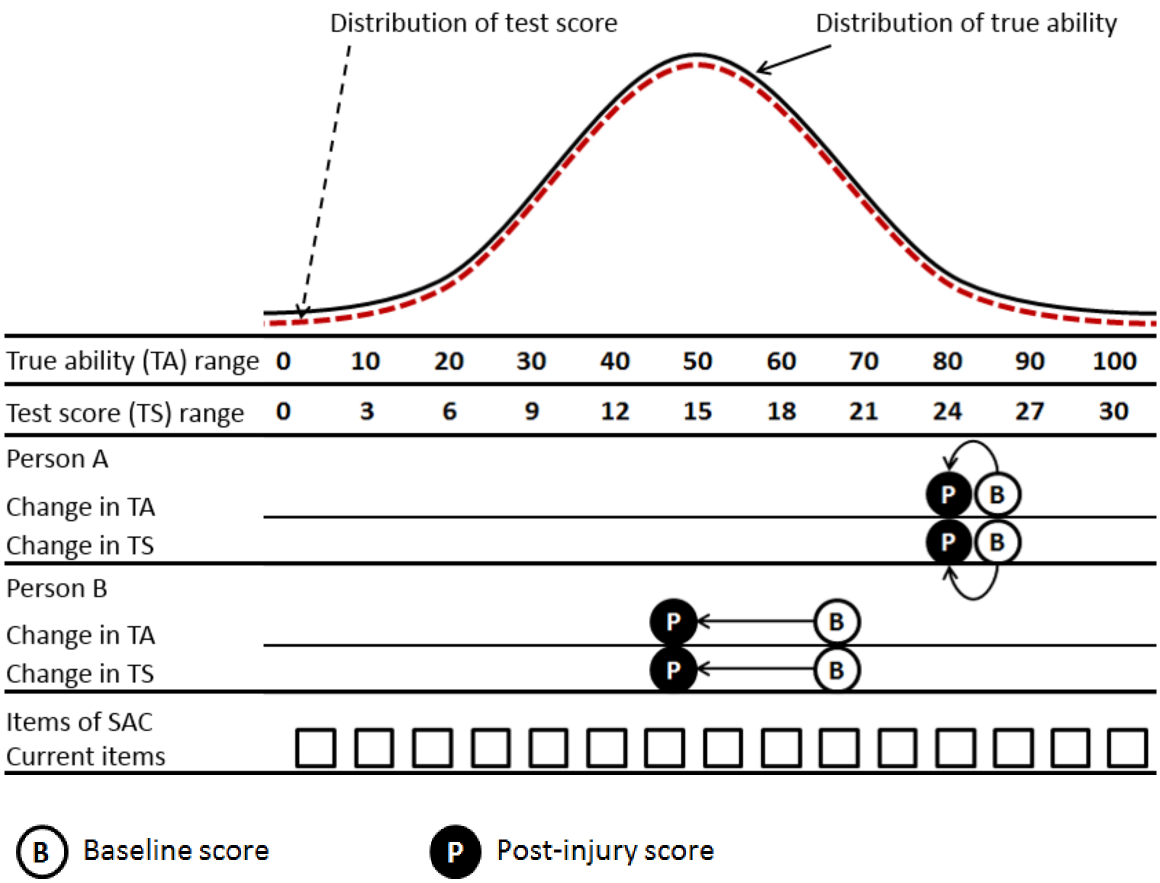

Figure 1. A Case of Meeting Assumptions for Use of Individual-centered Standard. Adapted from Ragan BG[134]. *An empirical investigation of several critical psychometric issues in neuropsychological testing of mild traumatic brain injuries*. University of Illinois at Urbana-Champaign, Urbana, IL.

Figure 2 illustrates a case of violating the assumptions for the use of individual-centered standard.[132, 134] In this case, the SAC cannot measure accurately in people with high ability because there are no items to evaluate high cognitive function. People with true ability of more than 60 cannot score more than 30 points in SAC. As a result, the distribution of SAC scores skewed negatively (i.e., ceiling effects) while the distribution of true ability was normal. It implies that the test score from SAC cannot reflect adequately true ability of the participant. The true cognitive function of person A (i.e., high ability) is significantly reduced from baseline, and a concussion should be suspected. However, a test score of SAC with a reduction of less than 3 points indicates that person A does not have concussion. For person B (i.e., low ability), the true ability and test score of SAC are significantly reduced and the changes indicate a concussion. In this case, SAC provides invalid measurement value, and the diagnosis of a concussion is incorrect in the participant with high true ability.

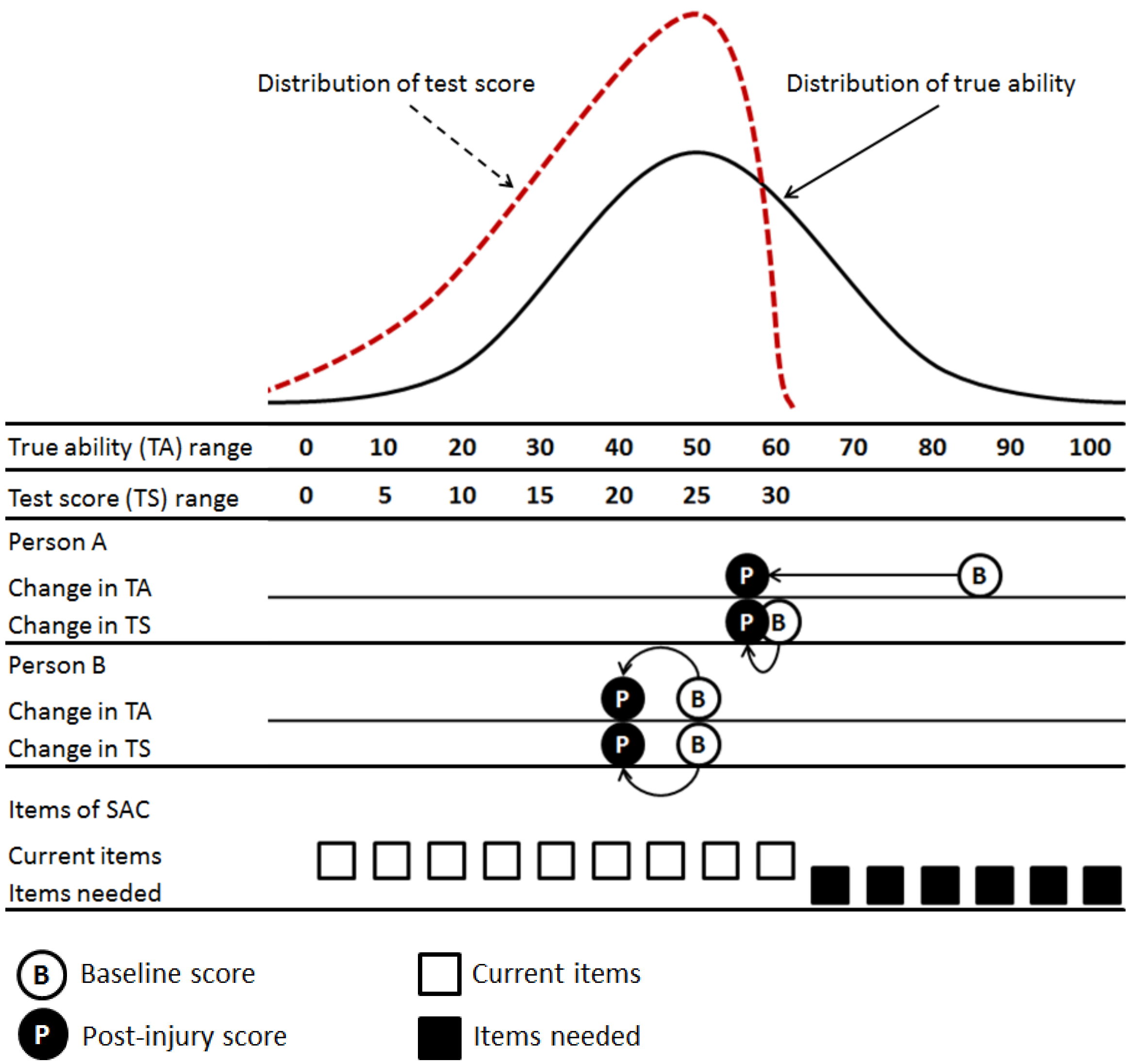

Figure 2. A Case of Violating Assumptions for Use of Individual-centered Standard. Adapted from Ragan BG[134]. *An empirical investigation of several critical psychometric issues in neuropsychological testing of mild traumatic brain injuries*. University of Illinois at Urbana-Champaign, Urbana, IL.

Poor Psychometric Properties and Potential Solutions

Unfortunately, the published results of the SAC indicate that there are violations of assumptions for the use of individual-centered standard. Previous studies reported poor psychometric properties of SAC such as a ceiling effect and poor items with respect to item difficulty. Average SAC scores from the previous studies ranged from 25.6 to 27.7 for baseline measurement and from 21.5 to 24.94 for post-injury measurement, respectively.[87, 91, 92, 102, 135] In addition, about 7% of participants scored 30 points on the SAC, which is a perfect score.[92] In the baseline measurement, a majority of participants scored very high points from the SAC (e.g., approximately 26 to 28 out of 30), which presents a high risk of ceiling effects. Easy items seem to associate with ceiling effects. About 63% to 70% of items on the SAC are too easy for healthy young adults in baseline measurement.[135] An acceptable item difficulty (p) range is $p \geq 0.1$ or $p \leq 0.92$[136], where p is a proportion of examinees who answered an item correctly. The average item difficulty of the orientation and immediate memory section is greater than 0.92.[135] Other sections of SAC have moderately high averages that are equal to or greater than 0.69.[135] Based on these results, the current SAC does not have the ability to measure accurately a wide range of true ability in baseline measurement.[132, 135] Individual-centered standard is inappropriate to interpret test scores from the current SAC.[132, 135]

To solve these issues of SAC, several researchers suggest that SAC should include more difficult items than the current SAC items.[132, 135] Figure 2 illustrated (see bottom lines of this figure) a well concept of this solution.

Modification of existing items or addition of difficult items is considered an effective solution for increasing overall difficulty of SAC.[132, 135] A study[137] modified existing items of memory section to increase item difficulty of SAC. They just changed the word list (i.e., from 5 words to 10 words) and its administration method (i.e., from three times to one time). For the original SAC, a list of five words is administrated three times to measure immediate memory. For the modified SAC, a list of ten words is administered one time. These simple modifications improve significantly in the immediate and delayed memory section as well as the SAC. 85% of items in the immediate and delayed memory sections were in acceptable range of item difficulty, and no one scored 30 points out of 30 in the modified SAC.[137]

Summary

Test scores have to be reliable and valid for accurate concussion evaluation, but the current SAC has some problems when used with the individual-centered standard, which is recommended in concussion evaluation practice. Some modifications in items are inevitable to solve the problems such as ceiling effects and item difficulty. Further research should increase item difficulty to improve the psychometric properties of the SAC and examine if the items are psychometrically sound for a population with a wide range of cognitive function.

Methods to Evaluate Psychometric Properties

When developing a test or items, developers should examine the psychometric properties of the items and examinees' response to the test items. There are many ways to evaluate the psychometric properties of a developing or existing measurement instrument. Commonly used methods to examine if a test has desired psychometric properties include the classical test theory (CTT), item response theory (IRT), and Rasch model. CTT is representative of a traditional approach, while IRT and Rasch model are a relatively new approach to evaluate measurement scales. Each method has advantages and disadvantages. The following sections are a brief introduction to each method and its advantages and disadvantages for use with this study.

Brief Introduction to CTT, IRT, and Rasch Model

CTT is a theory about observed test score and true ability based on a simple linear model that cannot be proven or falsified; however, CTT has been widely used in test development due to its simplicity of theoretical assumptions and easiness of application in many situations.[138] In the CTT, the total score represents a person's ability that a test measured, and two item parameters (i.e., item difficulty and discriminant) are estimated to evaluate items in a test. Item difficulty is a proportion of examinees who answered correctly to an item among total examinees. Item discriminant reported generally in CTT is point-biserial correlation of responses on an item with total test scores.

The IRT and Rasch model are advanced mathematical models (i.e., a family of probabilistic models) to describe response patterns of examinees to each item.[138] Both methods map the relationship between total score and person ability (i.e., level of a latent trait measured by a test). A person who has a higher test score has higher ability when compared to a person who has a lower test score. Unlikely CTT, the test score has a non-linear relationship (i.e., ogive-shaped curve) with true ability. This relationship has been well established empirically from observed data.[139] IRT and Rasch model estimate person ability (θ) and item difficulty (b). The larger logit score in item difficulty indicates a more difficult item. Larger logit score in a person's ability indicates higher level of ability. If a person's ability is higher than an item's difficulty, the probability to answer correctly will be high. If a person's ability is lower than an item's difficulty, the probability to answer correctly will be low. If a person's ability is equal to an item's difficulty, the probability to answer correctly will be 50%.

Advantages of IRT and Rasch Model over CTT

Interval Measures. The IRT and Rasch model have several advantages in evaluating psychometric properties of a test. CTT primarily focuses on total test scores, which is the total number of items answered correctly.[138] Total test scores indicate examinees' ability. Despite points (e.g., 0 for failure and 1 for success to answer) obtained from items actually being ordinal scores, they are added like interval or ratio scores to estimate an examinees' ability in CTT. Thus, interpretation of test scores should be limited to ordering examinees' ability. For example, total score does not provide the information that person A has more ability than person B by this much. In addition, all items in a test contribute equally to the total test score. In other words, CTT does not account for the item difficulty of each item. It is reasonable that a difficult item should be weighted higher than an easy item. On the other hand, IRT and Rasch mainly focus on the pattern of examinees' responses on each item, which is item-level information.[139, 140] These methods can provide interval measures of item and person parameters.[139, 140] The item and person parameters can be added and compared each other because they are interval measures in the same unit of logits. For instance, the difference of 1 between a persons' ability can be interpreted that person A has a higher ability than person B by 1 logits. Person A with an ability of 1 logits has about a 73% probability to answer correctly for an item with difficulty of 0 logits in the Rasch dichotomous model. When estimating person ability, each item has different weights depending on its difficulty.

