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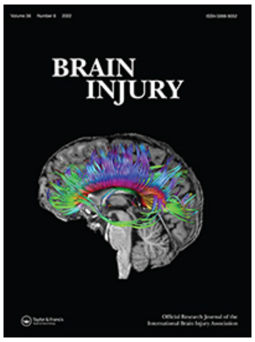

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Test–retest reliability of the neurotracker compared to the impact test for the management of mild traumatic brain injuries during two consecutive university sport seasons

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ABSTRACT

Introduction: Neurocognitive assessment tools such as the Neurotracker and ImPACT have been proposed to optimize sports-related mild traumatic brain injury (mTBI) management. Baseline testing is recommended with such assessments to individualize monitoring of athletes' remission. While the ideal timeframe between baseline updates has been studied for the ImPACT, these data are missing for the Neurotracker.
Objective: The current study aimed to compare the test–retest reliability of the ImPACT and Neurotracker for two consecutive seasons in university athletes participating in sports at risk for mTBI.
Methods: At the start of two consecutive seasons, 30 athletes with no recent history of mTBI completed a baseline assessment including the Neurotracker and the ImPACT. The test–retest reliability of the results was analyzed by considering intra-class correlation (ICC), Becker's standardized mean difference (d_B) and Bland-Altman' plot of each outcome.
Results: The Neurotracker and the Visual Motor Speed composite score of the ImPAC were the only outcomes with significative ICCs and acceptable d_B between the two seasons. Neurotracker was the only outcome with a significative bias (+0.179).
Conclusion: Our research suggests that the Neurotracker has an acceptable level of test–retest reliability after one year in comparison to the ImPACT.

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Concussion; mild traumatic brain injury; neurotracker; 3D-MOT; ImPACT

Introduction

Mild traumatic brain injury (mTBI) is a common injury in sport (1) that has seen its incidence progress considerably since the start of the century (2). Student athletes from high school to university represent the majority of the population at risk of sustaining an mTBI (1,3,4) especially if they play a contact sport such as hockey or soccer (4). mTBI is the result of direct or indirect biomechanical forces transmitted to the head which are common when playing sports, such as head-to-head (direct contact) or a fall on the buttocks (indirect) (5). This injury is due to a complex local cerebral pathophysiological process leading to the rapid onset of neurological symptoms (5,6). Usually, patients present with physical and cognitive symptoms, sleep disturbance and psychological alterations (6). It is expected that the majority of athletes recover within a month after the injury (7–9); however, 10% to 30% of individuals experience a delayed recovery (10–12).

To ensure the appropriate management, an athlete must receive a diagnosis shortly upon injury. Still, identifying and treating sport-related mTBI is complex since health care professionals (HCP) must take quick and reliable decisions in order to limit a player's withdrawal time while protecting them without any clear pathognomonic signs. In fact, to date, there is no single test or imaging method capable of detecting this pathology (6,13,14). This leaves some HCP to trust mostly their clinical suspicion of mTBI when a direct or indirect hit to the head is associated with symptoms, a situation less than ideal to ensure optimal management (15). To overcome this challenge, multimodal assessments should be repeated over time and include physical and neurocognitive functions, signs and symptoms, cranial nerves, and balance (6). The objective of these assessment tools is first to identify the affected functions following the injury and then to follow the athletes' progress throughout recovery.

Symptoms questionnaires are at the basis of the diagnostic assessment because of their low cost and simplicity. But, a weakness inherent in all questionnaires is the use of self-reported measures since up to a third of athletes involuntarily fail to mention symptoms(16) and others voluntarily distort their answers, hence the importance of not using them alone (17,18). Cognitive functions can be evaluated objectively and tend to return to normal later than symptoms (19,20) thus providing an opportunity to be more sensible to the later recovery stages of mTBI. The use of diverse neurocognitive tests investigating memory, attention, executive functioning, language and perception is recommended (5,8,21,22) as it reflects cerebral capacities (23,24). In the absence of direct measurement of brain function sensible to mTBI, these indirect measurements represent the best avenue for HCP (25).

