Normative Data in a Sample of Canadian University Athletes Using ANAM Tests

Michael Hutchison, Paul Comper, Lynda Mainwaring, and Doug Richards
University of Toronto

The baseline / postconcussion neuropsychological (NP) assessment model has been shown to be of clinical value and currently contributes significant information in sport concussion evaluation. Computerized NP batteries are now widely used in elite sport environments and are rapidly becoming more commonly utilized at the community level. With the growth of computerized NP testing, it is important to identify and understand unique characteristics with respect to baseline NP performance. The Automated Neuropsychological Assessment Metrics (ANAM) is a library of computerized NP tests designed to detect speed and accuracy of attention, memory, and thinking ability. This article describes baseline ANAM test scores in a sample of Canadian university athletes and explores the following two factors: (a) performance differences between male and female student-athletes using ANAM tests and (b) the relationship between self-reported history of concussion and baseline NP performance.

Keywords: neuropsychology, sport, athlete, ANAM, concussion

Neuropsychological (NP) testing to assess athletes with sports-related concussion was first described by Barth nearly 30 years ago (Barth et al., 1983). Since then, the sports NP paradigm has received considerable attention, with a sizeable and growing body of literature devoted to the topic. The “baseline”/postconcussion NP assessment model (Barth et al., 1983) is currently considered by many clinicians to be an essential element of sports concussion management. Compared with the more “traditional” approach to NP testing in other contexts (for example, in a rehabilitation hospital setting, where the comprehensive NP assessment of an individual can take several hours to several days), NP baseline assessment of athletes in a sports context is frequently done in groups and is usually quite brief, typically taking no more than 1 hr.

In the early years of sports NP testing, measures were comprised exclusively of paper-and-pencil tests familiar to most neuropsychologists, including the Trail
Making Test (Partington & Leiter, 1949), the Symbol Digit Modality Test (Smith, 1982), the Controlled Oral Word Association Task (Lezak, 1995), verbal learning tests (e.g., Hopkins Verbal Learning Test [Brandt, 1991]), and others. NP tests such as these were used because of their known reliability in assessing cognitive changes following mild traumatic brain injury. However, the reliance on traditional paper-and-pencil tests to conduct baseline and postconcussion NP testing in the sports environment declined with the advent and widespread application of computer technology.

Computerized NP testing affords some obvious advantages over paper-and-pencil testing, including portability, ease of repeatability, a high degree of measurement sensitivity, and rapid data analysis. On the downside, however, computers can malfunction and differences in microprocessors can lead to measurement error, potentially leading the researcher to spurious conclusions. Moreover, although computers are seen by many as being more reliable and generally better than traditional testing methods, the importance of clinical acumen and interpretation might be minimized with an over-reliance on technology. At best, computerized NP protocols are essentially a good screening tool suitable to augment, but not replace, comprehensive neuropsychological testing. Despite the availability and ease of test administration of computerized NP tests, test administration is fundamentally different than test interpretation (Echemendia, Herring, & Bailes, 2009). NP tests results require an understanding of the interactions among test data, psychometric properties, sources of error, and clinical history and symptom(s) profile (Echemendia, Herring, & Bailes, 2009).

Presently, several computerized NP platforms are widely used to screen for cognitive changes that might occur in various populations affected by a number of adverse conditions, including the effects of sports-related concussion. These protocols include ImPACT (Iverson, Lovell, & Collins, 2003, 2005; Iverson, Lovell, Podell, & Collins, 2003), CogSport (Collie et al., 2003; Makdissi et al., 2001), Concussion Resolution Index (CRI; Erlanger et al., 2003; Erlanger et al., 2001), and the Automated Neuropsychological Assessment Metrics (ANAM; Reeves, Winter, Bleiberg, & Kane, 2007). Despite potential limitations, computerized NP tests now play an important role in the assessment and postconcussion management of large groups of athletes across professional (Lovell et al., 2006), college/university (Collins et al., 1999; Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; McCrea et al., 2003), and high school levels (Lovell, Collins, Iverson, Johnston, & Bradley, 2004; Moser, Schatz, & Jordan, 2005).

