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Preseason Assessment as a Predictor of Post-Concussion Performance of Athletes on the Immediate Post-Concussion Assessment and Cognitive Test

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Dedication

I would like to dedicate this research project to my mother, Janet Lambeth. Thank you for the constant support, love, and encouragement to be successful my whole life. None of my success could have been possible without you. I love you.

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By

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Abstract

Ideally, athletes are assessed pre-season to establish their cognitive-communicative status for comparison purposes if the athlete suffers a concussion during their season. Post-concussion (PC) assessment comparison with the baseline (BL) assessment will provide clinical information for treatment of the athlete's concussion. *The Immediate Post-Concussion Assessment and Cognitive Testing* (ImPACT) *test* was used for assessment of pre-and post-concussion. Because the literature indicates that some athlete's attempt to actively perform poorly on the preseason assessment to misrepresent their performance post-concussion it would be interesting to determine if there is a score on the ImPACT pre-season test that would predict their post-concussion test performance. This information may help in the management of sports-related concussions by identifying athletes at preseason assessment who are potentially underperforming. The current study examined the Cognitive Efficiency Score (CEI) because the CEI score measures accuracy and speed of the Symbol Match subtest which is a reliable indicator to determine the extent to which the athlete tried to work fast on the symbol match (decreasing accuracy) or attempted to improve their accuracy by taking a more deliberate and slow approach (jeopardizing speed). In this study, 52 participants underwent a preseason evaluation and then were reevaluated within 0-7 days after they sustained their injury. Results showed there were statistically significant difference between the baseline CEI and the post-season scores, which permitted the evaluation to determine if the baseline CEI could predict how athletes would perform on their post-concussion assessment. The participants were organized into three groups based on the results of their preseason CEI score (Group 1=.00-.20, N=11), (Group 2=.21-.40, N=26), and (Group 3=.41-.60, N=15)) to determine if performance on baseline CEI predicted their performance on the PC test. When separated into the three groups, the results were more specific. The results from this study suggest that the preseason CEI score for only Group 1 is a significant predictor for how athletes will perform on the PC ImPACT test. This study supports the potential use of the CEI score as an important clinical variable for assessing the compliance of an athlete's efforts to perform to their maximum abilities. Additionally, total symptom scores for BL CEI and PC CEI were both considered significant so it is important to continue to identify a measure(s) that could potentially be predictive factors of BL performance to PC performance which could provide clinicians with appropriate prognosis and return-to-play decisions for our athletes.

Databases: UTEP Ebsco, Google Scholar, www.impacttest.com

Keywords: concussion, ImPACT, effort, “sandbagging,” motivation, neurocognitive testing, symbol match test, symbol digit modalities test, cognitive efficiency index, reported symptoms

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Chapter 1: Literature Review

1.1 Introduction to Concussions

A concussion, also known as a mild traumatic brain injury (mTBI), is caused by a force to the head that causes the brain to move rapidly inside the skull (Bailey, Echemendia, & Arnett, 2006). The diagnosis, treatment, and management of sports-related concussion has gained attention in recent years, in the fields of neuropsychology and sports medicine (Schatz, Pardini, Lovell, Collins, & Podell, 2006). This increase in interest is due to the approximately 1.6 to 3.8 million concussions that occur each year in the United States (Lau, Collins, & Lovell, 2011). Concussions are especially prevalent for high school and collegiate athletes because of the increase in joining competitive team sports. Despite the extensive number of concussions suffered on a yearly basis, data to aid in the diagnosis and management of sports concussion have only begun to emerge (Schatz, Pardini, Lovell, Collins, & Podell, 2006). This emerging data will assist in future concussion management guidelines as well as contribute to a clinician's appropriate prognosis and return-to-play decision.

Furthermore, there is no consensus as to the definition of "recovery" nor the exact time to determine an athlete has fully "recovered." Overall, recovery from a concussion varies amongst individuals. Since every concussion is different, recovery could range from a few days to more than a year to "fully recover." Some of the most important decisions that clinicians make when assessing concussed athletes are determining the accuracy of the neurocognitive testing scores, the athletes' prognosis, and reasonable return-to-play decisions (Lau, Collins, & Lovell, 2011; Bailey, Echemendia, & Arnett, 2006; Moss, Jones, Fokias, & Quinn, 2003).

1.2 Neurocognitive Testing and Symptom Reporting

In the past, the process of diagnosing, determining a prognosis, and making return-to-play decisions of a sports-related concussion were based on paper/pencil tests and the athletes reported symptoms (Bailey, Echemendia, & Arnett, 2006). This caused for low rates of sensitivity or specificity of the diagnosis, prognosis, and return-to-play decisions from a sports-related concussion (Bailey, Echemendia, & Arnett, 2006). These results may have been due to some athletes not being completely aware of what type of symptoms are characteristics of a concussion and/or because they do not want to be removed from the game that they are passionate about and have dedicated countless hours to compete at their current level (Bailey, Echemendia, & Arnett, 2006).

Today, there are computerized standardized neurocognitive assessments that are available to help certified professionals determine appropriate prognosis, maintenance, and return-to-play decisions following a sports-related concussion (Nelson, Pfaller, Rein, & McCrea, 2015). These computerized neurocognitive assessments provide measures that help determine if there have been changes in an individual's cognitive performance due to a concussion (Nelson, Pfaller, Rein, & McCrea, 2015). The standard method for managing a sports-related concussion is to complete a baseline assessment (BL) prior to the start of their season and then reevaluated again, known as a post-concussion (PC) assessment, after they suffer a concussion (Nelson, Pfaller, Rein, & McCrea, 2015). The *Immediate Post-Concussion Assessment and Cognitive Testing* (ImPACT) is the most popular used neurocognitive assessment tool today (Nelson, Pfaller, Rein, & McCrea, 2015). However, it is important to note that the ImPACT is not designed to diagnose a concussion, but rather to be used as an appropriate instrument to provide healthcare professionals with a measure of current neurocognitive functioning for evaluation and managing a concussion (ImPACT Administration and Interpretation Manual, 2016). The ImPACT is composed of 6 modules: Word Memory Learning (WML), Design Memory Learning (DSL), Xs and Os (XO), Symbol Match, Color Match, and Three Letters (TL) (Nelson, Pfaller, Rein, & McCrea, 2015). After completion of all the modules, each is calculated and scored which contributes to five main composite scores: verbal memory, visual memory, processing speed, reaction time, and impulse control (Nelson, Pfaller, Rein, & McCrea, 2015). The verbal memory composite score is based on the individual's attentional ability, learning, and memory within the verbal domain (ImPACT Administration and Interpretation Manual, 2016). The visual memory composite score is based on the individual's visual attention and scanning, as well as learning and memory within the visual domain (ImPACT Administration and Interpretation Manual, 2016). The processing speed composite score evaluates visual processing, learning, and memory, as well as visual-motor response speed (ImPACT Administration and Interpretation Manual, 2016). The reaction time composite score is based on an individual's average response speed (ImPACT Administration and Interpretation Manual, 2016). Lastly, the ImPACT also provides a score called impulse control that describes the number of errors made on the test (ImPACT Administration and Interpretation Manual, 2016).