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Because a higher risk of re-injury is associated with misdiagnosis and early return to sport (26), the selected assessment tools must be particularly sensitive and reliable to identify injured athletes with certainty. While a variety of assessments tools exists, first-line HCP are only reporting a moderate level of self-efficacy in the assessment and management of athletes sustaining a sport-related mTBI (27). The challenge keeps rising since specific populations and age groups (28–31) are known to perform at different levels during neurocognitive tests even when healthy. Thus, for athletes, the comparison to normative data to identify the extent of the injury and follow the recovery is associated with a higher risk of false-negative (32). Recommendation is then to use a preseason baseline assessment to subsequently compare the result in case of a mTBI (5,32,33).

Frequently used as a baseline, the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT application inc., USA) is the most widely used and studied computer-based neurocognitive assessment of mTBI in both sport and clinical settings in North America (18). Consisting of six different tests and one symptoms questionnaire, the ImPACT has high internal reliability and can effectively identify neurocognitive changes resulting from mTBI in athletes (14,18,34). In addition, the results are reported to remain stable over time despite repeated exposure (35). A recent meta-analysis concluded that for the acute assessment of mTBI, the sensitivity is 81.9–91.4% and the specificity is 69.1–89,4% for a population of athletes (18). However, its detection capacity is limited beyond eight days post-mTBI (36). This represents quite a limitation for HCP tasked to follow the recovery of athletes over a longer period to ensure a proper return to sport.

In order to find a better assessment for the later stages of recovery from mTBI, the Neurotracker (CogniSens Industries, Canada) was proposed (37). Originally designed to assess and train sport performance in a virtual reality setting, the Neurotracker (37) is one of the most popular perceptual-cognitive training tool in sport (38). This device represents an interesting innovation in the context of mTBI because of its design which uses three-dimensional multiple object tracking (3D-MOT) to evaluate an individual's ability to follow different moving targets through identical distractors, a sport-specific skill, while providing a measure of performance on the attentional standpoint (37,39). Following mTBI, the perceptual-cognitive cerebral capacities allowing the execution of tasks integrating several stimuli seem to be the last to recover (40). A study among professional athletes, which evaluated participants at 48 hours after mTBI and at the time of the return play, showed that 3D-MOT correlated with mTBI symptoms and may be an indicator of the state of recovery through the entire process (41). Comparable results support the association between 3D-MOT performance and mTBI symptoms and suggest it could be an effective assessment tool after the initial injury (42). Studies among the paediatric population demonstrated the same trend as symptomatic youths exhibited delayed performance progression after repeated 3D-MOT exposure following mTBI (43,44). Although promising, there are no specific criteria for the clinical use of the Neurotracker to guide management after a mTBI and no studies have evaluated the test–retest reliability of 3D-MOT with regard to mTBI.

We aimed to compare the test–retest reliability of the ImPACT and Neurotracker tests for two consecutive years in university athletes playing sports at risk for mTBI to guide a complementary baseline utilization.

Methods

Participants

A convenience sample of university athletes practicing a sport at risk for mTBI were recruited in fall 2019 to be enrolled in a two-year research project (sporting seasons 2019–2020 and 2020–2021). These came from the university soccer, hockey and cheerleading teams from University of Quebec at Trois-Rivières. At the start of the season, the participants included had to be 18 years of age and over, play competitively a sport representing a high risk of mTBI at the university level and be fluent in French or English. Athletes with an uncorrected vision disorder, a major neurological or orthopedic disorder limiting the assessment process, those who sustained a mTBI less than three months prior to enrollment and those using a new psychoactive medication during the last six months were excluded. Ethical approval was granted by the University of Quebec at Trois-Rivières' research ethics committee and consent were obtained from all participants.

Procedure

At the beginning of the first sporting season (2019–2020), a series of demographic information including sports background, mTBI history and health status were recorded before initiating data collection (Figure 1). Afterward, participants completed the Neurotracker and ImPACT, in random order, inside a low-light closed room under the supervision of a member of the research team. It took participants one hour

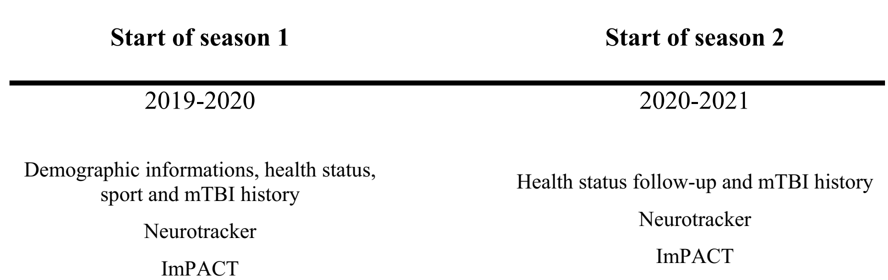

Figure 1. Experimental protocol.