Parameters Invariance. The important difference between CTT and a new approach (i.e., IRT and Rasch model) is invariance of item difficulty and person ability prameters.[138, 139, 140] The parameters of a person and an item from CTT are heavily dependent on each other because CTT is descriptive and sample dependent. In CTT, item difficulty and discrimination are calculated based on the overall examinees' ability (i.e., total test scores), and the test scores can be changed based on item difficulty and discrimination. Thus, it limits comparing examinees' ability that is estimated from different forms of the test as well as comparing item parameters estimated from different samples of examinees.[138] Contrastively, person ability estimated in the IRT and Rasch model is not test-dependent, and item parameters estimated are not sample-dependent because these methods are probabilistic and inferential.[139, 140] Both methods can provide stable items and ability parameters across different samples and forms of a test. The IRT and Rasch model can be easily applied to test equating, computerized adaptive testing, identification of biased items, linking and building item banks.[138]

Usefulness in Evaluation of Psychometric Properties. Another difference is that the main focus of CTT is on test-level information, while IRT and Rasch model focus mainly on the item-level information. CTT has little consideration of the examinees' response to any specific items although it can provide item difficulty and discriminate. In addition, Item and person parameters estimated by CTT have different units and implications, so that the interpretation should be performed separately. The IRT and Rasch model provide test developers very useful information to determine the exact relationship between any specific items and examinees' ability. The IRT and Rasch model provide item and ability parameters on the same common scale in logits unit. These allow test developers to examine the distribution of items' difficulty across a wide range of examinees' ability that will be useful to identify gaps and redundancy of items.[139, 140] IRT and Rasch model provide useful information to make a wide range of interpretation at the item level with varying individual ability.[138]

Assumptions & Weakness. IRT and Rasch model have stricter assumptions that may not be easy to meet in observed response data from a test when compared to CTT. IRT and Rasch model assumes unidimensionality of tested latent variables and local independence of items.[139, 140] Unidimensionality means that all items in a test should measure only a single latent ability. Operationally, it means that non-random variance in data should be explained by a single dimension of item and person parameters.[142] If unidimensionality assumption is violated, the probability of examinee's answering correctly on an item will not be solely determined based on person and item parameters. It may imply that there is another psychometric dimension to influence an examinee's response.[142] Local independence indicates that response for an item should not influence the response for other items in a test. In other words, all items should not be correlated with each other in a test. If local independence assumption is violated, the estimation of person and item parameters will be biased, and the unidimensionality assumption will be influenced.[142, 143] In addition, the IRT and Rasch model require a heterogeneous and larger sample size than CTT to insure stable item and person parameter estimation.[138]

Difference between IRT and Rasch Model

The IRT and Rasch model were developed concurrently but independently in 1960s. The Rasch model is mathematically similar to the IRT model with 1-parameter. For this reason, the Rasch model has been considered a special case of the IRT model. However, fundamental differences exist between the IRT model and Rasch model.[139, 144]

IRT is a set of logistic models (i.e., 1-parameter, 2-parameter, and 3-parameter models).[140] One-parameter IRT model assumes that only item difficulty is necessary to describe an item. Two-parameter IRT model assumes that item difficulty and discrimination are necessary to describe item. Three-parameter IRT model assumes that item difficulty, discrimination, and guessing parameter are necessary to describe an item. The Rasch model assumes that item difficulty is only necessary to describe an item, and the probability of an examinee to answer correctly on an item is solely determined by the difference between item difficulty and person ability.[139] In general, the Rasch model is mathematically simpler than IRT, and the Rash model requires a smaller sample size for stable parameter estimates as compared to IRT.[138, 156, 157]

There is a difference between the IRT and Rasch model that is worthy to notice. Rasch people[144, 145] insisted that the Rasch model is only way to construct an accurate item-person map that shows items' difficulty and examinees' ability on the common scale to provide useful information for test developers. It is because additional parameters of IRT, such as discrimination and guessing parameters, entangle in the estimation of person ability and item difficulty.[144, 145] For example, IRT allows item characteristic curves to cross, which means that item discriminant is unequal across items in a test. This implies that item difficulty can be varied depending on person ability in the 2- or 3-parameter IRT models. In those IRT models, the relationships between examinees' ability and items' difficulty cannot be presented in a particular way on an item-person distribution map. The 2- or 3-parameter IRT models cannot show the distribution of person ability and item difficulty parameters on the same unidimensional logit scale, but the Rasch model can.[144, 145]

When developing or calibrating a test, there is a distinct fundamental philosophical difference between the IRT and Rasch model. IRT pursues a goal to find the best-fit model to the data that explains maximally the variance in the item response data (i.e., variance explanation-oriented), but the goal of the

Rasch model is to examine if the item response data fits to the ideal measurement model requirements (measure-oriented).[139] For example, if model-data fit is poor, IRT changes the model to identify the best model among the three models, while the Rasch model changes or modifies data or items in a test. In other words, Rasch model has paramount measurement model requirements such as invariant-interval measures, and tests if item response data from a test satisfies its requirements. The application of the Rasch model seems to be more appropriate for developing or calibrating a measurement instrument.

Rasch Dichotomous Model

There are commonly used Rasch models such as the Rasch dichotomous model, rating scale model, partial credit model, and many-facets model. This section will discuss only the Rasch dichotomous model (RDM) because all items in K-SAC have dichotomous responses, correct (i.e., 1 point) or incorrect (i.e., 0 point) answers. RDM creates a unidimensional common scale like a ruler. There are logits as a measured unit on a kind of ruler instead of cm or inches. The ruler with logits can measure item difficulty and person ability. Individuals and items placed on the right of the ruler have more ability and difficulty, respectively. Individuals and items placed on the left place of the ruler have less ability and difficulty. In addition, person ability and item difficulty can compare with each other in a very meaningful manner.

In RDM, the responses to each item are coded as 0 for “failure” or “incorrect answer” and 1 for “success” or “correct answer”. The RDM assumes that the likelihood of an examinee’s response to an item is only determined by item difficulty (b) and person ability (θ). Unlike the IRT, Rasch models including RDM assume that item discrimination is equal to 1 across all items, and there is no error caused by guessing, which is 0. The response patterns of examinees to answer on an item can be delineated mathematically and graphically in Equation [1] and Figure 3.[146]

$$P(\theta) = \frac{e^{(\theta - b)}}{1 + e^{(\theta - b)}} \qquad [1]$$

Where *P* (θ) is the probability that an examinee with ability *θ* answer correctly to an item with difficulty *b*. The character of *e* is the base of the natural logarithmic, which is mathematical constant, 2.712828.

The value of θ and b can range from - ∞ to + ∞, where ∞ stands for infinity. They typically range from - 3 to + 3 in unit of logits. Larger value of logits in item difficulty and person ability indicates more ability and difficulty than lower value of logits. Individuals placed on the right have more ability of a latent variable. Items placed on the left are less difficult. The probability of a correct answer entirely depends on the difference between θ and b. The equation [1] can present an ogive-shaped curve, which is called an item characteristic curve (ICC, see Figure 3). If item difficulty and person ability are same, the probability of a correct answer is 50%. If person ability is higher than item difficulty, then the probability of a correct answer is greater than 50%. Conversely, if person ability is lower than item difficulty, then the probability of a correct answer is lower than 50%.

In RDM, each item has a unique ICC that represents the relationship between examinees and each item. All items have same shape of ICC, but the locations are different based on their difficulties. Item difficulty of an item is a point on the unidimensional continuum, where the probability of a correct answer is 50% (see Figure 4). For instance, item difficulties are -1, 0, and 1 for item 1, item 2, and item 3, respectively. The easiest one is item 1, and the most difficult one is item 3.

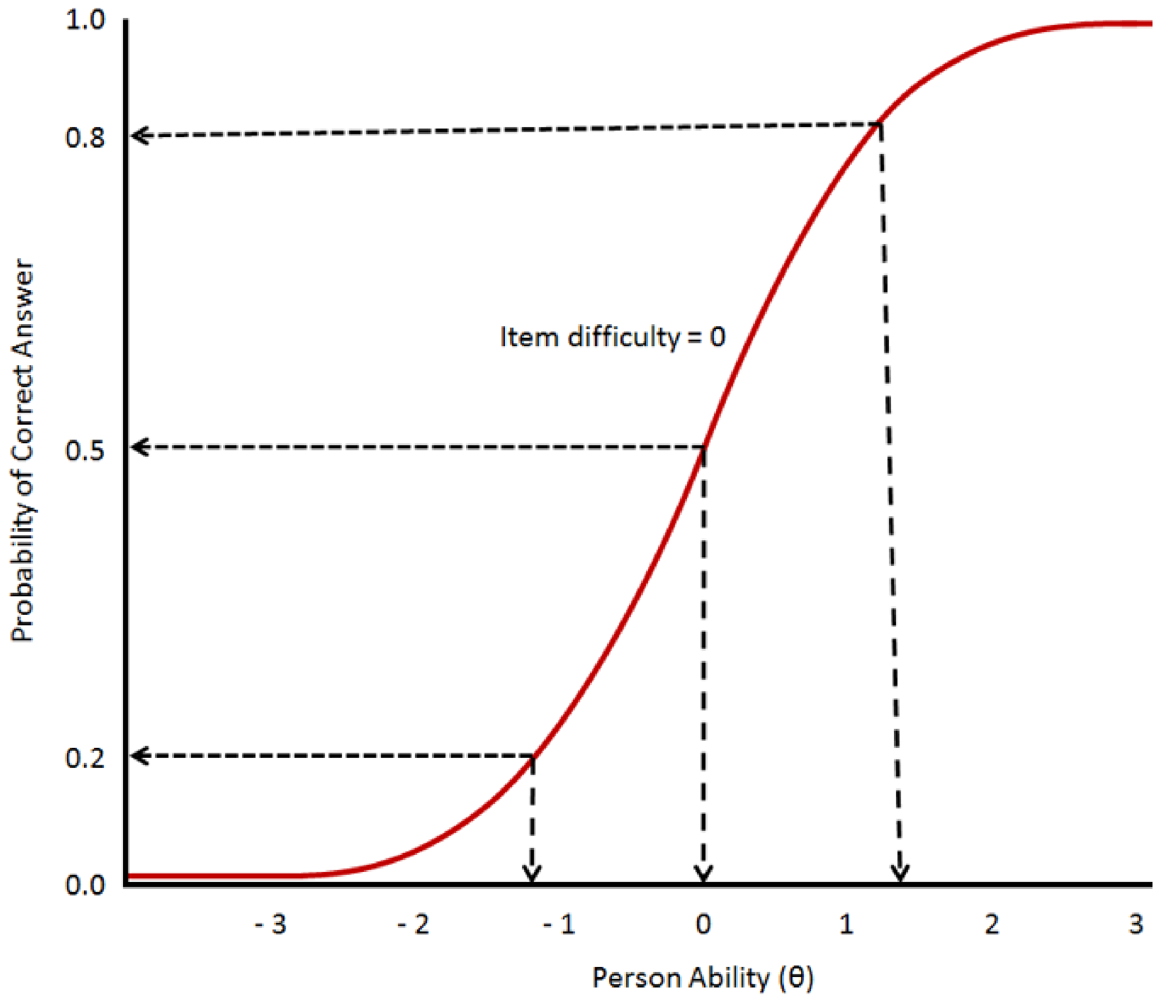

Figure 3. Item Characteristic Curve

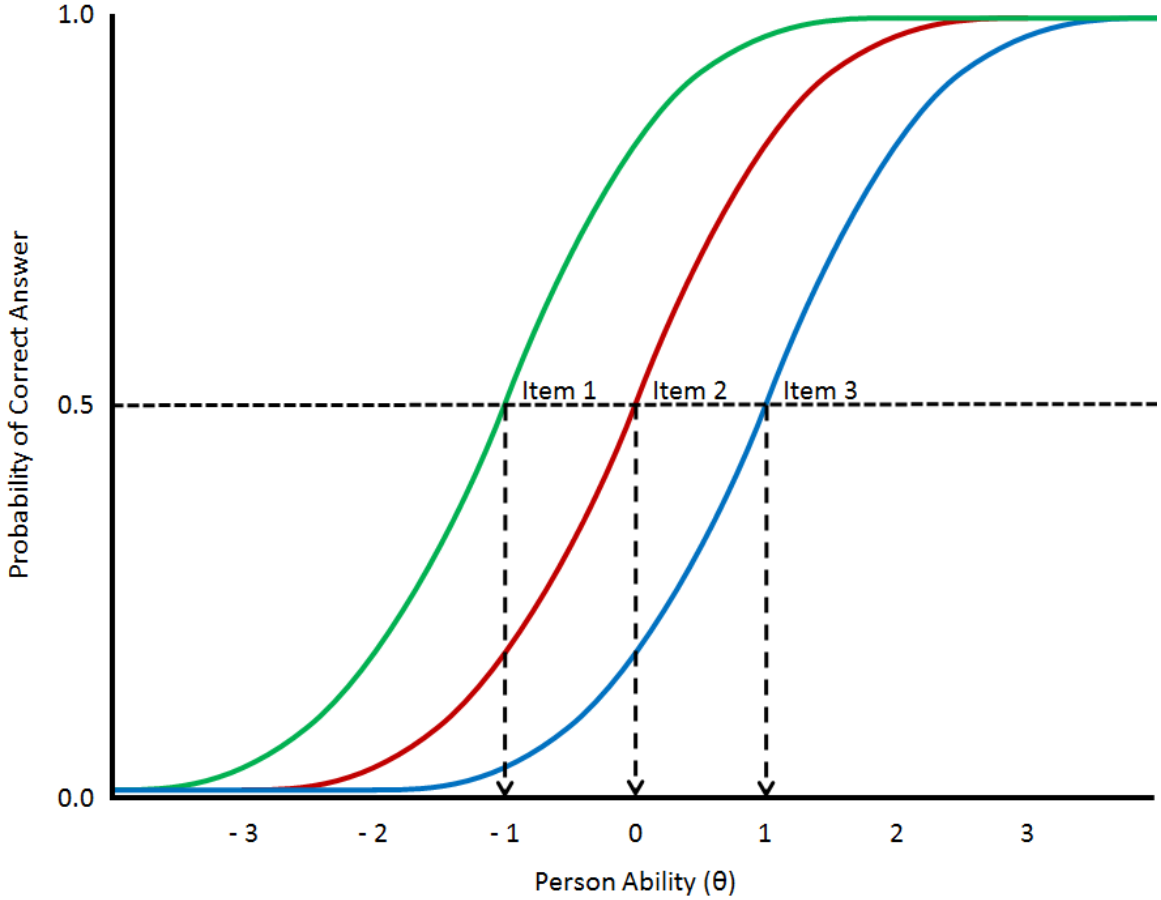

Figure 4. Item Difficulty

Summary

The Rasch model is a relatively new measurement model to evaluate psychometric properties of a developing concussion evaluation scale. To resolve measurement issues in concussion evaluation, such as inappropriate item difficulty construction and ceiling effects, the Rasch model can provide very useful and accurate information like invariant and independent parameter (i.e., item difficulty and person ability) estimates and item-person distribution mapping on a unidimensional common scale. Considering the purpose of this study, the application of the Rasch dichotomous model is suitable to examine psychometric properties of the developing concussion evaluation scale due to its dichotomous type of response patterns.

Translation

Commonly Used Approaches to Translation

An important issue in this study is the difference in language between instrument and target population. Typical methods to translate tests in an original language to a target language are adoption, adaption, and assembly.[147, 148, 149]

Adoption is a traditional translation practice that just involves a simple translation process from one language to another language. The purpose of adoption is to create a target language version of the instrument that is very similar in linguistic features with the original language version of the instrument.[147, 148, 149] This method has been widely used in the empirical research settings due to its simplicity and easiness to conduct.[149] The translated version of an instrument by adoption method involves minimum changes, and scores from translated and original instruments can be compared easily with each other.[147, 148, 149] However, these advantages are not always guaranteed in the use of adoption, rather it can have huge disadvantages if cultural differences influence largely the understanding of instructions and items in the target population.[147, 148, 149]

Adaptation is a modern translation method that involves a literal translation process and a process of fine-tuning to account for the cultural context and lifestyle of the target population.[148, 149, 150] The adaptation method is a more comprehensive approach of translation than the adoption method. Sometimes, the same item in linguistic perspective has different connotations in different cultures. For example, ‘King’ means king for children in the United Kingdom, but president for children in US. While adaptation can overcome the limitation of use of adoption in translation by accounting for cultural differences, it requires more complex procedures and expertise in both languages and cultures.[149, 150]

Assembly is an alternative method that involves developing a new item or instrument when adoption and adaptation do not provide a well-translated version of an item or instrument in terms of linguistic and cultural equivalence.[149, 150] Because the assembly method can lead to significant changes in an item or instrument, this method may result in the development of a new instrument.[149, 150] Assembly method can attain maximal cultural equivalence between the original and translated version of instruments, but the comparisons of results (i.e., scores) from the original and translated version of instruments may be meaningless unless psychometric properties are well examined, such as constructing validity and equating tests scores between both instruments. [149, 150]

There is no gold-standard method for translating an instrument. The best method for translation into different languages can be varied depending upon the purpose of translation as well as the characteristics of items in the instrument and culture of the target population.[147, 148, 149, 150] If the primary purpose of translation is to compare results (e.g., raw scores) obtained from an instrument between populations with different languages and cultures, adoption may be preferred for researchers because it minimizes differences between the original and translated version of the instrument.[147, 148, 149] On the other hand, if the main purpose of translation is to measure adequately a latent psychological construct across different populations or nations, adaptation or assembly may be preferred for researchers because it minimizes influence of cultural differences in the translated items or instrument.[147, 148, 149]

Practical Guidelines of Translation

Despite adequate translation being very important, many researchers have conducted translation without any consideration associated with linguistic and cultural equivalence.[151] A majority of researchers used the forward translation approach with an unqualified translator.[151] There exist a lot of recommendations or guidelines for adequate translation; however, they are inconsistent across previous studies and difficult to follow for a researcher.[152, 153] To solve this problems, Sousa et al[152] incorporated the most recommended guidelines in a user-friendly format. The detailed processes of translation are as follows.

