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Measurement Invariance of Impact in Bilingual and Monolingual High School Athletes

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MEASUREMENT INVARIANCE OF IMPACT IN BILINGUAL AND MONOLINGUAL HIGH SCHOOL ATHLETES

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Abstract

Given the reported negative consequences of sport related concussion (SRC), establishing the validity of concussion management tools is essential if they are used to determine the severity of concussion, track recovery or decline, implement effective interventions, and assist in return-to-play decision making. Previous research has found cognitive and symptoms differences on ImPACT, the most widely used SRC assessment measure, between monolingual and bilingual student athletes. Before further investigation of these differences can occur, measurement invariance of ImPACT must be established to ensure that differences are not attributable to measurement error. The current study has two aims: 1) to replicate a four-factor model recently identified using subtest scores of ImPACT on baseline and post-concussion assessments in monolingual English-Speaking athletes and bilingual English- and Spanish-speaking athletes and 2) to establish measurement invariance across groups at both baseline and at post-concussion. Participants included high school athletes who were administered the ImPACT for baseline assessment and following suspected concussion. Baseline assessments included 7,948 monolingual English-speaking athletes and 7,938 bilingual English and Spanish speaking athletes, and post-concussion assessments included 562 monolingual and 558 bilingual athletes. The monolingual and bilingual groups were matched on age, sex, and sport type at baseline assessment and at post-concussion assessment. Confirmatory factor analysis (CFA) was used to test a number of competing models to determine if the four-factor model provided the best fit of the data. Eighteen independent test scores selected from ImPACT cognitive tests were used in the CFAs. Multigroup CFA was used to examine invariance of the best fitting model. Results from CFAs indicated that the four-factor model provided the best fit in all samples. The four factors in the model included Visual Memory, Visual Reaction Time, Verbal Memory, and

Working Memory. Additionally, residual invariance, the strictest level of invariance, was achieved at baseline and post-concussion across groups. The current results provide strong support for measurement invariance for a four-factor model of cognitive abilities estimated from ImPACT test scores. The results further suggest that any differences between monolingual English-speaking and bilingual Spanish- and English- speaking athletes reported in ImPACT studies are not caused by measurement error but may reflect real group differences. The reasons for these differences remain unclear. Given the increase in bilingual individuals in the United States, and among high school athletics, future research should investigate other forms of error such as item bias and predictive validity to further understand if group differences reflect real differences between these athletes.

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Chapter 1 – Literature Review

Over the past two decades, there has been an increased awareness of the potential negative consequences of sport related concussion (SRC) which has prompted the development of numerous methods to determine the severity of concussion, effective interventions, and assist in return-to-play decision making (McCrea et al., 2017; McCrory et al., 2017). Given the steady increase in sport engagement in high school athletics, with approximately eight million high school athletes in the United States (The National Federation of State High School Associations, 2019), and a consequent increase in concussion rate over the years (Kerr et al., 2019; Lincoln et al. 2011), development of valid measures to assess SRC is vital for this group of athletes. Recently, differences in cognitive and symptom scores between monolingual and bilingual groups have been reported at baseline concussion testing (Becker et al., 2022) although the reason for these differences remains unclear. Considering the increasing diversity among high school athletes including language differences, assessment tools for concussion management must be cross-culturally validated to ensure proper management of SRC. Moreover, exploring and establishing measurement invariance across diverse populations in commonly used tools is integral in assuring that differences in test scores between groups do not simply result from measurement bias or other factors. The present study uses multigroup confirmatory factor analysis with invariance analyses to determine whether the latent structure of cognitive abilities is invariant among monolingual English speaking and bilingual Spanish-English speaking high school athletes on baseline and post-concussion cognitive test scores from one of the most commonly used computerized concussion management tools, Immediate Post-Concussion Assessment and Cognitive Testing Battery (ImPACT; Lovell, 2020).

Overview of Sported-Related Concussion

According to the Concussion in Sport Group (CISG) consensus statement (2017), sport-related concussion (SRC) is defined as, “a traumatic brain injury induced by biomechanical forces” that can be caused by “a direct blow to the head, face, neck, or elsewhere on the body with an impulsive force transmitted to the head” (p. 2). SRC is a form of mild traumatic brain injury. Its effects are present in the absence of structural change in the brain when standard neuroimaging studies (e.g., computerized tomography or magnetic resonance imaging) are examined, reflecting a more functional injury (McCrory et al., 2017).

SRC risk has been associated with a number of factors including sport, sex, and neurodevelopmental history. Various descriptive epidemiologic studies over the last two decades have consistently found the highest concussion rates in American football (Lincoln, et al., 2011; Kerr et al., 2019; O’Connor et al., 2017), with higher rates in games rather than practice (Marar et al., 2012; Zuckerman et al., 2015). Overall, males have been reported to have more SRC given their participation in collision sports such as football, but in gender-comparable sports such as soccer, higher concussion rates have been consistently evidenced in girls than in boys (Kerr et al., 2019; Lincoln et al., 2011; Marar et al., 2012; O’Connor et al., 2017). Additionally, individuals with neurodevelopmental disorders (e.g., attention deficit hyperactivity disorder) are more likely to report a history of concussion or sustain a SRC than athletes without a neurodevelopmental history (Iaccarino et al., 2018; Iverson et al., 2016; Nelson et al., 2016).

Several reviews have documented a myriad of cognitive, neurologic, and psychological health concerns secondary to SRC in the acute and chronic phases post-injury in youth (Alosco & Stern, 2019; Covassin et al., 2017), collegiate athletes (Rice et al., 2018), and retired athletes (Cunningham et al., 2020; Manley et al., 2017). While findings have been mixed, disruptions in various cognitive processes have been observed immediately following SRC including impairments in attention (Moore et al., 2015), memory (Covassin et al., 2013), cognitive flexibility (McGowan et al., 2018, Howell et al., 2013), reaction time (Covassin et al., 2013), processing speed (Gardner et al., 2010; Shuttleworth-Rdwards & Radloff, 2008), and inhibitory control (McGowen et al., 2019, Moore et al., 2015). These disruptions typically resolve within five to seven days (Belanger & Vanderploeg, 2005; McCrea et al., 2003), but lingering cognitive deficits after the acute phase have also been documented (Howell et al., 2013; Iverson et al., 2017; McGowan et al., 2019). Psychological health concerns such as symptoms of depression and anxiety have also been linked to SRC in elite, professional (Rice et al., 2018) and youth athletes (Covassin et al., 2017). Finally, predictors for post-concussion outcome have been explored including the effects of repetitive head injuries and concussions (Alosco & Stern, 2019; Covassin et al., 2013; McAllister & McCrea, 2017) and pre-injury characteristics such as race (Holmes et al., 2016; Kontos et al., 2010), age (Covassin et al., 2012, Field et al., 2003), sex (Covassin et al., 2012), and psychiatric comorbidities (see Iverson et al., 2020 for review). Although many of these factors have shown to variably influence outcomes across studies, greater initial symptom severity following injury appears to be the most consistent predictor of slow recovery (see Iverson et al., 2017 for review).

Given the significant amount of attention SRC has received over the years, concussion management has evolved over the last two decades. Protocol has shifted from the rest and recuperate mindset to current protocols including pre-season (i.e., baseline) and post-concussion cognitive assessments, thorough clinical and neuropsychological evaluations when warranted, and focused interventions to make return to play decisions (McKeithan et al., 2019). Given that many of the approaches that were historically used to identify brain injury are often impractical for diagnosing acute SRC, screening measures that can be administered for immediate assessment following suspected SRC on the sideline or shortly thereafter are commonly used and are an integral part of concussion management. These screening measures involve the assessment of a range of clinical domains including clinical symptoms (e.g., somatic, cognitive, emotional), physical signs (e.g., loss of consciousness, balance impairment), cognitive impairment (e.g., slowed reaction times), neurobehavioral features (e.g., irritability), and sleep/wake disturbance (McCrory et al., 2017). One of the most widely used screening measures is the ImPACT, which is used to assesses cognitive abilities as well as symptoms at pre- and post-concussion (Lovell, 2021). Given the need to inform clinical decision making and return-to-play determinations in SRC, it is crucial to ensure that concussion assessment tools like the ImPACT are well-validated and psychometrically sound.

ImPACT

The ImPACT (Lovell, 2020) is a brief computerized test of cognitive abilities that has demonstrated high sensitivity and specificity for detecting concussion and monitoring recovery (Schatz & Sandel, 2013). It includes a demographic, academic, and health history questionnaire, a post-concussion symptom scale (PCSS), and a series of cognitive tests. Performance on the cognitive tests is determined using five composite scores, including four that are purported to assess cognitive abilities sensitive to concussion (Verbal Memory, Visual Memory, Visual Motor Speed, and Reaction Time) and one that is used to evaluate test validity (Impulse Control) (Lovell, 2020; pp.16). Some studies indicate the composite scores have adequate test-retest reliability (Elbin et al., 2011; Schatz, 2010) while others suggest otherwise (Broglio et al., 2007; Bruce et al., 2014). The test manual indicates that “the composite scores were derived logically rather than through factor analysis” (Lovell, 2020; pp.21). A number of concerns have been raised regarding their use, including evidence suggesting that the composite scores may not adequately represent the latent structure of the individual ImPACT test scores, and that they show differential effects based on linguistic factors (Maietta et al., 2021).

Latent Structure

Regarding latent structure, some factor analytic studies of the ImPACT composite scores indicate that the latent structure is best represented by two, rather than five constructs (Iverson et al., 2005; Schatz & Maerlender, 2013; Gerrard et al., 2017; Echemendia et al., 2020; Masterson et al., 2019). In these studies, the logically derived composite scores (i.e., Verbal Memory, Visual Memory, Visual Motor Speed, and Reaction Time), rather than individual test scores were used in the analyses. Iverson and colleagues (2005) were the first to identify a two-factor model and their results were subsequently supported in a large-scale study by Schatz and Maerlender (2013). Schatz and Maerlender (2013) utilized exploratory factor analysis (EFA) of the ImPACT core composites in 21,357 middle school, high school, and collegiate athletes at baseline and 560 athletes at post-concussion. In both samples, Verbal Memory and Visual Memory composite scores formed a “Memory” factor and Visual Motor Speed and Reaction Time scores formed a “Speed” factor. This two-factor model was consistent in other EFA studies of the composite scores across multiple samples including a broader sample of high school athletes with less stringent exclusion criteria (Gerrard et al., 2017) and concussed NHL players (Echemendia et al., 2020). This two-factor model has also been supported by studies utilizing confirmatory factor analysis (CFA) of the composite scores (Masterson, et al., 2019; Maietta et al., 2021) and has been shown to have higher test-retest reliability (Brett et al., 2018; Schatz & Maerlender, 2013) as well as higher sensitivity and specificity than the ImPACT composite scores alone (Schatz & Maerlender, 2013). Given the evidence of a two-factor model as representing the underlying factor structure of ImPACT composite test scores, the most recent ImPACT 4 manual now includes a Two-Factor score comprised of a Memory component and Speed component in addition to the Composite Scores for interpretation (Lovell, 2021, pp. 14-17).

However, exploratory and confirmatory factor analyses of ImPACT subtest scores (rather than the composites scores) indicate a more complex latent structure, suggesting that the two-factor model is not an optimal representation of the latent structure of the ImPACT scores (Allen & Gfeller, 2011; Maietta et al., 2021). Allen and Gfeller (2011) used EFA to analyze the ImPACT subtest scores that contribute to the composite scores and identified a five-factor model that was not consistent with the existing composite scores including: Forced Choice Efficiency, Verbal and Visual Memory, Inhibitory Cognitive Abilities, Visual Processing Abilities and a factor with only one loading from the Color Match Total Commissions score. Most recently, utilizing EFA of all the subtest scores, Maietta et al. (2021) identified an 18 variable four-factor model (i.e., Visual Memory, Visual Reaction Time, Verbal Memory, and Working Memory) in 18,046 high school athletes with valid baseline tests. This four-factor model was subsequently confirmed using CFA as the best fitting model in an independent cross-validation sample of 18,045 high school athletes. Maietta et al. (2021) also examined the two-factor model which had good fit when composite scores were entered into the analyses but did not provide good fit when subtest scores were examined. Similarly, a five-factor model was specified that corresponded to the logically derived composite scores and it also provided a poor fit, suggesting that the currently used composite scores are not factorially pure, raising questions about the validity of factors that are identified using composite rather than individual test scores. Given these considerations, Maietta et al. (2021) concluded that a four-factor model provided the best fit. This was the first study that utilized CFA to identify the latent structure of the ImPACT cognitive subtest scores (rather than composite scores) and suggests that ImPACT cognitive tests may be best interpreted based on four factor analytically derived scores rather than the two or five composite scores reported in the test manual.

Cultural and Linguistic Influence on ImPACT

Validity concerns have also been raised about the five ImPACT composites because of differences in performance that have been reported based on language-related factors. The influence of various linguistic characteristics on baseline neurocognitive performance has been documented in several studies using the ImPACT composite scores and have revealed mixed findings. While some studies have found no differences across groups of varying language abilities (Tsushima et al., 2017), others have reported differences in all core composite scores (Jones et al., 2014; Ott et al., 2014), two or more composite scores (Becker et al., 2021; Bruce et al., 2014; Echemendia et al., 2020; Jones et al., 2014; Karr et al., 2020; Lehman Blake et al., 2015; Ott et al., 2014; Vartiainen et al., 2019), or one composite score (Jones et al., 2014; Iverson et al., 2021; Wallace et al., 2021).