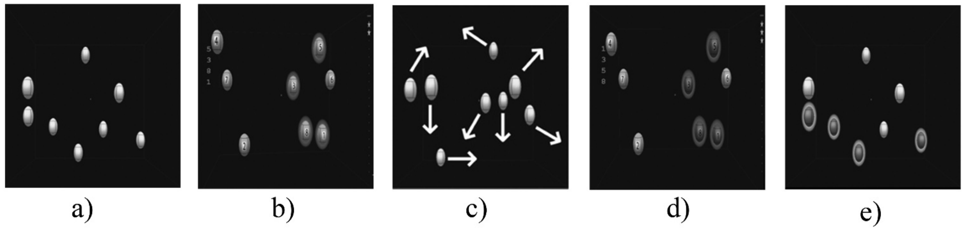

Figure 2. Neurotracker's trial's five steps.

to complete the assessment. In the fall of 2020 at the beginning of the second sporting season (2020–2021), our team reconnected with the athletes from the 2019 to 2020 sporting season that still evolved within the same university teams. Following an update of their state of health and their sports practices, participants again completed the evaluations by Neurotracker and ImPACT, similarly to season. The athletes did not take part in any Neurotracker or ImPACT evaluations between the two seasons aside from this study.

Measures

3D-MOT (neurotracker)

Using a projector, the Neurotracker's three-dimensional interface was presented to the participants wearing active 3D glasses and seated 1.5 meter from a 60-inch screen. Referring to Figure 2, a Neurotracker trial consists of the following five steps: a) eight balls of similar shape and color are randomly arranged in the Neurotracker interface: participants are encouraged to fixate a dot in the center of the projection throughout the assessment; b) four balls which are identified as the targets to be tracked during the trial become highlighted for a few seconds; c) targets return to their original appearance as a period of random movement lasting a total of 8 seconds begins; d) the participant must identify the targets through the distractors; e) feedback on trial performance is visually provided to the participant. The CORE assessment mode, being the most widely utilized in the Neurotracker literature, was selected (42–52). A series of 20 trials corresponds to one session and each laboratory encounter a total of three sessions. Each session provides a measure of performance on the task, known as speed threshold, a measure of visual perceptual skills in meters per seconds. The speed at which targets move within the 3D environment depends on participants' performance and varies according to Levitt's staircase theory (53). A positive response causes the balls (targets and distractors) to move faster, while an incorrect response reduces the speed of the next trial (37,49). A two-minute break was provided to participants between sessions, until three speed thresholds were obtained.

Immediate post concussion assessment and cognitive test (impacT)

The ImPACT Online Version test battery was completed on a laptop using the keyboard and touchpad, in an isolated room (18). The assessment begins with the Post-Concussion Symptom Scale (PCSS), a questionnaire reporting intensity of 22 common symptoms following mTBI, on a Likert scale from 0 to 6 (6 = severe). Then, participant completed six neuropsychological assessment modules: word memory, design memory, X's and O's, symbol match, color match and three letters. The ImPACT system uses these modules to calculated composites scores of verbal and visual memory, visual processing speed, reaction time and cognitive efficiency along with the symptom score (54).

Analysis

We analyzed test–retest reliability between the two sporting seasons for the Neurotracker and the composite scores of the ImPACT with three main criteria: intra-class correlation (ICC), Becker's standardized mean difference (dB) and a Bland-Altman plot. ICC is an analysis of variance which reflects both the degree of correlation and agreement between repeated measurements (55). We selected a minimal degree of significance of < 0.05 to ensure the presence of a significant correlation between the two measures. dB was used to measure the effect that sporting season 1 scores have on the repeated measure the following year (sporting season 2). This method shows a limited bias and is recommended for one-group within-subjects designs such as the present study (56). The result represents the mean change between measurements as a multiple of the effect size. An outcome has higher reliability when it's dB is close to 0 and has a small confidence interval. Finally, a Bland-Altman plot for each outcome was created to illustrate the level of agreement between season 1 and 2 results (55). The analysis produces a scatterplot of every participants in which the X-axis represents the average results of both seasons [$(T0 + T1)/2$], and the Y-axis represents the difference ($T0 - T1$) between the two seasons (57). The agreement level can be observed from the distribution of the individual data points on either side of the zero. The Bland-Altman allows us

Table 1. Participants' characteristics.