Step 1. At least two independent translators translate separately an original language (OL) version of an instrument into the target language (TL) version of instrument, which is called forward-translation. The translators should be bilingual and bicultural, and their mother language should be target language. Ideally, one of the translators should be knowledgeable about the content area of the construction of the instrument in the TL, and the other translator should be knowledgeable about cultural and linguistic contents in the TL.

Step 2. A third bilingual and bicultural translator should review the two forward-translated version of instrument. If discrepancies and ambiguities of words, sentences and meanings are identified, committee approach (two translator and third translator) should be used to discuss and resolve these problems and derive a consensus which is the preliminary initial translated version of instrument in TL.

Step 3. At least two other independent translators should translate separately the preliminary initial translated version of instrument into OL, which is called back-translation. The qualifications and characteristics are the same as listed above step 1, but their mother language should be OL.

Step 4. Committee approach should be used to evaluate similarity of the instructions, items and response format regarding wording, sentence structure, meaning and relevance between the two back-translated versions of the instrument as well as the original version. The committee should include all four translators in step 1 and step 3 and one methodologist (e.g., researcher or a member of the research team). The developer of the original instrument should participate in the discussions if possible. If ambiguities and discrepancies cannot be resolved, Steps 1 through 4 may be repeated as many times as necessary. If the three versions of the instrument in the OL have enough similarity or all identified problems are resolved, a pre-final version of the instrument in the TL can be developed.

Step 5. Pilot testing of the pre-final translated version of the instrument should be performed among the target population. The instructions, items and response format clarity should be examined using a small sample. Further examination of the instrument for clarity of the instructions, items and response format, and content equivalence by expert panel is recommended. Some modifications in the pre-final translated version of instrument are made based on the results of a pilot test.

Step 6. Psychometric properties of the pre-final translated version should be examined in large and heterogeneous samples from the target population. Reliability and validity properties should be evaluated intensively to revise and refine the items of the pre-final translated version of the instrument. Lastly, the final translated version of the instrument is developed.

Summary

The optimal linguistic and cultural equivalence is incomparable, and adequate translation requires a good balance between the linguistic and cultural equivalence.[147, 149, 150] To maintain balance when conducting translation, the three methods can be flexibly applied in accordance with the characteristics of items in an instrument and culture of the target population.[147, 149] One of the important considerations for appropriate translation is the main purpose of translation.[147, 149] The purpose of translation in this study is to accurately measure cognitive function in the target population using a translated version of the adapted SAC, not to compare the scores between the original and target populations. When considering the primary purpose of this study, adaptation and assembly are more useful methods than adoption.

CHAPTER 3

METHODS

This dissertation includes two phases: development of the Korean version of the adapted SAC (K-SAC) and evaluation for psychometric properties of the K-SAC in a target population (phase 1); and examination of the validity of the K-SAC in concussion assessments (phase 2). Each phase consists of participants and procedures, instrument, and statistical analysis sections.

Phase 1

Participants and Procedures

A convenient sampling method was used for this study. Participants were cadets (i.e., 18 to 25 years old) of the Korea Military Academy (KMA, which is equivalent with United States Military Academy) with no previous history of a concussion or head injury in the previous 6 months. For this, participants were recruited by the investigators on the KMA campus in Seoul, South Korea. Flyers were placed around campus to recruit participants (see Appendix C). The investigators entered physical education classrooms and orally recruited participants on a strictly volunteer basis. Club sports also were recruited using the recruitment script (see Appendix C). Interested cadets were given the opportunity to take a consent document to read and consider, which has been approved by the University's Institutional Review Board (see Appendix A). KMA allowed us to conduct this study (see Appendix I).

Generally, a sample size of 200 is recommended as an appropriate sample size to produce statistically stable measures in the Rasch measurement model.[156, 157] Because it was unknown how the developed K-SAC would function in SKS, it did not know how many modifications and re-evaluations of the modified K-SAC would be required for this study. Thus, a pilot study was conducted to prevent wasting time and effort until the K-SAC showed acceptable psychometric properties. For the initial pilot study, about 50 participants, which is a minimum sample size required for the Rasch analysis[156], were recruited from KMA to evaluate psychometric properties of the developed K-SAC. As the results from the recruited sample indicated that the K-SAC had sound psychometric properties, participants were recruited additionally to finally confirm if the modified K-SAC had sound psychometric properties in a target sample.

Orientation was completed in a silent cadet lounge at KMA where they read and signed the informed consent (see Appendix E). They had an opportunity to ask questions about this study. Each participant verified that they have not had a concussion or head injury within the last 6 months. Participants were asked to fill out an injury history form that included their age, sex, height, weight, and history of head injury (see Appendix G). Researchers gave the K-SAC instructions described on the instrument orally (see Appendix H). It took approximately 3 - 5 minutes to complete.

Instrument

As described in the section of measurement issues in concussion evaluations of literature review, the current SAC (see Appendix J) needs more difficult items to measure accurately all levels of cognitive function, and the upgraded SAC needs to be adapted for the South Korean soldiers with considering cultural and language equivalence. For this, a committee approach was employed. The committee consisted of four measurement specialists, and three of them had high expert knowledge and many research experiences in concussion assessment, especially about SAC. Two of them had measurement and athletic training backgrounds in MS and/or a PhD, and their mother language was English. Another two of them had measurement backgrounds in MS and/or a PhD, and their mother language was Korean. Many different approaches were suggested by the committee members through extensive literature review. Multiple meetings and discussions were made to find optimal ways to increase item difficulty and maintain balance between cultural and linguistic equivalence. An upgraded and adapted SAC in English was derived after consensus of the committee was achieved.

The adapted SAC for SKS is consisted of orientation (n=5), immediate memory (n=10), concentration (n=12), and delayed recall (n=10) sections like the original SAC. Most of items were adapted from the original SAC, but they are significantly different. The items on the orientation section are the same as the original SAC because the items are globally common questions to measure orientation. Therefore, they did not need cultural adaptation for SKS. For the immediate and delayed recall section, a new word list including 10 words were developed for the SKS to increase the difficulty level of items, taking into accounts for syllables, syllabic pattern, and relevance between the words. For digits backwards of the concentration section, three strings of 7, 8, and 9 numbers were added onto previous strings of numbers with a length of 3 to 6 to increase difficulty level of items. For the month in reverse order of concentration section, it was removed from the original SAC because months said in reverse order are too easy in the Korean language and similar with digits backward. Recitation of months in reverse order is the same as counting from 12 to 1 in the Korean language. For the concentration section, serial sevens were added to improve the overall difficulty of the concentration section. The serial sevens, counting down from one hundred by seven, are a clinical test that has been commonly used to test concentration.[158, 159, 160] The serial sevens are more difficult than recitation of months in reverse order. In a study, approximately 50% of high school athletes answered correctly on the serial sevens test while approximately 90% of high school athletes answered correctly on recitation of months in reverse order.[159]

The English version of the adapted SAC was translated into Korean following translation procedures recommended by Sousa et al.[152] First, two bilingual PhD students of MTSU whose mother language is Korean translated the instrument independently into Korean. Second, any ambiguities and discrepancies of words, sentences, and meanings between the two translated versions of the instrument in Korean were discussed and resolved using a committee approach (including a principal investigator and the two translators). This process derived a preliminary Korean version of the instrument. Third, a bilingual American who has a bachelor and master's degree of Korean translated the preliminary Korean version of the instrument into English. Fourth, another committee approach (including a principal investigator, the two PhD students, the American, and a bilingual professor with a psychology major) was used to discuss and resolve ambiguities and discrepancies regarding conceptual and semantic equivalence among the original English version, the back-translated English version, and the preliminary Korean version of the instrument. Eventually, a final version of the adapted SAC in Korean was derived after a consensus from the committee was achieved. The K-SAC is presented on Appendix H.

The K-SAC consists of 37 items, and the responses are scored based on dichotomous category, 1 for a correct answer and 0 for an incorrect answer, respectively. The total score of the K-SAC can be ranged from 0 to 37, where a higher score indicates a higher level of cognitive function.

Statistical Analysis

Descriptive statistics were computed for age, sex, weight, height, body mass index, and K-SAC scores. Normality of K-SAC total scores was examined to evaluate celling effects. Due to a large sample size (n = 232), graphical methods (i.e., histogram and Normal Q-Q plot) were used. Descriptive statistic calculations and normality testing were conducted using SPSS (version 20).

The psychometric properties of the K-SAC were investigated using the Winsteps computer program (version 3.65) based on the Rasch dichotomous model. The model-data fit was evaluated by Infit and Outfit statistics for each item of the K-SAC in the Rasch dichotomous model. Both Infit and Outfit statistics are mean square residuals between observed and expected responses ranging from zero to positive infinity. Values of Infit and Oufit close to 1.0 indicates an adequate fit, and the Infit and Outfit statistics between 0.5 and 1.5 are considered acceptable for model-data fit.[161, 162] The Infit and Outfit statistics less than 0.5 (i.e., little variation in responses) and/or greater than 1.5 (i.e., large variation in responses) indicate a poor fit. [161, 162]

The Rasch dichotomous model estimated two facets, such as item difficulty and person ability (i.e., individual's level of cognitive function), in units of logits. High logit score for an item indicates high item difficulty which means the probability of a correct answer to the item is relatively low when comparing to other items with low logit scores. High logit scores for a person indicate high levels of cognitive function. The separation index and separation-reliability index for item and person parameters were estimated by the Rasch dichotomous model. Item separation index indicates how well items in the K-SAC were spread out along the unidimensional common scale, while person separation index indicates how well the persons’ ability was spread out along the unidimensional common scale. Separation-reliability index indicates the degree of confidence to replicate item or person parameters within measurement error for another sample. A high separation index indicates adequate discrimination for both the item and person (acceptable value: ≥ 2.00).[139] A separation-reliability close to 1.00 indicates a high degree of confidence (acceptable value: ≥ 0.80).[139]

Distribution of item difficulty and person ability was compared by an item-person map. The Rasch model provides an item-person map that is a single dimensional graph linking item difficulty and person ability estimates on the same common scale in units of logits. The item-person map illustrates the distributions of item difficulty and an individual's level of cognitive function as well as the relative position of the both item and person parameters.

Phase 2

Participants and Procedures

Participants were recruited in a similar manner to phase 1. Unlike phase 1, three times testing were conducted at baseline, time of injury (i.e., concussion), and after 48 hours from the time of injury to examine the validity of the K-SAC in concussion assessment. Because we could not expect who would have a concussion, participants were recruited for baseline assessment among cadets who were taking or participating in boxing, martial arts, and military obstacle course training, which have a high risk of concussions. Among them, participants who had a concussion were recruited as the concussed group. For matching the sample size with the concussed group, non-concussed participants were recruited randomly from cadets who were taking or participating in the same activities. When recruited the non-concussed group, sex and age were also considered as matching characteristics.

Appropriate sample sizes were estimated using G*power software (version 3.1.2). For the main statistical analysis of the two-way (two groups × three measurements) repeated measure ANOVA, the statistical test was set as "ANOVA; Repeated measures, within-between interaction"; effect size was set as a medium effect size (i.e., $f = 0.25$); alpha level was set at .05; power value was set as value of 0.80; the number of groups were entered 2 times(concussed vs. non-concussed group); the number of measurement was entered 3 times (baseline, time of concussion, and after 48 hours); and correlations were set at 0.38 (for concussed group) and 0.66 (non-concussed group), respectively.[163] Both values of correlation coefficient (r) were adopted from a previous study[93], which is very similar in research design when compared to this study. The estimated total sample sizes from G*power were ranged from 20 to 34. In conservative perspective, an approximate sample size of 40 was determined as an appropriate total sample size for this study.

Orientation was completed in a silent cadet lounge at KMA where they read and signed the informed consent (see Appendix F). They had an opportunity to ask questions about this study. Each participant verified that they did not have a concussion or head injury within the last 6 months. Participants were asked to fill out an injury history form that included their age, height, weight, and history of head injury (see Appendix G). Baseline assessment was conducted by researchers for participants who were taking or participating in boxing, martial arts, and military obstacle course training. At the time of injury, the K-SAC was given to participants who had a concussion. Concussion is defined as a transient alteration in brain function induced by direct or indirect traumatic and biomechanical forces to the head.[4, 5, 6, 7, 8] The standards to identify concussed participants included mechanism of concussion (i.e., direct or indirect acceleration, deceleration, and rotational forces to the head), reported symptoms, and/or presented signs (e.g., headache, dizziness, confusion, difficulty in attention/concentration, loss of consciousness, and poor balance).[4, 5, 6, 7, 8, 28, 93] These standards have been widely used methods to define concussions in previous studies[28, 93] because of no universal operational definition and criterion assessment tool for concussions. The standards to identify concussions were evaluated by trained main instructors of the classes or trainings and researchers of this study. Again, the concussed participants had administration of the K-SAC after 48 hours from the time of concussion. The same protocol was applied to randomly selected participants who did not have concussion in the same class or training. All these procedures have been approved by the University's Institutional Review Board (see Appendix B).

Instrument

The K-SAC developed in phase 1 was used to measure cognitive function levels of participants at baseline, time of concussion, and after 48 hours from the time of concussion measurements for concussed and non-concussed groups. The K-SAC is presented on Appendix H.

Statistical Analysis

Descriptive statistics were computed for age, sex, weight, height, and body mass index for concussed and non-concussed groups, respectively. To compare the characteristics of participants at baseline, independent t-tests were conducted between concussed and non-concussed groups.

The basic methods of examining validity of K-SAC are to demonstrate a statistical difference in scores of the K-SAC between concussed and non-concussed groups (i.e., known-groups validity) and/or measurements at baseline and time of concussion (i.e., changes in scores for concussion).[131] A two-way repeated measured ANOVA with concussion status (i.e., concussed group vs. non-concussed group) as a between-subjects factor and testing points (i.e., baseline, time of injury, and after 48 hours) as a within-subjects factor was conducted to examine if the K-SAC can detect change in cognitive function induced by concussion.[163]

All statistical analyses were performed using SPSS (version 23). Unless otherwise specified, alpha level of .05 was used to determine statistical significance.

CHAPTER 4

RESULTS

This chapter contains the results of statistical analyses with regard to examining psychometric properties of K-SAC in a target population (phase 1) and the validity of the K-SAC in concussion assessment (phase 2). Each phase consists of descriptive and inferential statistics for characteristics of participants and the K-SAC.

Psychometric Properties of the K-SAC (Phase 1)

Brief Results of the Pilot Study

55 participants were included for initial pilot study. Total scores of the K-SAC ranged from 17 to 29 points. In the initial analyses using the Rasch model, model-data fit was marginally good as evaluated based on the Infit (ranged from 0.87 to 1.21 logit) and Outfit statistics (ranged from 0.49 to 1.36 logit). Item difficulty ranged from -4.59 to 2.93 logit. Item separation index and reliability were 3.00 and 0.90, respectively. Item difficulties were appropriately spread out and estimated in a high degree of confidence to replicate in another sample. Participants' cognitive function level ranged from -0.50 to 1.98 logit. Person separation index and reliability were 0.34 and 0.11, respectively. Levels of participants' cognitive functions were not distributed well and were estimated in a low degree of confidence. Item difficulty covered all levels of participants'

cognitive function levels. Based on these results, the K-SAC has not made any modifications, and then additional participants were recruited for definitive estimations of item difficulties and participants' cognitive function levels.