In addition to the six modules and five composite scores, the ImPACT test provides a total symptom score (TSS) regarding the athlete's self-reported symptom data (ImPACT Administration and Interpretation Manual, 2016). A higher score reflects a greater symptom total (ImPACT Administration and Interpretation Manual, 2016). There are a total of 22 concussion symptoms that the athletes rate based on a 7-point Likert scale (with 0 meaning that the athlete is not experiencing the symptom at all to 6 meaning that the athlete is severely experiencing the symptom). The ImPACT asks the athletes to rate the following symptoms: headache, nausea, vomiting, balance problems, dizziness, fatigue, trouble falling asleep, sleeping more/less than usual, drowsiness, sensitivity to light/noise, irritability, sadness, nervousness, feeling more emotional, numbness or tingling, feeling slowed down, feeling “mentally foggy,” difficulty concentrating, difficulty remembering, and visual problems (ImPACT Administration and Interpretation Manual, 2016).

Previous literature has indicated that one could predict that when an athlete suffers a concussion, there would be higher symptom scores reported during the PC assessment compared to the baseline assessment (Lovell et al., 2006). There are some possibilities as to why symptoms reported increase after suffering a concussion. First, it could be the organic reason of suffering a concussion and the inevitable effects from it that cause the symptoms to occur. Second, symptoms could increase because the athletes’ are in a condition of sickness and they believe they have to report higher symptoms. Lastly, gender could possibly have an effect on symptom reporting, since females are more likely to sustain a concussion, susceptible to be reporting more symptoms than males, and may take longer to recover than males (Lovell et al., 2006; Covassin, Elbin, Harris, Parker, & Kontos, 2012). All of these possibilities exist and each one relies on the patients’ self-report of their symptoms, which could be variable amongst individuals.

1.3 Symbol Match Test/Cognitive Efficiency Index (CEI) Score

As previously mentioned, there are six modules on the ImPACT test. One of those modules is the Symbol Match test. This subtest evaluates visual processing speed, learning, and memory (ImPACT Administration and Interpretation Manual, 2016). During this task, the participant is required to quickly substitute a number for a randomized series of common geometric symbols (Iverson, Lovell, & Collins, 2005). The participant is required to click the matching number as quickly as possible and to remember the symbol/number of pairings for a total of 27 trials (ImPACT Administration and Interpretation Manual, 2016). After completion of the trials, the symbols disappear and one symbol reappears at the bottom of the screen one at a time and the participant must attempt to recall the correct symbol/number pairing by clicking the corresponding number button. For a symbol to be remembered and discriminated from other symbols, both featural and spatial orientation information must be encoded (Gilmore, Royer, & Gruhn, 1983). The Symbol Match tests are speeded, which require information from the visual environment to be encoded and processed, and set goals regarding the fast turnover of items requiring completion (Stephens, 2006). The Symbol Match test is easily administered, and the procedures for administration and scoring of the test leave little room for variation (Hoyer, Stawski, Wasylyshyn, & Verhaeghen, 2004). The familiar task of filling numbers in boxes, and the availability of an oral administration, make this a popular screening task for brain impairment (Sheridan, Fitzgerald, Adams, Nigg, Martel, Puttler, & Zucker, 2006). Tests of information-processing speed directly reflect the global neurophysiological processing rate of the central nervous system (Piccinin & Rabbitt, 1999).

In addition to the five main composite scores and symptom scores on the ImPACT, there is a score called the Cognitive Efficiency Index (CEI) score that is calculated from the Symbol Match subtest on ImPACT. The CEI score measures the interaction between accuracy (percentage correct) and speed (reaction time) in seconds on the Symbol Match subtest (ImPACT Administration and Interpretation Manual, 2016). It is important to note that this score was not created to make return-to-play decisions. However, it is used to help assist in determining the extent to which the athlete tried to work very fast on the symbol match (decreasing accuracy) or attempted to improve their accuracy by taking a more deliberate and slow approach (jeopardizing speed) (ImPACT Administration and Interpretation Manual, 2016). The range of scores for the CEI is from approximately 0 to .70 with a mean of .34 (ImPACT

Administration and Interpretation Manual, 2016). A higher score (above .20) indicates that the athlete did perform well in speed, accuracy, and memory domains on the symbol match test (ImPACT Administration and Interpretation Manual, 2016). A low score (below .20) means that they performed poorly on both the speed and accuracy component (ImPACT Administration and Interpretation Manual, 2016). In some cases, athletes score a negative number, which suggests that they performed very poorly on the reaction time component on the Symbol Match test (ImPACT Administration and Interpretation Manual, 2016). Because of this information, it is reasonable to question if it could be used to determine athletes' level of effort or motivation during baseline testing. Some observations from healthcare professionals of post-concussed athletes have shown that they sometimes perform better on the post-concussion assessment compared to their baseline assessment (Bailey, Echemendia, & Arnett, 2006). Such observations question the motivation of performance of these particular athletes' during their baseline assessment.

When athletes suffer a concussion, there is a complex pathophysiological process that affects the brain, which ultimately disrupts the neurocognitive pathways, which result in low scores on neurocognitive assessments (Covassin et al., 2012; Lovell et al., 2001). Therefore, when post-concussed athletes perform better on the ImPACT test compared to their baseline test, an athlete's motivation for performance on the baseline test is taken into consideration. Since, the CEI score measures the accuracy and speed of the symbol match test, there have been questions raised about the possibility that the CEI could be a predictor value when determining an athlete's level of motivation during baseline testing.