Specifically, overall equivalence on ImPACT baseline composite scores was found in native English and non-native English-speaking athletes in Hawaii who took the test in English (Tsushima et al., 2017). Researchers concluded that the use of US neurocognitive normative data (i.e., English) may be appropriate to use in this sample when baseline data are not available. In contrast, various Spanish-English language comparisons have revealed differences across several studies. Jones et al. (2014) found significant differences in native English and native Spanish speakers on all ImPACT core composite scores and total symptom score. However, when corrected for education, differences remained in Visual Motor Speed, Reaction Time, and Visual Memory in those with a high school education and without the ability to speak a second language, but in the college-educated group, the only difference was in Visual Motor Speed. They concluded that while education seems to minimize group differences, it does not account for all the differences in composite scores. Ott et al., (2014) also found that English-speaking athletes outperformed Spanish-speaking peers on all four ImPACT core composites with the greatest difference in Visual Motor Speed and Reaction Time and also indicated lower Total Symptom scores than Spanish-speaking athletes tested in Spanish. Furthermore, Spanish-speaking athletes who took the test in Spanish performed worse than Spanish-speaking athletes who took the test in English in Verbal Memory, Visual Motor Speed, and Reaction Time. This was one of the first studies that examined Spanish-English bilingual individuals taking the test in Spanish or in English (Ott et al., 2014). Using a within-subject design, Lehman Blake et al. (2015) also found cognitive test score differences (i.e., Verbal Memory and Visual Motor Speed) but no symptom reporting difference when comparing the performance of 58 bilingual Spanish-English speaking individuals who each took the ImPACT in both languages. They concluded that valid interpretations are unlikely when comparing performance on Spanish language versions to English norms. Karr et al., (2020) found that athletes tested in Spanish performed lower on Visual Motor Speed and Reaction time and had higher total symptom score compared to athletes tested in English who were matched on age, gender, health, and academic history. Most recently, Becker et al. (2021) compared baseline ImPACT assessments for monolingual English-Speaking athletes tested in English, bilingual English-Spanish speaking athletes tested in English, and bilingual and monolingual English-Spanish speaking athletes tested in Spanish. Consistent with prior research, the monolingual English-Speaking athletes tested in English outperformed all other groups on Visual Motor Speed and Reaction Time scores.

Aside from Spanish-English language comparisons in the United States, other language-based comparisons have also revealed differences across groups. Bruce et al., (2014) examined 1-year test-retest reliability of ImPACT in a multilingual sample of professional hockey players and found significant variability in test-retest reliability among different language versions including English, French, Czech, and Swedish. Related, Vartiainen et al. (2019) found that Finnish professional male ice hockey players' performance on Visual Motor Speed and Reaction Time composites differed from the previously published English and Czech language samples (Bruce et al., 2014). On a slight variation of ImPACT, ImPACT quick test (ImPACT QT; Lovell, 2017), Wallace et al. (2021) found poorer performance on Motor Speed in Zambian football players compared to North American normative data and most recently, Iverson et al. (2021) found that boys tested in Mandarin performed significantly higher than boys tested in English on Visual Motor Speed.

Although ImPACT can be administered in 21 languages, there are few published language-specific normative data that are used for comparison for non-English administrations (Echemendia et al., 2020, Tsushima et al., 2018, Vartiainen et al., 2019). To our knowledge, there are also no published factor analytic studies of the ImPACT cognitive scores with a focus on a diverse sample across language or language abilities despite the evidence of possible influence or bias. Language effects appear variable, though patterns of Visual Motor Speed and Reaction Time differences are notable, and appear to demonstrate some influence on ImPACT at baseline.

Measurement Invariance

Before conducting cross-cultural comparative research, measurement invariance should be examined to ensure that the testing procedures used are assessing similar constructs across cultural groups (Boer et al., 2018). Measurement invariance is defined as “whether or not, under different conditions of observing and studying phenomena, measurement operations yield measures of the same attribute” (Horn & McArdle, 1992, p.117). Establishing measurement invariance helps ensure that differences across conditions (e.g., language) are meaningful by demonstrating that groups differences are not the result of lack of test invariance across different groups. Previous studies have demonstrated the potential consequences of assuming measurement invariance rather than testing it, by finding artificial interactions effects between constructs (Chen, 2008). Put another way, meaningful interpretations about group differences cannot be made until measurement invariance is established.

There are four different levels of invariance that are generally discussed in cross cultural research (e.g., Milfont & Fischer 2010). *Functional equivalence* refers to whether or not the construct of interest has the same psychological meaning across cultures. This level of equivalence is not tested statistically but rather through theoretical analysis, or other qualitative research. Thus, the first level of invariance that can be statistically tested is *configural invariance*. *Configural invariance* is met if factor loadings are all in the same direction across groups – if the same items load on the same latent variables across groups - meaning the same observed variables or items can be used to measure the theoretical construct. *Configural invariance* is recognized as the lowest or weakest level. If this level is not met, the assessment cannot be assumed to be measuring the same construct across groups (Horn & McArdle, 1992). The next level, *metric invariance,* is met if the factor loadings are identical across groups. For this level to be met, the measurement units are the same across groups and thus, comparisons of correlations and patterns of means can be made. *Scalar invariance* is met when the measurement scale has the same intercept across groups. This level of invariance must be established to directly compare latent means (van de Vijver & Leung, 1997). Finally, the most difficult form of invariance to achieve is *residual invariance. Residual invariance* means that the sum of specific variance and error variance is similar across groups. Meeting this strict level of invariance suggest that the scale measures the same underlying construct between groups with an equal degree of accuracy.

While there are various ways to test for invariance in cross-cultural studies, multigroup confirmatory factor (MGCFA) procedures are the most frequently used approach (Chen, 2008; Milfont & Fischer, 2010). In MGCFA, different models with different constraints are tested and compared with each other in a multistep approach to provide a rigorous test of configural, metric, and scalar invariance. While this theory driven, confirmatory approach has the ability to detect different biases and establish equivalence, the model restrictions have also been criticized for being too strict for cross-cultural research (Lubke & Muthen, 2004; van de Shoot et al., 2013). Specifically, scalar invariance has been difficult to achieve in prior studies (Boer et al., 2018). However, it is also important to recognize that scalar invariance is not always necessary if the goal is comparing associations of variables across cultural contexts (i.e., metric invariance). Thus, when full measurement invariance is not achieved, partial measurement invariance has been recognized as an alternative and requires only a subset of parameters to be invariant, allowing the other subset to vary across cultures (Byrne et al., 1989).

Measurement Invariance Analyses of ImPACT

Until the invariance of the ImPACT latent structure across language-based groups has been established, differences (or lack of differences) in ImPACT performance for language-based groups cannot be determined. None of current studies have utilized measurement invariance analyses to better understand equivalence between groups on the latent structure of the assessment tool itself, which may account for inconsistent findings across studies and language groups. In fact, performance differences on ImPACT baseline assessments have been documented based on several other factors including age (Covassin, Elbin, Harris, et al., 2012), gender (Cottle et al., 2017; Covassin, Elbin, Harris, et al., 2012), race (Houck et al., 2018; Kontos et al., 2010; Wallace et al., 2018), neurodevelopmental history (Cottle et al., 2017; Elbin et al., 2013), depression (Covassin, Elbin, Larson, et al., 2012), socioeconomic status (Houck et al., 2018), and motivation (Rabinowitz et al., 2015), but to our knowledge, there are no studies of measurement invariance across any groups on the cognitive tests.

To date, the only study that has examined measurement invariance is of the symptom scale that is included in ImPACT (i.e., PCSS) in a recent study by Karr and Iverson (2020) where they found partial-to-full invariance for each model at baseline across demographic (e.g., age, sport type) and health history groups (e.g., history of concussion, neurodevelopmental diagnoses). While testing for measurement invariance across groups is a logical prerequisite to conducting meaningful cross-group comparisons, few cross-cultural studies, not limited to ImPACT or concussion management tools, have incorporated this step in their methodology (Vandenberg & Lance, 2000; Boer et al., 2018). In the current investigation, we aim to 1) determine an optimal factor structure for the ImPACT at baseline and post-concussion assessments among monolingual English-speaking and bilingual English- and Spanish-speaking high school athletes and 2) examine the measurement invariance in these two groups. This will be the first study to investigate invariance in the latent structure of the ImPACT cognitive test scores.

Chapter 2-The Present Study

This study aimed to strengthen interpretations of cross-cultural comparative research relevant to SRC. Based on the literature, the following aims and hypotheses were made.

Specific Aim and Hypothesis 1

There have been no factor analytic studies of the ImPACT cognitive test scores in bilingual Spanish-English speaking athletes and recent research suggests that the currently used two- and five-composite scores do not represent the latent structure of the scores. Thus, the first aim of this study was to determine an optimal factor structure for ImPACT baseline and post-concussion assessment among monolingual English-speaking and bilingual English- and Spanish-speaking high school athletes. Specifically, we conducted a CFA for the four-factor model (Visual Memory, Visual Reaction Time, Verbal Memory, and Working Memory; Maietta et al., 2021) and other competing models (i.e., one-factor, two-factor, and three-factor) to evaluate model fit at baseline and at post-concussion.

It was hypothesized that the four-factor model of ImPACT cognitive test scores would provide best fit in baseline and post-concussion assessments of monolingual English-speaking and bilingual English- and Spanish-speaking athletes at baseline.

Specific Aim and Hypothesis 2

Language-based group differences in ImPACT cognitive performance have been reported across various language-related factors (e.g., language of administration, native versus non-native language, bilingualism). However, group differences may result from variances in latent structure attributable to language. Thus, the second aim of the present study was to examine measurement invariance of ImPACT cognitive test scores between monolingual English-speaking and bilingual English- and Spanish-speaking high school athletes. Specifically, configural, metric, scalar, and residual levels of invariance were assessed through MGCFA.

It was hypothesized that the MGCFA would indicate strict (i.e., residual) measurement invariance across monolingual English-speaking and bilingual English- and Spanish-speaking athletes at baseline and post-concussion assessments.

Chapter 3-Method

Participants

Participants consisted of two samples of athletes selected from a larger database of athletes from a southwestern state who completed ImPACT Version 2.0 and 2.1 between 2008 and 2020. The first sample included athletes with valid baseline assessments and the second sample included athletes with post-concussion assessments. Both samples consisted of bilingual Spanish/English speakers and case-matched monolingual English speakers. Demographic information for the two samples are presented in Table 1.

The monolingual sample met the following criteria: age 13 to 19, completed a valid baseline (indicated by ImPACT software validity indicators) or post-concussion assessment in English, and endorsed English as their only language on the demographic questionnaire. The bilingual group met the same criteria but endorsed English and Spanish for their first or second language on the ImPACT demographic questionnaire. For athletes with multiple baselines, their initial valid baseline assessment was included. Athletes in the baseline sample were also excluded if they had a history of concussion. For athletes with multiple post-concussion assessments, their initial post-concussion assessment from their first injury was included. Participants were excluded if they had a self-reported history of Autism, ADHD, learning disability or self-reported treatment history of epilepsy or seizures, brain surgery, meningitis, psychiatric disorders or substance/alcohol use. Athletes were also excluded if they had patterns of scores that indicate non-responsiveness (e.g., scores of zero on reaction time and total correct/incorrect).

As the number of monolingual athletes was substantially larger than the number of bilingual athletes, for both samples (baseline and post-concussion), monolingual athletes were randomly selected to match the bilingual athletes on age, sex, and sport category (e.g., contact-collision, contact-non-collision, limited contact, and non-contact; Brett & Solomon, 2017; Rice, 2008; Montalvo et al., 2019). Random case-matching was conducted in *R* using the Matchit package (Ho et al., 2011). A detailed description of inclusion and exclusion criteria is shown in Figure 1.

All bilingual athletes who met study criteria were included in the final baseline and post-concussion samples. The final baseline sample consisted of 7948 monolingual athletes and 7938 bilingual athletes. The post-concussion sample consisted of 562 monolingual athletes and 558 bilingual athletes. As seen from Table 1, the groups were closely matched on age, sex and sport, indicating that the matching procedure was successful and limiting the influence that these demographic variables might have on MGCFA and invariance results.

Measures

ImPACT

ImPACT (Lovell, 2020) is a brief computerized neurocognitive test that is widely used for sport concussion assessment and management. It includes a demographic, academic, and health history questionnaire, a symptom scale (i.e., PCSS), and a series of cognitive tests. The six cognitive subtest scores form five composite scores: Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control. Previous psychometric research has demonstrated 91.4% sensitivity and 69.1% specificity for the subscales (Schatz & Sandel, 2013) and 80% sensitivity and 62% specificity for the composites (Schatz & Maerlender, 2013). Research regarding the reliability of ImPACT have revealed inconsistent findings with some studies reporting adequate reliability for the composite scores with test-retest intraclass correlation coefficients between .62 and .85 (Elbin et al., 2011) and others reporting poor to adequate intraclass correlation coefficients between .22 to .81 across a one-year time period (Bruce et al., 2014). Convergent validity has been generally supported while predictive and discriminant has been less conclusive (Alsalaheen et al., 2016).

The current study will focus on the following cognitive subtest scores that make up the recently identified four-factor structure (Maietta et al., 2021); they are listed here in order of subtest: Word Memory — Hits (Immediate), Correct Distractors (Immediate), Hits (Delay), Correct Distractors (Delay); Design Memory —Correct Distractors (Immediate), Hits (Delay), Correct Distractors (Delay); X's and O's — Total Correct (Memory), Total Correct (Interference), Average Correct Reaction Time (Interference), Average Incorrect Reaction Time (Interference); Symbol Match — Total Correct Reaction Time (Visible), Total Correct (Hidden), Total Correct Reaction Time (Hidden); Color Match — Average Correct Reaction Time; Three Letters — Total Sequence Correct, Average Time to First Click, and Average Counted Correctly.

Procedures

ImPACT was administered to high school athletes as part of routine concussion management protocols at the beginning of the sport season and then again after an athlete sustained a concussion during sport-participation. When possible, athletes were tested within 72-hours after sustaining a concussion. Baseline ImPACT was typically administered in a group setting by personnel who were trained in proper administration procedures (e.g., distraction-free testing environment, standardized instructions, etc.). This study utilized de-identified archival data which was deemed exempt by the local social/behavioral institutional review board for protection of human subjects.

Statistical Plan and Approach

Data Screening

Data screening was conducted in *R* version 4.0.3. First, cases with zeros on multiple scores within a subtest were flagged as missing data and removed from the dataset. Second, univariate and multivariate outliers were addressed in each sample (i.e., baseline and post-concussion). A case was considered a univariate outlier if a value was 3.29 standard deviations away from the mean on each variable (Tabachnick & Fidell, 2013). Once univariate outliers were identified, those cases were assigned a raw score one unit larger or smaller than the next most extreme score in the distribution in order to reduce their impact (Tabachnick & Fidell, 2013). If more than 1% of the data was identified as an outlier, the raw score replacement was conducted in a way to maintain the general distribution of the data. For example, for anything greater than a z-score of ±3.29, the score was changed to be one unit further than the last extreme score. For anything greater than a z-score of ±4, the score was changed one more half unit to maintain the order. Multivariate outliers were identified using Mahalanobis distance and influence values (i.e., Cook's distance). Third, normality was assessed through examination of histograms and values of skewness and kurtosis. Fourth, multicollinearity was assessed through examining a correlation matrix as well as high variable inflation factor (VIF) values. Finally, group differences in age, sex, sport type, and language group, were explored using chi-square tests of independence and ANOVAs.

