ImPACT Normative Data of Ethnically Diverse Adolescent Athletes

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ABSTRACT

Objective: The aim of this research was to develop preliminary norms for the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) administered to a large sample of adolescent athletes from diverse ethnic backgrounds.

Design: A retrospective records review

Setting: Middle and high school athletic departments

Participants: 5741 male and female adolescent athletes in Hawaii, ages 13-18, grades 9-12

Independent Variables: Age, sex, ethnicity, and sport

Main Outcome Measures: ImPACT Composite scores (Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, Impulse Control) and Total Symptom score from baseline testing.

Results: The results indicated statistically significant differences between age and sex groups, as well as between ethnic and sport groups.

Conclusions: The findings support the continued use of stratified norms for age and sex for ethnically diverse adolescent athletes. Comparisons of ethnic and sport groups deserve further investigation. When baseline scores are not available for post-concussion comparison, present observations tentatively support the cautious use of standard ImPACT norms with ethnically diverse athletes.

Key Words: neuropsychological, ethnic minority, age, sex, concussion

This large-scale study is, to date, the first to present the scores of a widely used sport-related computerized neuropsychological test battery with a population of ethnically diverse adolescent athletes.

INTRODUCTION

While traditional medical neurodiagnostic methods remain at the forefront in examining sport-related concussions, neuropsychological assessment is being increasingly employed in the evaluation and management of head injuries across a wide range of sports and levels of play.[1,2] In recent times, customary paper-and-pencil neuropsychological tests are often replaced by user-friendly computerized neuropsychological instruments, based on peer-reviewed evidence for their use in sport medicine. Examples include the Automated Neuropsychological Assessment Metrics (ANAM),[3] Cog Sport,[4] CNS Vital Signs,[5] and the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).[6] From among these instruments, ImPACT has emerged as one of the most widely used neuropsychological tools in North America for the assessment of concussion.[7] A typical application of ImPACT involves the comparison of the concussed athlete's test performance with pre-season baseline testing levels that assists in medical clearance and return-to-play decisions. On other occasions, when an athlete has not completed baseline testing, post-injury ImPACT test data can be effectively compared to normative data provided by the developers of this test battery.[8,9] Updated normative ImPACT standards for adolescent athletes are available online,[10] but very limited information is available as to the potential influence of demographic and sociocultural factors on neuropsychological tests, like ImPACT.[11,12,13] When test scores are interpreted based on the norms of the mainstream population, an overestimate of neurocognitive deficits could occur among minority individuals, who tend to obtain lower scores on standard psychological tests.[14,15] Hence, there are reasonable concerns that

ImPACT norms developed across the United States may not be an appropriate reference base for athletes from certain areas of the country with significant ethnic minority populations.[16,17] In these situations, when a neuropsychological test instrument, such as ImPACT, is used, representative comparative data from ethnically diverse populaces may be needed to avert the misdiagnosis of concussed young athletes.

Studies that examine the ImPACT composite scores of ethnic minority athletes are sparse, with inconsistent findings. A study in South Africa found that the ImPACT neurocognitive scores of English-speaking black and mostly white South African rugby players were similar to U.S. football players, although the South African group reported higher concussion-related symptoms. [12] The investigators concluded that U.S. derived ImPACT normative data were appropriate for use with South African athletes. Researchers who compared 48 White and 48 African American high school and collegiate student athletes found no significant group differences on baseline ImPACT composite scores and total symptoms, but reported lower post-concussion ImPACT performances for the African American athletes compared with the White athletes.[11] The authors stated that ImPACT is a culturally equivalent neurocognitive measure and suggested that separate norms for African Americans are not warranted. In contrast, researchers who examined the ImPACT results of professional baseball players, found that native Spanish-speaking players performed more poorly on five of the six ImPACT scores (Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, and Total Symptom) compared with native English-speaking U.S. players.[18] However, when education was considered, the differences in Verbal Memory and Total Symptom became non-significant. The investigators, nonetheless, stated that sociocultural factors could

influence ImPACT and other similar test instruments. A large-scale study of high school athletes revealed small but significant differences on Verbal Memory, Visual Motor Speed, and Reaction Time scores of 9,733 bilingual Hispanic high school athletes compared with 11,955 English-speaking high school athletes.[13] The authors highlighted the importance of cultural and language differences when comparing the test scores of bilingual athletes with ImPACT normative data that could result in false positive misdiagnoses of post-concussion test performances.