Characteristics of Participants

To examine the psychometric properties of K-SAC, a total of 232 participants were recruited from KMA. Approximately 93% of the participants were men (*n* = 216) and 7% were women (*n* = 16). The average age was 20.87 ± 1.40 years.

Table 4. Participants Characteristics in Phase 1

Variables	*Mean*	*Standard Deviation*
Age (years)	20.87	1.40
Height (m)	174.33	5.91
Weight (kg)	69.64	8.21
BMI (kg/m^2)	22.87	2.06
K-SAC[a]		
Orientation	4.79	0.44
Immediate Memory	5.26	1.11
Concentration	9.25	1.91
Delayed Memory	3.98	1.16
Total Score	23.28	2.91
	Frequency (n)	*Percent (%)*
Sex		
Men	216.00	93.10
Women	16.00	6.90

[a] Possible points = 5 for orientation, 10 for immediate memory, 12 for concentration, 10 for delayed memory, and 37 for total score, respectively.

Total Scores of K-SAC

The total scores of the K-SAC were ranged from 15 to 30 points (out of 37). Average K-SAC score was 23.28 ± 2.91 points. As illustrated in Figure 5 & 6, the distribution of K-SAC total scores was approximately normal, which indicates that there was no celling effect.

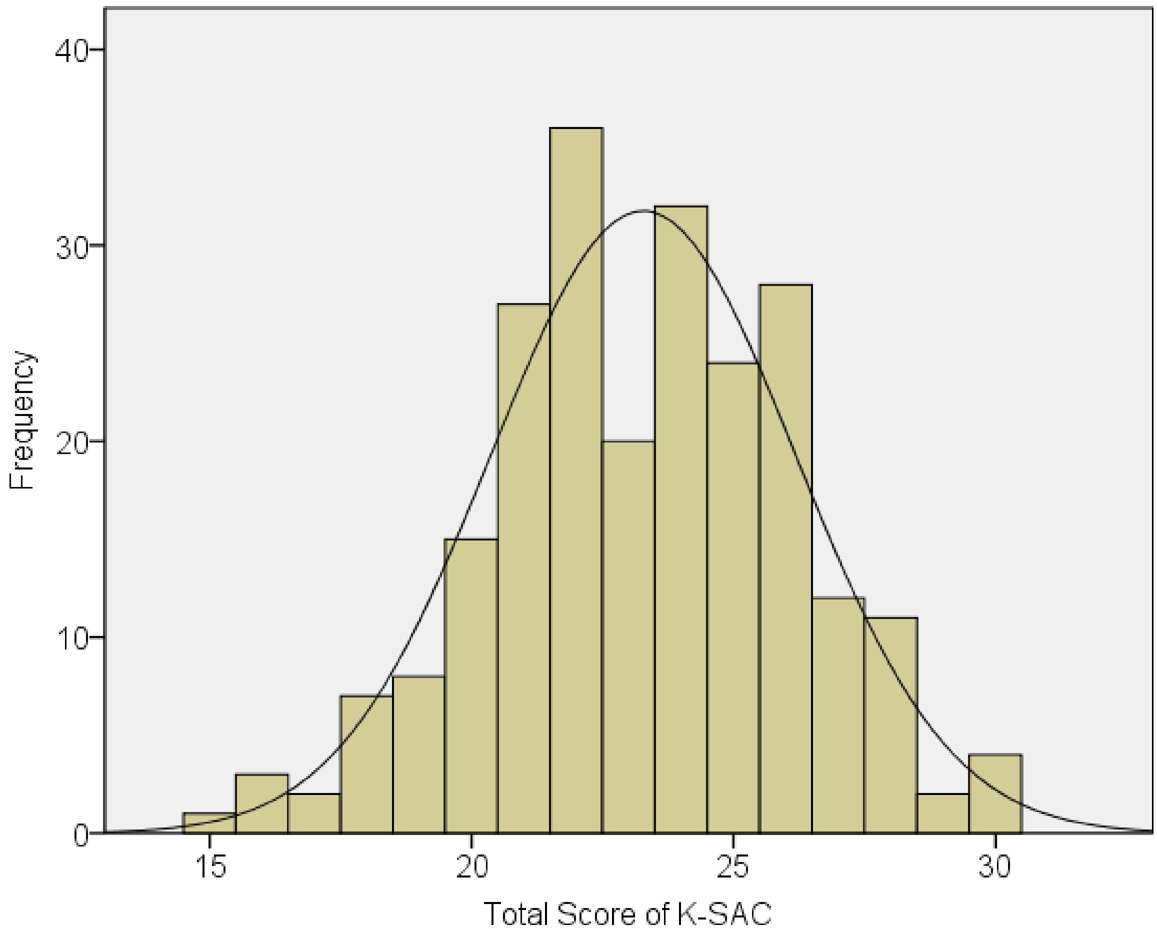

Figure 5. Histogram of K-SAC Total Scores

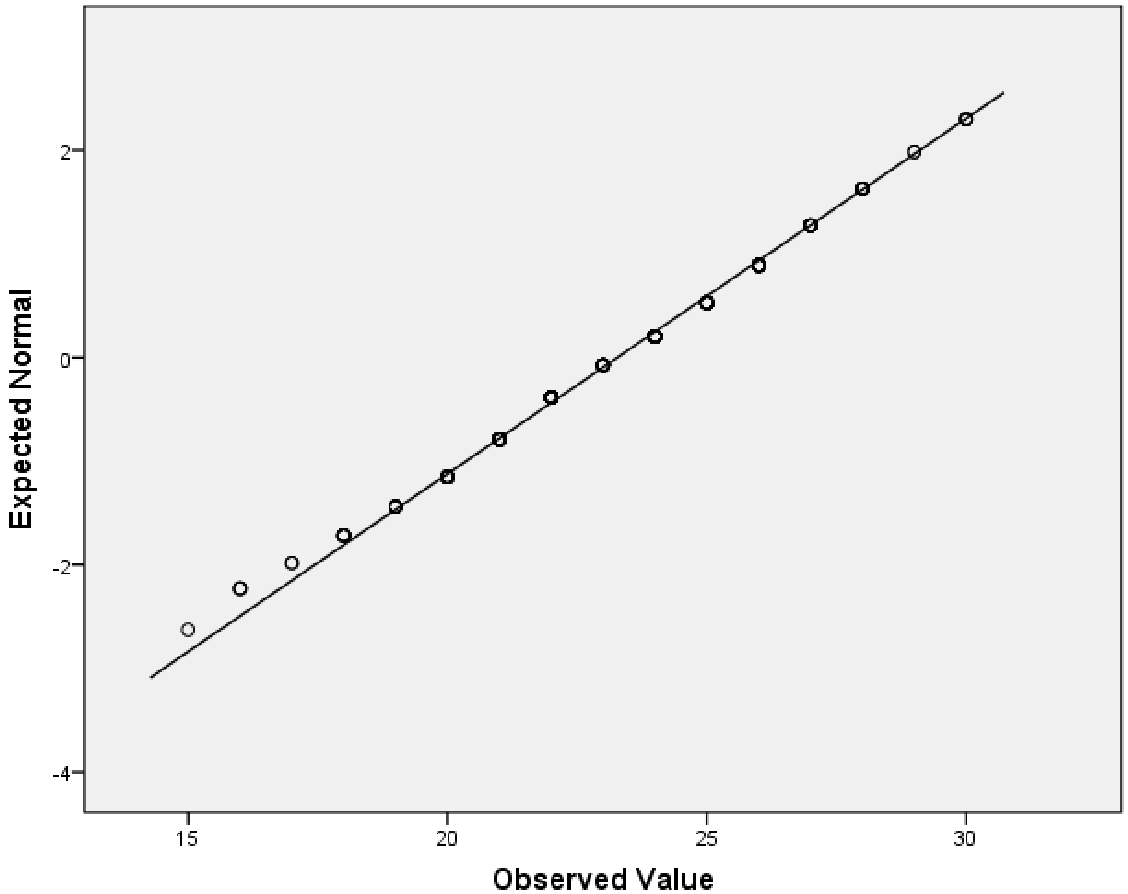

Figure 6. Normal Q-Q Plot of the K-SAC Total Scores

Model-data Fit

Overall, the data fitted to the unidimensional Rasch dichotomous model well. For all items, values of Infit statistics were ranged from 0.88 to 1.11 (average ± standard deviation = 1.00 ± 0.06), and Outfit statistics were ranged from 0.55 to 1.45 (average ± standard deviation = 0.99 ± 0.17). Both the Infit and Outfit statistics of 37 items were within the appropriate range of 0.50 < and < 1.50. The details of Infit and Outfit statistics for each item are presented on Table 5.

Table 5. Summary of K-SAC Items in Phase 1

Items	*Calibration Logit*	*SE Logit*	*Infit MnSq*	*Outfit MnSq*
(Orientation Section)				
Item 1. What month is it?	-3.62	0.58	1.01	0.87
Item 2. What is the date today?	-0.79	0.18	1.04	1.13
Item 3. What is the day of the week?	-5.93	1.83	1.00	1.00
Item 4. What year is it?	-5.93	1.83	1.00	1.00
Item 5. What time is it right now?	-2.90	0.42	0.99	0.74
(Immediate Memory Section)				
Item 6. Age	-2.74	0.39	1.01	1.04
Item 7. Korean Flag	-2.27	0.31	1.01	1.45
Item 8. Watermelon	-0.27	0.16	1.01	1.04
Item 9. Airplane	1.53	0.14	1.01	1.03
Item 10. Singer	2.06	0.16	1.06	1.18
Item 11. Bicycle	2.72	0.19	1.00	1.04
Item 12. Desk	2.01	0.15	1.00	1.04
Item 13. Monkey	0.19	0.14	1.01	1.01
Item 14. Sea	1.11	0.14	1.01	1.02
Item 15. Rainbow	1.00	0.14	1.07	1.09
(Concentration Section)				
(Digits Backwards)				
Item 16. 4–9–3	-2.17	0.30	0.92	0.55
Item 17. 3–8–1–4	-1.86	0.26	0.92	0.65
Item 18. 6–2–9–7–1	-0.32	0.16	0.89	0.83
Item 19. 7–1–8–4–6–2	0.76	0.14	0.88	0.86
Item 20. 2–7–3–9–1–5–8	0.41	0.14	0.92	0.90
Item 21. 8–1–5–7–3–9–4–6	1.30	0.14	0.88	0.86
Item 22. 5–9–6–2–7–4–1–8–3	1.60	0.14	0.93	0.92
(Subtraction by 7 from 100)				
Item 23. 100 - 93	-3.62	0.58	0.99	1.21
Item 24. 93 - 86	-2.01	0.28	0.95	0.73
Item 25. 86 - 79	-2.74	0.39	0.98	0.82
Item 26. 79 - 72	-1.73	0.25	1.01	1.15
Item 27. 72 - 65	-1.61	0.24	1.00	0.88

Table 5. Summary of K-SAC Items in Phase 1 (Cont')

Items	*Calibration Logit*	*SE Logit*	*Infit MnSq*	*Outfit MnSq*
(Delayed Memory Section)				
Item 28. Age	0.11	0.14	1.08	1.09
Item 29. Korean Flag	-0.55	0.17	1.11	1.27
Item 30. Watermelon	0.94	0.14	1.06	1.06
Item 31. Airplane	1.85	0.15	1.03	1.06
Item 32. Singer	2.04	0.16	1.06	1.12
Item 33. Bicycle	3.03	0.21	0.99	1.01
Item 34. Desk	2.19	0.16	1.00	1.01
Item 35. Monkey	0.53	0.14	1.01	1.01
Item 36. Sea	1.97	0.15	1.01	1.01
Item 37. Rainbow	1.85	0.15	1.04	1.08

Item Difficulties of K-SAC

Estimated item difficulty and standard error of the K-SAC from the Rasch model are summarized in Table 5. High logits score for an item indicates high item difficulty which means the probability of a correct answer to the item is relatively low when compared to other items with low logit scores. Average item difficulty of the K-SAC was -0.32 ± 2.30 logit, and the range was from -5.93 to 3.03 logit. The easiest items to answer correctly were items 3 & 4 with an item difficulty of -5.93 logit. All participants of the 232 answered correctly to items 3 & 4. The most difficult item to answer correctly was item 33 with an item difficulty of 3.03. Twenty seven out of 232 participants answered correctly to item 33. Item separation index was 4.59, indicating that the items of the K-SAC were properly spread out along the unidimensional common scale. Item separation-reliability index was 0.95, which indicates a high degree of confidence to replicate item parameters within measurement error for another sample. Item difficulties of the K-SAC were adequately distributed and reliably estimated.

Cognitive Function Level of Participants

Range of cognitive function level was from -0.82 to 2.26 logits (average ± standard deviation = 0.88 ± 0.58 logit). High logits score for a person indicates high levels of cognitive function which means the probability of a correct answer to an item is relatively high when compared to others with lower logit scores. Person separation index and separation-reliability were 0.71 and 0.34, respectively. Person separation index and separation-reliability that were poor indicate small variability of participants' cognitive function level and a low degree of confidence to replicate person estimations within measurement error, respectively.

Item-person Map of K-SAC

Figure 7 illustrates the distribution of K-SAC item difficulties and participants' cognitive function level and the relative position of the both item and person estimates. The numbers on the left end of the map indicates logit scale. The histogram, marked by dots and "#"s, on the left side of map is the distribution of participants' cognitive function level. K-SAC items, indicated by "q" and item number, are placed on the right side of the map according to their difficulties. Overall, the items were moderately distributed along the unidimensional common scale, although several small gaps are between items. All levels of participants' cognitive function were covered by the items of K-SAC at baseline assessment. K-SAC seems to have redundant items (i.e., too easy items) as against the levels of participants' cognitive function at baseline assessment, but the easy items will be necessary to assess participants with a concussive event who may have a reduced cognitive function level. In other words, the items cover a wide range of cognitive function levels, indicating that the items of K-SAC can measure adequately all levels of participants' cognitive function at baseline and time of concussion.

```
          PERSONS - MAP - ITEMS
               <more>|<rare>
    3                +  q33
                     |
                     |  q11
                     |
                     |
                 .#  |
                     |  q34
    2             . T+  q10    q12    q32    q36
               .###  |S q31    q37
                     |
               ####  |  q22    q9
         .######### S|
           ########  |  q21
                     |  q14
    1   .##########  +  q15    q30
            .###### M|
                     |  q19
       ############  |  q35
          #########  |  q20
              ##### S|
                     |  q13    q28
    0           .##  +M
                .##  |
                    T|  q18    q8
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                  #  |  q29
                     |
                  .  |  q2
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                     |S q17
   -2                +  q24
                     |  q16
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                     |
                     |  q25    q6
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                     |  q3     q4
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EACH '#' and "." represent 3 participants and 1 participant, respectively.
```

Figure 7. Item - Person Distribution Map

Validity of K-SAC in Concussion Assessment (Phase 2)

Characteristics of Participants

A total of 50 participants, including 25 concussed participants and 25 non-concussed, were recruited from a boxing class of KMA. Approximately 92% of the participants were men (n = 46) and 8% were women (n = 4). The average age was 21.56 ± 1.15 years. Overall, there were no differences between the concussed and non-concussed groups in age, height, and proportions of sex and grade, except for weight and BMI (see Table 6).

All participants in the concussed group had experienced mechanism of concussion (i.e., direct or indirect acceleration, deceleration, and rotational forces to the head) as observed by the principal researcher of this study and the trained instructor, who was a former national representative amateur boxing athlete and is currently a boxing coach of the classes. 72% (n = 18) of participants reported one or more concussion symptoms and signs, while the rest of them (n = 7) did not report any concussion symptoms and signs. The details about concussion symptoms and signs sustained by concussed participants were summarized in Table 7.