The Present Study

Data indicate that concussion rates in high school and college/university football have ranged between approximately 3–4% (McCrea, Kelly, Randolph, Cisler, & Berger, 2002; Powell & Barber-Foss, 1999) and 7–9% (Covassin et al., 2006; Maciocchi, Barth, Alves, Rimel, & Jane, 1996). Consistent with these prevalence rates, the incidence of concussion among athletes at our own university ranges from 5 to 10% in a given year (Comper, 2007; Hutchison, Mainwaring, Comper, Richards, & Bisschop, 2009; Kristman et al., 2008; Mainwaring, Richards, Comper, Hutchison,
With these high numbers, it becomes imperative to accurately and efficiently assess for and manage sports-related concussion, and make return-to-play decisions that are in the best interest of the athletes with whom we work. Therefore, a main goal of our work has been to validate objective measures and clinical practice guidelines to assist physicians in making safe, but not overly cautious, return-to-play decisions for athletes who have sustained concussions. Since 1999, our work has led us to a better understanding of the natural history of recovery from sports-related concussion using a variety of outcome measures. Similar to many other sports-related concussion research programs/studies, we have employed various NP measures including both traditional paper-and-pencil batteries, as well as newer computerized test protocols to measure cognitive abilities at baseline and changes after concussion. With the advent and use of computerized test protocols, it is prudent to evaluate these tools and consider potential unique characteristics among the athletic population. Since 2003, we have primarily used Automated Neuropsychological Assessment Metrics (ANAM; Reeves et al., 2007) tests as our assessment test protocol to detect and monitor cognitive deficits.

The ANAM test battery is a module-based library of computerized cognitive tests developed by the U.S. Department of Defense to measure cognitive performance and change under a variety of normal and adverse circumstances (Reeves et al., 2007). Applications of ANAM tests in clinical populations such as multiple sclerosis (Wilken et al., 2003), Alzheimer’s disease (Levinson, Reeves, Watson, & Harrison, 2005), and sports-related concussion. The ANAM tests included in the sports medicine context have varied over the years since the inception of concussion testing, but overall, the tests assess a number of cognitive constructs believed to be vulnerable to concussion (e.g., reaction time, cognitive processing speed, working memory, visuospatial memory). Previous research has shown that the ANAM is able to detect cognitive deficits in individuals in the days immediately following a concussion and can also be used to monitor recovery (Bleiberg et al., 2004; Warden et al., 2001).

Especially in the past 10 years, particular interest has focused on the potential effects of multiple concussions on cognitive functioning. Although there is a body of research that indicates a person’s past history of concussions has little or no effect on computerized NP testing at baseline (Babbs, 2000; Broglio, Ferrara, Piland, Anderson, & Collie, 2006; Bruce & Echemendia, 2009; Collie, McCrory, & Makdissi, 2006; Ivins, Kane, & Schwab, 2009; Straume-Naesheim, Andersen, Dvorak, & Bahr, 2005), the potential long-term effects of concussion require further exploration. For example, a recent study by De Beaumont and colleagues showed that individuals with a remote history of concussion can exhibit neurocognitive deficits linked to earlier concussions that may have occurred decades earlier (De Beaumont et al., 2009). Furthermore, potential differences between male and female athletes on brief NP measures are not well understood. For example, some preliminary work has shown that male athletes perform better than females on visual memory tasks (Covassin, Schatz, & Swanik, 2007; Covassin et al., 2006), whereas females score higher on tests targeted to assess verbal memory (Covassin et al., 2006). Therefore, with this in mind, the current study examined normative data in a sample of Canadian university athletes, with consideration of the following two factors as they relate to baseline neuropsychological test scores, using the ANAM:
(a) differences between male and female student-athletes and (b) the relationship between self-reported history of concussion and baseline NP testing.

**Method**

**Participants**

Having conducted sports-concussion research at our university since 1999–2000, we have found that approximately 325 athletes participate in high-risk sports each season, and we have continuously experienced recruitment rates between 90–95% for our research program over the duration of this project. Athletes who volunteer for our research study are monitored for occurrence and symptoms of concussion. As previously noted, in any given year, the incidence of concussion ranges from 5 to 10% in our samples.