Two studies comprised largely of ethnic minority Hawaii high school athletes found that the ImPACT test performance of Hawaii athletes, based on visual comparisons of test data, were mostly similar to the ImPACT norms, but with a trend toward slightly lower ImPACT scores among the Hawaii participants.[19,20] The 2008 Hawaii study, consisting of 751 student-athletes, failed to report details regarding sociocultural factors, such as ethnicity and bilingualism, and the more recent 2014 Hawaii investigation, comprised of only 247 male high school athletes, also did not examine sociocultural factors.

Normative studies of ImPACT scores with a large sample of ethnic minorities are, to our knowledge, non-existent. The goal of this research was to obtain ImPACT normative test data of adolescent athletes in Hawaii, where a high percentage of individuals of ethnically diverse backgrounds is present. An ImPACT normative data set, stratified in terms of age and sex, obtained from a multi-ethnic population could be of value for those managing the care of young concussed athletes from ethnically diverse origins, particularly when relevant baseline test results are not available. Approval for the use of the research data was granted by the State of Hawaii Department of Education.

The archival study was reviewed by the Hawaii Pacific Health Research Institute and was determined to be exempt from institutional review board review.

METHODS

Test Measures

This study utilized the ImPACT battery, which has been employed in several studies of concussions among high school athletes.[21] ImPACT is a web-based computerized neuropsychological test battery developed for the assessment of sport-related concussion in youth, collegiate, and professional athletes. ImPACT consists of computerized instructions and testing procedures in a routine group setting. The test battery, which takes about 30 minutes to complete, was administered in small groups of about 20 participants prior to the season, monitored by certified athletic trainers trained in the standardized administration of the examination.

ImPACT produces five neurocognitive Composite scores, including Verbal Memory, Visual Memory, Visual Motor Speed, Reaction Time, and Impulse Control. The testing also yields a Total Symptom score, based on the ImPACT Post-Concussion Symptom Scale that consists of 22 commonly reported symptoms, e.g., headache, dizziness. The test provides self-reported demographic and health information, such as age, sex, years of education, ethnicity, native language, sport played, prior concussion, and history of seizures, psychiatric illness, learning disability, or attention deficit disorder. Despite the popular usage of ImPACT, the reliability and validity of this instrument has been debated.[7,22,23] A more complete description of ImPACT can be found elsewhere.[10]

Participants

From an original pool of 6341 Hawaii adolescent athletes, 600 (9.5%) were excluded from the study because of invalid profiles that were automatically identified by the online ImPACT version that incorporates various validity criteria, includes the following cut-off scores: Impulse Control Composite score ≥30, X's and O's–Total Incorrect >30, Word Memory–Learning Percent Correct <69, Design Memory–Learning Percent Correct <50, and Three Letters–Total Letters Correct <8.[10] The rate of invalid baseline ImPACT test results among high school and college athletes ranges from 6 to 12%.[24]

The participants for this normative study were 5741 English-speaking athletes (3313 males, 2428 females) in 36 schools, grades 8 to 12. The mean age of the participants was 15.06 years (*SD* = 1.21). Athletes included 1383 8th graders, 1507 9th graders, 1517 10th graders, 944 11th graders, and 71 12th graders (319 had missing data for their grade). Consistent with the ImPACT normative categories,[10] participants were divided into sex and age (13 to 15 year olds and 16 to 18 year olds) categories. There were 2024 males and 1573 females in the 13 to 15 year-old age range, and 1289 males and 855 females in the 16 to 18 year-old age range.

The racial/ethnic makeup of the participants included 1570 Native Hawaiians or other Pacific Islanders, 1266 Asians, 470 Caucasians, 129 Hispanics, 92 African Americans, 17 Native Americans or Alaskan Natives, and 1712 mixed racial backgrounds (485 had missing data for their race/ethnicity). In reporting their primary language, 5545 participants identified English as their primary language. Those who reported non-English primary languages included Filipino (*n* = 51), Samoan (*n* = 27), Japanese (*n* = 23), Spanish (*n* = 18), Tongan (*n* = 16), and others (*n* = 61).