Table 6. Participants Characteristics in Phase 2

Variables	Total (*N* = 50)[a]	Concussed (*n* = 25)[a]	Non-concussed (*n* = 25)[a]
Age (years)	21.56 (1.15)	21.56 (1.12)	21.56 (1.19)
Height (m)	174.18 (5.43)	173.44 (5.42)	174.92 (5.45)
Weight (kg)[b]	70.22 (9.32)	66.00 (6.32)	74.44 (10.01)
BMI (kg/m^2)[b]	23.08 (2.31)	21.91 (1.52)	24.25 (2.40)
	n (%)	*n (%)*	*n (%)*
Sex			
Men	46 (92.00)	23 (92.00)	23 (92.00)
Women	4 (8.00)	2 (8.00)	2 (8.00)
Grade			
Sophomore	2 (4.00)	1 (4.00)	1 (4.00)
Junior	26 (52.00)	13 (52.00)	13 (52.00)
Senior	22 (44.00)	11 (44.00)	11 (44.00)

[a] Data are presented as mean (standard deviation).
[b] indicates significant difference between concussed and non-concussed groups ($p < .05$).

Table 7. Symptoms & Sign of Concussion in Concussed Group[a]

Symptoms & Signs[b]	Frequency (*n*)	Percent (*%*)[c]
Yes	18.00	72.00
Headache	11.00	44.00
Dizziness	6.00	24.00
Nausea	4.00	16.00
Momentary Loss of Consciousness	3.00	12.00
Balance Problem	1.00	4.00
Blurred Vision	1.00	4.00
No	7.00	28.00

[a] Sample size = 25.
[b] Participants reported multiple symptoms & signs
[c] Percent was calculated by dividing frequency (*n*) by concussed participants of 25.

Difference in K-SAC Scores for Concussion

Descriptive statistics of K-SAC scores are presented in Table 8. The results of a two-way repeated measured ANOVA indicated that there was a significant interaction between concussion status (i.e., concussed group vs. non-concussed group) and testing points (i.e., baseline, time of concussion, and after 48 hours), F (1.88, 90.08) = 11.96, mean square error (MSE) = 3.57, Greenhouse-Geisser (G-G) $p < .001$, $\eta^2 = .20$. There were significant main effects for testing points, F (1.88, 90.08) = 12.14, MSE = 3.57, G-G $p < .001$, $\eta^2 = .20$, while no significant main effect for concussion status was found, F (1, 48) = 1.52, MSE = 20.31, G-G $p = .224$, $\eta^2 = .03$.

Due to the significant interaction effect between concussion status and testing points, tests of the simple effects were conducted to follow up the significant interaction. Significance of mean difference for the simple effects tests were examined using adjusted alpha levels. For simple main effects for concussion status (i.e., known-groups validity), one-way ANOVAs were conducted to compare the average K-SAC scores between concussed and non-concussed groups separately for each testing point: baseline ($\alpha = .0167$), time of concussion ($\alpha = .0167$), and after 48 hours ($\alpha = .0167$). The K-SAC score did not significantly differ by concussion status in baseline measurement, F (1, 48) = 1.18, MSE = 11.50, $p = .284$, $\eta^2 = .02$, and after 48 hours measurement, F (1, 48) = 2.74, MSE = 7.48, $p = .104$, $\eta^2 = .05$. However, a significant difference in K-SAC score was identified between the concussed group and non-concussed group at time of concussion measurement, F (1, 48) = 9.58, MSE = 8.03, p

= .003, η^2 = .17. The average score of the K-SAC in the non-concussed group was statistically significantly higher than the average in the concussed group (mean difference = 2.48 points; 98.33% *CI* = 0.49 - 4.47) at the time of concussion, indicating an evidence of the known-groups validity.

For simple effect for testing points (i.e., changes in scores for concussion), one-way repeated measure ANOVAs and Sidak pairwise comparisons (see Table 9) were conducted to compare the average K-SAC scores across testing points for each concussion status: concussed group (α = .025) and non-concussed group (α = .025). The K-SAC score differed significantly across the testing points in the non-concussed group, F (1.89, 45.39) = 16.64, *MSE* = 2.52, *G-G* p < .001, η^2 = .41. The K-SAC score in baseline was lower than the K-SAC scores at time of concussion and after 48 hours (mean differences = -1.68 and -2.68 points, respectively). In the concussed group, significant differences in K-SAC score was also found across the testing points, F (1.84, 44.22) = 8.84, *MSE* = 4.28, *G-G* p = .001, η^2 = .27. The score of the K-SAC at the time of concussion was significantly lower than the K-SAC scores in baseline and after 48 hours (mean differences = 1.84 and -2.20 points, respectively), while the K-SAC score was not different between baseline and after 48 hours measurements. The K-SAC scores were statistically significantly reduced when a concussion occurred while the scores were increased again after 48 hours from the time of concussion (see Figure8).

Table 8. Descriptive Statistics for K-SAC Total Scores at Each Assessment

Assessments	*Mean*	*SD*[a]	*SE*[b]	95% *CI*[c]	
				Lower	Upper
Non-concussed Group					
Baseline	25.84	3.39	0.68	24.48	27.20
Time of Concussion	27.52	3.06	0.57	26.38	28.66
After 48 Hours	28.52	3.32	0.55	27.42	29.62
Concussed Group					
Baseline	26.88	3.40	0.68	25.52	28.24
Time of Concussion	25.04	2.59	0.57	23.90	26.18
After 48 Hours	27.24	1.98	0.55	26.14	28.34

[a] Standard deviation
[b] Standard error
[c] Confidence interval

Table 9. Sidak Pairwise Comparisons for SAC Total Scores among Assessments in Concussed and Non-concussed Groups

I	*J*	*MD*[b] (*I* - *J*)	SE	97.50% *CI*[c]	
				Lower	Upper
Non-concussed Group					
Baseline	Time of Concussion	-1.68[a]	0.43	-2.92	-0.44
Baseline	After 48 Hours	-2.68[a]	0.52	-4.18	-1.18
Time of Concussion	After 48 Hours	-1.00	0.45	-2.29	0.29
Concussed Group					
Baseline	Time of Concussion	1.84[a]	0.56	0.24	3.44
Baseline	After 48 Hours	-0.36	0.63	-2.17	1.45
Time of Concussion	After 48 Hours	-2.20[a]	0.49	-3.60	-0.80

[a] indicates significant difference between concussed and non-concussed groups ($p < .025$).
[b] Mean difference
[c] Confidence interval

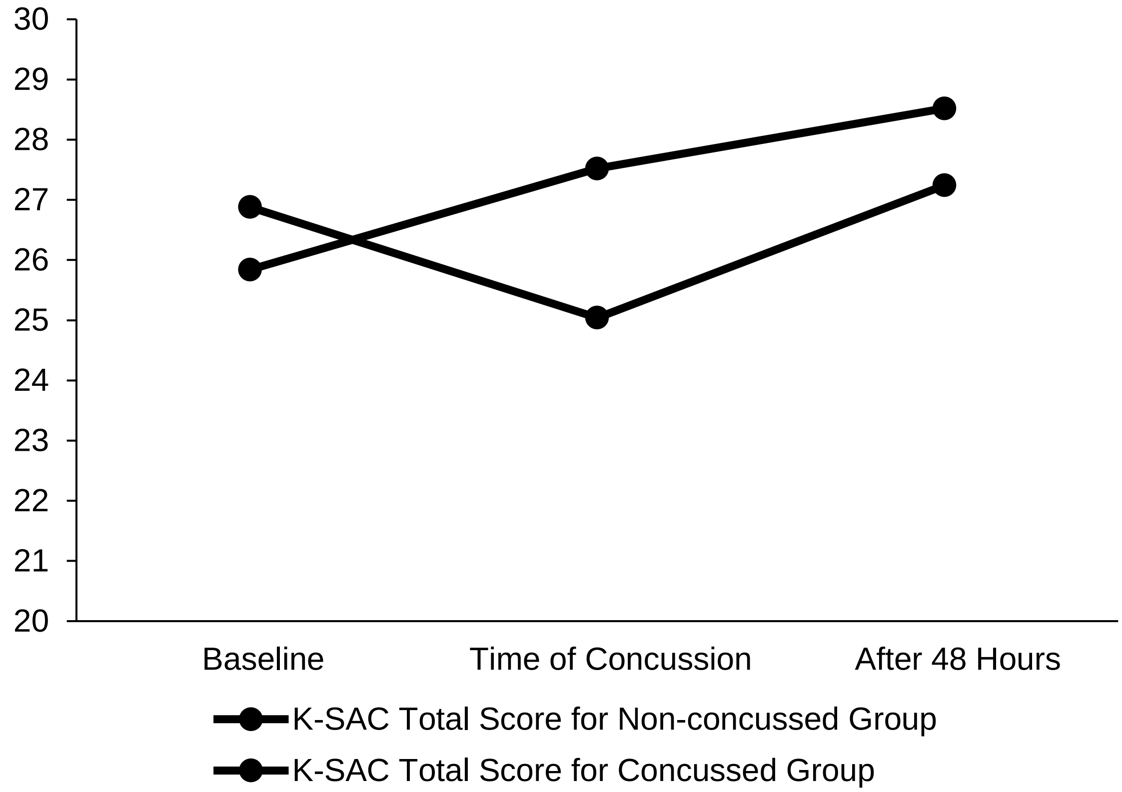

Figure 8. K-SAC Total Scores at Baseline, Time of Concussion, and After 48 Hours for Concussed and Non-concussed Groups

CHAPTER 5

DISCUSSION

Concussions have been a critical concern on service members' combat performance and health in peacetime and wartime. Early detection and accurate evaluation of concussions at the place where the concussive event occurs are very important to prevent service members from returning to duty with concussion symptoms and initiate concussion management procedures in a timely fashion. Unfortunately, there have not been any practical concussion assessment instruments available for SKS. For the purpose of providing a practical concussion assessment tool for SKS, this study has adapted and upgraded the current SAC, and then translated the upgraded SAC into Korean with considering cultural and linguistic equivalence. These procedures involved substantial changes that led to the development of the K-SAC. Because it is unknown how the developed K-SAC will function in a target population, the psychometric properties of the developed K-SAC were examined in phase 1 of this study, and the validity of the K-SAC in concussion assessment was investigated in phase 2 of this study using samples of cadets from KMA.

Psychometric Properties of the K-SAC (Phase 1)

Many previous studies have focused on examining the reliability and validity of concussion assessment instruments, but there has been a lack of research to provide scientific evidence and information in item-level.[132, 135] This study provided useful item-level information about the developed K-SAC. Overall, the developed K-SAC in this study seems to make up for the weak points of the current SAC in relation to poor psychometric properties, especially a lack of difficult items, while maintaining the simplicity and practicality of the SAC as a good field concussion testing tool. For the baseline assessment, the K-SAC could be administrated in 3 to 5 minutes by researchers without expert knowledge and experiences in neuropsychological tests and medicine. The results of phase 1 support that the K-SAC has sound psychometric properties for measuring cognitive function levels of healthy young adults. The data was fitted to the unidimensional Rasch dichotomous model. It may statistically support that the K-SAC measures a single latent variable (i.e., cognitive function level), which could be an evidence of construct validity. There were no signs of ceiling effects on the total K-SAC scores and no perfect scores, indicating improvement in item difficulty of the K-SAC. In addition, the K-SAC has items with a wide range of difficulties (i.e., from very easy items to very difficult items) that can measure appropriately all levels of cognitive function.

The developed K-SAC from this study has improved in psychometric perspective when compared to the current SAC. The SAC has suffered severe ceiling effects. Previous studies reported that the average SAC scores were ranged from 25.6 to 27.7 for baseline measurement.[87, 91, 92, 102, 135] A majority of participants obtained high scores, and the distributions of the SAC scores were negatively skewed in the previous studies. [87, 91, 92, 102, 135] In addition, approximately 7% of participants had a perfect score (i.e., 30 out of 30 point) when their cognitive function levels were measured using the SAC.[92] Unlike the current SAC, there was no perfect total score of the K-SAC among participants, and the total scores of the K-SAC were normally distributed, indicating no ceiling effect in baseline measurement. In this study, the average total scores of the K-SAC were 23.28 ± 2.91 points, and the maximum score was 30 out of a possible 37 points.

The ceiling effect is a critical issue in use of the current SAC with individual-centered standards for test score interpretation. The individual-centered standard has been most recommended and widely used to interpret many concussion testing results in the field and research, including SAC. When applied individual-centered standard in interpretation of SAC test score, post-injury score is compared with the baseline score, and more than 2 points reduction in SAC test score indicates that a patient has a concussion. Baseline score should be accurately measured to ensure accurate evaluation of a concussion with the individual-centered standard. As mentioned earlier, ceiling effect has been reported in baseline measurement using the SAC. It indicates that the current SAC may have no ability to accurately discriminate between participants with above middle to high levels of cognitive function. For example, some participants with high levels of cognitive function may obtain the same scores with above middle level of cognitive function because of the many that can obtain high scores close to a perfect score, and participants with high or very high cognitive function cannot obtain more than perfect score. In addition, participants with high levels of cognitive function may obtain a perfect score in measurements at baseline and time of injury. It could lead to an inaccurate evaluation of a concussion when using the current SAC with individual-centered standard for interpreting the test score.

A lack of difficult items of the SAC was speculated as a main cause of the ceiling effect.[132, 135] Approximately 60% to 70 % of items on the SAC were categorized into being too easy for baseline cognitive function measurement of healthy young adults.[135] Range of item difficulty (p) ≥ 0.1 or p ≤ 0.92 is considered acceptable[136], where p is a proportion of examinees who answered an item correctly. The average item difficulty of the orientation and immediate memory section ranged from 0.95 to 0.97.[135] Other sections of the SAC have moderately high averages of item difficulty, ranged from 0.69 to 0.79.[135] In this study, modification of existing items and addition of difficult items helped improve the overall difficulty of the K-SAC. The K-SAC includes 15 items that can discriminate the participants who have above average cognitive function and 3 items to discriminate the participants with very high cognitive function (see Figure 7). The increased overall item difficulty of the K-SAC seems to result in no ceiling effect and perfect score.[135, 136] It may indicate that the K-SAC can accurately evaluate participants with high cognitive function.

A noticeable result of this study is that the developed K-SAC has a wide range of item difficulties. The item difficulties ranged from -5.93 to 3.03 logit, and they were distributed adequately along the common scale (item separation index = 4.59; acceptable range of item separation index ≥ 2.00) and estimated with a high degree of confidence. When considering the recommended interpretation method of concussion test score (i.e., individual-centered standard), accurate measurement at time of injury is also important as well as accurate baseline measurement.[132] For ensuring accurate evaluation of concussion, an instrument should evaluate accurately all levels of the participants' cognitive function (i.e., from very low to very high) because there may be various levels of cognitive function among participants, and the cognitive function will be reduced after concussion. In phase 1 of this study, only baseline measurement was conducted among KMA cadets. For this reason, the item-person map depicted as if K-SAC includes many easy items with item difficulty of ≤ -1 logit as against participants' cognitive function. The relatively easy items, however, will be also essential when evaluating participants with various cognitive function levels and a concussed injury(s). These results support that the scores of the K-SAC reflect more accurately a wide range of the true participant's cognitive function level as compared to the current SAC.