For the present analysis, data from a convenience sample of 764 university athletes were used. All participants read an information letter and completed an informed consent form before participation. Participants completed a demographic questionnaire that assessed background information including age, sex, height, weight, and previous concussion history (up to five previous concussions). Any student-athlete (“athlete”) who reported a prior history of a learning disability or psychiatric disorder was excluded from this analysis. The study was approved by the university’s Ethics Review Board of the Office of Research Services.

Of the 764 athletes, 64.7% were male ($n = 494$) and 35.3% were female ($n = 270$). Male athletes were significantly older at baseline assessment: $20.29 \pm 2.44$ for males, versus $19.88 \pm 2.69$ years for females; $t(753) = 2.30; p = .02$; the average age of all athletes was $20.16 (SD = 2.54, range 17–30)$. Not surprisingly, males were also significantly taller, $182.52 \pm 7.55$ cm for males, versus $169.21 \pm 7.48$ cm for females; $t(753) = 16.82; p < .001$ and weighed, on average, 21 kg more than females, $t(728) = 21.95, p < .0.001$. The number of previously reported concussions was not significantly different between male and female participants ($p = .13$).

**Measure: Automated Neuropsychological Assessment Metric (ANAM) Tests**

All of the athletes completed Automated Neuropsychological Assessment Metrics (ANAM) tests before participation in varsity sports. The ANAM is a brief, self-directed, computerized neuropsychological assessment battery that assesses neuropsychological functioning. The battery takes approximately 25–30 min to administer and includes a number of subtests/modules. Given the longitudinal design of our research program, various iterations of ANAM have been used, with Procedural Processing, Spatial Processing, and Memory Search included in more recent versions. Currently, the set of ANAM tests for concussion surveillance and management is referred to as the Automated Sports Medicine Battery (ASMB; Cernich et al., 2007). The ANAM tests used in the current study were Simple Reaction Time (SRT), Code Substitution – Learning (CDS) and Delayed (CDD), Procedural Reaction (PRO), Match to Sample (MSP), Spatial Processing (SPD), and Memory Search (ST6). For the purpose of clarity, herein we refer to the sports
medicine version simply as ANAM. Only subtests common in the most recent version were used in the present analyses. All tests contained in ANAM yield raw performance measures such as number correct, speed of response, and number of errors. In addition, ANAM raw data are converted to an outcome measure referred to as “throughput,” which is a derivative score based on a participant’s speed and accuracy on any given test. Higher throughput scores and lower reaction times reflect better performance.

Studies have established the validity of ANAM by reporting moderate correlations with ANAM subtests and traditional neuropsychological measures (Bleiberg, Kane, Reeves, Garmoe, & Halpern, 2000; Woodard et al., 2002). The ANAM has also been shown to be sensitive to the effects of concussion in athletic samples (Bleiberg et al., 2004; Richards, Comper, Mainwaring, & Hutchison, 2009). In addition, ANAM reliabilities have been assessed in military and adolescent samples and reliabilities have ranged from 0.38 to 0.87 (Cernich et al., 2007).

**Results**

In the current study, throughput measures and mean reaction times (mean RT) from each ANAM subtest were analyzed. Data were excluded for individuals who attained accuracy below 65% on an ANAM subtest, except for the Simple Reaction Time (SRT) subtest. For SRT, individuals with accuracy below 90%, or mean reaction time above 500 ms on the SRT, had their data for that test excluded. These predetermined cutoffs have been used in other studies using the ANAM; scores below the cutoffs are often excluded because this indicates that such individuals did not understand the test instructions or provide an optimal effort (Bleiberg et al., 2004; Reeves et al., 2006; Warden et al., 2001). In total, 20 participants were excluded from the analyses, representing 3% of our sample, and the specific breakdown by each subtest is as follows: M2S (n = 6; 3 males, 3 females), SRT (n = 3; 2 males, 1 female), CDS (n = 3; 1 male, 2 females), PRO (n = 3; 3 males), CDD (n = 2; 1 male, 1 female), SPD (n = 2; 1 male, 1 female), and ST6 (n = 1; 1 female).