Data Analyses

Confirmatory factor analysis (CFA) was conducted in *R* version 4.0.3 using the 'lavaan' (Rosseel, 2012) and 'semTools' (Jorgensen et al., 2018) packages. The four-factor model by Maietta et al., (2021) was investigated for the bilingual baseline sample, monolingual baseline sample, bilingual post-concussion sample, and monolingual post-concussion sample using the maximum likelihood estimation with robust standard errors (MLR; Satorra & Bentler, 2001).). The factors included Visual Memory, Visual Reaction Time, Verbal Memory, and Working Memory. Competing models based on prior empirical and theoretical evidence were also explored including a one-factor model that served as an informed baseline model, testing the assumption that the latent structure of ImPACT test scores might best be accounted for by a single or global factor. More complex models must improve fit over this informed baseline model to be considered parsimonious. Based on the previous literature that has identified Memory and Speed constructs using exploratory and confirmatory factor analysis, and have suggested use of these two factors rather than 4 or 5 composite scores as improving test-retest reliability of ImPACT's scores (Schatz & Maerlender, 2013), a two-factor Memory and Speed model was also examined. An alternate two-factor (Verbal and Visual) model was also included given the visual and verbal nature of the subtests included in the ImPACT and the well documented differences in cognitive processing of verbal and nonverbal information. Finally, a three-factor model was examined that drew a distinction between long term memory and short term/working memory by combining the visual and verbal memory factors into a long term memory factors, while retaining the working memory factor and visual reaction time factors as separate factors. These models are presented in Table 2. Overall model fit was determined using the following fit indices: comparative fit index (CFI; Bentler, 1990), Tucker-Lewis index (TLI; Tucker & Lewis, 1973), root-mean-square error of approximation (RMSEA; Browne & Cudeck, 1993), standardized root-mean-square residual (SRMR; Hu & Bentler, 1999). According to cutoffs established by Hu and Bentler (1999) and Schreiber et al. (2006), fit indices are considered satisfactory when CFI and TLI > .90 and superior when CFI and TLI > .95. SRMR and RMSEA values less than .08 represent acceptable fit while values less than .06 represent superior fit (Schreiber et al., 2006). Given the sensitivity of chi-square statistics in larger sample sizes, chi-square was only used for descriptive purposes and were not used to examine model fit (Meade et al., 2008; Tabachnick & Fidell, 2013).

MGCFA was conducted on the optimal ImPACT cognitive structure to assess measurement invariance between the monolingual and bilingual groups at baseline and at post-concussion. Through increasingly restrictive MGCFAs, configural, metric, scalar, and residual levels of invariance were assessed. Specifically, we first tested configural invariance and assessed the pattern of loadings across groups. Next, we tested metric invariance, which requires factor loadings to be the same across groups. Then, we tested scalar invariance, which requires the intercepts to be invariant across groups. Finally, we tested residual invariance, which requires the factor loadings, intercepts, and residuals to be the same across groups. Significant reductions in model fit at any of these sequential steps suggest that the model is variant across groups. The primary indicators of variance and cut-offs that were used are ΔCFI $\leq$ -0.01, and ΔRMSEA $\leq$ 0.015 (Chen, 2007). While $\Delta \chi^2$ is often used to assess measurement invariance, it was not used given its sensitivity to large sample sizes (Meade et al., 2008).

Chapter 4- Results

Confirmatory Factor Analysis of ImPACT

Descriptive statistics for the ImPACT test scores are presented in Table 3 for the baseline and post-concussion samples. The goodness-of-fit statistics for the CFAs that examined the competing factor structures of ImPACT are presented in Table 4 for each group. For every group (i.e., baseline monolingual, baseline bilingual, post-concussion monolingual, post-concussion bilingual), the four-factor model had better fit than all other competing models (ΔCFI > .01). However, the four-factor model only met the cutoffs on two of the four goodness-of-fit indices, thus, we aimed to improve the model fit by re-evaluating the variables theoretically and examining the modification indices.

Through theoretical exploration of each observed variable in the four-factor model and examination of modification indices, the residual variances were allowed to correlate for the following pairs of variables: Word Memory – Hits (Immediate) with Hits (Delay), Design Memory – Correct Distractors (Immediate) with Correct Distractors (Delay), Word Memory – Correct Distractors (Immediate) with Correct Distractors (Delay), Three Letters – Average Time to First Click with Average Counted Correctly, X's and O's – Average Correct Reaction Time (Interference) with Total Correct Interference and with Average Incorrect Reaction Time (Interference), and Symbol Match – Average Reaction Time (Visible) with Average Reaction Time (Hidden). Given that these pairs of variables are each part of the same respective subtests, it made logical sense to add these parameters and allow the rest of the model to remain the same.

As seen in the Table 5, CFA results of the modified four-factor model indicated adequate to superior fit and met criteria for all four goodness-of-fit indices in both of the baseline and post-concussion samples. The baseline models for monolingual and bilingual athletes are presented in Figures 2 and 3, respectively, along with factor loadings, inter-item correlations, and inter-factor correlations. Similarly, the post-concussion models for monolingual and bilingual athletes are presented in Figures 4 and 5, respectively, along with factor loadings, inter-item correlations and inter-factor correlations as well. The modified 4-factor model was retained as the configural model to test measurement invariance for monolingual and bilingual groups at baseline and at post-concussion.

Measurement invariance analyses

Multigroup confirmatory factor analysis (MGCFA) was conducted using the modified four-factor, 18-variable model by language group at baseline and at post-concussion. The results of measurement invariance testing across the groups are presented in Table 6. For the baseline comparisons (i.e., bilingual baseline group to monolingual baseline group) and the post-concussion comparisons (i.e., bilingual post-concussion group to monolingual post-concussion group), measurement invariance was established at all four levels of testing. As seen in the Table 6, ΔCFI and ΔRMSEA were nonsignificant in all instances, suggesting that the overall fit of the four-factor structure is consistent between monolingual to bilingual samples at baseline and post-concussion. Metric invariance was achieved with adequate fit indices suggesting that the factor loadings are consistent between the monolingual and bilingual samples. Scalar invariance was also found with adequate fit indices, suggesting that the item intercepts are consistent between the monolingual and bilingual samples at baseline and post-concussion. Finally, residual invariance was supported with adequate to superior fit indices at baseline, and adequate fit indices at post-concussion. This suggests that the item residuals are equivalent across monolingual and bilingual groups at baseline and at post-concussion. As such, measurement invariance of the modified four-factor, 18- variable model was supported at the strict level at baseline and at post-concussion for the monolingual and bilingual groups.

Chapter 5-Discussion

The current study examined the factor structure of the ImPACT, a computerized assessment of cognitive abilities for concussion management, in monolingual English-Speaking and bilingual English- and Spanish-speaking high school athletes. Models evaluated included an 18-variable four-factor model (i.e., Visual Memory, Visual Reaction Time, Verbal Memory, and Working Memory; Maietta et al., 2021), one-factor baseline model, two-factor model (Speed and Memory), alternative two-factor model (Visual and Verbal), and three-factor model (Memory, Visual Reaction Time, Working Memory). These models were empirically evaluated to determine how well they fit the structure of cognitive data collected at preseason baseline assessment and following assessment for suspected concussion. They were further evaluated to determine whether the models were consistent and comparable (i.e., established measurement invariance) across monolingual English-speaking and bilingual English- and Spanish-speaking high school athletes assessed at baseline and at post-concussion.

Factor Structure of ImPACT

The current results indicated a four-factor model provided the best fit of ImPACT cognitive test scores at baseline and post-concussion assessments when compared to the other competing models that were examined. This four-factor model was hypothesized to be the best fitting model based on recent findings which initially identified the model utilizing EFA and subsequently confirmed it using CFA in a large sample of valid baseline assessments of high school athletes (Maietta et al., 2021). Unlike other studies that have utilized CFA to identify a two-factor (i.e., Speed and Memory) model (Masterson, et al., 2019; Maietta et al., 2021), the four-factor model identified by Maietta et al. (2021) and identified in this study utilized 18 subtest scores. Subtest scores are preferable to composite scores for examining ImPACT latent structure for a number of reasons, including that use of composite scores artificially limits the number of factors that can be identified to two, which may obscure its more complex latent structure. Consistent with previous studies that have examined ImPACT factor structures using the subtest scores, one-factor, two-factor, and three-factor models provided poorer fit than the four-factor model, confirming that a more complex model is needed to estimate the latent structure of ImPACT test scores at baseline and post-concussion (Maietta et al., 2021, Allen & Gfeller, 2011).

Interestingly, in the current baseline and post-concussion samples, while the goodness of fit statistics indicated that the four-factor model was the best model evaluated, some of the fit statistics for this model fell below cutoffs for adequate fit. Given that the four-factor model had overall better fit than the other models, post-hoc model modification was conducted on the four-factor model by reconsideration of the theoretical basis for assigning subtest scores to factors and examination of the modification indices. A modified four-factor baseline model with added paths between subtest scores of Design Memory, X's and O's, Word Memory, Three Letters, and Symbol Match indicated adequate to superior model fit across groups. The added paths paired scores from the same subtests, but were determined to be unique (e.g., immediate vs. delayed scores), and thus, were retained in the model with added paths, rather than being removed from the model completely. This approach allowed the four-factor model to be specified in a manner that retained the latent constructs present in the original model. These same modifications were applied to the post-concussion assessment and resulted in adequate model fit across groups.

In addition to replicating the four-factor model at baseline, this was the first study to examine the four-factor model on ImPACT assessments administered after suspected concussion. Other studies that have examined the factor structure of ImPACT assessments after suspected concussion have utilized EFA (Iverson, 2005; Echemendia et al., 2020) and CFA (Masterson, et al., 2019) using the composites scores only to identify the two-factor model. Given that the four-factor solution identified several key domains that are frequently disrupted post-SRC including working memory, processing speed, and memory (Belanger & Vanderploeg, 2005; Howell et al., 2013; McGowan et al., 2019), and that less complex models were clearly inferior to the four-factor model, the four-factor model better reflects that latent structure of cognitive abilities post-injury compared to the two-factor model. Notably, while the goodness of fit statistics indicated the four-factor model provide adequate fit for all groups, it appeared to provide a somewhat better fit on baseline assessments compared to post-concussion assessments.

Measurement Invariance of ImPACT Cognitive Subtests

Multigroup confirmatory factor analysis was performed on the modified four-factor model by language group at baseline and at post-concussion assessment and achieved all levels of invariance including residual invariance, the most difficult form of invariance to attain. This indicates that the residuals associated with each latent variable, factor loadings, and intercepts are equal across language groups at baseline and post-concussion assessments. As such, any differences between monolingual English-speaking and bilingual Spanish- and English- speaking athletes may be due to group differences rather than measurement issues.

This study provides a meaningful contribution to the growing body of literature on concussion assessment tools as this is the first study to examine measurement invariance of the cognitive variables on ImPACT. Furthermore, it is the first study to examine measurement invariance between bilingual and monolingual athletes on any concussion assessment measure. Previous related studies have examined measurement invariance on ImPACT symptom scale (i.e., PCSS) and have found partial-to-full invariance across gender, age, sport type, neurodevelopmental history, and psychiatric treatment groups at baseline and partial invariance from pre-injury to post-injury assessments (Karr et al., 2021). However, language-related variables (e.g., language of administration, bilingualism) were not included. Given the reported differences across these language-related variables in performance on cognitive scores at baseline assessment (Becker et al., 2021; Jones et al., 2014; Karr et al., 2020; Lehman Blake et al., 2015; Ott et al., 2014), it is necessary to assure that these differences in test scores between groups do not simply result from measurement error or other factors. This study provides a foundation to enable meaningful group comparisons between ImPACT performance at baseline and after suspected injury across monolingual English and bilingual Spanish- and English-speaking athletes.

Limitations and Future Directions

There are a number of limitations to note in the present study. All demographic and health history information were based on self-report (e.g., ADHD, prior concussions, treatment history). Additionally, athletes indicated whether they were monolingual or bilingual by endorsing items "Native language" and "Second language," which provide no specific information regarding language proficiency and are open to interpretation. Bilingualism is a multifaceted concept given the range of proficiency levels (e.g., balanced, mixed, receptive bilingualism), processes of language acquisition (e.g., single or simultaneous), developmental considerations (early or late), and other characteristics unique to an individual's language ability (e.g., socioeconomic status, parental education). While the current results suggest that differences reported between monolingual and bilingual athletes are not the result of measurement variance, future studies are needed to more comprehensively assess language proficiency including variables such as vocabulary knowledge, fluency, and spoken context, to determine associations between these variables and group differences. Additionally, the use of an archival database allowed for the large sample sizes required for our statistical analyses, however, limited our ability to gather sociodemographic information that can be related to language use and cognitive performance.

All concussions were only suspected based on the use of a post-injury ImPACT assessment by athletic trainers or other trained personnel. The diagnosis of this suspected concussion could not be verified based on the information that was available (e.g., a review of clinical signs of concussion or injury characteristics). A more stringent inclusion criteria such as having taken at least two post-concussion follow-up assessments (i.e., not cleared to return to play at the acute post-concussion assessment and requiring a subsequent follow-up) could be applied in future retrospective studies examining post-concussion assessments.

The current study examined monolingual English-speakers and Spanish and English-speaking bilingual athletes. The English- and Spanish-speaking bilingual individuals in this study chose to take the ImPACT in English rather than in Spanish and, thus, may include a specific subset of individuals with strong English fluency or preference. Additionally, we only examined English- and Spanish-speaking bilingual athletes, so the findings may not generalize to bilingual individuals who speak languages other than Spanish and English. Future studies should include athletes who speak other languages to better understand the possible effects of bilingualism on cognitive processing and test performance, as well as other non-English speaking monolingual groups, such as Spanish-speaking athletes.

A longitudinal examination of measure invariance from baseline to post-concussion assessment was not conducted in this study because it would have limited sample size. Demonstrating that the factor structure of ImPACT is invariant from baseline to post-concussion assessment in the same individuals would provide further support for the longitudinal invariance of ImPACT latent structure.