1.4 Level of Motivation

Motivation is required when athletes complete a neurocognitive assessment before their season starts and after they sustain a concussion during their season so that professionals could get an accurate or “true” score of their cognitive function both before and after their injury. As discussed earlier, for some athletes during the baseline assessment, motivation to perform at their best ability is often disregarded. Several factors that might result in the motivation to minimize their symptoms reported, as well as their performance on the ImPACT for athletes who have suffered a concussion (Bailey, Echemendia, & Arnett, 2006). First, athletes tend to be very passionate about the sport(s) that they play, their team, and the possibility of having a future athletic career (Bailey, Echemendia, & Arnett, 2006). Most dedicated athletes put in countless hours of hard work during practice and games to improve their abilities. Thus, the chance of athletes being removed from the game (even for a short period) can have negative consequences for the individual athlete as well as the team (Bailey, Echemendia, & Arnett, 2006). Therefore, an athlete’s apparent fear of removal from a game or of losing his or her position on the team may tempt some athletes to deny or underreport post-concussive symptoms and possibly “sandbag” their baseline assessment (Van Kampen, Lovell, Pardini, Collins, & Fu, 2006; Bailey, Echemendia, & Arnett, 2006). Secondly, it is also important to recognize the difficulty that some individuals might experience in acknowledging that an injury has possibly altered their cognitive abilities at all (Bailey, Echemendia, & Arnett, 2006). Given the possible increased motivation to do well post-injury due to the fear of not being able to play due to a concussion, it is likely that the results from the post-injury assessment is an accurate depiction of the athlete’s cognitive functioning (Bailey, Echemendia, & Arnett 2006). However, during the baseline assessment, these motivating factors are not always present, which does not accurately reveal the athletes’ true cognitive capabilities before they sustained an injury. The obscure true cognitive repercussions in post-injury assessment may be due to the lack of interest of taking the assessment, which can impact the accurate measurement of cognitive ability at baseline (Bailey, Echemendia, & Arnett 2006). When it comes to the comparison of the baseline and PC assessments, in many cases, the healthcare professionals may be left with questions because of the athletes' overall better performance on the PC assessment than the baseline assessment. Therefore, it is of prime importance that the results of the baseline and post-injury neurological assessments are a true and valid estimation of the athletes' cognitive function (Moss, Jones, Fokias, & Quinn, 2003).

1.5 Purpose of Study

The purpose of this study was to investigate if there are predictive variables between composite, CEI, and total symptom scores on the baseline assessment and the PC assessment, with a special interest in the CEI. The following research questions will be asked and answered. (1) Could the CEI score reflect the level of motivation on baseline from the post-injury CEI score? (2) Are there significant differences between the baseline and PC composite, total symptoms, and CEI scores on the ImPACT test (with the baseline composite and symptom scores being better than the PC test)? (3) Are PC assessment scores significantly better than the performance on the BL CEI scores among 3 separated groups?

Chapter 2:

Methods and Procedures

2.1 Participants

This study sample included 52 amateur athletes who underwent a baseline assessment prior to the start of their season and then were reevaluated for their PC assessment following their concussion between the years of 2007-2014. Participants ranged in age from 15-24 years old. The athletes underwent baseline and post-concussion evaluation using the ImPACT neurocognitive assessment at the UTEP Concussion Management Clinic (CMC). The participants took their PC assessment anytime between 0-49 months from the time that they took their baseline assessment and when they suffered an injury and came back to the UTEP CMC for their PC assessment. There were a total of 26 participants that were tested 0-12 months between their baseline and PC assessment, 13 participants that were tested 13-24 months between their baseline and PC assessment, 8 participants that were tested 25-36 months between their baseline and PC assessment, 4 participants that were tested 37-48 months between their baseline and PC assessment, and 1 participant that was tested 49 months between their baseline and PC assessment. However, all 52 participants came back to the UTEP CMC for their PC evaluation within 0-7 days after they sustained their concussion injury. There were 33 (63.4%) male and 19 female athletes (36.5%). Of the 52 participants, 44 (84.6%) were collegiate athletes, 3 (5.7%) were high school athletes, and 5 (9.6%) were semi-professional athletes from the local hockey team. All of the participants that were included in this study reported no diagnosis of the following: attention deficit disorder, autism, dyslexia, no strenuous exercise in the past three hours, learning disability, no repeated years of school, did not receive speech therapy or attend special education classes, no history of brain surgery, no history of meningitis, and no treatment for headaches/migraines, substance/alcohol abuse, epilepsy/seizures, or psychiatric conditions.

For this study, no participant recruitment was necessary since all the data needed was already obtained from the existing database in the UTEP CMC.

2.2 Instrument

The current study used the *Immediate Post-Concussion and Assessment and Cognitive Testing* (ImPACT) software.

2.3 Procedures

The UTEP CMC is a referral-based clinic and advertises their services across the entire city of El Paso. All the participants in the current study underwent a baseline assessment and then a PC assessment following an injury (0-49 months after their baseline assessment). PC evaluations for this sample were conducted anywhere between 0-7 days after the athletes sustained their concussion. Undergraduate and graduate student research assistants who volunteered or worked in the UTEP CMC evaluated the baseline and PC assessments.

For an athlete to be cleared to gradually return-to-play, two important criteria needed to be met. First, the PC composite scores are required to return to the baseline composite scores. Second, the PC total symptom scores need to be below the score of 7. Overall, resolution of post-concussion symptoms, in combination of normal neurocognitive test scores is generally regarded as a requirement for return-to-play decisions (Aubrey et al., 2002; Echemendia & Cantu, 2003).

All data that is collected during the baseline and PC evaluations are entered into the computerized databases located in the UTEP CMC under password protection. Names of participants are coded to keep their personal information and results confidential. Either a graduate or undergraduate research assistant entered the data into the databases and a different graduate or undergraduate research assistant completed a reliability check of the data to make sure everything was entered properly and accurately.