The numbers of athletes in the varied sports were football (n = 1954), soccer (n = 1049), basketball (n = 804), volleyball (n = 709), cheerleading (n = 390), softball (n = 150), baseball (n = 127), and others (n = 140) (418 had missing data for their sport). Regarding concussion history, 648 athletes reported having a previous concussion, including 474 with one concussion, 114 with two concussions, and 60 with three or more concussions.

Included in the study were athletes who reported a history of learning disability (n=70, 1.22%), or ADD/ADHD (n=149, 2.60%), which was below the 5-15% prevalence found in the general population.[25]

Statistical Analyses

The *Ms* and *SDs* for the six ImPACT baseline test scores were calculated, stratified by age groups (13-15 and 16-18) and sex. MANOVA comparisons of age and sex were performed. Because of the marked differences in the sample sizes of the seven ethnic groups, MANOVA was performed only on the three largest groups: Asian (n = 1266), Hawaiian/Pacific Islander (n = 1570), and Mixed (n = 1712). The sample sizes of the 15 sport groups also varied considerably. Thus, MANOVA was conducted only on the four largest groups: football (n = 956), soccer (n = 1049), basketball (n = 804), and volleyball (n = 709). With significant MANOVA results, post-hoc Pillai's Trace was conducted.

Bonferroni corrections were applied to account for multiple comparisons (0.05/6), resulting in an alpha level of P = .008. Effect size was reported as *partial* η^2 for MANOVA. Statistical analyses were conducted with SPSS Statistics, Version 17.

Our request to obtain ImPACT raw normative data from the test publishers for direct statistical analyses with the Hawaii data was unsuccessful. Thus, we were only able to present the normative data collected in Hawaii, along with the published ImPACT normative tables, for non-statistical, visual comparisons. For the purpose of comparing specific data sets, the following classification ranges for the ImPACT composite scores, corresponding to the published normative tables, were employed with the Hawaii data (showing percentile ranks in parentheses): Very Superior (98+), Superior (91-97), High Average (76-90), Average (25-75), Low Average (10-24), Borderline (2-9), and Impaired (<.13-1.9).

RESULTS

The means (*M*) and standard deviations (*SD*) of the six ImPACT scores of the age groups are presented in Table 1. MANOVA, using Pillai's trace, revealed significant age differences, $V = .036$, $F\ (6, 5734) = 35.96$, $P < .001$. The effect size, *partial* $\eta^2 = .036$, was small. Athletes ages 16-18 scored better on all five Composite scores than those ages 13-15. No age difference was seen in the Total Symptom score.

The *M*s and *SD*s of the six ImPACT variables of the sex groups are shown in Table 2. Differences between sex groups were statistically significant, $V = .037$, $F\ (6, 5734) = 36.54$, $P < .001$. The effect size, *partial* $\eta^2 = .037$, was small. Post-hoc tests indicated that girls obtained better scores than boys in Visual Motor Speed, Reaction Time, and Impulse Control, and had higher Total Symptom scores than boys. Boys obtained higher scores than girls in Visual Memory.

The *M*s and *SD*s of the ImPACT scores of the three ethnic groups are seen in Table 3. Signficant differences were found between the ethnic groups, $V = .053$, $F\ (12,$

9082) = 20.86, P <.001. The effect size, *partial* η^2 = .027, was small. Post-hoc tests revealed that the Asian participants obtained significantly better scores on all six ImPACT variables than the Hawaiian/Pacific Islander participants, and better on three ImPACT scores (Visual Motor Speed, Reaction Time, Impulse Control) than the Mixed group. The Mixed group had better scores then the Hawaiian/Pacific Islander group on all of the ImPACT variables, except Impulse Control.