Implications

From a clinical perspective, the current results suggest that factor scores of ImPACT may be interpreted as assessing similar cognitive abilities for monolingual and bilingual athletes on baseline and post-concussion assessments, despite differences in overall performance levels observed in previous studies (Becker et al., 2022; Jones et al., 2014; Karr et al., Ott et al., 2014). However, the reasons for these differences are unclear and were not directly examined in the current study. Future investigations of validity examining subtests using item-response theory (IRT) to determine the degree of differential item functioning could further establish the presence or absence of possible item (or subtest score) bias. Similarly, investigations of predictive validity to evaluate any bias in prediction, a crucial aspect of a concussion management measure, could be done using simple regression. While there may be more to investigate, current findings ensure that reflected differences are not a result of measurement error and gives more confidence that they may reflect real differences in group performance that can be used to inform decisions about concussion severity, recovery, and return-to-play.

In addition to bias as a factor contributing to group differences, these observed differences could result from other factor such as socioeconomic factors, cultural factors, educational experiences, and parent education. Similarly, differences could reflect differences in cognitive processing between individuals who are monolingual and bilingual. For example, a phenomenon sometimes referred to as the *bilingual advantage* indicates that bilingual individuals outperform monolingual individuals on tasks that require cognitive control (Biaylystok et al., 2009, Paap et al., 2014). Other studies report that slowed naming speed

(Gollan et al., 2007) and more interference in lexical decision tasks (Fabbro et al., 2000) are observed in bilingual individuals. Given the toll that inhibitory control may take at acute post-concussion (McGowen et al., 2019, Moore et al., 2015), bilingualism could serve as a protective mechanism for post-concussion outcome and recovery. On the other hand, it could also be that bilingual individuals are affected more globally post-concussion due to the inhibitory control being the most affected, and thus diminishing compensatory strategies that might be otherwise present (Ratiu & Azuma, 2017). These research findings highlight the complexity of factors that may contribute to the observed differences in cognitive performance between monolingual and bilingual individuals on ImPACT and should be considered in future studies.

In summary, the current investigation builds upon recent work in the area of cultural and language-based variation in post-concussion outcomes, the use of the four-factor structure of the ImPACT cognitive scores, and the application of advanced statistical techniques in testing measurement invariance. Results suggest that factor scores of ImPACT may be interpreted as assessing similar cognitive abilities for monolingual English-speaking and bilingual English- and Spanish-speaking athletes on baseline and post-concussion assessments. Additional research is necessary to explain the growing evidence suggesting differences in cognitive and symptoms scores between these monolingual and bilingual athletes.

Appendix A: Tables

Table 1

Demographics for Baseline and Post-Concussion Samples.

Variable	Baseline		Post-Concussion	
	Monolingual	Bilingual	Monolingual	Bilingual
	Mean (*SD*) / Frequency	Mean (*SD*) / Frequency	Mean (*SD*) / Frequency	Mean (*SD*) / Frequency
Age (years)	14.87(*1.10*)	14.87 *(1.09)*	15.56 *(1.18)*	15.53*(1.17)*
Education (grade)	8.86 *(1.34)*	9.01 *(1.36)*	9.44 *(1.23)*	9.48(1.40)
Gender (% female)	45.1%	45.0%	43.1%	43.0%
Sport				
Contact/Collision	19.8%	19.9%	39.9%	39.6%
Contact/Non-Collision	51.3%	51.2%	41.6%	41.6%
Limited contact	14.7%	14.7%	7.7%	7.7%
Non-contact	13.0%	13.0%	2.0%	1.8%
Missing sport category	1.2%	1.2%	8.9%	9.3%

Note. Baseline monolingual sample n = 7948. Baseline bilingual sample n=7938. Post-concussion monolingual sample n = 562. Post-concussion bilingual sample n = 558. Sport categories are based on previous literature (Brett & Solomon, 2017; Rice, 2008).

Table 2

Models used for Confirmatory Factor Analyses.

Subtest Scores	1	2	2-Alt	3	4 *
DM Correct Distractors (Immediate)	General	MEM	VIS	MEM	VIS MEM
DM Correct Distractors (Delay)	General	MEM	VIS	MEM	VIS MEM
DM Hits (Delay)	General	MEM	VIS	MEM	VIS MEM
SM Total Correct (Visible)	General	MEM	VIS	MEM	VIS MEM
XO Total Correct (Memory)	General	MEM	VIS	MEM	VIS MEM
XO Average Correct RT (Interference)	General	SPEED	VIS	VIS RT	VIS RT
XO Total Correct (Interference)	General	SPEED	VIS	VIS RT	VIS RT
XO Average Incorrect RT (Interference)	General	SPEED	VIS	VIS RT	VIS RT
SM Average Correct RT (Visible)	General	SPEED	VIS	VIS RT	VIS RT
SM Average Correct RT (Hidden)	General	SPEED	VIS	VIS RT	VIS RT
WM Correct Distractors (Delay)	General	MEM	VERB	MEM	VERB MEM
WM Hits (Delay)	General	MEM	VERB	MEM	VERB MEM
WM Hits (Immediate)	General	MEM	VERB	MEM	VERB MEM
WM Correct Distractors	General	MEM	VERB	MEM	VERB MEM
TL Average Counted Correctly	General	SPEED	VERB	WRK MEM	WRK MEM
TL Average Time to First Click	General	SPEED	VERB	WRK MEM	WRK MEM
CM Average Correct RT	General	SPEED	VERB	WRK MEM	WRK MEM
TL Total Sequence Correct	General	MEM	VERB	WRK MEM	WRK MEM

Note. DM = Design Memory; SM = Symbol Match; XO = X's and O's; WM = Word Memory; TL = Three Letters; CM = Color Match; RT = reaction time; *Maietta et al., (2021)

Table 3.

Descriptive statistics for ImPACT subtest scores at baseline and post-concussion assessment.

	Baseline		Post-Concussion	
	Monolingual	Bilingual	Monolingual	Bilingual
Variable	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*	Mean *(SD)*
Design Memory				
Correct Distractors (Immediate)	9.16 *(2.36)*	8.96 *(2.39)*	8.85 *(2.42)*	8.74 *(2.48)*
Correct Distractors (Delay)	8.40 *(2.54)*	8.26 *(2.51)*	8.21 *(2.37)*	8.08 *(2.42)*
Hits (Delay)	9.73 *(1.68)*	9.61 *(1.7)*	8.99 *(1.94)*	9.03 *(1.87)*
Symbol Match				
Total Correct (Visible)	6.16 *(2.03)*	6.16 *(2.01)*	6.10 *(2.03)*	6.20 *(2.01)*
Average Correct Reaction Time (Visible)	1.65 *(0.45)*	1.71 *(0.48)*	1.72 *(0.53)*	1.72 *(0.5)*
Average Correct Reaction Time (Hidden)	1.63 *(0.52)*	1.71 *(0.56)*	1.67 *(0.54)*	1.72 *(0.57)*
X's and O's				
Total Correct (Memory)	8.17 *(2.26)*	7.96 *(2.27)*	7.91 *(2.45)*	7.81 *(2.39)*
Average Correct Reaction Time (Interference)	0.53 *(0.07)*	0.54 *(0.07)*	0.56 *(0.13)*	0.55 *(0.11)*
Total Correct (Interference)	110 *(8.23)*	109 *(8.17)*	107.11 *(12.76)*	107.74 *(12.03)*
Average Incorrect Reaction Time (Interference)	0.44 *(0.12)*	0.45 *(0.14)*	0.47 *(0.18)*	0.46 *(0.18)*
Word Memory				
Correct Distractors (Delay)	11 *(1.36)*	10.9 *(1.35)*	10.12 *(2.01)*	10.13 *(2.05)*
Hits (Delay)	10.6 *(1.38)*	10.6 *(1.4)*	9.95 *(1.92)*	10.15 *(1.7)*
Hits (Immediate)	11.6 *(0.65)*	11.6 *(0.65)*	11.01 *(1.39)*	11.15 *(1.22)*
Correct Distractors	11.7 *(0.63)*	11.7 *(0.64)*	10.97 *(1.7)*	10.97 *(1.72)*
Three Letters				
Average Counted Correctly	14.40 *(4.06)*	13.00 *(3.97)*	14.64 *(4.24)*	13.86 *(4.25)*
Average Time to First Click	2.39 *(0.68)*	2.57 *(0.77)*	2.32 *(0.63)*	2.39 *(0.67)*
Total Sequence Correct	4.01 *(0.96)*	3.94 *(0.97)*	3.75 *(1.29)*	3.82 *(1.27)*
Color Match				
Average Correct Reaction Time	0.80 *(0.13)*	0.83 *(0.13)*	0.84 *(0.17)*	0.83 *(0.15)*

Table 4.
Goodness-of-fit Statistics for ImPACT factor models outlined in Table 2.

Model	Sample	χ^2 (*df*)	CFI	TLI	SRMR	RMSEA [90% CI]
1-Factor						
	BL Monolingual	15847.33(135)*	0.547	0.486	0.121	.127[.125-.129]
	BL Bilingual	15327.63(135)*	0.562	0.504	0.118	.124[.122-.125]
	PC Monolingual	1487.31(135)*	0.663	0.619	0.102	.141[.134-.147]
	PC Bilingual	1527.50(135)*	0.651	0.604	0.108	.141[.134-.147]
2-Factor						
	BL Monolingual	7193.55(134)*	0.798	0.769	0.072	.085[.084-.087]
	BL Bilingual	7345.02(134)*	0.794	0.765	0.072	.085[.083-.087]
	PC Monolingual	858.34(134)*	0.819	0.794	0.071	.103[.097-.110]
	PC Bilingual	926.27(134)*	0.802	0.774	0.073	.106[.100-.113]
2-Alternative Factor						
	BL Monolingual	14151.96(134)*	0.599	0.542	0.116	.120[.118-.122]
	BL Bilingual	14022.71(134)*	0.606	0.550	0.113	.118[.116-.119]
	PC Monolingual	1301.09(134)*	0.707	0.666	0.108	.132[.125-.138]
	PC Bilingual	1363.07(134)*	0.695	0.652	0.110	.132[.126-.138]
3-Factor						
	BL Monolingual	5718.39(132)*	0.841	0.816	0.063	.076[.074-.078]
	BL Bilingual	6189.62(132)*	0.829	0.802	0.065	.078[.076-.080]
	PC Monolingual	909.87(132)*	0.807	0.777	0.076	.108[.101-.114]
	PC Bilingual	975.05(132)*	0.793	0.760	0.078	.110[.103-.116]
4-Factor						
	BL Monolingual	3838.17(129)*	0.895	0.876	0.055	.063[.061-.064]
	BL Bilingual	4100.83(129)*	0.889	0.868	0.056	.064[.062-.065]
	PC Monolingual	777.58(129)*	0.842	0.812	0.089	.099[.092-.105]
	PC Bilingual	817.32(129)*	0.833	0.802	0.081	.100[.093-.106]

Note. Baseline monolingual sample n = 7948. BL bilingual sample n = 7938. PC monolingual sample n = 562. PC bilingual sample n = 558. BL = Baseline; PC = Post-concussion; CFI = comparative fit index. TLI = Tucker-Lewis index. SRMR = standardized root mean-square residual. RMSEA = root mean-square error of approximation. 90% CI = root mean-square error of approximation 90% confidence interval. * $p < .001$.

Table 5.

Goodness-of-fit Statistics for Modified 4-Factor Model.

Sample	χ^2 (*df*)	CFI	TLI	SRMR	RMSEA [90% CI]
Baseline					
Monolingual	1846.40(122)*	0.952	0.939	0.037	.044[.042-.044]
Bilingual	1932.15(122)*	0.949	0.937	0.038	.044[.042-.046]
Post-Concussion					
Monolingual	389.81(122)*	0.936	0.919	0.055	.065[.057-.072]
Bilingual	406.74(122)*	0.930	0.913	0.057	.066[.059-.073]

Note. Baseline monolingual sample n = 7948. Baseline bilingual sample n = 7938. Post-concussion monolingual sample n = 562. Post-concussion bilingual sample n = 558. BL = Baseline; PC = Post-concussion; CFI = comparative fit index. TLI = Tucker-Lewis index. SRMR = standardized root mean-square residual. RMSEA = root mean-square error of approximation. 90% CI = root mean-square error of approximation 90% confidence interval. * $p < .0001$.

Table 6.

Measurement Invariance Analysis for the ImPACT modified 4-Factor model at baseline and at post-concussion across language group.