A one-way ANOVA, a paired sample *t*-test, Wilcoxon Signed Ranks Test, Spearman's Nonparametric Correlations, Kruskal-Wallis Test, Chi-square, Mann-Whitney Test and a One-Sample Kolmogorov-Smirnov Test were used as statistical analyses for this study. The one-way ANOVA and paired sample t-test were used in order to compare group means and to be able to make inferences about the population means. The Wilcoxon Signed Ranks Test was used to compare two sets of scores from one time point to another from the same participants. The Spearman's Nonparametric Correlations was used to measure the strength and direction of association between two variables. The Kruskal-Wallis test was used to compare the baseline CEI means among the 3 groups. The 3 groups are as follows: Group 1=.00-.20 (N=11); Group 2= .21-.40 (N=26); Group 3= .41-.60 (N=15). A Chi-square analysis was used to determine if there were any significant difference between the groups in the PC scores. The Mann-Whitney test was used to investigate mean differences between pairs to determine if they had more significance then the other two possibilities on having significant results with the PC scores. Another Wilcoxon Signed Ranks Test was used to determine if the separated groups had a significant difference between all the baseline and PC scores. Lastly, the One-Sample Kolmogorov-Smirnov analysis to determine if the sample that performed as "expected" (all participants baseline CEI score was higher then their PC CEI score) was normally distributed.

Chapter 3: Data Analysis

This study was designed to research and examine if the baseline CEI could be a predictive value on the ImPACT test for the PC scores, as well as determining differences and correlations between the composite and total symptoms scores from baseline assessment to the same PC assessment scores following a sports-related concussion. Data was collected and analyzed using the athletes baseline and first PC composite, total symptoms, and CEI scores on the ImPACT. Athletes were initially split into groups in regards of time between when they completed their baseline evaluation and by the time they were injured and returned to the UTEP CMC for their PC evaluation. The groups were classified as 0-12 months, 13-24 months, 25-36 months, 37-48 months, and greater than 49 months. Potential differences from these five groups were explored using a one-way ANOVA analysis (Table 1.1). The CEI for each participant in regards to their baseline evaluation and PC evaluation were also explored using a paired sample t-test analysis (Table 2.1). Days since injury and the differences between baseline and PC scores were explored using the Wilcoxon Signed Ranks Test (Table 3.1). There were 38 participants in the 0-3 days group and 14 participants in the 4-7 days group. Next, the Spearman's Nonparametric Correlations analysis was used to determine if any of the composite scores for both baseline and PC scores correlated with the CEI score (Table 4.1-4.2). Furthermore, the baseline CEI was tested through the Spearman's Rho Nonparametric Correlations to see if it correlated with any of the PC scores (Table 5.1). Next, the participants were later divided into three groups (Table 6.1) based on their baseline CEI score and were identified as Group 1 (.00-.20), Group 2 (.21-.40), and Group 3 (.41-.60). They then were analyzed as a whole with the Kruskal-Wallis Test (Table 6.2) and then switching between two of the three groups with the Mann-Whitney Test (Table 6.3-6.5). Also, each group was later analyzed individually to determine if there were any significant results when comparing the baseline scores to the corresponding PC scores using the same statistical test (Table 7.1-7.3). Finally, all the participants who performed "as expected" which included only the participants that performed higher for the CEI on the BL assessment than on the PC assessment (N=24). The One-Sample Kolmogorov-Smirnov analysis was used to determine if there were any significant changes between the composite, CEI, and total symptom scores from baseline to PC assessment (Table 8.1) Lastly, the BL and PC CEI's were separated to determine any significance from the variables that were significant in Table 8.1 (8.2-8.3).

3.1 Group Differences

In Table 1.1, a one-way ANOVA was used for a statistical analysis to determine if there was any variation between the by time groups in their composite, CEI, and total symptom scores between the time they took their baseline evaluation and when they were seen again for their PC evaluation. There was a total of 26 post-concussed participants that were post-tested 0-12 months post-concussion, 13 participants in the 13-24 months post-concussion, 8 participants in the 25-36 months post-concussion, 4 participants in the 37-48 months post-concussion, and one individual was tested greater than 49 months post-concussion. There was no statistically significant difference between the group means since the value was p= .121, which is greater than .05 as determined by the one-way ANOVA.

Since there was no significant different by months post onset of their concussion, the paired sample t-test was used to determine if there was a significant difference between the baseline CEI and PC CEI for all 52 participants. Based on Table 2.1, there was a significant difference of p=.000. This showed that there was a statistically significant difference with the correlation of scores from baseline CEI to PC CEI scores since the value was less than .05.

Further analysis then investigated the differences between the numbers of days the athletes were tested for their post-concussion evaluation and those differences between the baseline and PC scores (Table 3.1 Wilcoxon Signed Ranks). The baseline verbal memory composite score and PC verbal memory composite score difference (between 0-3 days since injury) had a value of p=.470, indicating no statistical significance. Next, the baseline visual memory and PC visual memory composite score difference (between 0-3 days since injury) had a value of p=.234, indicating no statistical significance. The baseline processing speed and PC processing speed score difference (between 0-3 days since injury) had a value of p=.706, indicating no statistical significance. Next, the baseline reaction time and PC reaction time composite score difference (between 0-3 days since injury) had a value of p=.512, indicating no statistical significance. The baseline impulse control and PC impulse control composite score difference (between 0-3 days since injury) had a value of p=.404, indicating no statistical significance. Next, the baseline CEI and PC CEI score difference (between 0-3 days since injury) had a value of p=.688, indicating no statistical significance. Finally, the baseline total symptoms and PC total symptom score difference (between 0-3 days since injury) had a value of p=.000. There was a statistically significant difference between the Baseline and PC total symptoms since the significant value was p=.000, which is less than .05 as determined by the Wilcoxon Signed Ranks analysis. The baseline verbal memory composite score and PC verbal memory composite score difference (between 4-7 days since injury) had a value of p=.529, indicating no statistical significance. Next, the baseline visual memory and PC visual memory composite score difference (between 4-7 days since injury) had a value of p=.255, indicating no statistical significance. The baseline processing speed and PC processing speed score difference (between 4-7 days since injury) had a value of p=.594, indicating no statistical significance. Next, the baseline reaction time and PC reaction time composite score difference (between 4-7 days since injury) had a value of p=.593, indicating no statistical significance. The baseline impulse control and PC impulse control composite score difference (between 4-7 days since injury) had a value of p=.893, indicating no statistical significance. Next, the baseline CEI and PC CEI score difference (between 4-7 days since injury) had a value of p=.753, indicating no statistical significance. Finally, the baseline total symptoms and PC total symptom score difference (between 4-7 days since injury) had a significant value of p=.004, which is less than .05 as determined by the Wilcoxon Signed Ranks analysis.