**Sex Differences**

Since age differences between male and female athletes were significantly different in our preliminary analysis, we examined the extent to which age and NP test performance were related. Specifically, correlation coefficients were calculated between age and both throughput and mean RT. Our analyses showed no meaningful relationship between age and test performance in our athlete sample with correlation coefficients ranging from –0.12 to 0.12; therefore, independent t tests were conducted to assess differences between male and female athletes on ANAM performance at baseline assessment (summary data are presented in Table 1). There were significant differences for SPD, t(315) = 3.03, p = .003 and MSP, t(759) = 2.31, p = .021, throughput scores. Specifically, males on average obtained higher test scores on both SPD (95% CI: 0.95, 4.48) and MSP (95% CI: 0.24, 3.95) subtests compared with females. No significant differences were observed for throughput scores across other subtests. In terms of mean RT scores, the only significant subtest was SPD, t(317) = 2.45, p = .015, with males’ reaction times appearing faster than females’ (95% CI: -232.8, -25.32).
Self-Reported History of Concussion

Summary data of self-reported history of concussion are presented in Table 2. To evaluate the relationship between self-reported history of concussion and baseline neuropsychological performance, analyses of variance (ANOVAs) were used to compare ANAM subtest performance among four groupings of history of concussion (0, 1, 2, ≥ 3) and sex. Post hoc analyses were conducted with the Tukey test. Analyses were performed for both throughput and mean RT scores. No significant interactions for sex and history of concussion were found (see Table 3). ANOVAs revealed no significant differences in cognitive performance among athletes with no previous concussion, one concussion, two concussions, and three or more concussions for all subtests, except for the Procedural Processing (PRO) throughput scores, \( F(3,311) = 3.84, p = .01 \) (see Table 4). Post hoc analyses revealed that athletes with one concussion scored higher on PRO than athletes with no concussion \( (p = .038, 95\% \text{ CI: } -9.05, -0.17) \). In addition, athletes with three or more concussions had lower scores on PRO compared to athletes with no previous concussion and one concussion.

Table 1  ANAM Performance at Baseline Assessment

<table>
<thead>
<tr>
<th>Subtest</th>
<th>N</th>
<th>Mean (SD)</th>
<th>95% CL</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRT</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>473</td>
<td>232.90 (31.95)</td>
<td>230.01–235.79</td>
<td>104.26–327.49</td>
</tr>
<tr>
<td>Females</td>
<td>258</td>
<td>230.46 (29.67)</td>
<td>226.82–234.01</td>
<td>121.59–304.41</td>
</tr>
<tr>
<td>SPD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>228</td>
<td>34.61 (7.39)</td>
<td>33.64–35.57</td>
<td>16.76–51.78</td>
</tr>
<tr>
<td>Females</td>
<td>89</td>
<td>31.89 (6.53)</td>
<td>30.52–33.27</td>
<td>17.34–50.49</td>
</tr>
<tr>
<td>MSP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>490</td>
<td>39.76 (12.72)</td>
<td>38.63–40.89</td>
<td>6.84–84.28</td>
</tr>
<tr>
<td>Females</td>
<td>267</td>
<td>37.57 (11.18)</td>
<td>36.22–38.91</td>
<td>9.93–70.16</td>
</tr>
<tr>
<td>CDD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>485</td>
<td>58.67 (14.77)</td>
<td>57.35–59.99</td>
<td>8.07–93.00</td>
</tr>
<tr>
<td>Females</td>
<td>266</td>
<td>57.34 (15.50)</td>
<td>55.47–59.21</td>
<td>5.32–91.84</td>
</tr>
<tr>
<td>CDS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>493</td>
<td>60.22 (10.99)</td>
<td>59.25–61.20</td>
<td>19.99–89.31</td>
</tr>
<tr>
<td>Females</td>
<td>268</td>
<td>59.10 (10.42)</td>
<td>57.85–60.35</td>
<td>12.18–90.37</td>
</tr>
<tr>
<td>ST6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>251</td>
<td>80.20 (18.97)</td>
<td>77.84–82.56</td>
<td>21.32–141.18</td>
</tr>
<tr>
<td>Females</td>
<td>153</td>
<td>81.54 (18.49)</td>
<td>78.59–84.49</td>
<td>27.86–129.63</td>
</tr>
<tr>
<td>PRO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Males</td>
<td>225</td>
<td>109.99 (14.78)</td>
<td>108.05–111.93</td>
<td>44.45–146.64</td>
</tr>
<tr>
<td>Females</td>
<td>92</td>
<td>111.70 (12.70)</td>
<td>109.07–114.33</td>
<td>63.99–149.09</td>
</tr>
</tbody>
</table>