	Number (% female)	Mean age (years)	Sport Experience (years)	History of mtbi (n)	Average number of previous mtbi[†]
Hockey	15 (0)	21.9	15.8	10	1.2
Soccer	11 (0.45)	21.6	17.0	4	4.0
Cheerleading	4 (0.75)	23.1	5.0	2	1.5
Total	30 (0.27)	22.0	14.8	16	2.0

mTBI: Mild Traumatic Brain Injury †: Average number of previous mTBI among those who reported a prior history of mTBI to calculate the bias between each season and its associated slope. The bias is considered systematic between the measurements if its slope has a p > 0.05. We additionally subjected our results to paired t tests and calculated Pearson's correlation coefficients (r).

Results

Participants

University athletes (n = 77) were enrolled in the study protocol at the start of season 1. Of those, 30 took part in the season 2 evaluation (Table 1). Most of the attrition is due either from athletes resigned from their team, not on campus for sport participation due to the COVID-19 pandemic or not responding to our contact efforts during the season 2 recruitment period. Thus, the sample size for both sporting seasons consisted of 30 participants (22 males: 8 females) with a mean age of 22.0 years (SD = 0.78) and practicing either ice hockey (n = 15), soccer (n = 11) or cheerleading (n = 4). A total of 16 athletes reported prior mTBI history, however, none of the returning participants sustained an mTBI between the two assessments. A total of six participants had incomplete ImPACT data (technical issue with the software or participants' schedule) which led to the analysis of 30 pairs of Neurotracker results and 24 pairs for the ImPACT.

Test-retest reliability

ICCs between the two seasons ranged between 0.171 and 0.628 for the Neurotracker and ImPACT. Significant ICC (*p* value < 0.05) were solely reported for the Neurotracker (0.628; 95% C.I. 0.355–0.803) and the Visual Motor Speed (VMS) score of the ImPACT (0.543; 95% C.I. 0.185–0.776) (Table 2 .

Becker's d (dB) varied between −1,861 and 1.154 with five outcomes out of eight under the 1.0 mark. As illustrated by the forest plot (Figure 3), VMS (0.230; 95% C.I. −0.15–0.61), Reaction Time (−0.352, 95% C.I. −0.87–0.17), Cognitive Efficiency Index (0.333; 95% C.I. −0.22–0.89), Total Symptom Score (0.107; 95% C.I. −0.37–0.58) and Number of Symptoms (0.233; 95% C.I. −0.28–0.75) of the ImPACT all had a CI crossing zero demonstrating good reliability between the average results of the two seasons. Neurotracker (0.436; 95% C.I. 0.14–0.73) had a smaller CI than every ImPACT outcome which could demonstrates less variability between individuals., but it's CI did not cross zero. The scores of Verbal Memory (1.15; 95% C.I. 0.46–1.84) and Visual Memory (−1.86; 95% C.I. −2.64 – −1.08) demonstrated poor reliability with high dB values and wide CIs.

Neurotracker's Bland-Altman plot (Figure 4) demonstrates an acceptable distribution of the participants' performances. A positive bias of 0.179 is represented by the bold black dotted line while the bold line is the bias' slope (0.083; −0.244–0.41). Since the slope's *p* value of 0.607 is greater than previously established significance level, we can conclude that the bias is systematic because it is not statistically different from the horizontal. A similar analysis was performed for every ImPACT outcome and we reported the error of measurement along with the minimal detectable change (MDC).

Pearson's correlations between baseline assessments ranged from 0.03 to 0.697. These results were in accordance with the ICCs as only Neurotracker (0.697) and Visual Motor Speed of the ImPACT (0.548) presented a moderate but significant correlation.

While Visual Memory (−.030) and Cognitive Efficiency Index (0.045) of the ImPACT showed the lowest scores.