In Tables 4.1-4.2, Spearman's Non-parametric Correlations analysis was used to determine if any of the Baseline composite scores correlated with the Baseline CEI score and to investigate if the PC composite scores correlated with the PC CEI score. The Baseline verbal memory, visual memory, processing speed, and reaction time had a significant correlation (p=.000) with the Baseline CEI score. However, the Baseline impulse control did not have a significant correlation (p=.580) with the Baseline CEI score. The PC verbal memory and PC visual memory scores both had a significant correlation of p=.000 with the PC CEI score. The PC processing speed had a significant correlation of p=.001 with the PC CEI score. Additionally, PC reaction time had a significant correlation (p=.013) with the PC CEI score. However, the PC impulse control did not have a significant correlation (p=.575) with the PC CEI score.

In Table 5.1, Spearman's Rho Nonparametric Correlations analysis was also used to determine if the Baseline CEI score could correlate with the PC CEI score, PC composite scores, and the PC total symptom scores. Results showed that there were significant correlations with the following scores: PC CEI (p=.000), PC verbal memory (p=.000), PC visual memory (p=.000), PC processing speed (p=.000), and PC reaction time (p=.002). The baseline CEI score did not have a significant correlation with PC impulse control (p=.903) and PC total symptom score (p=.050).

To further determine if the Baseline CEI score could predict how the athletes would perform on their PC assessment, the participants were reorganized into 3 groups based upon their CEI score at Baseline (Table 6.1). The first group were individuals who scored between .00-.20 on their Baseline CEI score (N=11). The second group were individuals who scored between .21-.40 on their Baseline CEI score (N=26). Finally, the last group were individuals who scored between .41-.60 on their Baseline CEI score (N=15). The Kruskal-Wallis Test analysis (Table 6.2) was used to compare the three groups to the PC CEI score, PC composite scores, and the PC total symptom scores. There were significant results for the following scores: PC CEI (p=.000), PC verbal memory (p=.005), PC visual memory (p=.000), PC processing speed (p=.005), and PC reaction time (p=.020). There were no significant findings for the PC impulse score (p=.888) and the PC total symptom score (p=.388). Next, Table 6.3-6.5 used the Mann-Whitney Test analysis to determine which Baseline CEI groups had a significant difference on the PC CEI, PC composite scores, and PC total symptom scores. Groups 1 and 2 were first evaluated and only the PC verbal memory score (p=.041) and the PC visual memory score (p=.001) had significant results. The PC CEI (p=.087), PC processing speed (p=.273), and PC reaction time (p=.118) did not have significant results when compared to Baseline CEI groups 1 and 2. Groups 2 and 3 were the next groups that were evaluated and only the PC CEI (p=.001) and PC processing speed (p=.012) had significant results. The PC verbal memory (p=.051), PC visual memory (p=.542), and PC reaction time did not have significant results when compared to Baseline CEI groups 2 and 3. Lastly, groups 1 and 3 were evaluated. The PC CEI (p=.000), PC verbal memory (p=.003), PC visual memory (p=.000), PC processing speed (p=.002), and PC reaction time (p=.005) all had significant results when compared to Baseline CEI groups 1 and 3.

Next, Table 7.1-7.3 used the Wilcoxon Signed Ranks Test to determine if the three baseline CEI groups had a significant difference when compared to the PC scores. For all groups, there was a significant difference with the PC TSS (p=.000). There was no significant difference between PC CEI (p=.629), PC verbal memory (p=.777), PC visual memory (p=.710), PC processing speed (p=.938), PC reaction time (p=.765), and PC impulse control (p=.471). For group 1, there was a significant difference with the PC CEI (p=.006) and the PC TSS (p=.011). There was no significant difference for PC verbal memory (p=.154), PC visual memory (p=.327), PC processing speed (p=.929), PC reaction time (p=1.00), and PC impulse control (p=.894). For group 2, as shown in Table 8.2, there was a significant difference with the PC TSS (p=.001). There was no significant difference for PC CEI (p=.864), PC verbal memory (p=.760), PC visual memory (p=.936), PC processing speed (p=.909), PC reaction time (p=.919), and PC impulse control (p=.374). Lastly for group 3, as shown in Table 8.3, there was a significant difference with PC TSS (p=.005). There was no significant difference for PC CEI (p=.098), PC verbal memory (p=.286), PC visual memory (p=.124), PC processing speed (p=.955), PC reaction time (p=.555), and PC impulse control (p=.844).

Additionally, in Tables 8.1-8.3, another analysis was tested to see if there were any significant changes between the composite, CEI, and total symptom scores of the athletes that performed "as expected" which included a higher CEI performance on the BL assessment then on the PC assessment. On Table 8.1, there were no significant differences between BL CEI (p=.200), PC CEI (p=.200), BL verbal memory (p=.200), BL visual memory (p=.200), BL processing speed (p=.148), PC visual memory (p=.200), PC processing speed (p=.173), and PC impulse control (p=.200). However, there were significant differences between BL reaction time (p=.040), BL impulse control (p=.000), BL total symptom score (p=.000), PC verbal memory (p=.017), PC reaction time (p=.000), and PC total symptom score (p=.000). Table 8.2 explored the correlations between BL CEI and the scores that were considered significant in Table 8.1 (Spearman's Non-Parametric Correlations). There were significant differences with the BL reaction time (p=.012) and PC verbal memory (p=.028). However, there were no significant differences with the BL impulse control (p=.114), BL total symptom scores (p=.364), PC reaction time (p=.131), PC total symptom scores (p=.890). Table 8.3 explored the correlations between PC CEI and the scores that were considered significant in Table 8.1 (Spearman's Non-Parametric Correlations). There were significant differences with the BL reaction time (p=.018) and PC verbal memory (p=.001). However, there were no significant differences with the BL impulse control (p=.162), BL total symptom scores (p=3.95), PC reaction time(p=.196), and PC total symptom scores (p=.683).