Model	χ^2 (*df*)	$\Delta\chi^2$	CFI	ΔCFI	TLI	SRMR	ΔSRMR	RMSEA	ΔRMSEA
			Baseline Comparison (Monolingual to Bilingual)						
Configural	3777.47(244)*	--	0.951	--	0.938	0.036	--	0.044	--
Metric	3802.47(258)*	46.41 (14)***	0.950	-0.001	0.941	0.036	0.000	0.043	-0.001
Scalar	4119.18(272)*	323.60 (14)***	0.946	-0.004	0.939	0.037	0.001	0.044	0.001
Residual	4394.08 (290)*	274.00 (18)***	0.940	-0.006	0.936	0.041	0.004	0.044	0.000
			Post-Concussion Comparison (Monolingual to Bilingual)						
Configural	796.37 (244)*	--	0.933	--	0.916	0.053	--	0.065	--
Metric	826.18(258)*	35.00 (14)**	0.929	-0.004	0.916	0.061	0.008	0.065	0.000
Scalar	855.62(272)*	28.01 (14)*	0.928	-0.001	0.919	0.062	0.001	0.064	-0.001
Residual	840.81(290)*	13.47 (18)	0.929	0.001	0.925	0.064	0.002	0.062	-0.002

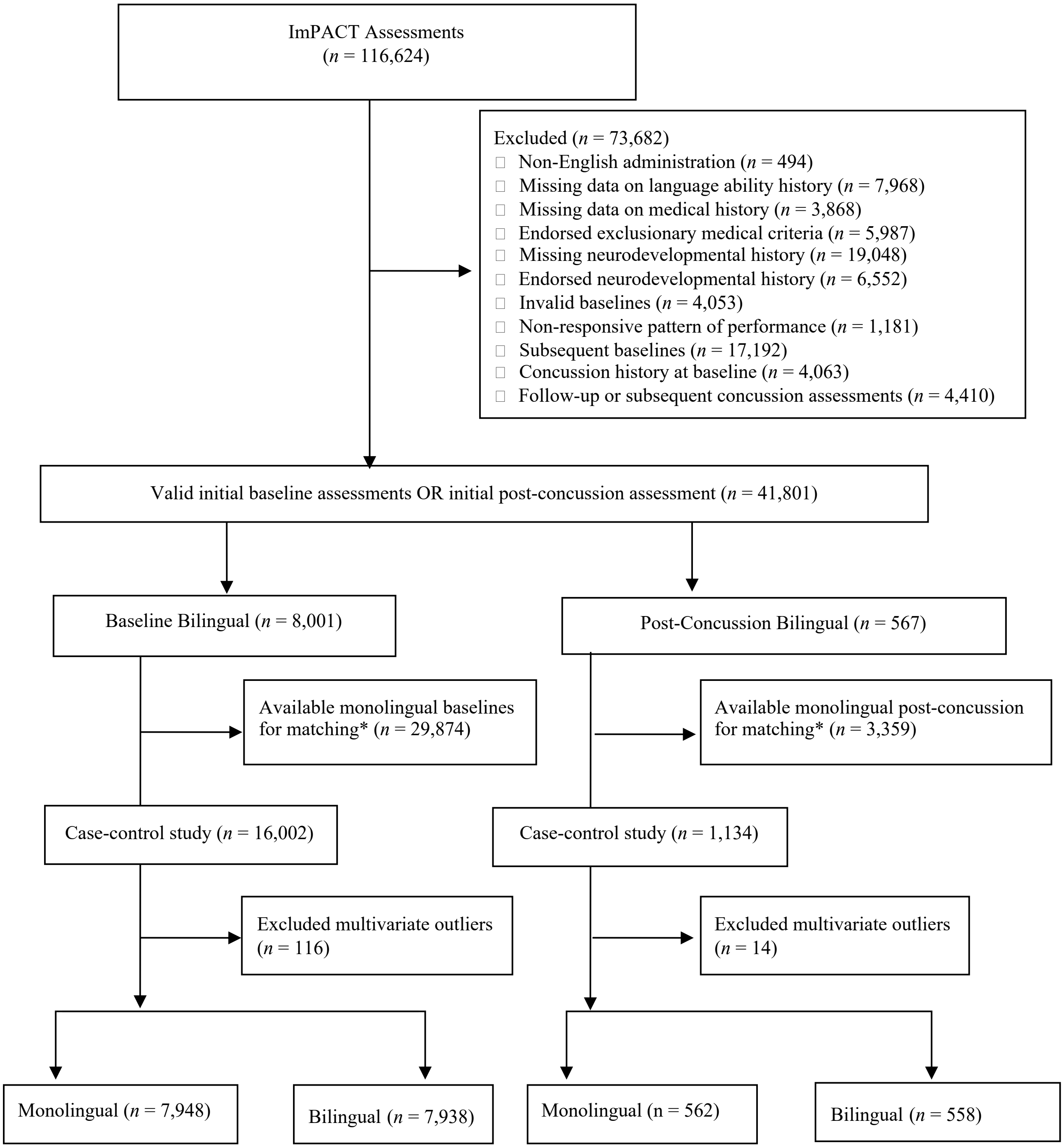
Note. $\Delta\chi^2$ = change in χ^2. CFI = comparative fit index. ΔCFI = change in CFI. TLI = Tucker-Lewis index. SRMR = standardized root mean-square residual. ΔSRMR = change in SRMR. RMSEA = root mean-square error of approximation. ΔRMSEA = change in RMSEA.

*** $p < .001$. ** $p < .01$. *$p < .05$

Appendix B: Figures

Figure 1.

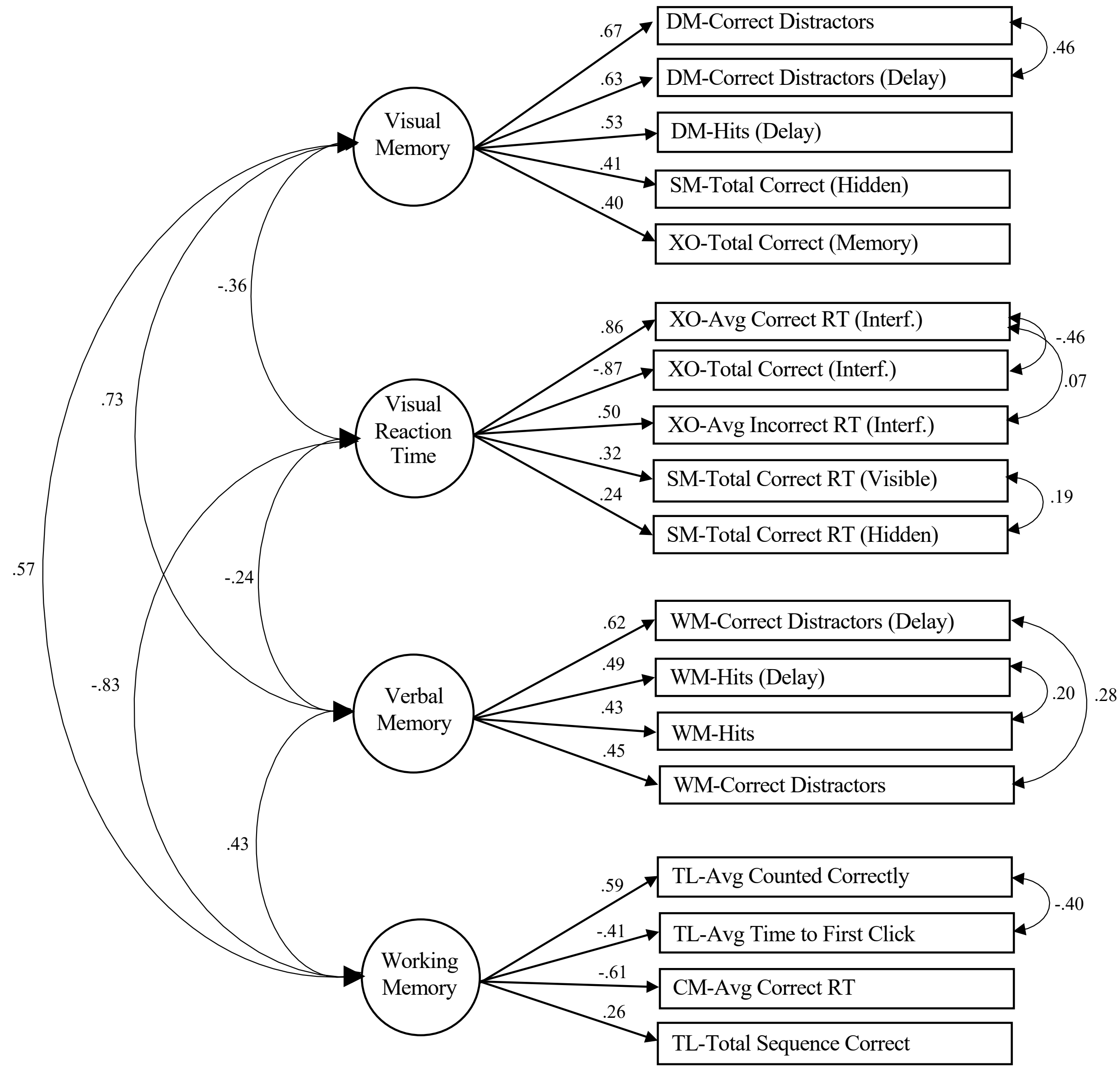
Flow Diagram Depicting Participant Selection



Note. *Matched by Age, Gender, and sport type

Figure 2.

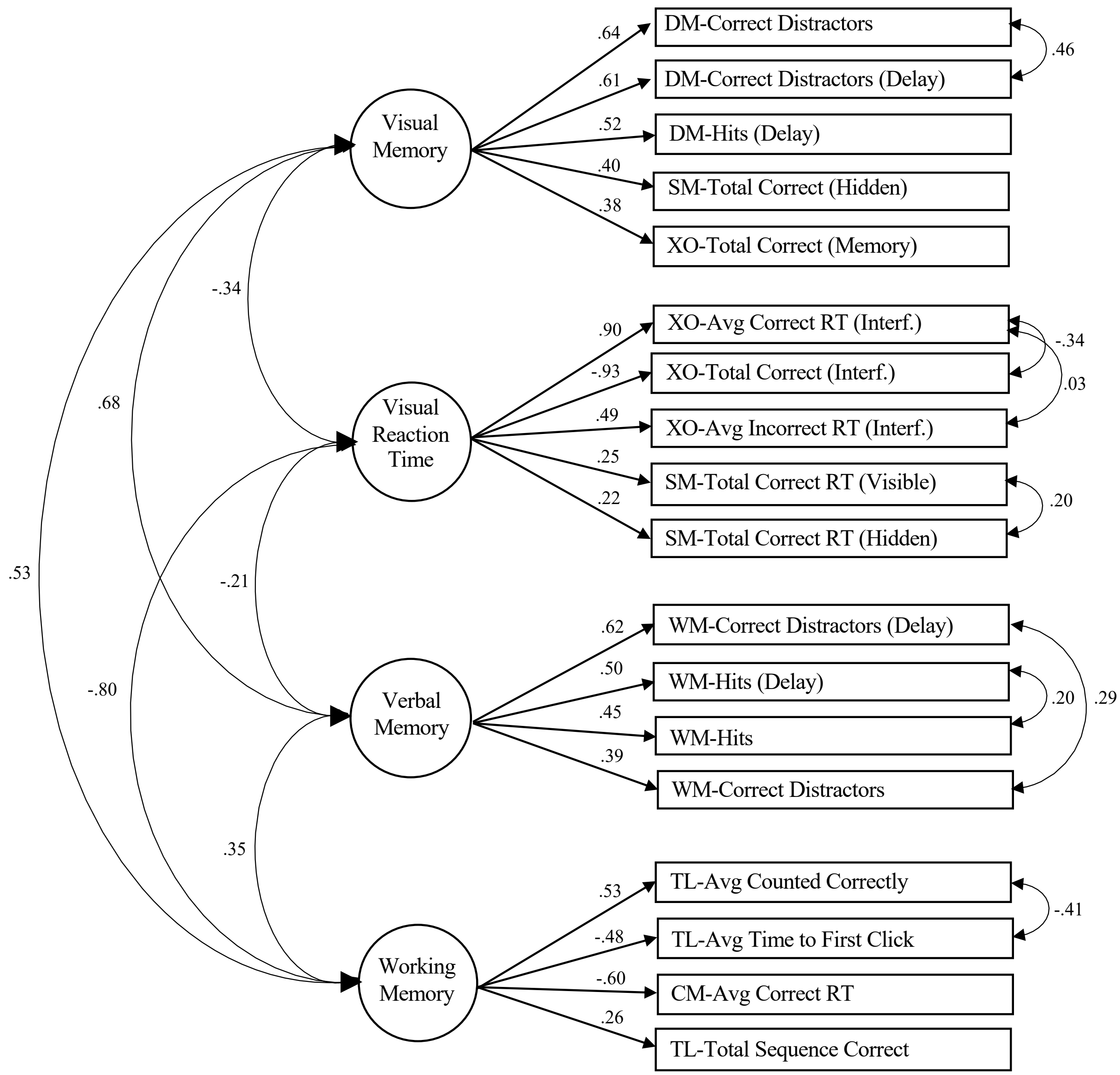
Modified 4-Factor model for ImPACT in Monolingual Athletes at Baseline.



Note. DM = Design Memory; SM = Symbol Match; XO = X's and O's; WM = Word Memory; TL = Three Letters; CM = Color Match; Interf. = interference; RT = reaction time.

Figure 3.

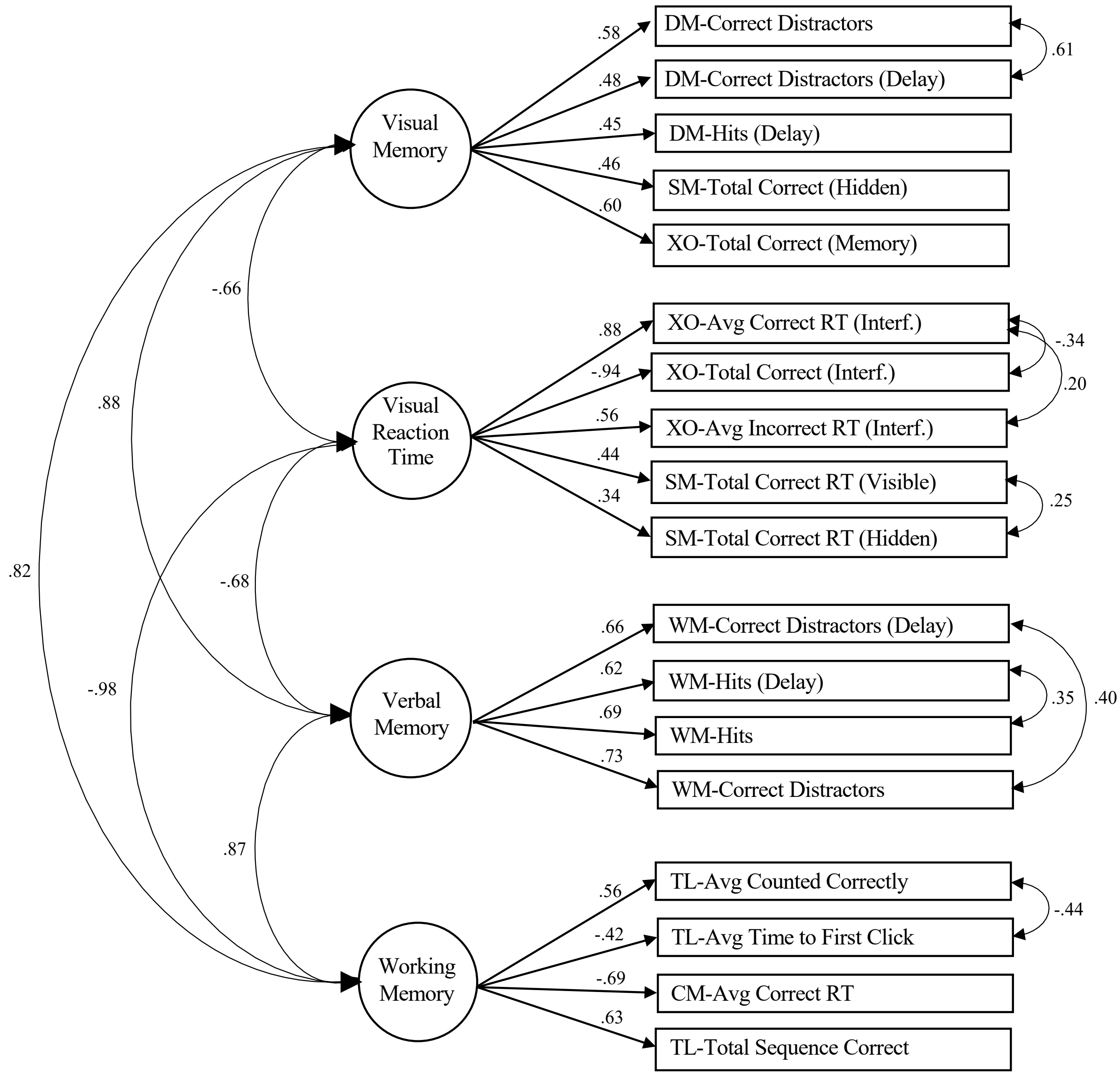
Modified 4-Factor model for ImPACT in Bilingual Athletes at Baseline.