Although an individual-centered standard has been recommended to interpret SAC test scores in concussion assessment practices, both individual-centered and criterion-referenced standards may need to be considered according to the item characteristics of the SAC or K-SAC. Currently, the total score of these instruments is calculated by summing the scores of all items, and the total score interpreted using the individual-centered standard. The interpretation of items in the orientation section may not be appropriate for the individual-centered standard. The orientation section of mini-mental status examination (MMSE), which is the almost same with the orientation section of the SAC and K-SAC, has been used to examine cognitive mental status for the elderly and patients with cognitive impairment, including dementia and depression, and the score has been interpreted using criterion-referenced standard.[133] The items in the orientation section were considered too easy for measuring the cognitive function of healthy young adults in previous studies[135, 137] and this study. In addition, it is unclear if the items of the orientation section are sensitive enough for the evaluation of a concussion because previous studies reported inconsistent results about differences in scores of the orientation section between a concussed group and non-concussed group.[91, 92, 93] Further investigation is needed to find out if it is better to use a criterion-referenced standard for the orientation section and an individual-centered standard for other sections in order to accurately interpret the scores of the SAC and K-SAC than to use only the individual-centered standard for all sections.

The sample used in phase 1 of this study seems to have homogeneous characteristics in the levels of cognitive function. The person parameters indicated that the levels of participants of cognitive function were not adequately distributed along the unidimensional common scale (person separation index = 0.71) and were estimated in a low degree of confidence (separation-reliability = 0.34). It may be caused by small variation of participants in cognitive function.[164] Participants in this study were recruited cadets of the Korea Military Academy, which is equivalent with the United States Military Academy. The eligibility of KMA for admission is very strict and challenging due to the specialized-purpose of KMA. To be admitted into KMA, candidates should have outstanding overall performances in high school grades, 1st examination (i.e., written examination of Korean, English, mathematics), 2nd examination (i.e., physical examination, fitness test, multiphasic personality inventory tests, and depth individual interviews), and the College Scholastic Ability Test. During the past 5 years, the admission rate of KMA ranged from 3.21% to 5.52%.[165] Cadets of KMA who passed severe strict admission procedures may be likely to have similar characteristics in intelligence, learning ability, language, memory, and reasoning. The small variations in these characteristics could be lead to poor person separation index and reliability.

Validity of K-SAC in Concussion Assessment (Phase 2)

The developed K-SAC seems to have a good validity in detecting cognitive function impairment at the time of concussion. The results of this study indicates that a non-concussed group had significantly higher average K-SAC scores than the concussed group (mean difference = 2.48 points, $p < .05$), and the K-SAC score was significantly reduced at time of injury when compared with baseline assessment (mean difference = 1.84 points, $p < .0167$). These results are consistent with previous studies examining the validity of the current SAC. [91, 92, 93, 94, 104] The mean differences between concussed and non-concussed groups were ranged from 3.65 to 5.07 points in the previous studies.[91, 92, 93, 94, 104] Averages of change score between measurements at baseline and time of concussion were reported from 3.50 to 4.68 points. [92, 93, 104] Based upon the evidences of the known-groups validity and score reductions for concussion, it indicates that the K-SAC has a good validity to detect cognitive function impairment when a concussive injury occurs. It implies that the K-SAC may work well for detection of concussions in the target population.

Considering the current concussion management procedures, a concussion assessment tool should be sensitive to measure recovery from impaired cognitive function as well as cognitive function impairment induced by concussion. It has been recommended from major sports and military-related research groups and associations that people with a concussive injury should have an appropriate concussion screening in a timely fashion, and then the individual with a concussion should be removed from duty or play on the day of injury.[4, 5, 6, 7, 8, 62] The patients should be monitored with a series of concussion evaluations until all signs and symptoms of the concussion are fully resolved to prevent premature return.[4, 5, 6, 7, 8, 62] The developed K-SAC also showed a good validity in detecting recovery of cognitive function impairment after a concussion. The score of the K-SAC measured at time of concussion was returned to the score at the baseline assessment when measured after 48 hours. Similar results were reported from previous studies[92, 93, 104] that the score of the SAC after 48 hours from the time of concussion returned to the baseline levels of SAC scores. This implies that the K-SAC can be a potentially useful instrument to help the related personnel (e.g., field leaders/commanders, military training leaders, and allied medical professionals) make a right decision for returning to duty.

Potential learning/practice effects were identified when repetitively administrated K-SAC. In the non-concussed group, the score of the K-SAC at baseline was significantly lower than the scores at the second and third assessments although there were no significant differences between the second and third assessments. These results are not consistent with previous studies[92, 93, 101, 104, 112] that examined the SAC test. The SAC scores tended to slightly increase in the previous studies, but the increases were not statistically significant. The inconsistent results between the previous studies and this study may be due to the different number of test forms used. The SAC test has three different test forms, and the different SAC forms were used for the previous studies, while the K-SAC has only one test form and the one form was used for this study. As mentioned earlier, multiple assessments of the K-SAC are required to follow the currently recommended concussion management procedures. Under this circumstance, learning/practice effects could be a typical concern. In despite of learning/practice effects, the K-SAC provided reduced test score after a concussion, but it could increase the false negative rate. Until one can definitively clarify the issues regarding learning/practice effects, caution should be required to interpret the score of the K-SAC.

In this study, change scores between measurements at baseline and time of concussion were smaller than the change scores of the previous studies [92, 93, 104] although different concussion evaluation instruments (i.e., K-SAC vs. SAC) were used to measure cognitive function impairment of different samples. One possible reason for this difference may be learning/practice effects. Another possible reason may be different samples who have different levels of cognitive function impairment. In the previous studies, most of participants were high school and college football players[91, 92, 93, 94, 104], and approximately 10% to 16% of participants were experiencing loss of consciousness and/or posttraumatic amnesia[93, 104]. According to the results of a previous study[104], participants with loss of consciousness and/or posttraumatic amnesia had more severe impairment compared to those without loss of consciousness and/or posttraumatic amnesia. The participants of phase 2 in this study were non-athletes, and only 4% (*n* =1) of participants had momentary loss of consciousness.

The developed K-SAC is a simple and practical instrument to evaluate concussions in a timely fashion at the place where concussive injury occurs. The K-SAC has inherited good characteristics of the current SAC that is quick and easy to use, portable, inexpensive, objective to measure, and usable by anyone.[6, 76, 86] The K-SAC is an orally administrated questionnaire that is 1 page long, and can be made as a pocket-sized card for convenience of carrying. Even though about 7 items were added on the current SAC, it took approximately 3 - 5 minutes to complete the developed K-SAC. The K-SAC was administrated within 5 - 10 minutes right at the place where a concussive injury occurred. In this study, the K-SAC has been easily administered by researchers without any neuropsychological testing experiences or medical expert knowledge, and there have not been any kind of difficulties and issues in administration of the K-SAC. These characteristics of the K-SAC including simplicity and practicality also support the clinical utility of the K-SAC for the evaluation of concussions in SKS as a useful field test for concussion evaluation.

Limitations

There are several limitations in this study. First, samples in this study probably are not representative of entire SKS. As mentioned earlier, the samples have been collected voluntarily from cadets of KMA having similar characteristics in intelligence, learning ability, language, memory, and/or reasoning, and majority of them may be highly educated and more intelligent when compared with the entire SKS. Although the samples were appropriate to be examined if the K-SAC has adequate item difficulty to evaluate the participants with high levels of cognitive function, there may be a limitation to generalize the results of this study for the entire SKS. Second, there is limited comparability between the test scores from current SAC and newly developed K-SAC. Several more difficult items were added to resolve the poor item and test characteristics and ceiling effects of the current SAC. To maintain linguistic and cultural equivalence, a testing adaptation method was applied to translate the English version of the upgraded SAC into a Korean version of SAC. Significant changes of the items were inevitable during the procedures of improving item difficulty and testing adaptation. The total score was also changed from 30 to 37. Although the results of this study demonstrated that the K-SAC is valid for concussion assessment like the current SAC, the same scores from both tests may not reflect the same level of cognitive function due to different item difficulty and total scores. Lastly, the K-SAC is a brief concussion evaluation instrument to detect impairments in orientation, immediate memory, concentration, and delayed memory when a concussive event occurs, not a comprehensive concussion screening instrument to measure comprehensive cognitive function and all possible signs and symptoms caused by a concussion. The K-SAC is originally intended to detect the concussed patients immediately at the place where the concussive injury occurs, so that further evaluation and appropriate concussion management procedures could be implemented. In other words, the K-SAC is a potential field test of concussion evaluations with sound psychometric properties and validity for concussion assessment, but the K-SAC cannot be a substitute for formal and in-depth neurologic or neuropsychological examinations.[91, 92, 93] The potential users of the K-SAC should be aware of its limitations and fully understand the recommended guidelines for administration, scoring, and interpretation methods.[93]

Directions for Future Research

The purpose of this study was to develop and provide a practical and accurate primary field test of concussion evaluations for the SKS. For this, the main focus of this study was to demonstrate that the K-SAC has improved psychometric properties and good validity when it measures cognitive function levels in the target population, the SKS. This is the first study that developed and examined the K-SAC with samples recruited from a specific organization of the Korean Army. The generalizability of the K-SAC still remains unclear due to a lack of research in various aspects of reliability and validity. There are still several issues that need to be addressed in order to improve the accuracy of K-SAC and provide informative scientific evidences for clinical utility and feasibility of the K-SAC.

For the generalizability of the K-SAC, extensive studies will be required to verify if the K-SAC measures accurately all levels of cognitive function with a high degree of confidence in representative samples of the SKS and various samples that have a wide range of cognitive function levels. In addition, concussed participants in this study were identified in only boxing classes, and they were included for data analysis. Thus, further research is necessary to verify the validity of the K-SAC for cognitive function impairment during different activities, such as military trainings, other sports, and various activities in various military and sports settings.

For improvement of the accuracy of the K-SAC, the reliable change score should be examined to improve discrimination ability of the K-SAC between concussed and non-concussed participants in future research. In a series of multiple administrations of a concussion testing, a certain extent of variance in test performance, including the true variance by concussion and the error variance by other factors (e.g., learning/practice effects, unstable responses, just chance of variation, and motivation and efforts of participants), should be expected.[94, 166] Identification of true change score (i.e., differences in test performance) induced by concussion could be basis to establish an accurate cut-point for concussion evaluation and improve diagnostic accuracy of the K-SAC. Intensive reliability examinations of the K-SAC with test-retest design will be needed to clarify the presence and/or extent of any learning/practice effects on the K-SAC. At the same time, development multiple test forms of the K-SAC needs to be considered to prevent learning/practice effects. The equivalence in psychometrical properties between different forms of the K-SAC should be established for interchangeable use and accurate measurement of cognitive function in future research.

Another important next step for future research is to develop various Korean versions of concussion instruments, from simple and practical concussion evaluation tests to comprehensive concussion evaluation tests. To maximize the accuracy of concussion evaluation, use of multifaceted assessment batteries, such as SCAT3 and the updated version of MACE, has been recommended.[4, 85, 95, 130] Although the suggested multifaceted assessment tools sacrifice efficiency and practicality for more comprehensive evaluation of a concussion[4, 76, 130], they are also valuable tools for more accurate and thorough concussion screenings when time constraints are not severe, and various resources are available.

CHAPTER 6

CONCLUSIONS

The followings are the summary of the main findings from this study: 1) The K-SAC was developed by following the recommended standard test adaptation procedures based on the SAC that is one of the most widely used assessment tools both as an individual assessment tool and as a main component of SCAT3 and MACE in sports and military-related settings; 2) The K-SAC inherited the good characteristics of the current SAC as a useful field test, which is quick and easy to use, portable, inexpensive, objective to measure, and usable by anyone; 3) All items of the developed K-SAC contributed to measure adequately cognitive function in the target population; 4) The K-SAC had a wide range of item difficulty that can measure accurately all levels of cognitive function in the target population, which indicates that the K-SAC overcomes the measurement issues of the SAC in regard to ceiling effects and lack of difficult items; 5) The K-SAC had a good validity in detection cognitive function impairment induced by concussion and recovery from the impairment of cognitive function after concussion.

Based on these findings, it can be concluded that the developed K-SAC is a potentially practical and valid concussion assessment instrument for SKS. The K-SAC will play a very important role as a primary concussion evaluation tool at the field and/or frontline in peacetime and wartime because it can provide the field leaders/commanders, military training leaders, and allied medical professionals accurate and useful information pertaining to concussion status immediately following an injury at the place where concussive injury occurs. It could be expected that the developed instrument of the K-SAC in this study will contribute to protect SKS from concussions and its severe impacts on health and combat performance. Further research will be required to verify and improve the accuracy and generalizability of the K-SAC.

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APPENDICES

APPENDIX A: IRB Approval for Phase 1

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN007 – EXEMPTION DETERMINATION NOTICE

Thursday, September 08, 2016

Investigator(s): Junbae Mun (PI), and Minsoo Kang (FA)
Investigator(s') Email(s): *jm5x@mtmail.mtsu.edu*
Department: Health and Human Performance

Study Title: Validation of a newly developed concussion assessment tool for the Korean military
Protocol ID: **17-1011**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXEMPT** review mechanism under 45 CFR 46.101(b)(2) within the research category *(2) Educational Tests* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	EXEMPT from furhter IRB review***	
Date of expiration	NOT APPLICABLE	
Participant Size	200	
Participant Pool	College Students of Korea Military Academy (KMA)	
Mandatory Restrictions	All participants should consent.	
Additional Restrictions	**College students with no previous history of a concussion or head injury in the previous 6 months.**	
Comments	N/A	
Amendments	**Date**	**Post-Approval Amendments**
	N/A	None

***This exemption determination only allows above defined protocol from further IRB review such as continuing review. However, the following post-approval requirements still apply:

- Addition/removal of subject population should not be implemented without IRB approval
- Change in investigators must be notified and approved
- Modifications to procedures must be clearly articulated in an addendum request and the proposed changes must not be incorporated without an approval
- Be advised that the proposed change must comply within the requirements for exemption
- Changes to the research location must be approved – appropriate permission letter(s) from external institutions must accompany the addendum request form
- Changes to funding source must be notified via email (irb_submissions@mtsu.edu)
- The exemption does not expire as long as the protocol is in good standing

- Project completion must be reported via email (irb_submissions@mtsu.edu)
- Research-related injuries to the participants and other events must be reported within 48 hours of such events to compliance@mtsu.edu

The current MTSU IRB policies allow the investigators to make the following types of changes to this protocol without the need to report to the Office of Compliance, as long as the proposed changes do not result in the cancellation of the protocols eligibility for exemption:

- Editorial and minor administrative revisions to the consent form or other study documents
- Increasing/decreasing the participant size

The investigator(s) indicated in this notification should read and abide by all applicable post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident.

All of the research-related records, which include signed consent forms, current & past investigator information, training certificates, survey instruments and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the sacure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:

Click here for a detailed list of the post-approval responsibilities.
More information on exmpt procedures can be found here.