Table 1.1: Differences of CEI performance from preseason to PC tests between time athletes sustained their concussion (ANOVA)

Time In-between pre-season and PC tests	N	Sig.
0-12 months	26	
13-24 months	13	
25-36 months	8	
37-48 months	4	
Greater than 49 months	1	
Total	52	
Between Groups		.121

Table 2.1: Differences of CEI Performance from all athletes (T-Test)

	N	Sig.
CEI & PC_CEI	52	.000

Table 3.1: Differences of scores between the time athletes sustained their concussion and took their PC test. (Wilcoxon Signed Ranks Test)

Time to Take Test Since Injury	BL Verbal Memory-PC Verbal Memory	BL Visual Memory-PC Visual Memory	BL Processing Speed-PC Processing Speech	BL Reaction Time-PC Reaction Time	BL Impulse Control-PC Impulse Control	BL CEI-PC CEI	BL TSS-PC TSS
0-3 days sig.	.470	.234	.706	.512	.404	.688	.000
4-7 days sig.	.529	.255	.594	.593	.893	.753	.004

Table 4.1: Correlations between BL CEI and BL Composite Scores (Spearman's Non-Parametric Correlations)

		BL Verbal Memory	BL Visual Memory	BL Processing Speed	BL Reaction TIme	BL Impulse Control
BL CEI	Correlations	.770**	.380**	.502**	-.623**	-.079
	Sig. (2-tailed)	.000	.006	.000	.000	.580
	N	52	52	52	52	52

Table 4.2: Correlations between PC CEI and PC Composite Scores (Spearman's Non-Parametric Correlations)

		PC Verbal Memory	PC Visual Memory	PC Processing Speed	PC Reaction TIme	PC Impulse Control
PC CEI	Correlations	.723**	.496**	.432**	-.341*	-.080
	Sig. (2-tailed)	.000	.000	.001	.013	.575
	N	52	52	52	52	52

Table 5.1: Correlations between BL CEI and PC CEI, PC Composite, and PC Total Symptom Scores (Spearman's Non-Parametric Correlations)

		PC CEI	PC Verbal Memory	PC Visual Memory	PC Processing Speed	PC Reaction Time	PC Impulse Control	PC Total Symptom Score
BL CEI	Correlations	.626**	.502**	.469**	.522**	-.425**	.017	-.274*
	Sig. (2-tailed)	.000	.000	.000	.000	.002	.903	.050
	N	52	52	52	52	52	52	52

Table 6.1: Separation of BL CEI Groups

	N
Group 1 (BL CEI=.00-.20)	11
Group 2 (BL CEI=.21-.40)	26
Group 3 (BL CEI=.41-.60)	15

Table 6.2: All BL CEI Correlation to All PC Composite and Total Symptom Scores (Groups 1, 2, and 3) (Kruskal Wallis Test)

	PC CEIs	PC Verbal Memories	PC Visual Memories	PC Processing Speeds	PC Reaction Times	PC Impulse Controls	PC Total Symptom Scores
BL CEI Sig.	.000	.005	.000	.005	.020	.888	.388

Table 6.3: Differences between BL CEI of Groups 1 & 2 and PC Composite and Total Symptom Scores

	PC CEIs	PC Verbal Memories	PC Visual Memories	PC Processing Speeds	PC Reaction Times
BL CEI Sig. (2-tailed)	.087	.041	.001	.273	.188

Table 6.4: Differences between BL CEI of Groups 2 & 3 and PC Composite and Total Symptom Scores

	PC CEIs	PC Verbal Memories	PC Visual Memories	PC Processing Speeds	PC Reaction Times
BL CEI Sig. (2-tailed)	.001	.051	.542	.012	.116

Table 6.5: Differences Between BL CEI of Groups 1 & 3 and PC Composite and Total Symptom Scores

	PC CEIs	PC Verbal Memories	PC Visual Memories	PC Processing Speeds	PC Reaction Times
BL CEI Sig. (2-tailed)	.000	.003	.000	.002	.005

Table 7.1: Differences between BL CEI, BL Composite Scores, BL Total Symptom Scores and PC CEI, PC Composite Scores, and PC Total Symptom Scores from Group 1 (Wilcoxon Signed Ranks Test)

	BL CEI-PC CEI	BL Verbal Memory-PC Verbal Memory	BL Visual Memory-PC Visual Memory	BL Processing Speed-PC Processing Speed	BL Reaction Time-PC Reaction Time	BL Impulse Control-PC Impulse Control	BL Total Symptom Scores-PC Total Symptom Scores
Sig. (2-tailed	.006	.154	.327	.929	1.000	.894	.011
BL CEI Mean	.1236						
PC CEI Mean	.2200						

Table 7.2: Differences between BL CEI, BL Composite Scores, BL Total Symptom Scores and PC CEI, PC Composite Scores, and PC Total Symptom Scores from Group 2 (Wilcoxon Signed Ranks Test)

	BL CEI-PC CEI	BL Verbal Memory-PC Verbal Memory	BL Visual Memory-PC Visual Memory	BL Processing Speed-PC Processing Speed	BL Reaction Time-PC Reaction Time	BL Impulse Control-PC Impulse Control	BL Total Symptom Scores-PC Total Symptom Scores
Sig. (2-tailed	.864	.760	.936	.909	.919	.374	.001
BL CEI Mean	.2885						
PC CEI Mean	.2762						

Table 7.3: Differences between BL CEI, BL Composite Scores, BL Total Symptom Scores and PC CEI, PC Composite Scores, and PC Total Symptom Scores from Group 3 (Wilcoxon Signed Ranks Test)

	BL CEI-PC CEI	BL Verbal Memory-PC Verbal Memory	BL Visual Memory-PC Visual Memory	BL Processing Speed-PC Processing Speed	BL Reaction Time-PC Reaction Time	BL Impulse Control-PC Impulse Control	BL Total Symptom Scores-PC Total Symptom Scores
Sig. (2-tailed	.098	.286	.124	.955	.555	.844	.005
BL CEI Mean	.4780						
PC CEI Mean	.4327						

Table 8.1: Significance of the BL CEI, BL Composite Scores, BL Total Symptoms, PC CEI, PC Composite Scores, and PC Total Symptoms from Athletes that Performed as "Expected" on ImPACT Test (Better scores on BL CEI than PC CEI) One-Sample Kolmogorov-Smirnov Test

	BL CEI	PC CEI	BL Verbal Memory	BL Visual Memory	BL Processing Speed	BL Reaction Time	BL Impulse Control	BL Total Symptom Score	PC Verbal Memory	PC Visual Memory	PC Processing Speed	PC Reaction Time	PC Impulse Control	PC Total Symptom Scores
N	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Sig. (2-tailed	.200	.200	.200	.200	.148	.040	.000	.000	.017	.200	.173	.000	.200	.000

Table 8.2: Correlations Between BL CEI and the Scores That Were Considered Significant in Table 8.1 (Spearman's Non-Parametric Correlations)