Table 2  Self-Reported History of Concussion

<table>
<thead>
<tr>
<th>History of Concussion</th>
<th>Male n (%)</th>
<th>Female n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>262 (53)</td>
<td>142 (53)</td>
</tr>
<tr>
<td>1</td>
<td>147 (30)</td>
<td>79 (29)</td>
</tr>
<tr>
<td>2</td>
<td>45 (9)</td>
<td>36 (13)</td>
</tr>
<tr>
<td>3</td>
<td>26 (5)</td>
<td>12 (4)</td>
</tr>
<tr>
<td>4</td>
<td>10 (2)</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>4 (1)</td>
<td>1 (0.4)</td>
</tr>
</tbody>
</table>

Note. \( N = 764; n = 494 \) for males; \( n = 270 \) for females.
performed significantly worse on the PRO subtest than athletes with one concussion ($p = .024$, 95% CI: 0.92, 18.49). Orthogonal contrasts further examined history of concussion in general; that is, previous history of concussion compared with no history of concussion: no significant differences were observed.

## Discussion

The present study examined the normative data “profiles” in a sample of Canadian interuniversity athletes stratified by sex and history of concussion using Automated Neuropsychological Assessment Metrics tests. First, we investigated potential differences in NP performance between male and female athletes at baseline. The data indicate that significant differences exist between male and female university-level athletes at baseline assessment on brief computerized cognitive screening measures. Second, we examined the potential influence of self-reported history of concussion on computerized NP performance. Our analyses indicate that a previous history of concussion has little adverse affect on baseline cognitive test scores.

### Sex Differences

Data from the current study indicate that male athletes differ from female athletes on a number of subtests at baseline. Specifically, male athletes scored significantly
higher on tasks involving spatial processing ability and visuo-spatial working memory, i.e., Spatial Processing (SPD) and Match-to-Sample (MSP), compared with their female counterparts. Males also performed significantly better than females in visual search and sustained attention cognitive domains, i.e., Code Substitution—Learning (CDS). Specific to computerized neuropsychological tests, it has been reported that male athletes perform better than females on visual memory tasks (Covassin et al., 2007; Covassin et al., 2006), which is consistent with our current findings.

Brown and colleagues (Brown, Guskiewicz, & Bleiberg, 2007) examined the effects of numerous factors, including sex, on baseline ANAM scores in 327 collegiate athletes. Similar to our results, they found significantly higher throughput scores on the Match-to-Sample subtest among males. However, they also reported that males performed better than females on Simple Reaction Test, whereas females scored significantly higher than males on the Memory Search subtest; this was not replicated in the current study. Yet, our findings of sex differences in NP testing largely support the existing research, not only within the sports concussion literature, but also within the broader, well-documented literature on sex differences in cognitive abilities (Andreano & Cahill, 2009; Johnson & Bouchard, 2007; Kimura, 2002). This suggests that the ANAM subtests that comprise the sports medicine battery may be valid and reliable for assessing cognitive function.

Previous research has reported small but consistent differences on tests targeted to assess verbal learning and memory. Covassin and colleagues (Covassin et al., 2007) evaluated baseline ImPACT scores in collegiate athletes and found that female athletes performed significantly better on verbal memory. In fact, outside of the sports context, females have been found to perform better than males on tests of verbal fluency and memory (Beatty, Mold, & Gontkovsky, 2003; Smith, 1982; Yeudall, Fromm, Reddon, & Stefanyk, 1986). The Coe Substitution-Delayed subtest is the one subtest in the ANAM test battery that is targeted to assess verbal working memory, yet we found no significant differences between male and female athletes. This subtest was not used in the study by Brown and colleagues (Brown et al., 2007), so direct comparisons cannot be made; however, it may be that the Code Substitution-Delayed subtest does not directly measure its intended targeted cognitive construct or sensitive enough to detect differences. This issue needs to be fully explored in future research.