Note. DM = Design Memory; SM = Symbol Match; XO = X's and O's; WM = Word Memory; TL = Three Letters; CM = Color Match; Interf. = interference; RT = reaction time.

Figure 4.

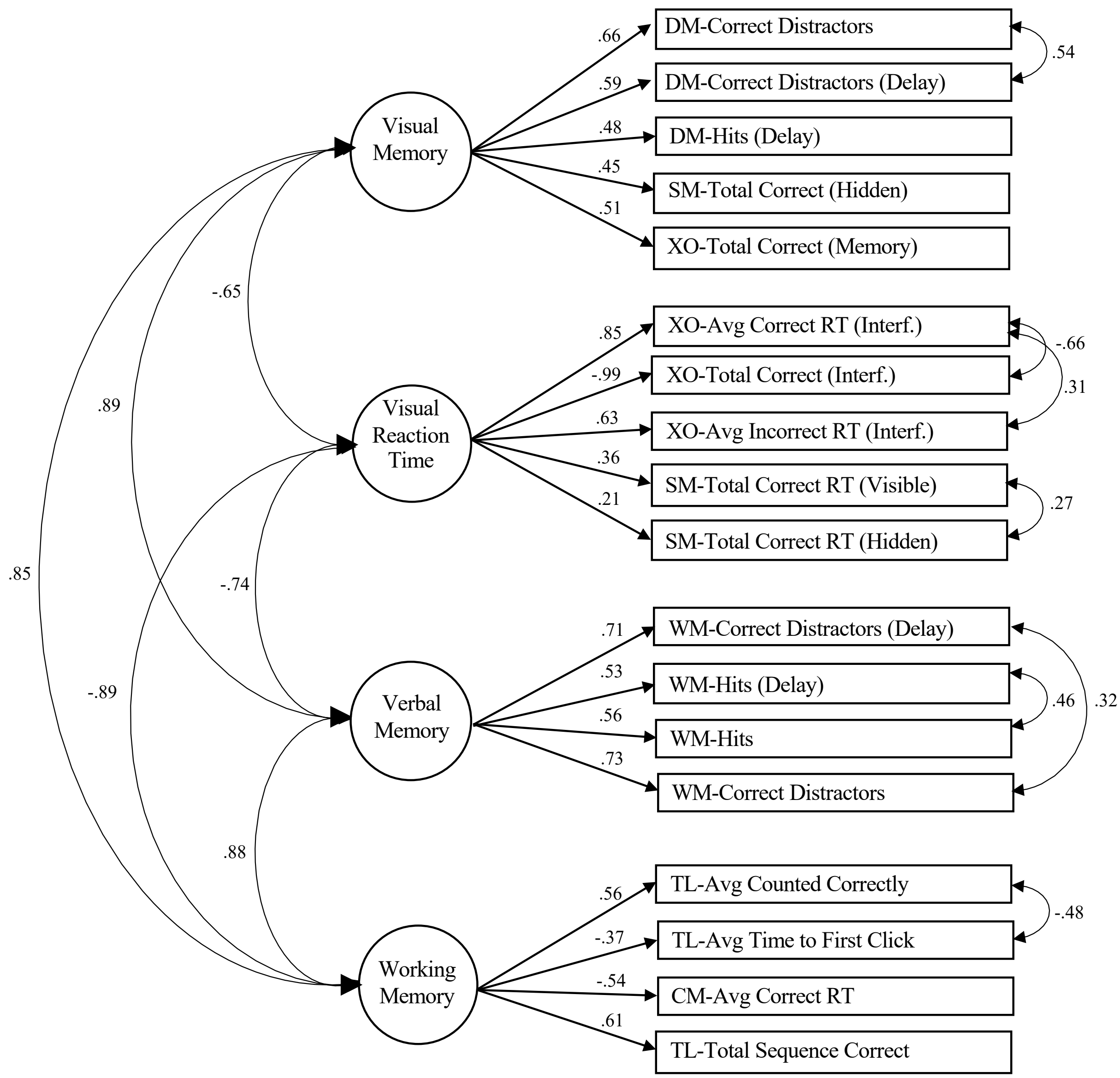
Modified 4-Factor model for ImPACT in Monolingual Athletes at Post-Concussion.



Note. DM = Design Memory; SM = Symbol Match; XO = X's and O's; WM = Word Memory; TL = Three Letters; CM = Color Match; Interf. = interference; RT = reaction time.

Figure 5.

Modified 4-Factor model for ImPACT in Bilingual Athletes at Post-Concussion.



Note. DM = Design Memory; SM = Symbol Match; XO = X's and O's; WM = Word Memory; TL = Three Letters; CM = Color Match; Interf. = interference; RT = reaction

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Vartiainen, M. V., Peltonen, K., Holm, A., Koskinen, S., Iverson, G. L., & Hokkanen, L. (2019). Preliminary normative study of ImPACT® in Finnish professional male ice hockey players. *Applied Neuropsychology: Adult*.

Wallace, J., Covassin, T., Moran, R., & Deitrick, J. M. (2018). Factors Contributing to Disparities in Baseline Neurocognitive Performance and Concussion Symptom Scores Between Black and White Collegiate Athletes. *Journal of Racial and Ethnic Health Disparities*, *5*(4), 894–900. https://doi.org/10.1007/s40615-017-0437-y

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Curriculum Vitae

Hana C. Kuwabara, M.A.
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EDUCATION

Doctor of Philosophy in Psychology — Expected 2023
University of Nevada, Las Vegas (APA-accredited)
Major Area of Study: Clinical Neuropsychology
Dissertation: *Measurement Invariance of ImPACT in Bilingual and Monolingual High School Athletes*
Defense Date: May 2022
Chair: Daniel Allen, Ph.D.

Master of Arts in Psychology — July 2017
University of North Carolina Wilmington
Thesis: *Computerizing Traditional Paper-Pencil Tests: Accommodation or Modification?*
Chair: Antonio E. Puente, Ph.D.

Bachelor of Arts in Psychology (Honors) — May 2014
University of North Carolina Wilmington
Honors Thesis: *Assessment and Regulation of Physical Activity in Children*
Chair: Carole Van Camp, Ph.D.

AWARDS & SCHOLARSHIPS

UNLV Patricia Sastaunik Scholarship ($2500)	Fall 2021– Spring 2022
UNLV Summer Doctoral Research Fellowship ($7000)	Summer 2021
2nd place poster presentation, Nevada Psychological Association	November 2020
UNLV Patricia Sastaunik Scholarship ($2500)	Fall 2020– Spring 2021
UNLV Summer Doctoral Research Fellowship ($7000)	Summer 2020
UNLV Graduate College Mentorship Certification Program	Fall 2019 – Spring 2020
UNLV Rebel Research and Mentorship Program ($2500)	Fall 2019 – Spring 2020
UNLV Patricia Sastaunik Scholarship ($2500)	Fall 2019 – Spring 2020
UNLV Summer Session Scholarship ($2000)	Summer 2019
UNCW Graduate Student Travel Grant (amounts vary)	Fall 2015- Fall 2016
UNCW E-TEAL Teaching Grant	Summer 2016
UNCW CSURF Research Supplies Grant	Fall 2013
Dean's List, UNCW	Fall 2011 - Spring 2014
Honors Scholars Program UNCW	Aug 2010 - Spring 2014
Diversity Scholarship, UNCW Honors College	Fall 2010 - Spring 2014

PEER – REVIEWED PUBLICATIONS

8. Goodwin, G., John, S., Donohue, B., Keene, J., Kuwabara, H., Maietta, J., Kinsora, T., Ross, S., Allen, D. (Submitted to Sports Medicine April 2022). Changes in Cognitive Networks as a Result of Sport-Related Concussion.
7. Becker, M., Maietta, J., Strong, M., Kuwabara, H., Kinsora, T., Ross, S., Allen, D. (Accepted). Language based differences in cognitive performance and symptom reporting on baseline concussion assessment. *Journal of Pediatric Neuropsychology*
6. Maietta, J., Kuwabara, H., Keene, J., Ross, S., Kinsora, T., Allen, D. (2021). Cognitive profiles following sport-related concussion in high school athletes. *Neuropsychology*.
5. Maietta, J., Ahmed, A. O., Barchard, K. A., Kuwabara, H. C., Donohue, B. D., Ross, S. R., Kinsora, T. F., & Allen, D. N. (2021). Confirmatory factor analysis of ImPACT cognitive tests in high school athletes. *Psychological Assessment.*
4. Maietta, J., Kuwabara, H. C., Cross, C. L., Flood, S. M., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2021). Influence of autism and other neurodevelopmental disorders on cognitive and symptom profiles: Considerations for baseline sport concussion assessment. *Archives of Clinical Neuropsychology.*
3. Maietta, J., Barchard, K. A., Kuwabara, H. C., Donohue, B., Kinsora, T. F, Ross, S. R., & Allen, D. N. (2020). Influence of special education, ADHD, autism, and learning disorders on ImPACT validity scores in high school athletes*. Journal of International Neuropsychological Society,* 1-11.
2. Eckard, M., Kuwabara, H., Van Camp, C. (2019). Using Heart Rate as a Physical Activity Metric. *Journal of Applied Behavior Analysis,* 52(3), 718-732.
1. Puente, A. E., Mejia, A. M., & Kuwabara, H. C. (2017). A Complex Case of Tri-lingual, Tri-cultural, Bi-racial, and Multiple Medical Comorbidities. *Journal of Pediatric Neuropsychology*, 1-14.

COMMENTARIES

2. Puente, A. E., Sekely, A., & Kuwabara, H. (2015). APA directorates key policies and presidential initiatives survey. *Psychogram: The Voice of Clinical Psychology in the Commonwealth*. Volume 40, Number 1, pp. 26-27.
1. Puente, A.E., Kuwabara, H., Mejia, A., & Eckard, M. (2015) The archives of Roger Sperry, Nobel Prize Laureate 1981. *History of Teaching of Psychology*, *18*(1), 100.

ENCYCLOPEDIA ENTRIES

Puente, A.E., Kuwabara H., Mejia, A. (2020). Monolingualism, bilingualism, multilingualism. *The Wiley-Blackwell encyclopedia of personal and individual differences: Clinical, applied, and cross-cultural research,* 209-214.

ORAL PRESENTATIONS

2. Maietta, J., Kuwabara, H., Keene, J., Ross, S., Kinsora, T., Allen, D. (2022, February) *Cognitive profiles following sport-related concussion in high school athletes: Relationship to symptom reporting, complicated recovery, and change from baseline* [Conference paper session]. International Neuropsychological Society 50th Annual Meeting, New Orleans, LA.

1. Eckard, M., Van Camp, C., Kuwabara, H. (2016) Utilizing a Biofeedback Approach to Increase Physical Activity in Children. Presented at Association for Behavioral Analysis International, Chicago, IL

POSTERS & PUBLISHED ABSTRACTS

* published poster abstract   [s] mentored undergraduate student

45. Goodwin, G. J., Kuwabara, H. C., Maietta, J., Kinsora, T. F., Ross, S. R., Allen, D. N. (2022, February). *Changes in Cognitive Networks as a Result of Sport-Related Concussion.* [Poster presentation] International Neuropsychological Society 50th Annual Meeting, New Orleans, LA.
44. *Rogers, E. A., Kuwabara, H. C., Goodwin, G. J., Moore, S., Hopkins, N., Goto, A., Maietta, J., Ross, S. R., Kinsora, T. F., & Allen, D. N. (2021, November). *Comparison of baseline and post-concussion ImPACT performance in Spanish-English bilingual and English monolingual athletes* [Poster presentation]. National Academy of Neuropsychology 41st Annual Conference, Washington, D.C.
43. *Goodwin, G.J., Maietta, J.E., Ahmed, A.O., Hopkins, N.A., Moore, S.A., Rodrigues, J., Pascual, M.S., Kuwabara, H.C., Kinsora, T.F., Ross, S.R., Allen, D.N. (2021, November). *Stability of ImPACT's latent structure from baseline to post concussion assessment* [Poster presentation]. National Academy of Neuropsychology 41st Annual Conference, Washington, DC.
42. Goodwin, G.J., Maietta, J.E., Maietta, L.N., Hopkins, N.A., Kuwabara, H.C., Kinsora, T.F., Ross, S.R., Allen, D.N. (2021). *Post-concussion symptom recovery in high school athletes with neurodevelopmental disorders* [Poster presentation]. American Psychological Association 129th Annual Convention, Virtual Conference.
41. Rogers, E. A., Kuwabara, H. C., Goodwin, G. J., Maietta, J., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2021). *Sleep duration not related to baseline cognitive performance in high school athletes* [Poster presentation]. American Psychological Association 129th Annual Convention, Virtual Conference.
40. *Hopkins, N., Maietta, J., Maietta, L., Kuwabara, H., Goodwin, G., Kinsora, T., Ross, S., & Allen, D. N. (2021). *Symptom reporting differences in athletes with psychiatric history* [Poster presentation]. International Neuropsychological Society 49th Annual Meeting, San Diego, CA, United States. (Conference held virtually).
39. *Goodwin, G., Maietta, J., Kuwabara, H., Moore, S., Hopkins, N., Kinsora, T., Ross, S., & Allen, D. N. (2021). *Post-concussion PCSS symptom scores among neurotypical and neurodevelopmental athletes* [Poster presentation]. International Neuropsychological Society 49th Annual Meeting, San Diego, CA, United States. (Conference held virtually).
38. *Maietta, L., Maietta, J., Goodwin, G., Kuwabara, H., Kinsora, T., Ross, S., & Allen, D. N. (2021). *Effects of helmet use on concussion rates across sport categories* [Poster presentation]. International Neuropsychological Society 49th Annual Meeting, San Diego, CA, United States. (Conference held virtually).
37. *Maietta, J., Hopkins, N. A., Maietta, L. N., Flood, S. F., Johnson, L. T., Kuwabara, H. C., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2020). *Are invalid baselines more frequent in those with concussion history?* [Poster presentation]. National Academy of Neuropsychology 40th Annual Conference, Chicago, IL, United States. https://doi.org/10.1093/arclin/acaa068.110 (Conference held virtually).

