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Utility of 1 Measurement Versus Multiple Measurements of Near Point of Convergence After Concussion

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Context: Increased near point of convergence (NPC) distance is a common finding after concussion and is associated with physical symptoms and worsened neurocognitive performance. Vestibular/Ocular Motor Screening measures NPC distance across 3 trials and uses the average measurement to inform clinical care. However, whether 3 trials are necessary, are consistent, or add clinical utility is unknown.

Objective: To investigate the consistency across 3 trials of NPC and establish the classification accuracy (ie, clinical utility) of 1 or 2 trials compared with the standardized average of 3 trials.

Design: Retrospective cohort study.

Setting: Sports medicine clinic and research laboratory.

Patients or Other Participants: Consecutively enrolled patients aged 10 to 22 years with diagnosed concussions (74% sport related; n = 380).

Main Outcome Measure(s): The previously reported clinical cutoff value of ≥5 cm across 3 trials was used. Pearson correlation and intraclass correlation coefficients were used to evaluate agreement between trials and average scores. Reliable change indices (RCIs) using 95% confidence intervals were also calculated.

Results: The Pearson correlation ($r = .98$) and intraclass correlation (0.98) coefficients revealed excellent agreement between the first measurement and average NPC distance across 3 measurements. The RCI across all trials was 2 cm. When the first NPC measurement was ≤3 cm or ≥7 cm, agreement existed within the RCI between the first measurement and the average of 3 measurements in 99.6% of cases. When we averaged the first and second measurements, 379/380 (99.7%) participants had the same classification (ie, <5 cm = *normal*, ≥5 cm = *abnormal*) as the average NPC distance across 3 measurements.

Conclusions: Our findings suggest limited utility of multiple or average NPC distance measurements when the initial NPC distance is outside of RCI clinical cutoffs (ie, ≤3 cm or ≥7 cm). Given the high consistency between the first measurement and average NPC distance across 3 trials, only 1 measurement of NPC distance is warranted unless the first measurement is between 3 and 7 cm.

Key Words: mild traumatic brain injury, convergence, Vestibular/Ocular Motor Screening (VOMS)

Key Points

- A single near point of convergence trial was highly consistent with the average of 3 trials.
- Near point of convergence measurements outside of the clinical cutoff (ie, ≤3 cm or ≥7 cm) repeated measures had limited utility.

Oculomotor dysfunction is common after concussion, with prevalence rates as high as 69% in adolescents.[1–3] Specific deficits in oculomotor function are often observed, including receded *near point of convergence* (ie, NPC; measurement of the distance from the nose to a fixation stick when 2 distinct images are seen), abnormal accommodation (ie, blurring of images when changing focus), and difficulty with smooth pursuits and saccadic eye movements (ie, side-to-side eye tracking).[4–6] These deficits have been associated with blurred vision, diplopia, pressure behind the eyes, reading difficulties, frontal headaches, and fatigue.[5,7,8] Receded NPC is associated with multiple vision diagnoses, including accommodative disorders and convergence excess, as well as convergence insufficiency,[9] but this was not the case in a recent study[9] of patients <21 years old who were >28 days postconcussion. Children and adolescents often report difficulty with visually demanding tasks, and visual symptoms have been associated with decreased academic performance beyond 30 days postinjury.[7] Further, oculomotor impairments contribute to poor performance on computerized neurocognitive testing after concussion[3,10] and are linked with protracted recovery.[11]

Due to poor outcomes associated with oculomotor dysfunction, the focus on developing screening tools to identify impairments has increased. One such measure is Vestibular/Ocular Motor Screening (VOMS), which allows for a brief assessment of the vestibular and oculomotor systems though symptom provocation and NPC distance measurement.[10] The VOMS has shown good internal consistency and sensitivity and a low false-positive rate.[10,12–14] Positive findings on the VOMS have also been

Table. Demographic and Group Descriptive Information

Variable	Normal NPC (n = 264)	Abnormal NPC (n = 116)
Sex, female	53.4%	44.8%
Age, range, y	15.3 (10–22)	15.2 (10–22)
Time from injury to first visit, d (range)	8.1 (1–30)	8.67 (1–30)
NPC, mean ± SD, cm	1.16 ± 1.45	10.46 ± 4.93
Trial 1	1.17 ± 1.53	9.94 ± 4.62
Trial 2	1.19 ± 1.53	10.46 ± 5.41
Trial 3	1.12 ± 1.50	19.97 ± 5.4
Prior concussions	No. (%)	
0	155 (58.7)	73 (62.9)
1	70 (26.5)	33 (28.4)
2+	39 (14.8)	10 (8.6)
Sport-related injury	190 (80)	94 (81)
History of ocular dysfunction	14 (5.3)	10 (8.6)
History of learning disability or attention-deficit/hyperactivity disorder	11 (4.2)	8 (6.9)
History of motion sickness	66 (25)	25 (22.6)
History of migraine	86 (32.6)	38 (32.8)
History of mood disorder	28 (10.6)	14 (12.1)