APPENDIX B: IRB Approval for Phase 2

IRB
INSTITUTIONAL REVIEW BOARD
Office of Research Compliance,
010A Sam Ingram Building,
2269 Middle Tennessee Blvd
Murfreesboro, TN 37129

MIDDLE TENNESSEE STATE UNIVERSITY

IRBN007 – EXEMPTION DETERMINATION NOTICE

Monday, April 17, 2017

Investigator(s): Junbae Mun (Student PI), Minsoo Kang (FA) and Hoyong Sung
Investigator(s') Email(s): jm5x@mtmail.mtsu.edu; minsoo.kang@mtsu.edu; hoyongsung86@gmail.com
Department: Health and Human Performance

Study Title: Examining sensitivity of the developed military concussion assessment tool in South Korean soldiers
Protocol ID: **17-1231**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the **EXEMPT** review mechanism under 45 CFR 46.101(b)(2) within the research category *(2) Educational Tests* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	EXEMPT from furhter IRB review***	
Date of expiration	NOT APPLICABLE	
Participant Size	400 (FOUR HUNDRED)	
Participant Pool	Cadets of Korea Military Academy (KMA, which is equivalent with United States Military Academy)	
Mandatory Restrictions	All participants need to consent.	
Additional Restrictions	18 years of age or older	
Comments	NONE	
Amendments	**Date**	**Post-Approval Amendments**
	N/A	NONE

***This exemption determination only allows above defined protocol from further IRB review such as continuing review. However, the following post-approval requirements still apply:

- Addition/removal of subject population should not be implemented without IRB approval
- Change in investigators must be notified and approved
- Modifications to procedures must be clearly articulated in an addendum request and the proposed changes must not be incorporated without an approval
- Be advised that the proposed change must comply within the requirements for exemption
- Changes to the research location must be approved – appropriate permission letter(s) from external institutions must accompany the addendum request form
- Changes to funding source must be notified via email (irb_submissions@mtsu.edu)

- The exemption does not expire as long as the protocol is in good standing
- Project completion must be reported via email (irb_submissions@mtsu.edu)
- Research-related injuries to the participants and other events must be reported within 48 hours of such events to compliance@mtsu.edu

The current MTSU IRB policies allow the investigators to make the following types of changes to this protocol without the need to report to the Office of Compliance, as long as the proposed changes do not result in the cancellation of the protocols eligibility for exemption:

- Editorial and minor administrative revisions to the consent form or other study documents
- Increasing/decreasing the participant size

The investigator(s) indicated in this notification should read and abide by all applicable post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident.

All of the research-related records, which include signed consent forms, current & past investigator information, training certificates, survey instruments and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the sacure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board
Middle Tennessee State University

Quick Links:
Click here for a detailed list of the post-approval responsibilities.
More information on exmpt procedures can be found here.

APPENDIX C: Recruitment Script for Phase 1 (English & Korean)

Recruitment Flyer & Script

Research Topic: Validation of a newly developed concussion assessment tool for the Korean military
Investigators: Junbae Mun, MS; Hoyong Sung, MS; Minsoo Kang, PhD

We are looking for research participants in estimating the validity of the developed Military Concussion Assessment Tool (MCAT) test. Participants include those who are not currently suffering from symptoms of a concussion. We estimate that your participation will take approximately 8 minutes. You are going to be given a brief oral test examining your orientation, immediate memory, concentration, and delayed recall. Participating in this research is by one's own voluntary choice, and you will not receive any type of compensation. However, the populations who will benefit from this research include field leaders/commanders, military training leaders, allied medical professionals, and most importantly the soldiers.
If you are interested in participating in this study, please contact Hoyong Sung (010-5071-1847; hoyongsung86@gmail.com) or Junbae Mun (jm5x@mtmail.mtsu.edu) or the Physical Education Department at Korea Military Academy (02-2197-2981). We will then set up a time that is convenient for you.

연구 참가자 모집 공고문

연구주제: 군 뇌진탕 평가도구의 타당성 검증 연구

주요 연구원: 문준배 교수, 성호용 교수, 강민수 교수

군 뇌진탕 평가도구의 타당성 검증 연구에 참가자를 모집하고 있습니다. 연구 참가는 뇌진탕 증상이 없는 사람을 대상으로 하며, 약 8 분의 시간이 소요 될 것 입니다. 연구 참가시 지남력, 즉각 기억력, 집중력, 그리고 지연 재인 검사를 포함하는 간단한 인터뷰가 진행될 것 입니다. 연구 참여는 오로지 개인의 자발적인 선택이며, 어떠한 보상도 주어지지 않을 것 입니다. 하지만, 본 연구는 야전 지휘자/지휘관, 군사훈련 담당자, 그리고 군 관련 의료기관 관계자들, 특히 한국군 장병에게 큰 도움이 될 것입니다.

연구 참여에 관심이 있으신 분들은 성호용 교수(010-5071-1847; hoyongsung86@gmail.com) 또는 문준배 교수(jm5x@mtmail.mtsu.edu) 또는 육군사관학교 체육학처(02-2197-2981)로 연락 바랍니다. 이후에 참가자가 편리한 연구 참가 시간을 정하도록 하겠습니다.

APPENDIX D: Recruitment Script for Phase 2 (English & Korean)

Recruitment Flyer & Script

Research Topic: Examining validity of the developed military concussion assessment tool in the South Korean soldiers

Investigators: Junbae Mun, MS; Hoyong Sung, MS; Minsoo Kang, PhD

We are looking for research participants in examining the validity of the developed Military Concussion Assessment Tool (MCAT) test. Participants include those who are not currently suffering from symptoms of a concussion. Cadets who are taking or participating boxing, martial arts, and military obstacle course training will be preferred as participants in this study. Participants will be asked to complete a cognitive function test three times at baseline, time of concussion, and 48 hours after concussion as well as fill out a brief injury history form. We estimate that your participation in each cognitive function test, which includes orientation, immediate memory, concentration, and delayed recall, will take approximately 5-8 minutes. Participating in this research is by one's own voluntary choice, and you will not receive any type of compensation. However, the populations who will benefit from this research include field leaders/commanders, military training leaders, allied medical professionals, and most importantly the South Korean soldiers.

If you are interested in participating in this study, please contact Hoyong Sung (010-5071-1847; hoyongsung86@gmail.com) or Junbae Mun (jm5x@mtmail.mtsu.edu) or the Physical Education Department at Korea Military Academy (02-2197-2981). We will then set up a time that is convenient for you.

연구 참가자 모집 공고문

연구주제: 군 뇌진탕 진단도구의 민감도 검증

주요 연구원: 문준배 교수, 성호용 교수, 강민수 교수

군 뇌진탕 평가도구의 민감도 검증 연구에 참가자를 모집하고 있습니다. 연구 참가는 뇌진탕 증상이 없는 사람을 대상으로 하며, 복싱, 무도, 장애물 극복 수업 및 문체활동에 참여하고 있는 인원을 우선적으로 참가자로 고려할 것입니다. 참가자는 한번의 부상 기록 양식을 작성하고 3 번의 군 뇌진탕 평가도구 검사(뇌진탕 발생 전, 뇌진탕 발생시, 뇌진탕 발생 48 시간 후)를 받을 것입니다. 지남력, 즉각 기억력, 집중력, 그리고 지연 재인 검사를 포함하는 각각의 인지능력 검사에 참여는 약 5-8 분의 시간이 소요 될 것 입니다. 연구 참여는 오로지 개인의 자발적인 선택이며, 어떠한 보상도 주어지지 않을 것 입니다. 하지만, 본 연구는 야전 지휘자/지휘관, 군사훈련 담당자, 그리고 군 관련 의료기관 관계자들, 특히 한국군 장병에게 큰 도움이 될 것입니다.

연구 참여에 관심이 있으신 분들은 성호용 교수(010-5071-1847; hoyongsung86@gmail.com) 또는 문준배 교수(jm5x@mtmail.mtsu.edu) 또는 육군사관학교 체육학처(02-2197-2981)로 연락 바랍니다. 이후에 참가자가 편리한 연구 참가 시간을 정하도록 하겠습니다.

APPENDIX E: Informed Consent for Phase 1 (English & Korean)

Informed Consent
Middle Tennessee State University

Project Title: Validation of a newly developed concussion assessment tool for the Korean military

Purpose of project: There are currently no available concussion assessment tools for Korean soldiers, so the military concussion assessment tool (MCAT) is developed. The brief, orally administered MCAT was created to offer field leaders/commanders, military training leaders, and allied medical professionals a way to test a concussion of a soldier on the field. The MCAT test uses four areas to help identify difficulty with orientation, immediate memory, concentration, and delayed recall. However, it is unknown how the developed MCAT will function in Korean soldiers. Therefore, the purpose of this study is to examine psychometric properties of the developed MCAT among the target population.

Procedures: You will be asked to complete the MCAT as well as fill out a brief injury history form. You will enter a quiet room with the researchers and be asked a series of questions. The test takes approximately 8 minutes to complete.

Risks/Benefits: A little mental fatigue associated with the MCAT test may occur, but no significant risks or discomforts are anticipated. There is no direct benefit to you for participating in this study. But, the population that will benefit from this research is wide spread including field leaders/commanders, military training leaders, allied medical professionals, and most importantly the soldiers. It could help provide a useful tool to evaluate a concussion right after sustaining a head injury.

Confidentiality: No information will be kept which could identify you. The summarized findings, without identifying information, may be published in an academic journal or presented at a scholarly conference.

Principal Investigator/Contact Information: If you have any questions regarding the research, participation or the process, and rights of research participants, please contact Hoyong Sung (hoyongsung86@gmail.com; 010-5071-1847) or Junbae Mun (jm5x@mtmail.mtsu.edu). You can also contact Hoyong Sung through his school office phone number at 02-2197-2981.

Participating in this project is voluntary, and refusal to participate or withdrawing from participation at any time during the project will involve no penalty or loss of benefits to which you might otherwise be entitled. All efforts, within reason, will be made to keep the personal information in your research record private but total privacy cannot be promised, for example, your information may be share with the Middle Tennessee State University Institutional Review Board. In the event of questions or difficulties of any kind during or following giving consent or your rights as a participant in this study, please feel free to contact the MTSU office of Compliance at 1-615-494-8918.

Consent

I have read the above information and my questions have been answered satisfactorily by project staff. I believe I understand the purpose, benefits, and risks of the study and give my informed and free consent to be participant.

______________________________	____________________
SIGNATURE	DATE

연구 동의서

미들 테네시 주립 대학교

연구주제: 한국군을 위한 뇌진탕 진단도구 개발

연구목적: 현재, 한국 군인들이 사용할 수 있는 뇌진탕 평가도구가 없기 때문에, 군 뇌진탕 평가도구를 개발 하였습니다. 군 뇌진탕 평가도구는 군 지휘자/지휘관, 군사훈련 담당자, 군 관련 의료기관 관계자들이 현장에서 장병의 뇌진탕 여부를 검사를 할 수 있도록 하기위해 개발되었습니다. 군 뇌진탕 평가도구는 뇌진탕으로 야기되는 인지능력 손상 여부를 진단을 위해 지남력, 즉각 기억력, 집중력, 지연 재인, 등 4 가지 영역의 검사를 포함하고 있습니다. 하지만, 개발된 군 뇌진탕 평가도구가 한국 군인들의 인지능력 수준을 정확히 측정하는지 확인되지 않았습니다. 따라서, 본 연구의 목적은 개발된 군 뇌진탕 평가도구의 심리측정학적 특성을 확인하는것 입니다.

연구절차: 참가자는 부상 기록 양식을 작성하고, 군 뇌진탕 평가도구 검사를 받을 것입니다. 연구자와 조용한 장소에서 지남력, 즉각 기억력, 집중력, 지연 재인 검사를 포함하는 인터뷰가 진행될 것 입니다. 검사는 약 8 분의 시간이 소요 될 것 입니다.

위험요소/혜택: 참가자는 군 뇌진탕 평가도구 검사를 받는 동안 약간의 정신적 피로가 있을 수는 있으나, 심각한 위험 또는 불편함은 전혀 없을 것 입니다. 연구 참가에 대한 어떠한 보상도 따르지 않습니다. 하지만, 본 연구는 야전 지휘자/지휘관, 군사훈련 담당자, 그리고 군 관련 의료기관 관계자들, 특히 한국군 장병에게 큰 도움이 될 것입니다. 군 뇌진탕 평가도구는 머리 부상 직후에 뇌진탕 검사할 수 있는 유용한 방법이 될 것 입니다.

비밀유지: 참가자를 분별할 수 있는 개인 신상정보는 기록 및 수집되지 않을 것입니다. 본 연구를 통해 발견된 결과(개인 신상정보와 관련 없는 종합된 정보)는 학회지 또는 학회를 통해 발표 될 수 있습니다.

주연구자/연락정보: 연구, 연구참가 및 절차, 연구 참가자의 권리에 대한 질문이 있을 경우, 성호용 교수(hoyoungsung86@gmail.com / 010-5071-1847) 및 문준배 교수 (jm5x@mtmail.mtsu.edu)에게 연락 바랍니다. 또는, 교내 성호용 교수 사무실(02-2197-2981)에 연락 및 방문 할 수 있습니다.

본 연구의 참여는 개인의 자발적인 선택임으로 언제라도 참여를 중단 할 수 있고, 연구 참가를 중단 및 거절 하더라도 어떠한 불이익도 없을 것입니다. 참가자의 개인정보는 보호 될 것이며, 요약 및 종합된 정보는 미들 테네시 주립 대학교의 연구윤리심의 위원회와 공유할 수도 있습니다. 본 연구에 참여함으로써 발생한 질문 및 애로사항, 연구 동의서, 참가자 권리에 대한 문의는 미들 테네시 주립 대학교의 규정 및 법규 준수 감사 사무실(1-615-494-8918)로 연락 하시기 바랍니다.

동의서

본인은 상기 정보를 모두 확인하였고, 궁금한 사항은 연구자의 의해 모두 확인 되었습니다. 본인은 연구목적과 연구 참가시 위험요소 및 혜택에 대해 충분히 이해하였고, 상기 연구에 자발적으로 참여함을 동의합니다.

______________________________	______________________
서명	작성일

APPENDIX F: Informed Consent for Phase 2 (English & Korean)

Informed Consent
Middle Tennessee State University

Project Title: Examining validity of the developed military concussion assessment tool in the South Korean soldiers

Purpose of project: There are currently no available concussion assessment tools for Korean soldiers, so the military concussion assessment tool (MCAT) is developed. The orally administered MCAT was created to offer field leaders/commanders, military training leaders, and allied medical professionals a way to test concussion of soldier on the field. The MCAT test uses four areas to help identify difficulty with orientation, immediate memory, concentration, and delayed recall. However, it is unknown how the developed MCAT will function in Korean soldiers. Therefore, the purpose of this study is to examine if the MCAT can detect changes of cognitive function induced by concussion.

Procedures: You will be asked to complete the MCAT three times at baseline, time of concussion, and 48 hours after concussion as well as fill out a brief injury history form. You will enter a quiet room with the researchers and be asked a series of questions. Each testing will take approximately 5-8 minutes to complete.

Risks/Benefits: A little mental fatigue associated with the MCAT test may occur, but no significant risks or discomforts are anticipated. There is no direct benefit to you for participating in this study. But, the population that will benefit from this research is wide spread including field leaders/commanders, military training leaders, allied medical professionals, and most importantly the soldiers.

Confidentiality: No information will be kept which could identify you. The summarized findings, without identifying information, may be published in an academic journal or presented at a scholarly conference.

Principal Investigator/Contact Information: If you have any questions regarding the research, participation or the process, and rights of research participants, please contact Hoyong Sung (hoyongsung86@gmail.com; 010-5071-1847) or Junbae Mun (jm5x@mtmail.mtsu.edu). You can also contact Hoyong Sung through his school office phone number at 02-2197-2981.

Participating in this project is voluntary, and refusal to participate or withdrawing from participation at any time during the project will involve no penalty or loss of benefits to which you might otherwise be entitled. All efforts, within reason, will be made to keep the personal information in your research record private but total privacy cannot be promised, for example, your information may be share with the Middle Tennessee State University Institutional Review Board. In the event of questions or difficulties of any kind during or following giving consent or your rights as a participant in this study, please feel free to contact the MTSU office of Compliance at 1-615-494-8918.

Consent

I have read the above information and my questions have been answered satisfactorily by project staff. I believe I understand the purpose, benefits, and risks of the study and give my informed and free consent to be participant.