36. *Maietta, J., Flood, S. M., Johnson, L. T., Hopkins, N. A., Maietta, L. N., Kuwabara, H. C., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2020). *Cognitive profiles in athletes with neurodevelopmental disorders on baseline testing* [Poster presentation]. National Academy of Neuropsychology 40th Annual Conference, Chicago, IL, United States. https://doi.org/10.1093/arclin/acaa068.062 (Conference held virtually).
35. *Kuwabara, H., Grant, K., Moore, S., Maietta, J., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2020). *The effect of language on invalid baselines on ImPACT* [Poster presentation]. National Academy of Neuropsychology 40th Annual Conference, Chicago, IL, United States. https://doi.org/10.1093/arclin/acaa068.208 (Conference held virtually).
34. *Kuwabara, H., Moore, S., Grant, K., Maietta, J., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2020). *Changes in frequency of ImPACT assessments over time* [Poster presentation]. National Academy of Neuropsychology 40th Annual Conference, Chicago, IL, United States. https://doi.org/10.1093/arclin/acaa068.127 (Conference held virtually).
33. Hopkins, N. A., Maietta, J. E., Kuwabara, H. C., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2020). *Invalid ImPACT baselines: Expansion of demographic predictors* [Poster presentation]. Nevada Psychological Association Annual Conference, Las Vegas, NV, United States. (Conference held virtually).
32. *Flood, S., Maietta, J., Kuwabara, H., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2020) *Symptom reporting in athletes with neurodevelopmental diagnoses or concussion history* [Poster presentation]. 6th Annual Conference of American Academy of Pediatric Neuropsychology, Las Vegas, Nevada (Conference held virtually).
31. Zink, D., Kuwabara, H., Reyes, E., Strauss, G., & Allen, D. (2020) *Convergent and Discriminant Validity of the Emotional Verbal Learning Test-Spanish (EVLT-S)* [Poster presentation]. Annual Conference of the International Neuropsychological Society, Denver, Colorado.
30. *Hussey, J., Kuwabara, H. C., Ng, W. W. Y. [s], Kinsora, T. F., Ross, S. R., & Allen, D. N. (2019, November). *Performance of ImPACT validity indices for athletes with neurodevelopmental disorders* [Poster presentation]. National Academy of Neuropsychology 39th Annual Conference, San Diego, CA, United States. https://doi.org/10.1093/arclin/acz034.138
29. *Flood, S[s], Kuwabara, H. C., Hussey, J. E., Fraga, B. C., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2019, November). *Frequency of sports-related concussion in athletes with neurodevelopmental conditions* [Poster presentation]. National Academy of Neuropsychology 39th Annual Conference, San Diego, CA, United States. https://doi.org/10.1093/arclin/acz034.133
28. Hussey, J., Barchard, K. A., Kuwabara, H., Kinsora, T. F., Ross, S. R., Flood, S., Allen, D. N. (2019). *Confirmatory factor analysis of the ImPACT in high school athletes* [Poster presentation]. American Psychological Association 127th Annual Convention, Chicago, IL, United States.
27. *Zink, D., Kuwabara, H., Reyes, E., Gomez-Batista, S., Reyes, A., Alvarez, E., Strauss, G., & Allen, D. (2019). *Influence of Acculturation on Emotional Learning and Memory in Spanish and English Speakers* [Poster presentation] Hispanic Neuropsychological Society 47th Annual Conference, New York City, New York.
26. *Reyes [s], E., Zink, D., Kuwabara, H., Strauss, G., & Allen, D. (2019). *Factorial Validity in the Emotional Verbal Learning Test-Spanish (EVLT-S)* [Poster presentation]. Hispanic Neuropsychological Society 47th Annual Conference, New York City, New York.

25. *Kuwabara, H., Sheikh R., Ng, W., Kinsora, T. F., Ross, S. R., & Allen, D. N. (2018). *Demographic factors of invalid baselines on ImPACT* [Poster presentation]. National Academy of Neuropsychology 38th Annual Conference, New Orleans, LA.
24. *Kuwabara, H., Juarez, N., Rodriguez, A., Azar, F., Zink D., Strauss, G., Allen, D. (2018). *Differences in Specific Emotion Categories in the Emotional Verbal Learning Test-Spanish* [Poster presentation]. National Academy of Neuropsychology 38th Annual Conference, New Orleans, LA.
23. *Kuwabara, H., Gomez S, Strong, M., Alvares, E., Zink, D., Strauss, G., Allen, D. (2018). *Validation of the Emotional Verbal Learning Test-Spanish (EVLT-S)* [Poster presentation]. National Academy of Neuropsychology 38th Annual Conference, New Orleans, LA.
22. *Kuwabara, H., Mejia, A., Ibanez-Casas, I., Puente, A. (2018). *Computerizing Traditional Paper-Pencil Tests: Accommodation or Modification?* [Poster presentation]. American Psychological Association Annual Conference, San Francisco, California.
21. Strong [s], M., Lee, B., Kuwabara, H., Strauss, G., & Allen, D. (2018). *Differences in Recall of Emotional and Non-Emotional Words Between Patients with Schizophrenia and Healthy Controls* [Post presentation]. Western Psychological Association, Portland, OR.
20. Melikyan, Z., Kuwabara, H., Rubino, S., Mejia, A., Nagorskaya, I., Puente, A. (2018). *Digit Span Performance in Russian and American Rural Populations: Cross-Cultural and Cross-Linguistic Considerations* [Poster presentation]. International Neuropsychological Society Annual Conference, Washington D.C.
19. Kuwabara, H., Cook, A., Mejia, A., Puente, A.E., Ibanez-Casas, I. (2017). *Computerizing Traditional Paper-Pencil Tests: A Systematic Review of Existing Computerized Versions* [Poster presentation]. American Psychological Association, Washington D.C.
18. Rios, J., Leonard, B., Kuwabara, H., Daughtry, J., Burneo, C., Perez-Garcia, M., Puente, A., Ibanez-Casas, I. (2017). *A Cross-Cultural Comparison in Social Cognition Between Hispanics and Non-Hispanics* [Poster presentation]. American Psychological Association, Washington D.C.
17. Nosovitskaya, M., Rubino, S., Kuwabara, H., Melikyan, Z., Puente, A. (2017). *Comparing Rural Russian and American Populations' Performance on Rey Complex Figure Test* [Paper presentation]. American Psychological Association, Washington D.C.
16. Phelps, A., Hiltbrand, D., Mejia, A., Kuwabara, H., Chen, C., Wang, Y., Puente, A. (2017). *Assessing the Reliability and Validity of a Large Military Dataset Using Data Mining Techniques* [Poster presentation]. Presented at American Psychological Association, Washington D.C.
15. Melikyan, Z.A., Mejia, A.M., Rubino, S.J., Kuwabara, H.C., Nagorskaya, I. A., Nosovitskaya, M., Wang, Y., Puente, A.E. (2017). *Rural Russian Americans Populations' Performance on Color Trails Test and Trail Making Test* [Poster presentation]. International Neuropsychological Society Annual Conference, New Orleans, Louisiana.
14. *Mejia, A.M., Kuwabara, H.C., Nosovitskaya, M., & Puente, A.E (2016). *Using Armed Forces Qualification Test Scores for a Baseline of Cognitive Functioning After Loss of Consciousness* [Poster presentation]. National Academy of Neuropsychology 36th Annual Conference, Seattle, Washington. *Archives of Clinical Neuropsychology* (2016) 31 (6): 650.

13. *Daughtry, J., Mejia, A., Leonard, B., Kuwabara, H., Hidalgo Ruzzante, N., Bueso Izquierdo, N., Fasfous, A., Perez Garcia, M., Puente, A. (2016). *Relevance of Subjective Socioeconomic Status Measures for Cross-Cultural Neuropsychological Performance: The EMBRACED Project* [Poster presentation]. National Academy of Neuropsychology 36th Annual Conference, Seattle, Washington. *Archives of Clinical Neuropsychology* (2016) 31 (6): 667.
12. Kuwabara, H., Mejia, A., Hayes, W., Sekely, A., Puente, A.E., (2016). *The Effects of Loss of Consciousness on Trail Making Test* [Poster presentation]. American Psychological Association Annual Conference, Denver, Colorado.
11. Mejia, A., Kuwabara, H., Hayes, W., Sekely, A., Puente, A.E., (2016). *Preliminary Analyses of Using AFQT Scores as a Premorbid Indicator of Cognitive Abilities* [Poster presentation]. American Psychological Association Annual Conference, Denver, Colorado.
10. Sekely, A., Daugherty, J., Kuwabara, H., Mejia, A., Chen, C., Wang, Y., Puente, A.E., (2016). *Factor Analysis of the Trauma Symptom Inventory Using a Military Sample* [Poster presentation]. American Psychological Association Annual Conference, Denver, Colorado.
9. Ibanez-Casas I., Padilla, J., Lozano V., Kuwabara H., Caracuel, A., Yetilú de Baesa, Fernández, R., Green, C., Puente, A. E., (2016). *Structural Equivalence Across UK, Spain and Guatemala Versions of the Green Paranoid Thought Scales* [Poster presentation]. American Psychological Association Annual Conference, Denver, Colorado.
8. Melikyan, Z.A., Kuwabara, H.C., Mejia, A.M., Rubino, S.J., Nosovitskaya, M., Puente, A.E., (2016). *Piloting Applied Graduate Students' Training Program In Cross-Cultural Neuropsychology Research* [Poster presentation]. ETEAL Applied Learning Summer Institute, Wilmington, NC.
7. Mejia, A., Sekely, A., Kuwabara, H., Melikyan, Z., Puente, A.E. (2015). *Preliminary Analysis of a Large Dataset with Military Personnel* [Poster presentation]. UNCW Spring Student Showcase, Wilmington, North Carolina.
6. Mejia, A., Kuwabara, H., Sekely, A., Melikyan, Z., Puente, A.E. (2015). *The Ins and Outs of Analyzing a Large Dataset of Military Personnel from Camp Lejeune* [Poster presentation]. North Carolina Psychological Association/North Carolina Psychological Foundation (NCPA/NCPF) Spring Conference, Raleigh, North Carolina.
5. Puente, A.E., Kuwabara, H., Mejia, A., Hernandez, M., Wisnowski, J. (2015) *Twenty-Five Years of Psychologically Based Pharmacological Intervention: Different Approaches to Expanding Psychology's Scope of Practice* [Paper presentation] American Psychological Association Annual Conference, Toronto, Canada.
4. Puente, A.E., Kuwabara, H., Mejia, A., Eckhart, M. (2015). *The Archives of Roger Sperry, Nobel Prize Laureate, 1981* [Poster presentation]. American Psychological Association Annual Conference, Toronto, Canada.
3. Eckard, M., Van Camp, C., Kuwabara, H., Schomo, A., Quinn, M. (2014) *Indices of Moderate and Vigorous Physical Activity Levels in Children* [Poster presentation]. Southeastern Association for Behavior Analysis Annual Conference, Wilmington, NC.
2. Kuwabara H., Van Camp C., Eckard M. (2014) *Assessment and Regulation of Physical Activity in Children* [Poster presentation]. Southeastern Association for Behavior Analysis Annual Conference, Wilmington, NC.

1. Hayes, L., Van Camp, C., Caudill, C., Hall S., Kuwabara, H. (2013) *Increasing Physical Activity of Children During Recess: An Evaluation of Self- Management and Reinforcement* [Poster presentation]. Southeastern Association for Behavior Analysis Annual Conference, Myrtle Beach, SC.

SUPERVISED CLINICAL TRAINING

08/2021 – Present

Las Vegas Neurology Center - Las Vegas, NV
Practicum Student
Supervisors: Denise LaBelle, Ph.D. & Davor Zink, Ph.D.

- Conducted comprehensive neuropsychological assessments for adult and geriatric patients in an outpatient medical clinic
- Interviewing (under live supervision), test administration, scoring, interpretation, and integrated report writing
- Common patient diagnoses include stroke, chronic vascular disease, traumatic brain injury, Alzheimer's disease referred from neurology.
- Attended weekly individual supervision meetings
- Participated in and presented at biweekly didactics and case conference

08/2020 - 07/2021

Cleveland Clinic Lou Ruvo Center for Brain Health – Las Vegas, NV
Practicum Student
Supervisors: Jessica Caldwell, Ph.D., ABPP-CN, Justin B. Miller, Ph.D., ABPP-CN, Christine Wong, Ph.D.

- Conducted comprehensive neuropsychological assessments for adult and geriatric clients within a specialty medical clinic focusing on dementia and movement disorder diagnoses.
- Common patient diagnoses include Alzheimer's disease, Progressive Supranuclear Palsy, Lewy Body dementia, Frontotemporal dementia, traumatic brain injury, Multiple Sclerosis, and Parkinson's disease
- Interviewing (under live supervision), test administration, scoring, interpretation, and integrated report writing
- Weekly individual supervision meetings in addition to weekly case conferences and didactics with neuropsychology supervisors and post-doctoral fellows. Presented case presentation.
- Weekly clinic-wide interdisciplinary didactic seminars with neurology, physical therapy, occupational therapy, speech pathology, and social work

06/2019 – 08/2020

Center for Applied Neuroscience - Las Vegas, NV
Practicum Student
Supervisors: Sharon Jones-Forrester, Ph.D. & Thomas Kinsora, Ph.D.

- Conducting neuropsychological assessments for children and adult clients in an outpatient private practice setting.