Abbreviation: NPC, near point of convergence.

associated with longer recovery after sport-related concussion in adolescents (age = 11–19 years).[15] When athletes (age = 9–24 years) with concussion were tested using the VOMS NPC measurement protocol, the prevalence of abnormal NPC was around 42% within the first month of injury,[3] and identification of normal or abnormal NPC distance increased the accuracy of diagnosing concussion by 34%.[10]

In a sample of 21 healthy adolescents, the test-retest reliability of the VOMS, including NPC, was strong when it was administered at different points on the same day (intraclass correlation coefficient [ICC] = 0.90–0.97).[14,16] Physical exertion did not affect the reliability of NPC measurements (ICC = 0.91) among healthy high school athletes evaluated at baseline, prepractice, and after removal from practice later that day (ie, when returning to the sideline).[14] Although the research to date would suggest that NPC is a reliable measure across time points in healthy adolescents, few investigators have addressed the effects of multiple NPC measurement trials, administered consecutively, as indicated in the VOMS protocol. This is important because authors[17] hypothesized that when repeated extensively, NPC measurements can increase in those with receded NPC due to poor convergence reserve and a possible "fatiguing" effect.

The first comprehensive evaluation[18] of various target stimuli and 10 repetitions of NPC, with both healthy control individuals and those with convergence insufficiency, showed that the latter had an increase in NPC measurements from trials 1 through 5, with little change in trials 6 through 10. Conversely, participants without convergence insufficiency showed little change across the 10 trials. As a result, researchers[7] suggested that a 5-trial repetition of NPC may be useful in some situations, while acknowledging that the time required to perform 5 NPCs may limit the clinical practicality. Based on these results, the NPC portion of the VOMS includes 3 measurement trials because this balances the accuracy of the tool with clinical utility.[10] In a study[3] of concussed adolescent athletes, investigators found good reliability using 3 NPC trials, with ICCs ranging from 0.95 to 0.98. A mild "fatiguing process" was also noted. However, this study was limited by a small sample size (of 75 participants, 45 had normal NPC), consisted only of athletes, and did not address single-trial classification accuracy beyond identifying mean group differences. The purpose of our retrospective chart review study was to evaluate the consistency of the 3 NPC measurements on the VOMS and determine if repeated NPC measurements are necessary or if modifications to this test item can make the tool more clinically efficient. Specifically, we compared trial 1 NPC with the average NPC, as well as trial 1 + trial 2 average NPCs with the 3-trial average NPC. Additionally, we aimed to establish a reliable change index (RCI) for NPC measurements.

METHODS

Participants

We conducted a retrospective chart review of 380 adolescents and young adults aged 10 to 22 years who presented to an outpatient concussion clinic and were diagnosed with a concussion by a licensed clinician based on the following criteria: (a) clear mechanism of injury, (b) the presence of acute markers of injury (eg, loss of consciousness, posttraumatic amnesia, disorientation or confusion), (c) symptom report at time of clinic visit (eg, headaches, dizziness, nausea), or (d) positive findings on neurocognitive testing or vestibulo-ocular screening. Exclusionary criteria were a history of 3 or more concussions, significant neurologic history (eg, seizure disorder), positive neuroimaging findings, preexisting vestibular or visual disorder (eg, benign paroxysmal positional vertigo, strabismus, diplopia), or time between injury and initial visit >30 days. The majority of participants sustained their injuries while engaged in a sporting event (n = 284; 74.9%). This study was approved by the university institutional review board. See the Table for complete demographics.

Measures

Vestibular/Ocular Motor Screening is a brief screening tool (approximately 5 minutes) used to assess vestibular and ocular dysfunction after concussion. Patients are asked

to rate the symptom severity of headache, dizziness, nausea, and fogginess on a scale from 0 to 10 at baseline (pretest) and then after each of the 7 components: (1) smooth pursuits, (2) horizontal saccades, (3) vertical saccades, (4) horizontal vestibulo-ocular reflex, (5) vertical vestibulo-ocular reflex, (6) visual motion sensitivity, and (7) NPC. Signs of possible vestibular dysfunction are indicated with a +2 increase in symptom severity from baseline. Patients are asked to rate the severity of their symptoms after a 10-second rest period following completion of the individual tests. Near point of convergence is measured in centimeters from the tip of the nose when patients report seeing 2 distinct images on a fixation stick (14-point font) or when the clinician observes an outward deviation of 1 or both eyes (for complete administration procedures, see the Appendix of Mucha et al[10]). The NPC test is repeated across 3 trials and the results averaged. Based on previous literature,[10,18–20] an average measurement $\geq$5 cm is considered abnormal and may warrant further evaluation. For the purposes of this study, the NPC measurements from patients' VOMS profiles were extracted from their charts and used for analysis.