		BL Reaction Time	BL Impulse Control	BL Total Symptom Score	PC Verbal Memory	PC Reaction Time	PC Total Symptom Scores
BL CEI	Correlation	-.505*	-.331	-.194	.448*	-.317	-.030
	Sig. (2-tailed)	.012	.114	.364	.028	.131	.890
	N	24	24	24	24	24	24

Table 8.3: Correlations Between PC CEI and the Scores That Were Considered Significant in Table 8.1 (Spearman's Non-Parametric Correlations)

		BL Reaction Time	BL Impulse Control	BL Total Symptom Score	PC Verbal Memory	PC Reaction Time	PC Total Symptom Scores
PC CEI	Correlation	-.480*	-.295	-.182	.630**	-.274	-.088
	Sig. (2-tailed)	.018	.162	.395	.001	.196	.683
	N	24	24	24	24	24	24

Chapter 4: Discussion

The results of this study will determine if the CEI score could predict how athletes will perform from baseline to PC testing. Addressing this question will help aide certified healthcare professionals in the future to predict how athletes will perform on the PC test based on their baseline test. Furthermore, this will also assist clinicians to educate athletes and their trainers on the importance of giving your best effort on any evaluation whether it's a baseline or a PC assessment. There were multiple findings in this study.

First, the results from Table 1.1 indicated that differences of CEI performance from BL test to PC test between time athletes sustained their concussion determined there was no significant difference. Thus, maturation and familiarity with the test were not a factor in this study.

Second, the results from Table 2.1 concluded that there was a statistically significant difference in CEI Performance from all athletes. Thus, this led to further analysis of determining if there were differences of scores between the time athletes sustained their concussion and came back to the CMC for their PC assessment (Table 3.1).

Thirdly, according to Table 3.1, the results concluded that there was only a significant difference for total symptom scores from the group that were evaluated 0-3 days post-concussion. None of the other values were significant, which led to the investigation of determining if the BL CEI correlated with the BL composite scores and if the PC CEI correlated with the PC composite scores.

For the fourth finding, Table 4.1 and 4.2 analyzed this investigation and concluded that the BL CEI and PC correlated with all of their corresponding composite scores except for the impulse control. This finding is important because the impulse score describes the number of errors that the athletes make on their test, and according to the analysis, this score has no importance for calculating the CEI score. This finding led to the investigation to determine if the BL CEI correlated with the PC CEI, PC composite, and PC total symptom scores (Table 5.1).

Fifth finding in Table 5.1 concluded that there was a significant correlation between the BL CEI and all of the scores except for the PC impulse score. This provided information that there was an important correlation between BL CEI and most of the PC scores, which then permitted the researchers to reorganize the BL CEI's into three groups according to their scores (seen in Table 6.1) to determine more findings (Tables 6.2-6.5).

Sixth finding in Table 6.2 investigated if all 3 BL CEI groups correlated with any of the PC scores. Results suggested that there were significant differences with all scores except for the PC impulse control and PC total symptom scores. These two variables were excluded from the next analyses (Tables 6.3-6.5). Table 6.3 investigated the correlation of BL CEI from groups 1&2 to determine if these athletes who scored low-average on the ImPACT test had significant result with PC scores that were considered significant from Table 6.2. Results concluded that the BL CEIs in groups 1 & 2 correlated only with the PC verbal and visual memory scores. This finding suggests that verbal memory and visual memory scores could be predicted based on athletes who score low-average on their BL CEI. Table 6.4 investigated the correlation of BL CEI from groups 2 &3 to determine if these athletes who score average-high on the ImPACT test had significant results with PC scores that were considered significant from Table 6.2. Results concluded that the BL CEIs in groups 2 &3 correlated only with the PC CEI and PC processing scores. This finding suggests that PC CEI and PC processing speed scores could be predicted based on athletes who score average-high on their BL CEI. Lastly, Table 6.5 investigated the correlation of BL CEI from groups 1 &3 to determine if these athletes who score low-high on the ImPACT test had significant results with PC scores that were considered significant from Table

6.2. Results concluded that the BL CEIs in groups 1 & 3 correlated with all of PC scores that were considered significant in Table 6.2. This finding suggests that PC CEI, PC verbal and visual memory, PC processing speed and PC reaction time could be predicted based on athletes who score low-high on their BL CEI. All of these findings led to the results of the research question by investigating the separated BL CEI groups individually to determine if low, average, or high scores correlated with any of the BL composite scores, BL total symptom scores, PC CEI, PC composite scores, and PC total symptom scores (Tables 7.1-7.3).

More findings were from the tables 7.1-7.3. In Table 7.1, the BL CEI group 1 determined that there was a significant difference between the BL CEI and BL total symptom scores to the PC CEI and PC total symptom scores. This led to the finding that the PC CEI and PC total symptom scores could be predicted based on athletes who score low on their BL CEI test. In other words, one could predict that if an athlete scores low on their BL CEI, then chances are they are going to score higher on their PC CEI. However, this prediction could not be made on athletes who scored average-high (groups 2 & 3) on their BL CEI. Nonetheless, there was a significant difference for total symptom scores for both of these groups. This suggests that future research should investigate other measures, especially the total symptom scores, that could predict how athletes perform on their PC test based on their scores on their BL test.

Lastly, the 24 athletes who performed "as expected," having a lower BL CEI than their PC CEI, were analyzed. In Table 8.1, the BL CEI, BL composite scores and BL total symptom scores, PC CEI, PC composite scores, and PC total symptom scores were analyzed to determine any correlation between each score. Results concluded that the BL reaction time, BL impulse control, BL total symptom score, PC verbal memory, PC reaction time, and PC total symptom scores correlated with the athletes BL CEI scores. These scores that were considered significant were used to determine if there were any correlations between BL CEI (Table 8.2) and PC CEI scores (Table 8.3). In Tables 8.2-8.3, the BL CEI and PC CEI only correlated with the BL reaction time and PC verbal memory scores. These results suggest for the athletes that scored as "expected" the BL CEI could not predict how athletes will perform on their PC CEI test. However, BL reaction time and PC verbal memory scores could be possible predictive factors for the group that performs as "expected."

Lastly, when the BL and PC CEI scores had significant differences with BL and PC total symptom scores. As previously mentioned, the symptom scores are subjective, in which they are based on self-report from athletes. Previous literature has stated that athletes are not completely honest about reporting their symptoms due to the fear of not wanting to be removed from the sport that they are passionate about (Bailey, Echemendia, & Arnett 2006). However, based on the sample that was collected, athletes reported that they were symptomatic and that correlated with the CEI scores, which means that the BL total symptom score could predict the CEI scores at baseline and at PC assessment from the Symbol Match subtest on the ImPACT neurocognitive test. These results refute what was discovered in previous literature, but further research needs to be conducted to support this finding.