______________________________ SIGNATURE

____________________ DATE

연구 동의서

미들 테네시 주립 대학교

연구주제: 군 뇌진탕 진단도구의 민감도 검증

연구목적: 현재, 한국 군인들이 사용할 수 있는 뇌진탕 평가도구가 없기 때문에, 군 뇌진탕 평가도구를 개발 하였습니다. 군 뇌진탕 평가도구는 군 지휘자/지휘관, 군사훈련 담당자, 군 관련 의료기관 관계자들이 현장에서 장병의 뇌진탕 여부를 검사를 할 수 있도록 하기 위해 개발되었습니다. 군 뇌진탕 평가도구는 뇌진탕으로 야기되는 인지능력 손상 여부를 진단을 위해 지남력, 즉각 기억력, 집중력, 지연 재인, 등 4 가지 영역의 검사를 포함하고 있습니다. 하지만, 개발된 군 뇌진탕 평가도구가 한국 군인들의 인지능력 수준을 정확하게 측정하는지 확인되지 않았습니다. 따라서, 본 연구의 목적은 개발된 군 뇌진탕 평가도구가 뇌진탕에 의해 유발된 인지능력의 변화를 감지할 수 있는지 확인하는것 입니다.

연구절차: 참가자는 한번의 부상 기록 양식을 작성하고, 3 번의 군 뇌진탕 평가도구 검사(뇌진탕 발생 전, 뇌진탕 발생시, 뇌진탕 발생 48 시간 후)를 받을 것입니다. 연구자와 조용한 장소에서 지남력, 즉각 기억력, 집중력, 지연 재인 검사를 포함하는 인터뷰가 진행될 것 입니다. 각각의 검사는 약 5-8 분의 시간이 소요 될 것 입니다.

위험요소/혜택: 참가자는 군 뇌진탕 평가도구 검사를 받는 동안 약간의 정신적 피로가 있을 수는 있으나, 심각한 위험 또는 불편함은 전혀 없을 것 입니다. 연구 참가에 대한 어떠한 보상도 따르지 않습니다. 하지만, 본 연구는 야전 지휘자/지휘관, 군사훈련 담당자, 그리고 군 관련 의료기관 관계자들, 특히 한국군 장병에게 큰 도움이 될 것입니다.

비밀유지: 참가자를 분별할 수 있는 개인 신상정보는 기록 및 수집되지 않을 것입니다. 본 연구를 통해 발견된 결과(개인 신상정보와 관련 없는 종합된 정보)는 학회지 또는 학회를 통해 발표 될 수 있습니다.

주연구자/연락정보: 연구, 연구참가 및 절차, 연구 참가자의 권리에 대한 질문이 있을 경우, 성호용 교수(hoyoungsung86@gmail.com / 010-5071-1847) 및 문준배 교수 (jm5x@mtmail.mtsu.edu)에게 연락 바랍니다. 또는, 교내 성호용 교수 사무실(02-2197-2981)에 연락 및 방문 할 수 있습니다.

본 연구의 참여는 개인의 자발적인 선택임으로 언제라도 참여를 중단 할 수 있고, 연구 참가를 중단 및 거절 하더라도 어떠한 불이익도 없을 것입니다. 참가자의 개인정보는 보호 될 것이며, 요약 및 종합된 정보는 미들 테네시 주립 대학교의 연구윤리심의 위원회와 공유할 수도 있습니다. 본 연구에 참여함으로써 발생한 질문 및 애로사항, 연구 동의서, 참가자 권리에 대한 문의는 미들 테네시 주립 대학교의 규정 및 법규 준수 감사 사무실(1-615-494-8918)로 연락 하시기 바랍니다.

동의서

본인은 상기 정보를 모두 확인하였고, 궁금한 사항은 연구자의 의해 모두 확인 되었습니다. 본인은 연구목적과 연구 참가시 위험요소 및 혜택에 대해 충분히 이해하였고, 상기 연구에 자발적으로 참여함을 동의합니다.

서명	작성일

APPENDIX G: Injury History Form (English & Korean)

Injury History Form

Date of Examination: ____________________ (day/month/year)

Age: ________ years

Sex: ________

Height: __________ cm

Weight: __________ kg

Head Injury Experiences within the Last 6 Months: _________________________

____
____
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부상 기록 양식

검사일: ________________ (년 / 월 / 일)

나이: (만) ____________ 세

성별: ____________

신장: ____________ cm

체중: ____________ kg

6 개월 이내 머리 부상 경험: ____

APPENDIX H: Korean Version of the Adapted SAC (English & Korean)

***Korean Version of the Adapted SAC* (K-SAC)**

(Words in ***Italics*** throughout the K-SAC are the instructions for tester.)

ORIENTATION (1 point for each correct answer)

** I am going to ask you some questions. Please listen carefully and give your best effort.*
** Score 1 point for each correct response.*

What month is it?	1.	0	1
What is the date today?	2.	0	1
What is the day of the week?	3.	0	1
What year is it?	4.	0	1
What time is it right now? (within 1 hour)	5.	0	1
Orientation Score			**of 5**

IMMEDIATE MEMORY (1 point for each correct answer)

** 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.*
** Score 1 point for each correct response.*
** Do not inform the participant that delayed recall will be tested.*

Age	6.	0	1
Korean Flag	7.	0	1
Watermelon	8.	0	1
Airplane	9.	0	1
Singer	10.	0	1
Bicycle	11.	0	1
Desk	12.	0	1
Monkey	13.	0	1
Sea	14.	0	1
Rainbow	15.	0	1
Immediate Memory score			**of 10**

CONCENTRATION: Digits Backwards (1 point for each correct answer)

** I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.*
** One point possible for each string length.*
** The digits should be read at the rate of one per second*.

4 – 9 – 3	16.	0	1
3 – 8 – 1 – 4	17.	0	1
6 – 2 – 9 – 7 – 1	18.	0	1
7 – 1 – 8 – 4 – 6 - 2	19.	0	1
2 – 7 – 3 – 9 – 1 – 5 – 8	20.	0	1

8 – 1 – 5 – 7 – 3 – 9 – 4 – 6	21.	0	1
5 – 9 – 6 – 2 – 7– 4 – 1 – 8 – 3	22.	0	1
Subtotal			**of 7**

CONCENTRATION: Counting Down from 100 by 7 (1 point for each correct answer)

* *I would like you to subtract 7 from 100. Then keep subtracting 7 from each answer until I tell you to stop. What is 100 minus 7? … Keep going*
* *Score 1 point for each correct answer (up to a maximum of five subtractions). The answer is correct if it is exactly 7 less than the previous answer, regardless of whether the previous answer was correct.*

100			
93	23.	0	1
86	24.	0	1
79	25.	0	1
72	26.	0	1
65	27.	0	1
Subtotal			**of 5**
Concentration Score			**of 12**

DELAYED RECALL (1 point for each correct answer)

* *Do you remember the list of words I read a few minutes earlier? Tell me as many words from the list as you can remember in any order.*
* *Score 1 point for each correct response.*

Age	28.	0	1
Korean Flag	29.	0	1
Watermelon	30.	0	1
Airplane	31.	0	1
Singer	32.	0	1
Bicycle	33.	0	1
Desk	34.	0	1
Monkey	35.	0	1
Sea	36.	0	1
Rainbow	37.	0	1
Delayed Recall Score			**of 10**

Total Score of K-SAC	**of 37**

한국어 버전 표준 뇌진탕 (Concussion) 평가 도구

(군 뇌진탕 평가도구의 ***이탤릭체*** 문장은 검사자가 피검사자에게 주는 지침 또는 점수 산정 지침 입니다.)

지남력 검사 (각 문항 정답시 1 점 획득)

** 설문 지침 : 지금부터 몇 가지 질문을 할 것입니다. 주의 깊게 듣고 성실하게 답해주시기 바랍니다.*

** 점수 지침 : 각 질문에 정확한 답변시 1 점씩 부여합니다.*

이번 달은 몇 월인가요?	1.	0	1
오늘은 몇 일인가요?	2.	0	1
오늘은 무슨 요일인가요?	3.	0	1
올해는 몇 년도인가요?	4.	0	1
지금은 몇 시인가요? (1 시간 이내의 오차는 정답 인정)	5.	0	1
지남력 점수 합계 (총 5 점)			**점**

즉각 기억력 검사 (각 문항 정답시 1 점 획득)

** 설문 지침 : 지금부터 당신의 즉각 기억력을 검사하기 위해 몇 개의 단어들을 읽어 드릴 것입니다. 단어들을 다 듣고 난 후, 순서에 상관없이 기억할 수 있는 모든 단어들을 말씀해 주시기 바랍니다.*

** 점수 지침 : 정확하게 기억한 각 단어에 1 점씩 부여합니다.*

** 주의 : 검사 참가자에게 잠시 후 지연 재인 검사가 있음을 알리지 마십시오.*

나이	6.	0	1
태극기	7.	0	1
수박	8.	0	1
비행기	9.	0	1
가수	10.	0	1
자전거	11.	0	1
책상	12.	0	1
원숭이	13.	0	1
바다	14.	0	1
무지개	15.	0	1
즉각 기억력 점수 합계 (총 10 점)			**점**

집중력 검사 : 숫자 역순으로 말하기 (각 문항 정답시 1 점 획득)

** 설문 지침 : 지금부터 일련의 숫자들을 읽어 드릴 것입니다. 모두 다 듣고 난 후에 읽어 드린 일련의 숫자들을 역순으로 말씀해 주시기 바랍니다. 예를 들어, 제가 7-1-9 라고 읽어 드리면, 9-1-7 이라고 말씀해 주시면 됩니다.*

** 점수 지침 : 각 질문에 역순으로 정확히 대답할 경우 1 점씩 부여 합니다.*

** 주의 : 1 초당 각 숫자 하나를 읽는 정도의 속도로 또박또박 읽어야 합니다.*

4 – 9 – 3	16.	0	1

3 – 8 – 1 – 4	17.	0	1
6 – 2 – 9 – 7 – 1	18.	0	1
7 – 1 – 8 – 4 – 6 - 2	19.	0	1
2 – 7 – 3 – 9 – 1 – 5 – 8	20.	0	1
8 – 1 – 5 – 7 – 3 – 9 – 4 – 6	21.	0	1
5 – 9 – 6 – 2 – 7– 4 – 1 – 8 – 3	22.	0	1
소계 (총 7 점)			**점**

집중력 검사 : 100 에서 7 연속 빼기 (각 문항 정답시 1 점 획득)

** 설문 지침 : 지금부터 100 에서 7 씩 뺄셈하세요. 제가 “그만” 할 때까지 대답한 값에서 7 을 뺀 값을 계속 말씀해 주시기 바랍니다. 100 에서 7 을 뺀 값은 무엇입니까? 계속해서 말씀해 주시기 바랍니다.*

** 점수 지침 : 최대 5 개의 값을 평가합니다. 각 정답에 1 점씩 부여합니다. 이전 대답의 정답 여부에 상관없이 이전에 대답한 값에서 정확하게 7 을 뺀 값을 대답할 경우 1 점씩 부여합니다.*

93	23.	0	1
86	24.	0	1
79	25.	0	1
72	26.	0	1
65	27.	0	1
소계 (총 5 점)			**점**
집중력 점수 합계 (총 12 점)			**점**

지연 재인 검사 (각 문항 정답시 1 점 획득)

** 설문 지침 : 즉각 기억력 검사에서 읽어 드렸던 단어들을 기억하십니까? 그 단어들 중 기억할 수 있는 모든 단어들을 순서에 상관없이 말씀해 주시기 바랍니다.*

** 점수 지침 : 기억한 각 단어에 1 점씩 부여합니다.*

나이	28.	0	1
태극기	29.	0	1
수박	30.	0	1
비행기	31.	0	1
가수	32.	0	1
자전거	33.	0	1
책상	34.	0	1
원숭이	35.	0	1
바다	36.	0	1
무지개	37.	0	1
지연 재인 점수 합계 (총 10 점)			**점**

총 점 (총 37 점)	**점**

APPENDIX I: Official Approval Electronic Document from Korea Military Academy (English & Korean)

Korea Military Academy (KMA)
Purpose of this document: Internal Approval Title: A request approval for Major Junbae Mun in conducting development and validation study of a concussion diagnostic tool
1. Related regulation A. Military security regulation 212 (3 : 88): Procedures of review and approval for security 2. If you approve to conduct this research, we will conduct the research following the research plan as described below. A. Title of study: Development and validation of a concussion assessment tool for the Korean military B. Purpose of study: Developing and validating a Korean version of the adapted SAC (K-SAC) to use for concussion diagnosis in physical education classes and military training C. Principal investigator: Major Junbae Mun Attached document: Plan of the research for developing and validating K-SAC
Officer of academic affairs in Department of Physical Education [DPE]: approved with signature (March 4th, 2016) Chair of DPE: approved with signature (March 7th, 2016) Chair of Department of Military Training: approved with signature (March 8th, 2016) Assistant Commandant of Cadets: approved with signature (March 8th, 2016) Commandant of Cadets (Brigadier General): approved with signature (March 9th, 2016) Document number: DPE-91 570 Hwarang-ro, Nowon-gu Seoul, Republic of Korea, 01805 (DPE / http://kma.army.mil) Phone: 950-2971 Fax: 950-2971

인쇄 : 김동민 / 체육학처 (2016-03-11 09:18:50)

1초의 관심, 전우의 생명을 지킵니다.

육 군 사 관 학 교

수신 내부결재
(경유)
제목 경미한 뇌진탕 진단 도구 개발 및 타당성 검증 연구계획(소령 문준배)에 따른 승인요청

1. 관련근거
   가. 육사예규 212 군사보안예규 제 3절 제 88조 보안성 검토 승인절차

2. 위 관련근거에 의거 아래의 내용과 같은 연구활동을 할 예정이오니 승인해주시면 계획된대로 진행토록 하겠습니다.
   가. 연구제목 : 경미한 뇌진탕 진단 도구 개발 및 타당성 검증
   나. 연구목적 : 생도 체육교육 및 군사훈련간 머리에 충격을 받는 상황 발생시 적절한 초기대응을 위한 진단도구 개발
   다. 연구인원 : 체육학 교수 소령 문준배

붙임 : 경미한 뇌진탕 진단 도구 개발 및 타당성 검증 연구계획(소령 문준배)

대위 김동민

체육학처 행정장교 김동민   체육학처 체육학처장 이상원   생도대 부생도대장 이철화   생도대장 2016. 3. 9. 황대일

협조자 ★군사훈련처 군사훈련처장 권영우

시행 체육학처-91   접수

우 01805 서울특별시 노원구 화랑로 570 (공릉동, 육사 체육학처) / http://kma.army.mil/
전화번호 950-2971 팩스번호 950-2971 /kdm720@army.mil /대국민 공개

내가 놓친 안전의 끈, 전우들의 생명의 끈

APPENDIX J: 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)

Word list	Trial 1		Trial 2		Trial 3		Alternative word list		
Elbow	0	1	0	1	0	1	Candle	Baby	Finger
Apple	0	1	0	1	0	1	Paper	Monkey	Penny
Carpet	0	1	0	1	0	1	Sugar	Perfume	Blanket
Saddle	0	1	0	1	0	1	Sandwich	Sunset	Lemon
Bubble	0	1	0	1	0	1	Wagon	Iron	Insect
Subtotal									
Immediate memory score total									**of 15**

CONCENTRATION: Digits Backwards (1 point for each correct answer)

Number list	Trial 1		Alternative digit list		
4–9–3	0	1	6–2–9	5– 2–6	4–1–5
3–8–1– 4	0	1	3–2–7–9	1–7–9–5	4–9–6–8
6–2–9–7–1	0	1	1–5–2–8–5	4–8–5–2–7	6–1–8–4–3
7–1–8–4–6–2	0	1	5–3–9–1–4–8	8–3–1–9–6–4	7–2–4–8–6–5
Subtotal					

CONCENTRATION: Month in Reverse Order (1 point for correct answer)

Dec-Nov-Oct-Sep-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan	0	1

Concentration score	**of 5**

DELAYED RECALL (1 point for each correct answer)

Word 1	0	1
Word 2	0	1
Word 3	0	1
Word 4	0	1
Word 5	0	1
Delayed recall score		**of 5**

Score Totals	**of 30**