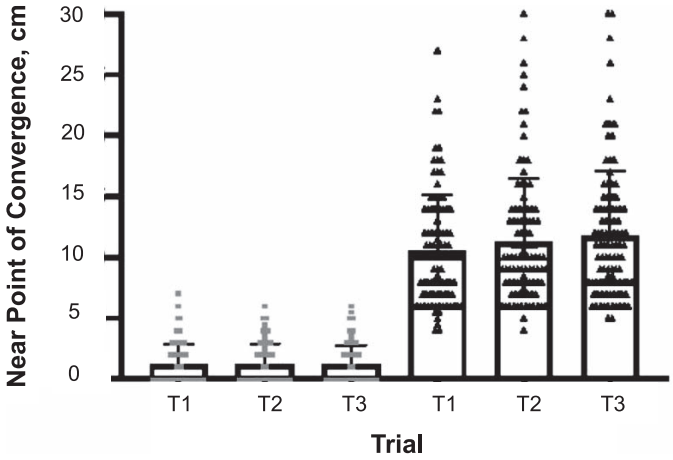

Figure 1. Near point of convergence (NPC) measurement differences across 3 trials (T1, T2, T3) between those with normal (gray circles) or abnormal (black triangles) NPC distance, based on a clinical cutoff of $\geq$5 cm. Error bars indicate standard deviations, and the top of the box indicates the mean.

Data Analyses

As part of standard clinical care after concussion, all participants completed a 1-time measurement of NPC, which included 3 consecutive trials during 1 clinical visit. Outcomes from NPC testing were the initial trial (T1) and the mean NPC of all 3 trials (AVG; mean of T1, T2, and T3). The difference between the T1 and AVG NPC scores was documented using a paired-samples *t* test, with the Cohen d as a measure of effect size. Agreement between T1 and AVG NPC scores was documented using the Pearson product moment correlation coefficient and ICC score. The Pearson *r* is considered a weak measure of test-retest reliability when group means are similar but individual scores vary considerably from time 1 to time 2[21]; the ICC can distinguish those sets of scores that are merely ranked in the same order from those that are not only ranked in the same order but are in low, moderate, or complete agreement.[22] A 2-way mixed-model ICC, consistency type, was applied using single measures."[23] An NPC cutoff of $\geq$5 cm for both T1 and AVG NPC scores was used to identify the proportion of participants whose scores fell above or below the NPC clinical cutoff established by Mucha et al,[10] and the Cohen κ was calculated as the measure of agreement between T1 and AVG NPC scores. To evaluate a potential fatiguing effect from repeated NPC measurements, we computed RCIs to determine the proportion of individuals who exhibited increases in NPC from T1 to T3. Reliable change indices assess whether a change between repeated measurements is reliable and clinically meaningful by providing an estimate of the probability that a given difference score would not result from measurement error.[24,25]

RESULTS

Demographic Data

Complete demographic information is summarized in the Table. The sample consisted of 380 patients with concussions (187 males, 193 females) with a mean age of 15.3 $\pm$ 2.16 years. The time to the first clinic visit was 8.32 $\pm$ 5.92 days (range = 1–30 days). The majority of participants (n = 275, 72.4%) were seen within 10 days of injury. The sample was divided into those with a normal and those with an abnormal NPC based on the clinical cutoff ($\geq$5 cm). In this sample, 30.5% of participants showed an abnormal NPC (n = 116). The group mean for normal NPC (n = 264) was 1.16 $\pm$ 1.45 cm, whereas the group mean for abnormal NPC (n = 116) was 10.46 $\pm$ 4.93 cm (range = 5–29 cm). Individual trial means by groups can be seen in Figure 1.

Near Point of Convergence Reliability Across Trials

The Pearson correlation (r = .98) and ICC (0.978) revealed considerably strong agreement between T1 and AVG NPC scores (Figure 2). A paired-samples *t* test revealed a small but statistically significant difference between T1 and AVG NPC scores ($t_{380} = -2.79$; $P = .006$; $d = 0.14$), with the T1 NPC score (3.84 $\pm$ 4.93 cm) differing from the AVG NPC score (4.00 $\pm$ 5.22 cm) by approximately 0.16 cm, reflecting a small effect size.