The *M*s and *SD*s of the ImPACT scores of the four sport groups are shown in Table 4. Comparisons between the sport groups were statistically significant, V = .067, F (18, 13527) = 17.12, P <.001. The effect size, *partial* η^2 = .022, was small. Post-hoc results indicated that the soccer group obtained significantly better scores than football on four variables (Verbal Memory, Visual Motor Speed, Reaction Time, Impulse Control), and better scores than volleyball participants on Visual Motor Speed. Basketball and volleyball participants obtained better scores than football on three ImPACT variables (Visual Motor Speed, Reaction, Impulse Control). No sport group differences were seen in Visual Memory and Total Symptom.

Clinical reference values for the ImPACT scores, with percentile ranks of the Hawaii scores and the ImPACT normative scores of the age and sex groups of this study, are shown in Tables 5 to 8. The Hawaii scores were predominantly similar to the classification ranges in the ImPACT normative sample for the 13 to 15 and 16 to 18 year-old age ranges, with some exceptions. Differences are seen in Tables 5 to 8, with the Hawaii athletes performing lower than the ImPACT norms in the following: (1) the Impaired and Borderline ranges of the Visual Motor Speed scores for males 13-15; (2) the Impaired, Borderline and High Average ranges of the Visual Motor Speed scores for

males 16-18; (3) all classifications in Verbal Memory for females 13-15; (4) the Impaired and Borderline ranges in Visual Motor Speed for females 13-15; and (5) the Impaired and Borderline ranges in Visual Motor Speed for females 16-18. It should be noted that the differences between our sample and the ImPACT norms were observed visually and were not based on statistical analyses.

DISCUSSION

This study represents one of the first efforts to obtain normative data for a computerized neuropsychological test battery when administered to a large ethnically diverse sample of English-speaking adolescent athletes. The significant age groups and sex differences in this study, as in prior research, support the standard practice of test publishers to separate normative data by age and sex. The statistical evidence provided here suggests that this practice be extended to include ethnicity. Age-specific norms are important to determine how an athlete is functioning compared to similar age peers, as notable cognitive development occurs during adolescence.[26,27] Sex-specific norms are also needed in view of the male-female differences seen in this study and in past neurocognitive testing of high school and collegiate athletes.[28,29]

The significant ethnic group differences found on ImPACT scores in this study are compatible with two prior investigations that compared bilingual Hispanic athletes with English-speaking players, although the ethnicity of the English-speaking participants was not specified.[13,18] The ImPACT scores of the present sample of diverse ethnic groups were predominantly similar to the ImPACT norms, but the notable differences seen between the three largest ethnic groups suggest that sociocultural influence and other demographic factors can affect the performance of ethnic minorities on computerized

neuropsychological test instruments. Given the absence of ethnic-related normative studies of the ImPACT battery, the specific reasons for the differences found between ethnic groups are not immediately explainable. A plausible cause of lower ethnic group test scores could be that skills assessed in these tests, such as speed and verbal memory, may be important in the mainstream culture, but may not be valued in varied ethnic cultures.[30] Less familiarity with test content and problem-solving experiences could also lower the performances of minority subjects.[32]

The above findings are at odds with two ImPACT studies that found no differences between White vs. African American high school and collegiate athletes and between U.S. football players vs. South African rugby players.[11,12] The relatively small sample size (48 white, 48 African American) in the Kontos et al. study lacked statistical power that probably contributed to their insignificant results.[11] The Shuttleworth-Edwards et al. study consisted of 11,257 participants who were predominantly white male athletes, with the South African athletes coming from relatively advantaged educational and occupational backgrounds, which may have constricted the socioeconomic range of the participants and resulted in insignificant ImPACT score differences.[12] In contrast, our 5741 participants consisted of a diversity of whites, Hawaiian/Pacific Islanders, Asians, Hispanics and African Americans, representing a broad cross-section of the Hawaii population that facilitated the significant ethnic differences in this study.