Significant difference of the mean scores calculated by *t* test was found for three outcomes: Verbal Memory (0.001), Visual memory (0.001), and Neurotracker (0.005). On average,

Table 2. Reliability statistics of the Neurotracker and the ImPACT.

	Season 1	Season 2	ICC [95% CI] (*p*)	Becker's d [95% CI]	Bias	Bias' slope [95% CI] (*p*)	Error	MDC	r (*p*)	*t* (*p*)
Neurotracker	M (SD) = 1,233 (0,401) SEM = 0,073	M (SD) = 1,413 (0,43) SEM = 0,079	0,628 [0.355; 0.803] (<.001*)	0,436 [0.14; 0.73]	0,179	0,083 [−.244; 0.410] (0.607)	0,636	0,665	0,697 (<.001*)	−3,026 (0,005*)
Verbal memory	M (SD) = 76,167 (12,398) SEM = 2,53	M (SD) = 90,958 (9,134) SEM = 1,865	−0,41 [−.690; −0.019] (0.980)	1,154 [0.46; 1.84]	14,79	−0,699 [−1.682; 0.284] (0.155)	32,4	35,73	−0,159 (0.457)	−4,384 (0,001*)
Visual memory	M (SD) = 91,375 (5,844) SEM = 1,193	M (SD) = 80,125 (13,44) SEM = 2,743	−0,232 [−.571; 0.178] (0.869)	−1,861 [−2.64; −1.08]	−11,25	1,394 [0.733; 2.055] (<.001*)	29,04	16,31	−0,030 (0.889)	3,72 (0,001*)
Visual motor speed	M (SD) = 39,583 (4,853) SEM = 1,012	M (SD) = 40,657 (4,645) SEM = 0,968	0,543 [0.185; 0.776] (0.003*)	0,230 [−.15; 0.61]	1,14	−0,042 [−.514; 0.430] (0.854)	8,68	8,88	0,548 (0.007*)	−1,14 (0,266)
Reaction time	M (SD) = 0,626 (0,085) SEM = 0,173	M (SD) = 0,595 (0,109) SEM = 0,222	0,171 [−.236; 0.529] (0.204)	−0,352 [−.87; 0.17]	−0,03	0,409 [−.305; 1.124] (0.248)	0,24	0,214	0,186 (0.385)	1,209 (0,239)
Cognitive efficiency index	M (SD) = 0,325 (0,085) SEM = 0,018	M (SD) = 0,344 (0,158) SEM = 0,034	0,055 [−.360; 0.456] (0.399)	0,333 [−.22; 0.89]	0,03	0,831 [0.081; 1.581] (0.031*)	0,34	0,257	0,045 (0.841)	−0,51 (0,616)
Total Symptoms Score	M (SD) = 7,833 (6,04) SEM = 1,233	M (SD) = 8,50 (6,852) SEM = 1,399	0,307 [−.096; 0.625] (0.065)	0,107 [−.37; 0.58]	0,66	0,398 [−.314; 1,109] (0.259)	15,07	14,03	0,293 (0.165)	−0,425 (0,675)
Number symptoms	M (SD) = 4,625 (3,118) SEM = 0,636	M (SD) = 5,375 (3,965) SEM = 0,809	0,193 [−.214; 0.545] (0.174)	0,233 [−.28; 0.75]	0,75	0,194 [−.456; 0.844] (0.541)	8,92	7,78	0,191 (0.371)	−0,807 (0,428)

ICC: Intraclass Correlation Coefficient; M: Mean; MDC: Minimal Detectable Change; r: Pearson's correlation; SD: Standard Deviation; SEM: Standard Error of the Mean; *t*: *t* test; *: p < 0.05