Absolute change (any increase or decrease in NPC score) was documented between T1 and T3, as well as between T1 and AVG NPC scores. Between T1 and T3, 20.8% (n = 79) displayed increased (longer) NPC and 10.5% (n = 40) displayed decreased (shorter) NPC. Similarly, comparing T1 and AVG, 25.0% (n = 95) demonstrated increased (longer) NPC and 11.6% (n = 45) demonstrated decreased (shorter) NPC. Between T1 and T3, RCIs using 90% (RCI = 1.68 cm) and 95% (RCI = 2 cm) confidence intervals (CIs) showed that 9.74% (6.58% longer and 3.16% shorter) of scores fell outside a 90% CI, and 5.00% (1.84% longer and 3.16% shorter) of scores fell outside a 95% CI. Comparing T1 and AVG NPC, 8.16% (5.00% longer and 3.16% shorter) of scores fell outside a 90% CI, and 5.00% (2.37% longer and 2.63% shorter) of scores fell outside a 95% CI.

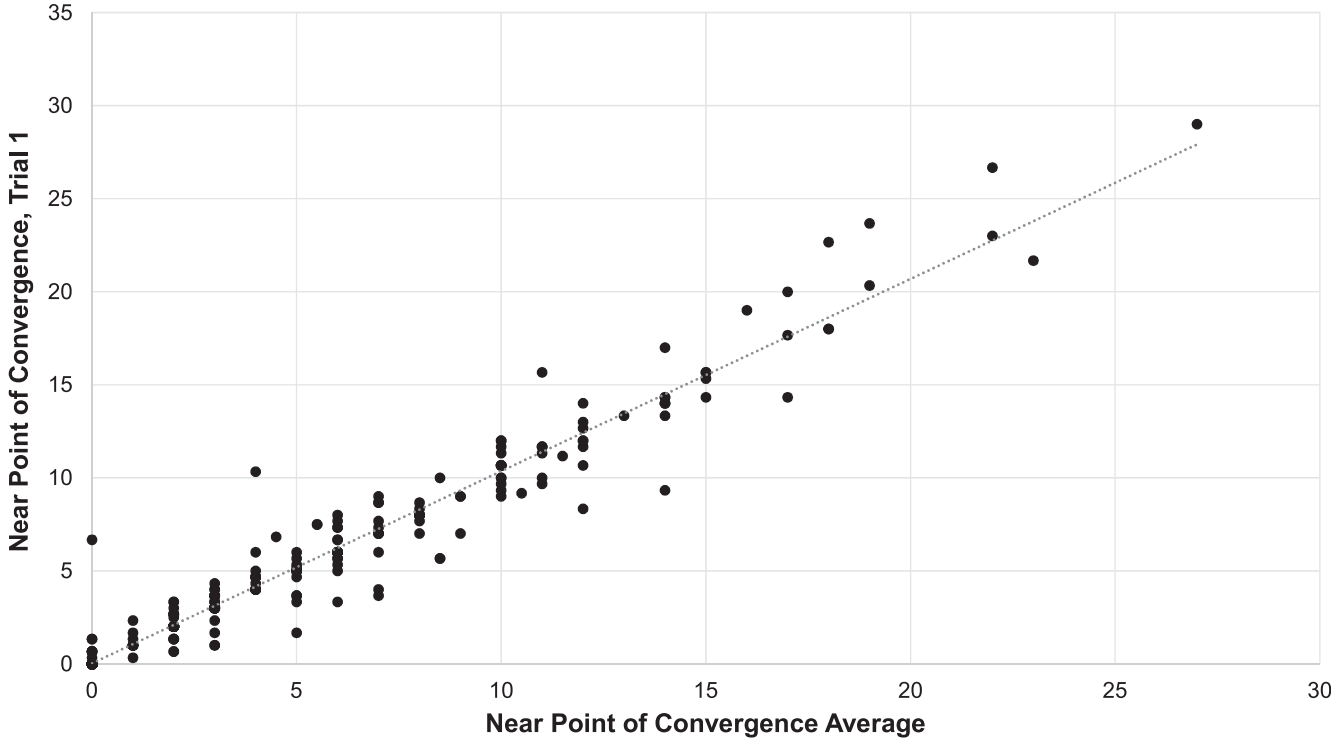

Figure 2. Scatter plot of individual near point of convergence (NPC) trial (T)1 measures compared with the NPC average (ie, mean of T1, T2, and T3).