- Common patient diagnoses include affective disorders, pervasive developmental disorders, learning disabilities, and traumatic brain injury.
- Interviewing (under live supervision), test administration, scoring, interpretation, and integrated report writing
- Weekly individual supervision and group supervision, as well as didactic training and case conferences

08/2018 – 08/2021 The Partnership for Research, Assessment, Counseling, Therapy, & Innovative Clinical Education (The PRACTICE) – Las Vegas, NV
2019 recipient of the Association of Psychology Training Clinic's Clinic Innovations Award – Training

08/2018 – 08/2019 *Practicum Student*
Supervisors: Michelle Paul, Ph.D. & Carolina Meza-Perez, Psy.D.

- Outpatient psychology department-sponsored community mental health training clinic serving children and adults of diverse backgrounds from the Las Vegas community.
- Provided individual therapy, initial and follow-up intakes, psychodiagnostic interviews and assessment, feedback sessions, and coordinated care with other health care professionals and schools; caseload of approximately 4-5 patients per week
- Implemented evidence-based interventions such as CBT, CPT, DBT, ERP, HRT, and ACT.
- Diagnoses included adults with severe mental illness, schizoaffective disorder, PTSD, borderline personality disorder, bipolar disorder, depression, obsessive compulsive disorder, and generalized anxiety disorder, children and adolescents with ADHD, depression, anxiety, selective mutism, Tourette's disorder, and tic disorder.
- Received weekly individual and group supervision with video review. Attended weekly staff meetings and practicum seminars, which included didactic, group supervision, and case conference components.

05/2020-08/2020 *Supervisor-in-Training*
Supervisors: Michelle Paul, Ph.D. & Amelia Black, Ph.D., CGP

- Supervised a junior clinical psychology doctoral student while enrolled in a Supervision course.
- Monitored caseload of junior clinician, documented weekly supervision sessions and reviewed supervisee's videotaped sessions and documentation.
- Received weekly individual and group supervision of supervision from a licensed clinical psychologist, including video review, and weekly case rounds.

- Implemented emerging philosophy of supervision that integrates competency-, and psychotherapy-based frameworks, as well as developmental and discrimination models.

08/2020 – 08/2021 *Graduate Assistant*
<u>Supervisors</u>: Michelle Paul, Ph.D. & Noelle Lefforge, Ph.D., MHA, CGP, ABPP

- Provided individual and family tele-therapy with a caseload of approximately 5-6 patients per week
- Diagnoses included adolescents and adults with depression, anxiety, borderline personality disorder, and adjustment disorder
- Interventions were informed by CBT approaches including DBT and ACT. Other interventions included grief support and crisis management for patients with acute suicidality.
- Provided tiered assessment supervision to junior clinical psychology doctoral students in administration, scoring, and interpretation of commonly used assessments

10/2018 – 08/2019 The PRACTICE Group Psychotherapy Clinic
Practicum Student
<u>Supervisors</u>: Noelle Lefforge, Ph.D., MHA, CGP, ABPP & Amelia Black, Ph.D., CGP

- Group therapy in an outpatient psychology department-sponsored mental health training clinic
- Co-facilitated a weekly CBT skills-based psychotherapy group for 8 months; clients presenting concerns included symptoms of depression and anxiety; conducted check-ins and practiced and applied CBT skills in session; provided case management for 4 patients
- Co-facilitated a weekly severe mental illness group for 8 months providing a supportive environment and basic daily coping skills and stress management techniques; provided case management for 4 patients
- Participated in weekly case rounds and group supervision
- Provided pre-group orientation for incoming group members since these were open groups
- Monitored outcomes of group patients (Outcome Questionnaire and Group Questionnaire)
- Participated in experiential group with peers for training purposes while enrolled in Group psychotherapy course

OTHER CLINICAL EXPERIENCE

2014 – 2017 University Neuropsychology Private Practice - Wilmington, NC
Testing and Forensic Technician
<u>Supervisor</u>: Antonio E. Puente, Ph.D.

- Test administration and scoring neuropsychological measures, behavioral observations write-ups, proofreading neuropsychological reports, reviewing records (e.g., medical, educational, legal records), participation in conference calls with attorneys, conducting literature reviews, assisting in preparation of professional/legal presentations.
- Administrative responsibilities and training other students.
- Population: Children and adults; military personnel; medical referrals; independent medical evaluations; worker's compensation, and forensic/death penalty cases. Individuals with aphasia, dementia, mild cognitive impairment, traumatic brain injury, posttraumatic stress disorder, Parkinson's disease, ADHD, learning disorders, stroke, depression, and anxiety.

2014 - 2017 Cape Fear Clinic - Wilmington, NC
Volunteer Testing Technician
Supervisor: Antonio E. Puente, Ph.D.
- Volunteered in an interdisciplinary clinic serving uninsured patients whose incomes were less than 200% of Federal Poverty Guidelines
- Administered and scored neuropsychological measures, report proofing; train new students (undergraduate and graduate), observed psychologist, psychiatrist, pharmacists, and social worker providing therapy and medication management in an integrated healthcare setting
- Presenting problems included somatoform disorder, depression, anxiety, cognitive impairment, grief, sexual trauma, family/marital conflict, and substance use disorders

2012 - 2013 Talisman Summer Camp - Zirconia, NC
Direct Care Staff
Supervisor: Carrie Burkhardt, M.A.
- Supervised children ages 8-14; recorded daily reports; produced summaries at the end of each of the three 3-week overnight session to present social, behavioral, and personal improvements and observations; encouraged social and personal growth through planned "challenge by choice" activities such as camping, hiking, rock climbing, as well as team building games.
- Populations: Children with various learning disabilities, autism, and ADHD.

ADDITIONAL CLINICAL TRAINING RECEIVED

Fall 2019 Comprehensive Training in Dialectical Behavior Therapy (DBT) – 21 hours
Alan and Armida Fruzzetti, Ph.D.,

	Sponsored by The Nevada Psychological Association, Las Vegas, NV • Comprehensive 3-day training focused on DBT theory, structure, targets, treatment strategies, skills, skill training, and skill coaching.
Spring 2019; 2020	Interprofessional Education Day – 16 hours *University of Nevada, Las Vegas* • Two-day training aimed at increasing awareness of interprofessional education, apply concepts, explore roles and responsibilities of participating professions, as well as initiating an understanding of how interprofessional teams should function to provide effective comprehensive patient care. Participating disciplines included medical, dental, physical therapy, counseling, and social work.
Fall 2018	Introduction to Acceptance and Commitment Therapy (ACT) – 16 hours *Steven C. Hayes, Ph.D.* Sponsored by Praxis CET & the Institute for Better Health; Las Vegas, NV • Two-day workshop with ACT co-founder Steven C. Hayes, Ph.D. establishing an understanding of: 1) An experiential understanding of the six basic processes of ACT's Psychological Flexibility Model. 2) The relationship between the six basic processes and Relational Frame Theory (RFT). 3) How to apply the Psychological Flexibility Model to case conceptualization and treatment planning. (4) Practical skills for meeting clients where they are and fostering their willingness and openness to change. 5)Ways to assess, observe, and influence client processes in session.

TEACHING EXPERIENCE

Fall 2021	Instructor - Introduction to Psychology, PSY101 *University of Nevada Las Vegas; Las Vegas, NV* Instructor of record for 2 sections; remote teaching; 60+ students
08/2019 – 05/2020	Instructor - Introduction to Psychology, PSY101 *University of Nevada Las Vegas; Las Vegas, NV* Instructor of record for 4 sections; 100+ students
08/2015 – 05/2017	Guest lecturer – Honors Brain & Behavior, PSY256 *University of North Carolina Wilmington; Wilmington, NC* Supervisor: Antonio E. Puente, Ph.D. <u>Topics</u>: Measuring Brain & Behavior Relationships, Learning, Memory, Multidisciplinary Integration of Technology Today, Spinal cord and brain overview, Structure of the brain, How to do Psychology

RESEARCH EXPERIENCES

08/2017 – Present

Neuropsychology Research Program
University of Nevada, Las Vegas
Supervisor: Daniel Allen, Ph.D.
Graduate Research Assistant (2017-2019)

- Supervise overall lab projects as well as 10 to 15 undergraduate Research Assistants
- Bi-weekly RA lab meetings with journal club and professional development components.
- Assisted in training other students with IRB, statistics, etc.
- Collaborated in research related to neuropsychology
- Conducted literature reviews, write, and review manuscripts

Relevant Projects
ImPACT Dataset of Athletes in Nevada
Advisors: Daniel Allen, Ph.D., Thomas Kinsora, Ph.D., Staci Ross, Ph.D.

- Experiences entail supervision/ training undergraduate Research Assistants in data cleaning, literature review, and abstract writing for longitudinal, state-wide database of over 100,000 athletes who took pre- and post-concussion assessments with ImPACT. Research topics include multicultural assessment, clinical utility of the ImPACT taking into account athlete sandbagging, and more.

Development of Emotional Verbal Learning Test- Spanish (EVLT-S)
Advisors: Daniel Allen, Ph.D., Davor Zink, M.A.
Graduate Research Assistant

- Experiences entail supervision/ training undergraduate Research Assistants in administration, scoring, data entry, overseeing all project duties. Research emphasizes the development of Spanish version of the Emotional Verbal Learning Test, a measure of social cognition.

05/2014 – 07/2017

Roger W. Sperry Neuropsychology Lab
University of North Carolina Wilmington
Advisor: Antonio E. Puente, Ph.D.
Graduate Research Assistant and Lab Manager

- Experiences entail undergraduate, post-undergraduate and graduate research endeavors; supervision/ training undergraduate students; assist in manuscript preparation for various studies (e.g., cross cultural and military).

Relevant Projects
Master's Thesis: Computerizing Traditional Paper-Pencil Tests: Accommodation or Modification?

Committee Chair: Antonio E. Puente, Ph.D.

- Research emphasizes the translation of traditional paper-pencil administered neuropsychological assessments into a computerized format and the implications of psychometric equivalence/un-equivalence.

EMBRACED Neuropsychological Battery
Advisors: Inmaculada Ibanez-Casas, Ph.D. & Antonio E. Puente, Ph.D.
Graduate Research Assistant

- Assisted in development of a European Domain-Specific Computerized Battery for Cross Cultural Neuropsychological Assessment. Helped develop computerized versions of existing traditional neuropsychological measures, as well as develop new variations of other measures. Administered pilot battery to gain qualitative data.

Neuropsychological Test Performance and Attitudes Towards Testing and Work of Psychologists in Healthy Rural Russian and American Adults
Funded by: UNCW E-Teal Research Grant
Advisors: Antonio E. Puente, Ph.D. & Zara Melikyan, Ph.D.
Lead Graduate Research Assistant

- Assisted in writing and editing grant proposal; recruitment/scheduling participants; trained undergraduate research assistants in administration of memory/problem solving measures; scoring, data entry, coding, data analysis, preparation of professional poster, paper, and oral presentation.

The Camp Lejeune Blast Neuropsychological Dataset
Advisors: Antonio E. Puente, Ph.D, Yishi Wang, Ph.D, Cuixian Chen, Ph.D.
Research Assistant

- Data entering/coding; data analyses; preparation/presentation of professional poster; preparation of manuscripts; collaborations with the Interdisciplinary Data Analytics Lab. Research encompasses validity testing, traumatic brain injuries, pre- and post-deployment comparisons.

08/2013 – 05/2014 Translation and Applied Behavioral Science Lab
University of North Carolina Wilmington
Advisor: Carole Van Camp, Ph.D.
Honors Thesis: *Assessment and Regulation of Physical Activity in Children*

- Research investigates the use of heart rate monitors and visual and vocal cues for children to assess their own heart rate levels while engaging in activities.

EDITORIAL EXPERIENCE

2015 — Journal of Interprofessional Education and Practice
Ad hoc reviewer-in training
Supervisor: Antonio E. Puente, Ph.D.

2021 — Applied Neuropsychology: Child
Ad hoc reviewer-in training
Supervisor: Daniel Allen, Ph.D.

2022 — Sports Medicine
Ad hoc reviewer-in training
Supervisor: Daniel Allen, Ph.D.

LEADERSHIP, MENTORSHIP, & ORGANIZATIONAL EXPERIENCE

08/2021 – Present — UNLV ANST Interest Group Co-Representative
University of Nevada, Las Vegas
Supervisor: Daniel Allen, Ph.D.

- Informing students and trainees in their program about training and professional issues relevant to the field of neuropsychology
- Ensuring reciprocal communication between graduate students and ANST as well as SCN.

08/2019 – 05/2020 — Graduate Mentor - Rebel Research and Mentorship Program (RAMP)
Co-sponsored by the Graduate College, Office of Vice Provost for Undergraduate Education and CSUN
University of Nevada, Las Vegas
Supervisor: Daniel Allen, Ph.D.

- Mentored an undergraduate student on a collaborative research project.
- Provided bi-weekly supervision to increase their knowledge and research skills critical for graduate education and professional development.
- Completed monthly progress report, attended cohort meetings, and attended 4 workshops
- Presented at UNLV Research Symposium and at a national conference

11/2018 — NAN Conference Volunteer
National Academy of Neuropsychology (NAN) 38th Annual Meeting, New Orleans, LA

08/2017 - 05/2018 — Clinical Student Committee Representative
Department of Psychology
University of Nevada, Las Vegas

- Organized events and assisted in facilitating a working relationship among faculty and students. Disseminated pertinent information to the clinical psychology graduate students.

01/2017 - 01/2018	Division 45 Program Student Reviewer *American Psychological Association 2017 Convention*
08/2017	Student Ambassador for President's Initiative for 125th APA Convention *American Psychological Association 2017 Convention, Washington D.C.* International Leader: James Kagaari, Ph.D., President of Uganda Council of Psychologists • Hosted an invited president of international psychology organization during 125th APA convention. Guide them to events, answer questions about APA and the convention, as well as general US and psychology related questions.
01/ 2015 - 11/ 2015	Campaign Manager for APA Presidential Election 2015 *American Psychological Association* Candidate: Antonio E. Puente, Ph.D. • Maintained campaign schedule and activities; delegated and oversaw campaign team of 15 members; developed and distributed various surveys via survey monkey™ and mailchimp™; designed, created, and maintained campaign website; distributed social media/ email/ listerv announcements to spread awareness to APA professionals and members.

PROFESSIONAL AFFILIATIONS / MEMBERSHIPS

American Psychological Association for Graduate Students, Member
Asian Neuropsychological Society, Student Member
Association of Neuropsychological Students and Trainees, Member
National Academy of Neuropsychology, Student Member