Our results also show that male athletes performed better on a greater number of tasks in this battery than female athletes, raising a question about potential sex bias in the subtests selected for the sports medicine-related subtests of ANAM. The specific subtests are selected to assess cognitive constructs vulnerable to concussion in a sports context. This focused framework, however, may potentially overlook cognitive abilities vulnerable to concussion beyond athletic competition. While on the surface it seems reasonable to select subtests that are most relevant to the immediate context of sport, this may not necessarily allow for a comprehensive assessment for the overall health of the athlete. For example, visuo-spatial ability is crucial in many high-risk sports; not surprisingly, there are more subtests in the sports medicine version of ANAM that target visuo-spatial abilities than other cognitive abilities. Results in this study and elsewhere show that males consistently score higher than females on tests targeting this domain. In other words, the ANAM’s sports medicine version may be designed to measure characteristics
that favor males’ cognitive abilities over females’ because the perceived nature of high-risk sport favors abilities more commonly identified as “masculine.” The potential problem with this is that females who sustain concussions may not be fully or properly assessed for safe return-to-play decisions. If this is the case, this could have serious implications for female athletes. Therefore, critically examining the literature on sex differences in cognitive abilities and matching known sex differences in cognitive abilities with more diverse NP tests may benefit (athletes/researchers/medical personnel) in at least two ways: (a) by providing a more gender-equitable/gender-specific test battery (if found to be necessary) and (b) by offering greater insight into how sports-related concussion affects athletes both on and off the playing field.

While the ANAM was developed and has been primarily administered to U.S. military personnel in various environmental contexts (Reeves et al., 2007), more recently, the ANAM has been used in the sports context. Yet to date, the ANAM battery has assessed predominantly male populations. Given that female sports participation has expanded significantly in the past decade, it is imperative that tests are developed and included with this cognitive functioning differentiation specific to sex in mind.

**Self-Reported History of Concussion**

The present study’s results are consistent with recent research, which has demonstrated little residual effects of self-reported history of concussion on baseline computerized neurocognitive testing performance (Babbs, 2000; Broglio et al., 2006; Bruce & Echemendia, 2009; Collie et al., 2006; Ivins et al., 2009; Straume-Naesheim et al., 2005). Of note, we observed a small group of athletes who demonstrated impaired performance on one measure, namely the Procedural Processing subtest. Having said this, a small subset of athletes with three or more self-reported concussions performed significantly worse than athletes with one previous concussion on this specific ANAM subtest. However, the observed significant difference for one of the six subtests in a particular group suggests that the possible residual neuropsychological changes are small.

Previous research has examined the influence of multiple concussions and baseline NP performance. For example, Broglio et al. (2006) examined collegiate athletes on two computer-based NP tests (ImPACT and CRI) and detected no significant differences between those without and with a self-reported history of concussion on either NP measure. Specific to the ANAM, Brown et al. (2007) also reported no differences between the group of athletes with zero or one self-reported previous concussion compared with those with two or more concussions. Other researchers found similar results (29, 30). Collectively, with the results of the present study, this research may suggest that self-reported history of concussion is either not associated with long-term cognitive deficits, or that any associated declines are not detectable by NP tests at this time.

The growing body of literature supporting the nonsignificant differences on NP testing between groups with and without a self-reported concussion coincides with the neurophysiological understanding of this type of injury. Sports-related concussion is described as a transient alteration in brain function, with no apparent structural abnormalities. In the majority of cases, this type of injury resolves
spontaneously within 7–10 days (Bleiberg et al., 2004; Collins et al., 1999; Field, Collins, Lovell, & Maroon, 2003; Hinton-Bayre, Geffen, & McFarland, 1997; Maciocchi et al., 1996; McCrea et al., 2005; McCrea et al., 2003), as measured by NP tests. Nevertheless, it is important to recognize the potential long-term cognitive risks associated with multiple concussions later in life. The present results suggest only that athletes currently participating at the university level do not appear to be adversely affected by previous concussions as measured by baseline NP testing; however, the long-term neurocognitive consequences of and risks for multiple concussions remain unclear. Despite the lack of a relationship between self-reported concussion history and NP functioning in the literature, recent research on retired professional football players has found that players who sustained three or more concussions during their sporting careers were more likely to be diagnosed with preclinical Alzheimer’s disease or depression (Guskiewicz et al., 2005; Guskiewicz et al., 2007).