Consistency Between T1, T2, and Average NPC

Comparison of normal/abnormal T1 to normal/abnormal AVG NPC yielded a high degree of consistency when using ±2 cm of the clinical cutoff (ie, RCI of 95%: ≤3 cm, ≥7 cm). Using this cutoff, 99.6% of those with a normal NPC on T1 had a normal AVG NPC (n = 245/246 of T1 ≤ 3 cm). Similarly, 0% of participants with a T1 NPC greater than 7 cm (RCI of 95% above clinical cutoff) had a normal AVG NPC. Furthermore, when using the average of both T1 and T2, compared with AVG, 99.7% (n = 379) of participants would have been correctly classified as normal or abnormal.

DISCUSSION

We are the first to examine the classification accuracy of individual NPC measurements on the VOMS after concussion. Consistent with the literature,[3,5,6,8,26] 30.5% of all concussed participants were classified as having abnormal NPC. Our primary finding was significant agreement between the initial trial (T1) of NPC, the third trial of NPC, and the average of all 3 trials (AVG) as standardized by VOMS administration. Although a statistically significant difference existed between T1 and AVG, the effect size was quite small, and this difference was not clinically significant. Consistent with prior research,[3,18,27] these results support the potential for a fatiguing effect in some patients: twice as many patients demonstrated an increase in measurement distance (n = 79) versus a decrease in distance (n = 40). However, this effect does not appear strong enough or consistent enough to affect classification accuracy between an initial VOMS trial and the average across 3 trials.

Using a 95% RCI above or below the clinical cutoff (which allows for measurement variability), we found that all but 1 participant was correctly classified by T1 alone. In other words, a T1 performance that was well above or well below the clinical cutoff was very consistent with the classification provided by all 3 trials. For example, all but 1 participant (245/246) with a T1 NPC between 0 and 3 cm would have been correctly classified by a single trial. When the T1 and T2 results were incorporated, all but 1 study participant (379/380) were consistently classified as having either normal or abnormal NPC. Taken together, it appears that a significant amount of redundancy exists for NPC repetition during VOMS administration when an initial trial is either close to the nose (0–3 cm) or well beyond the clinical cutoff (7+ cm). A second trial may be useful for those who fall into this range (ie, 3.1–6.9 cm). Even when a second trial is necessary, conducting a third trial changes the categorization less than 1% of the time.

Clinical Implications

Near point of convergence measurement is a vital component of concussion evaluation because it improves diagnostic certainty,[10] explains some degree of impairment on neurocognitive testing,[3] and can predict protracted recovery.[11,28] Concussion-assessment tools that incorporate NPC measurement, namely the VOMS, are being integrated into sideline evaluations[14] and added to screening measures such as the Military Acute Concussion Evaluation-2.[29] The NPC item on the VOMS currently uses 3 measurement trials, and vision experts suggest up to 10 trials to obtain an average NPC. However, multiple trials may not be feasible in some settings that require rapid screening for concussion, such as emergency departments or the sideline of a sporting event. Our results suggest that modification of the VOMS to reduce NPC repetition may be appropriate in these settings

with most patients, given the high consistency between the first trial and the average of all 3 trials. However, if the first trial finding is between 3 and 7 cm, the provider should administer a second trial.

Limitations and Future Research

We were unable to document any potential medications participants were taking, as well as the timeline of any relevant medical history (eg, last episode of motion sickness if such a history was indicated by the patient). Although we recruited patients 1 to 30 days postinjury, the majority of participants were seen within 10 days of injury and, therefore, these results may not be generalizable to patients with more chronic oculomotor impairments postconcussion. In contrast, research on NPC measurements postconcussion is largely based on evaluations obtained during clinical visits days after injury, and it is unclear if our findings would generalize to more acute patients (eg, sideline, emergency room) when a brief assessment approach may offer the most utility. Future researchers should examine NPC measurements in the emergency department and on the sideline after suspected concussion to determine the best approach to screening for abnormal NPC postinjury.

CONCLUSIONS

Near point of convergence is a critical component of concussion evaluation as it improves diagnostic accuracy[10] and can predict protracted recovery.[11,28] As a component of the VOMS, 3 consecutive trials of NPC measurements have been recommended, with the recorded outcome being the average of the 3 trials. However, in some instances, a quicker clinical assessment may be indicated, such as in the emergency department or during a sideline evaluation. Our results demonstrated that a second NPC measurement may be necessary only if the first measurement is between 3 and 7 cm, because the first NPC measurement trial was highly consistent with the 3-trial average if the distance was <3 or >7 cm. Therefore, we suggest that NPC measurements in this population be limited to 2 trials when these criteria are met.

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