The investigation of test data from a culturally unique population like Hawaii recognizes that diversity is a feature of the U.S. population that needs to be examined in our practice of neuropsychological testing of young athletes. Recent neuropsychological

studies have provided demographically corrected reference tables in response to the need for representative normative test data for different regional and cultural groups.[31,32] Likewise, the present research presented clinical reference percentiles that can serve as guides in assessing an athlete's ImPACT scores in Hawaii. Accuracy of neuropsychological assessments can improve when the norms applied to the athlete are demographically compatible with the individual.[16,33,34]

The significant differences between sport groups on ImPACT scores are noteworthy, with football players obtaining poorer test results than their cohorts in soccer, basketball, and volleyball. There is a paucity of studies that compare the cognitive test scores of athletes participating in different sports. Some researchers note few differences in neuropsychological test scores between contact sport athletes (e.g., football, ice hockey, soccer and rugby) and non-contact sport athletes (e.g., track, skiing, tennis, and swimming), and report no differences across a battery of neuropsychological tests.[35,36] Other investigators, in contrast, found significant differences between high contact sport athletes (football) and low contact sport athletes (wrestling, soccer, baseball, judo, basketball) on two of five ImPACT Composite scores (Processing Speed, Reaction).[37] Whether the cognitive test scores differences between high and low contact sport athletes are due to selective factors or to participation in certain sports remain to be determined.

Visual comparisons suggested that the ImPACT composite scores of 5741 Hawaii youth athletes were, with some exceptions, predominantly comparable to those of the available ImPACT normative data and were similar to the ImPACT scores previously obtained in Hawaii with much smaller samples.[19,20] At the same time, these tables

indicate that certain ethnic minority athletes tend to score lower than the ImPACT norms, such as female athletes ages 13-15, especially in Verbal and Visual Memory (See Table 7). The tables in this study can serve as a general guide for those who evaluate adolescent athletes in regions with a significant presence of ethnic minorities. Without statistical comparisons of the Hawaii and ImPACT norms, however, no other observations can be drawn.

LIMITATIONS

The limitations of the current work are worthy of note. Because of the unified state educational system in Hawaii, the normative data in this study include all of the public schools in the state, resulting in one of the largest number of participants in a study of this nature. The large sample size in this study provided more power to detect statistically significant differences, with small effect sizes, between the age, sex, and ethnic groups. At the same time, it is essential to recognize that the small effect sizes in these analyses indicate that the difference between the age, sex, and ethnic groups were small and of questionable clinical significance.[38] The findings of this study, which focused specifically on adolescent athletes, may not be applicable to other age groups, such as pre-teen and collegiate athletes. Another shortcoming of this retrospective study was the lack of information about the socioeconomic status, general intellectual abilities, language skills, and acculturation level that may have affected the results. Other than the exclusion of those who were identified as having invalid ImPACT profiles, there was no formal effort testing to assure optimal level of test performance by the athlete. Research indicates that 11% of high school football players provide baseline scores that reflect insufficient effort on neuropsychological tests.[39] Finally, the inability to compare

statistically the current ImPACT norms with the normative data of the Hawaii sample of adolescent athletes compromised the utility of the current ImPACT norms with the local population.

The drawbacks of separate normative datasets for a specific region should be mentioned. The regional norms may be of value to athletes whose demographic characteristics are similar to those of the local normative sample, but have limited relevance outside of the geographic area where the data were collected .[16] Moreover, the differences in norms could reinforce a negative stereotype of the subpopulation, particularly when the test scores are somewhat lower than the majority population, as it is in the present study. Finally, the availability of separate norms might lead to unnecessarily lower expectations for youths from minority groups who differ culturally and linguistically from the majority.[40]

CONCLUSIONS

The present study provided ImPACT normative data from a large sample of adolescent athletes from ethnically diverse backgrounds, and offered information regarding age, sex, and ethnic group differences not available in the earlier normative research with Hawaii high school athletes.[19,20] The scores revealed age and sex differences that were consistent with previous published reports of ImPACT test results. The findings support the continued practice of providing age- and sex-specific normative test data. The current results were also found to be predominantly similar to the standard ImPACT norms, which tentatively suggested that ImPACT norms can be utilized, albeit cautiously, with youth athletes in regions with a large presence of ethnic minorities.