It has been suggested that the computerized NP test batteries may not be sensitive enough to detect subtle changes in baseline cognitive performance of athletes with a previous history of concussion (Bruce & Echemendia, 2009). Earlier studies using traditional paper-and-pencil tests have, in fact, reported associations between a history of concussion and baseline NP performance (Collins et al., 1999; Moser et al., 2007; Moser & Schatz, 2002). Attrition of athletic participation may also affect the likelihood of risk for future concussion; Bruce and Echemendia (2009) have previously shown that neurocognitive deficits following sports-related concussion are more pronounced in high school athlete-subjects and that they disappear as athletes enter college/university. A possible explanation for this finding is that not all high school athletes continue athletic participation at the college/university level. Similarly, many athletes competing at the college/university level do not continue to play sports at a highly competitive level after graduation. As a result, the residual baseline neurocognitive deficits associated with multiple concussions are resolved over time in these athletes.

**Practical Implications**

Suffering a concussion is an unfortunate but inherent risk of many sports, regardless of level of play or age of the athlete. Consequently, it is imperative that every attempt is made to mitigate the risk of concussion and/or manage the injury appropriately if it occurs. Many sports organizations, especially at the elite level, have taken a proactive approach and implemented concussion management programs. Such programs often allow for baseline or preseason testing, from which an individualized standard of performance is obtained. Obtaining individualized baseline data is often considered to be the optimal method for monitoring recovery following sport-related concussion, yet access to baseline NP testing, especially at the amateur level, is not always possible. Therefore, the comparison of an athlete’s postinjury NP profile with normative data, even in the absence of a baseline profile, can be a helpful and necessary tool for clinicians (Collie et al., 2003; Lovell et al., 2003). Of importance, for normative data to have clinical relevance, demographic factors that may influence the expected performance should be fully understood.

The present study adds to the growing body of literature on normative NP data and potential modifying factors. We found that athletes’ self-reported history of
previous concussion appears to have little impact on computerized NP test scores. This finding should not undermine the clinical reality that an athlete with a history of concussion is at greater risk of a future concussion, with the potential of future compromised neurological health, the risks of which are not yet well understood.

The present results also highlight the particular importance of the athlete’s sex when making clinical interpretations about the effect of concussions on return-to-play decisions on the basis of NP testing. The identified cognitive differences between males and females call into question the historical development and practical utility of many computerized NP test batteries currently available. Research on normative data in NP testing has primarily focused on male athletes, particularly in football (Barr, 2003; Bleiberg et al., 2004; Collins et al., 1999). Making a clinical determination of impairment based on tests that do not adequately assess the domains of functioning for which a female athlete is dominant may potentially result in erroneous decisions (e.g., classifying a healthy female athlete as “impaired” or vice versa). Therefore, future studies need to be performed with larger and more diverse student-athletes, and using a multitude of validated computerized NP test batteries (Brown et al., 2007).

Computerized NP testing is attractive to researchers and clinicians because of its efficiency and precision. However, it is important for clinicians to understand that scores obtained from NP tests comprise only one component of recovery following concussion. Other important information, such as self-report of symptoms and balance deficits, should be used in combination with these tests in the assessment of the injured athlete to aid in the return-to-play decision-making process.

Conclusion

Computerized NP testing is attractive to researchers and clinicians because of its efficiency and precision. With the increased use of computerized NP tests in athletics, it is important to identify and understand unique characteristics with respect to baseline NP performance. In our study, we were able to identify significant differences between male and female university athletes on ANAM tests involving spatial processing ability and visuo-spatial working memory. Our results also indicate that a previous history of self-reported concussion has little effect on baseline ANAM test scores.

References