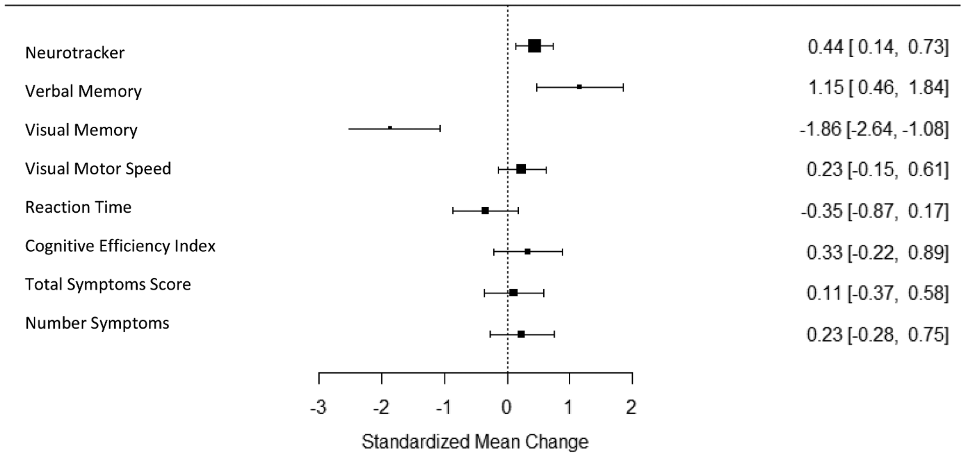

Figure 3. Becker's effect size forest plot.

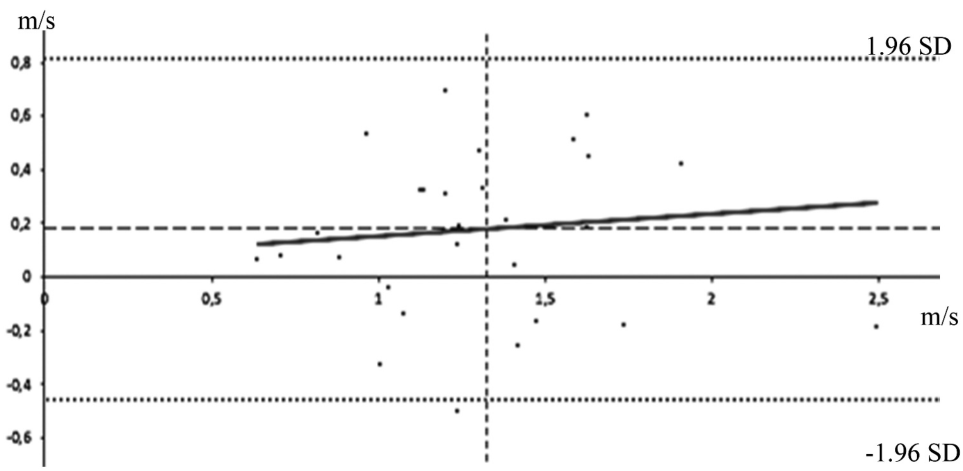

Figure 4. Bland-Altman plot: Neurotracker.

athletes performed better on the second year, although not significatively, for every outcome with the exception of Visual Memory and Symptoms on the ImPACT.

Discussion

We examined the one-year test–retest reliability of the Neurotracker's speed threshold and the ImPACT's composite scores among university athletes. Based on multiple statistical analysis, our results suggest that both the VMS of the ImPACT and the Neurotracker's speed threshold have an acceptable level of test–retest reliability while the other outcomes demonstrate limited reliability over a one-year period.

To our knowledge this study is the first to report test-retest reliability for the Neurotracker when used as a baseline measure of performance. A significant correlation from seasons 1 and 2 was observed for this measure with a moderate strength when considering its associated ICC (0.628). Effect size, portrayed by dB, was higher than most of ImPACT composite scores but had a smaller confidence interval, suggesting less variability among individuals.

The significant augmentation of the mean speed threshold scores between the two seasons, evidenced by the bias's slope and the *t* test, could justify a raise of effect size and imply a good level of reliability if practice effect is considered. Our results are consistent with a recent systematic review by Vater and al. (2021) which suggests that various populations (athletes, students, healthy young and old adults, military, children with mTBI, children with neurodevelopmental disorders) improve their speed threshold with various level of practice (38). This practice effect was acknowledged by the founders of Neurotracker who published in-house data suggesting that initial fluctuations are to be expected but tend to stabilize after the first three assessments (37).