REFERENCES

1. McCrory P, Meeuwisse WH, Aubry M, et al. Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Clin J Sport Med*. 2013; 23: 89-117.
2. Halstead ME, Walter KD. The Council on Sports Medicine and Fitness. Clinical report -- Sport-related concussion in children and adolescents. *Am Ped.* 2010; 126(3): 597-615.
3. Bleiberg J, Kane RI, Reeves DL, et al. Factor analysis of computerized and traditional tests used for mild brain injury research. *Clin Neuropsychol.* 2000; 14(3): 287-294.
4. Collie A, Darby, Maruff P. Computerised cognitive assessment of athletes with sports related head injury. *Br J Sports Med*. 2001; 35(5): 297-302.
5. Gualtieri CT, Johnson LG. Reliability and validity of a computerized neurocognitive test battery, CNS Vital Signs. *Arch Clin Neuropsychol.* 2006; 21: 623-643.
6. Collins MW, Iverson GI, Lovell MR, et al. On-field predictors of neuropsychological and symptom deficit following sports-related concussion. *Clin J Sport Med.* 2003; 13(4): 222-229.
7. Alsalaheen B, Stockdale K., Pechumer D, et al. Validity of the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT). *Sports Med*. 2016. doi: 10.1007/s40279-016-0532-y.
8. Echemendia RJ, Bruce JM, Bailey CM, et al. The utility of post-concussion neuropsychological data in identifying cognitive change following sports-related MTBI in the absence of baseline data. *Clin Neuropsychol.* 2012; 26(7): 1077-1091.

9. Schmidt JD, Register-Mihalik JK, Mihalik JP, et al. Identifying impairments after concussion: normative data versus individualized baselines. *Med Sci Sports Exer*. 2012; 44(9): 1621-1628. DOI: 10.1249/MSS.06013e3182a9fb.
10. Lovell MR. *ImPACT technical manual: Online ImPACT 2007-2012 (Vol. 2013).* Pittsburgh, PA: ImPACT Applications, Inc.; 2011.
11. Kontos AP, Elbin RJ III, Covassin T, et al. Exploring differences in computerized neurocognitive concussion testing between African American and White athletes. *Arch Clin Neuropsychol.* 2010; 25: 734-744.
12. Shuttleworth-Edwards AB, Whitefield-Alexander VJ, Radloff SE, et al. Computerized neuropsychological profiles of South African versus US athletes: a basis for commentary on cross-cultural norming issues in the sports concussion arena. *Phys Sportsmed.* 2009; 37(4): 45-52.
13. Ott S, Schatz P, Solomon G, et al. Neurocognitive performance and symptom profiles of Spanish-speaking Hispanic athletes on the ImPACT test. *Arch Clin Neuropsychol.* 2014; 29: 152-163.
14. Lezak MD, Howieson DB, Bigler ED, et al. *Neuropsychological Assessment. 5th ed*. New York: Oxford University Press; 2012.
15. Echemendia RJ, Harris JG. Neuropsychological test use with Hispanic/Latino populations in the United States: Part II of a national survey. *Appl Neuropsychol.* 2004; 11: 4-12.
16. Strauss E, Sherman EMS, Spreen O. *A Compendium of Neuropsychological Tests: Administration, Norms, and Commentary. 3rd ed.* New York: Oxford University Press; 2006.

17. Wong TM, Strickland TL, Fletcher-Jansen E, et al. Theoretical and practical issues in the neuropsychological assessment and treatment of culturally dissimilar patients. In: Fletcher-Jansen E, Strickland TL, Reynolds CR, eds. *Handbook of Cross-Cultural Neuropsychology.* New York: Kluwer Academic; 2000: 3-18.
18. Jones NS, Walter KD, Caplinger R, et al. Effect of education and language on baseline concussion screening tests in professional baseball players. *Clin J Sport Med.* 2014; 24(4): 284-288.
19. Tsushima WT, Oshiro R, Zimbra D. Neuropsychological test performance of Hawaii high school athletes: Hawaii ImPACT normative data. *Haw Med J.* 2008; 67:93-95.
20. Tsushima WT, Siu AM. Neuropsychological test performance of Hawaii high school athletes: updated Hawaii ImPACT data. *Haw J Med Publ Hlth*. 2014; 73(7): 208-211.
21. Lovell MR. Neuropsychological assessment of the professional athlete. In: Echemendia RJ, ed. *Sports Neuropsychology: Assessment and Management of Traumatic Brain Injury.* New York: The Guilford Press, 2006: 176-190.
22. Mayers LB, Redick TS. Clinical utility of ImPACT assessment for postconcussion return-to-play counseling: psychometric issues. *J Clin Exper Neuropsychol*. 2012; 34(3): 235-242.
23. Schatz P, Kontos A, Elbin R. Response to Mayers and Redick: "Clinical utility of ImPACT assessment for postconcusssion return-to-play counseling: psychometric issues." *J Clin Exper Neuropsychol.* 2012; 34(4), 428-434; discussion 435-442.