4.1 Limitations

There were two main limitations of this study. First, there may have been unidentified factors at baseline that may have influenced test performance. Factors such as test familiarity, the level of understanding regarding the purpose of baseline testing, the level of interest in cognitive testing, and the self-awareness of cognitive ability, among other factors may have influenced baseline performance. Thus, the results from this study should be interpreted cautiously in regard to future research. Secondly, there was a large span of time in-between the baseline evaluations and the PC evaluations from the five groups that were analyzed in the one-way ANOVA. So, future studies should investigate samples of participants that took the PC test just within 0-12 months of their baseline test.

4.2 Future Work

Future work should continue to examine the relationship between CEI scores, composite scores, and total symptoms reported scores that may be potential predictive factors of baseline scores to PC test scores. Additionally, to support or refute the maturation results from the current study, future studies should look at samples of participants that took the PC test within 0-12 months of their baseline test.

4.3 Conclusions

To answer the research question, according to the current sample, athletes who score lower on their BL CEI could predict that they would score higher on their PC CEI. However, this finding is not true for individuals who score average or higher on their BL CEI test.

For the individuals who score as “expected” (lower BL CEI and higher PC CEI scores) the BL CEI could not predict how athletes will perform on their PC CEI, however, BL reaction time score could predict how the athletes that score as “expected” will perform on their PC CEI.

Additionally, total symptom scores for BL CEI and PC CEI were both considered significant and should be investigated more to determine if the total symptom scores are a better predictive value of how an athlete will perform on their PC CEI.

Moreover, clinical data from the neurocognitive tests provide appropriate support to help determine when to allow athletes to return to play. Due to this, it is important to obtain accurate baseline and PC data from these athletes that identify their “true” cognitive performance. Discovering patterns and characteristics of athletes who may not put forth effort when being tested compared to those athletes that do put forth the effort and identifying the measure(s) on the ImPACT that could support these discoveries will be beneficial for clinicians to provide appropriate prognosis and make return-to-play decisions.

References

Aubry, M., Cantu, R., Dvorak, J., Graf-Baumann, T., Johnston, K., Kelly, J., ... & Schamasch, P. (2002). Summary and agreement statement of the first International Conference on Concussion in Sport, Vienna 2001. *British journal of sports medicine*, *36*(1), 6-7.

Bailey, C. M., Echemendia, R. J., & Arnett, P. A. (2006). The impact of motivation on neuropsychological performance in sports-related mild traumatic brain injury. Journal of the International Neuropsychological Society, 12(04), 475-484.

Covassin, T., Elbin, R. J., Harris, W., Parker, T., & Kontos, A. (2012). The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *The American journal of sports medicine*, *40*(6), 1303-1312.

Echemendia, R. J., & Cantu, R. C. (2003). Return to play following sports-related mild traumatic brain injury: the role for neuropsychology. *Applied neuropsychology*, *10*(1), 48-55.

Gilmore, G. C., Royer, F. L., & Gruhn, J. J. (1983). Age differences in symbol-digit substitution task performance. Journal of Clinical Psychology, 39(1),114-124.

Hoyer, W. J., Stawski, R. S., Wasylyshyn, C., & Verhaeghen, P. (2004). Adult age and digit symbol substitution performance: A meta-analysis. Psychology and Aging, 19(1), 211.

Iverson, G. I., Lovell, M. R., & Collins, M. W. (2003). Interpreting change on ImPACT following sport concussion. Clinical Neuropsychologist, 17(4), 460-467.

Iverson, G. L., Lovell, M. R., & Collins, M. W. (2005). Validity of ImPACT for measuring processing speed following sports-related concussion. Journal Of Clinical & Experimental Neuropsychology, 27(6), 683-689. doi:10.1080/13803390490918435

Lau, B. C., Collins, M. W., & Lovell, M. R. (2011). Sensitivity and specificity of subacute computerized neurocognitive testing and symptom evaluation in predicting outcomes after sports-related concussion. American Journal Of Sports Medicine, 39(6), 1209-1216. doi:10.1177/0363546510392016

Lovell, M. R., Iverson, G. L., Collins, M. W., Podell, K., Johnston, K. M., Pardini, D., ... & Maroon, J. C. (2006). Measurement of symptoms following sports-related concussion: reliability and normative data for the post-concussion scale. *Applied neuropsychology*, *13*(3), 166-174.

Moss, A., Jones, C., Fokias, D., & Quinn, D. (2003). The mediating effects of effort upon the relationship between head injury severity and cognitive functioning. *Brain Injury*, *17*(5), 377.

Nelson, L. D., Pfaller, A. Y., Rein, L. E., & McCrea, M. A. (2015). Rates and predictors of invalid baseline test performance in high school and collegiate athletes for 3 computerized neurocognitive tests: ANAM, axon sports, and ImPACT. The American Journal of Sports Medicine, 43(8), 2018-2026. doi:10.1177/0363546515587714 [doi]

Piccinin, A. M., & Rabbitt, P. (1999). Contribution of cognitive abilities to performance and improvement on a substitution coding task. Psychology and Aging, 14(4), 539.

Schatz, P., Pardini, J. E., Lovell, M. R., Collins, M. W., & Podell, K. (2006). Sensitivity and specificity of the ImPACT test battery for concussion in athletes. Archives Of Clinical Neuropsychology, 21(1), 91-99. doi:10.1016/j.acn.2005.08.001

Sheridan, L. K., Fitzgerald, H. E., Adams, K. M., Nigg, J. T., Martel, M. M., Puttler, L. I., & Zucker, R. A. (2006). Normative symbol digit modalities test performance in a community-based sample. Archives of Clinical Neuropsychology, 21(1), 23-28.

Stephens, R. (2006). Age-related decline in digit–symbol performance: eye-movement and video analysis. Archives of Clinical Neuropsychology, 21(1), 101-107.

Van Kampen, D. A., Lovell, M. R., Pardini, J. E., Collins, M. W., & Fu, F. H. (2006). The "value added" of neurocognitive testing after sports-related concussion. *American Journal Of Sports Medicine*, *34*(10), 1630-1635. doi:10.1177/0363546506288677

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