The ImPACT composites scores presented mixed results of test-retest reliability with the VMS outcome being the most reliable. Correlation of scores between seasons range from low to moderate strength in regard to ICC (0.171–0.543) with only VMS (0.543) attaining moderated strength (0.50–0.75) and reaching significance. Those values are notably low in comparison to previous reports. Using the same one-year timeframe as our study, ImPACT composite scores had higher values of ICC

(0.62–0.82) for high school athletes (58). Other studies using test–retest intervals ranging from 7 days to two-years also had higher ICCs (0.21–0.88) with most scores demonstrating moderate or strong correlation between assessments (35,59–62). Inspection of these reports highlights a tendency of reduced reliability over time for the ImPACT. Lower ICCs when evaluating test-rest reliability of the ImPACT, as in the case of our study, were previously reported by Broglio and al. (2007) who only found weak ICCs (0.23–0.39) after an interval of 45 days (16). Their protocol included three different cognitive assessments completed within the same session as the ImPACT, as opposed to most of the previously cited articles that focused solely on the ImPACT. The only exception being Nelson and al. who used two neurocognitive tests, but their results came from a protocol of repeated exposure within 1, 8, 15, and 45 days from baseline which could favor stability between sessions (62). Since we evaluated the Neurotracker and the ImPACT one after the other, it could be hypothesized that athletes suffered from fatigue and a lower level of attention which could explain less reliable results when multiples tests are utilized. The effect size results were favorable for all ImPACT composite scores with the exception of Verbal Memory and Visual Memory, two outcomes that changed significantly between both seasons, thus demonstrating a considerable level of variability.

Practice effect is an important limitation to retesting reliability and thus must be accounted for. If we are excluding Verbal and Visual Memory of the ImPACT because of their sub-bar reliability, our athletes only significatively improved their speed threshold (+0,179 m/s) on the Neurotracker. This phenomenon could represent a value of expected change between the first two measurements. Thus, an adjustment to deduct it from the follow-up performance could be considered to improve reliability. Nevertheless, the cause for such an improvement with limited exposition can be hypothesized to be the result of three processes (1): a true improvement of the cognitive function isolated by the test (2) improved familiarity with the test functioning (3); increase in test-specific knowledge, such as optimal strategy (63). To isolate true cognitive changes, it appears that repeated baseline testing could mitigate the other factors of performance (63). The absence of a significative practice effect for the ImPACT as oppose to Neurotracker's scores could be linked to two factors. First, the ImPACT uses different versions of each test within its program for every assessment while the Neurotracker trials are always similar. Second, the lack of experience athletes had with the 3D-screen of the Neurotracker in comparison to the laptop use for the ImPACT may have led to a more significant improvement in test-specific knowledge between evaluations.

Interestingly, the most reliable outcomes, Neurotracker's speed threshold and VMS of the ImPACT, both evaluate neurocognitive processes relying on visual functions. Similar to our results, across similar studies VMS is reported to be the most reliable outcome of the ImPACT (18). It is proposed that cognitive processes tested by VMS and Neurotracker are constantly solicited to perform activities requiring high visual indexing capacity like team sports (28,29). Since the goal when following athletes post-mTBI is to assess their ability to return to play safely, the evaluation of those outcomes seems to fit the need of both transferability and reliability. The actual recommendation to confirm mTBI associated impairments with the ImPACT is the presence of a significant reduction in a minimum of two of the five composite scores (18). However, our results of low reliability for the two memory outcomes suggest that this rule might need to be reconfirmed within the university population when baseline is done annually.

Finally, our results should be considered in regard to their limitations. Participants retention was low with more than half lost to follow-up leaving us with a limited sample size that could explain the generalized high MDC values. This situation also caused an imbalanced group of athletes in term of gender and sport. The context of the COVID-19 pandemic greatly affected sport participation of the included athletes who lost a major part of their training in the first season post-recruitment. Still, this represented a unique occasion to examine the effect of such a forced pause on concussion baseline testing, with the effects of sport participation taken out of the portray. Future research should investigate if organized sport's participation should be considered when selecting the optimal test-retest interval.

As sports teams try to optimize mTBI management with new technology, reliability data must be taken into account. We can conclude that the Neurotracker demonstrates an acceptable level of test-retest reliability after one year in comparison to the ImPACT. Although a predictable practice effect is present within the first sessions, the Neurotracker demonstrated equal or better reliability than every composite scores of the ImPACT. Among the composite scores of the ImPACT, VMS was the most reliable while Visual Memory and Verbal Memory should be analyzed with caution.

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Disclosure statement

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