24. Schatz P, Moser RS, Solomon GS, Ott SD, Karpf R. Prevalence of invalid computerized neurocognitive test results in high school and collegiate athletes. J Athl Train. 2012; 47(3): 289-296.

25. American Psychiatric Association. *Diagnostic and Statistical Manual, Fifth edition*, DSM-5. Washington, DC: American Psychiatric Association, 2013.

26. Russo Buzzini SR, Guskiewicz KM. Sport-related concussion in the young athlete. *Curr Opin Pediatr.* 2006; 18: 376-382.

27. Kirkwood MW, Yeates KO, Wilson PE. Pediatric sport-related concussion: a review of the clinical management of an oft-neglected population. *Pediatrics.* 2006; 117: 1359-1371. DOI: 1542/peds.2005-0994.

28. Broshek DK, Kaushik T, Freeman JR, et al. Sex differences in outcome following sports-related concussion. *J Neurosurg*. 2005; 102: 856-863.

29. Covassin T, Elbin RJ, Harris W, et al. The role of age and sex in symptoms, neurocognitive performance, and postural stability in athletes after concussion. *Am J Sports Med.* 2012; 40(6): 1303-1312. doi: 10.1177/0363546512444554

30. Roselli M, Ardila A. The impact of culture and education in non-verbal neuropsychological measurements: a critical review. Brain Cognition. 2003; 52(3): 326-333.

31. McKay CD, Brooks BL, Mrazik M, et al. Psychometric properties and reference values for the ImPACT neurocognitive test battery in a sample of elite youth ice hockey players. *Arch Clin Neuropsychol.* 2014; 29: 141-151.

32. Yang L, Unverzagt FW, Jin Y, et al. Normative data for neuropsychological tests in a rural elderly Chinese cohort. *Clin Neuropsychol.* 2012; 26 (4): 641-653.

33. Echemendia RJ, Iverson GL, McCrea M, et al. Advances in neuropsychological assessment of sport-related concussion. *Br J Sport Med.* 2013; 47: 294-298.

34. Merritt VC, Meyer JE, Cadden MH, et al. Normative data for a comprehensive neuropsychological test battery used in the assessment of sports-related concussion. *Arch Clin Neuropsychol*. 2017; 32: 168-183.

35. McAllister TW, Flashman LA, Maerlender A, et al. Cognitive effects of one season of head impacts in a cohort of collegiate contact sport athletes. *Neurol*. 2012; 78(22): 1777-1784.

36. Stephens R, Rutherford A, Potter D, et al. Neuropsychological consequence of soccer play in adolescent U.K. school team soccer players. *J Neuropsychiat Clin Neurosci.* 2010; 22(3): 295-303. PMID:20686136.

37. Tsushima WT, Geling O, Arnold M, et al. Are there subconcussive neuropsychological effects in youth sports? An exploratory study of high and low contact sports. *Appl Neuropsychol: Child*. 2016; 5*:*149-155. doi: 10.1080/21622965.2015.1

38. Page P. Beyond statistical significance: clinical interpretation of rehabilitation research literature. Int J Sports Phys Ther. 2014; 9(5): 726-736.

39. Hunt T, Ferrara M, Miller L, et al. The effect of effort on baseline neuropsychological test scores in high school football athletes. *Arch Clin Neuropsychol.* 2007; 22: 615-621.

40. Manly JJ. Advantages and disadvantages of separate norms for African Americans. *Clin Neuropsychol.* 2005; 19: 270-275.

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