NEAR POINT OF CONVERGENCE IN HIGH SCHOOL ATHLETES

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Master of Science in Exercise Science

Spring 2018

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ACKNOWLEDGEMENTS

A study of this magnitude does not come to fruition without a significant amount of help and support. I would like to recognize all the coaches from Hodgson Vocational Technical High School and, especially like to thank Dave Collins, athletic director, for making my life easy with assistance in communication with coaches and athletes. I would like to thank the teams and athletes themselves for their patience and agreement to participate in my study, for if they did not, I would have no data to analyze and interpret. Thank you also to Bethany Wisthoff and Jessie Oldham for their assistance and guidance in ensuring my success as a graduate student.

The University of Delaware professors will forever have my gratitude for their help throughout this process. Dr. Thomas Buckley and Dr. Joe Glutting, my committee members, have been such significant impacts on my study and I will never forget their support through this process. I would like to especially thank my committee chair and advisor, Dr. Thomas Kaminski. For without his strong encouragement and dedication, I would not have completed a thesis I am truly proud to call my own. I will always be grateful for the positive impact he has had on me.

I would like to thank my family and friends for their love and support. Lastly, I would like to acknowledge my wife, Alexis Sellars. She is a constant motivation and reminder of why I have such ambitions to succeed in life. This process would not nearly have been so manageable without her by my side. No words can describe the love and daily impact she has in our lives and how lucky I am to call her my wife.

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ABSTRACT

Context: Awareness of sport-related concussions (SRC) has increased significantly in recent years. The clinical diagnosis of SRC is typically performed with tools assessing postural stability, cognitive function, neurocognitive, vestibular, and ocular motor deficits. Recent evidence has indicated convergence dysfunction to be a complication following SRC. Near point of convergence (NPC) has been reported to be a useful assessment of convergence deficits following SRC. No investigation on differences in NPC values between different instrument methods has been performed. **Objective:** The primary purpose of this study was to determine if instrument method (tongue depressor or accommodative ruler) influences NPC values in high school athletes. The secondary purpose was to assess whether a difference exists in NPC values between contact and limited or non-contact sport type athletes. **Design:** Quasi-experimental, ex post facto. **Setting:** High School. **Patients or Other Participants:** 201 high school student-athletes (age = 15.7±1.2 yrs, height = 170.5±10.0 cm, mass = 69.9±16.2 kg) from 14 sports were assessed for NPC values. **Main Outcome Measures:** Near point of convergence values with tongue depressor (NPC-TD) and accommodative ruler (NPC-AR) instrumentation. **Results:** There was a significant difference between NPC-TD (2.0±2.8cm) and NPC-AR (2.8±2.7cm) values, $t(200)=5.85$, $p<0.001$. There was a significant difference between contact and limited/non-contact groups with NPC-TD, $t(199)=4.01$, $p<0.001$, and NPC-AR, $t(199)=2.71$, $p=0.004$. **Conclusions:** Instrumentation

and procedures affect NPC values in a high school student-athlete population. These data indicate the importance of consistent collection methods when utilizing NPC to assess convergence deficits following SRC.

Chapter 1

INTRODUCTION

Sport-related concussions (SRC) are continuously gaining attention in our society, and with nearly 8 million high school athletes participating annually, SRC recognition is of utmost concern to those who care for these athletes.[1,2] An SRC is a traumatic brain injury induced by biomechanical forces thought to include a combination of metabolic, physiological, and microstructural injuries to the brain.[3,4] At the high school level, reported SRC incidence rates range from 3.8-8.9% with injury rates ranging from 0.23-0.39 SRC per 1,000 athletic exposures.[2,5,6] In addition, underreporting of SRC among high school athletes has been suggested to be as high as 55%, furthering the need for accurate diagnostic measures to identify the injury.[7]

Currently, the most effective approach to identify SRC is to combine several methods as an assessment battery to clinically diagnose the injury.[4,8] Commonly used diagnostic tools include a self-reported symptom checklist, the Standardized Assessment of Concussion (SAC), Balance Error Scoring System (BESS), the Immediate Post-concussion Assessment Cognitive Test (ImPACT) or other neurocognitive assessment, and the Sport Concussion Assessment Tool—5th Edition (SCAT5) that includes a 22-item symptom checklist, SAC, and a modified BESS.[4,8,9] Other tools recently introduced include the King-Devick Test (K-D), Clinical Reaction Time (CRT) test, and the Vestibular/Ocular Motor Screening (VOMS) assessment.[10–12]

An assessment battery of self-reported symptoms, postural stability, and neurocognitive assessment has demonstrated a sensitivity of 89-96% in acute SRC diagnosis.[8] However, recent literature has recognized the need to screen for ocular motor deficits following SRC, and has since recommended such assessments be performed post-injury.[4,10,12,13] Potential impairments following SRC include convergence insufficiency (CI), blurry vision, and other ocular motor dysfunctions related to accommodation, vergence, pursuit, and saccades.[14–16] Specifically, the ocular motor system includes the versional, vergence, and accommodative systems working in conjunction with the vestibular system to maintain visual stability and scanning capabilities.[14,17]

Versional ocular motility involves a conjugate movement of the 2 eyes including movements of fixation, saccades, and pursuits.[17] Accommodation is the ability to focus visually, whether it's a single target or transitioning from near to far or vice versa.[17] Vergence ocular motility involves a disjunctive movement of both eyes.[17] Convergence occurs when the eyes rotate towards each other and divergence occurs when the eyes rotate away from each other.[18] Two main stimuli elicit vergence eye movements – disparity and blur.[19] Disparity is the stimulation by the same object of disparate or discordant points on the two retinas, so that the object is seen twice (diplopia).[19] Blur is the absence of clarity of the perceived image and independently concerns one eye or the other.[19] Structures within the brain including the frontal eye fields, supra-ocular motor area, and cerebellum all influence convergence and divergence movements and can potentially become affected following SRC.[19,20] Recent literature has reported CI to be a common ocular complication following SRC and mild traumatic brain injury (mTBI).[10,21–24]

A common assessment of convergence deficits following SRC is near point of convergence (NPC).[25,26] Near point of convergence was originally used as a vision assessment to diagnose CI, a binocular disorder in which the eyes do not work well at near fixation.[27] Symptoms of CI are similar to those following SRC including headache, eyestrain, double vision, and blurred vision.[10,27] Near point of convergence is defined as the point of intersection of the lines of sight when the eyes are maximally converged.[28] When assessed with an accommodative ruler (Bernell Incorp. Mishawaka, IN), NPC has previously been reported as a reliable tool.[29–31] Near point of convergence has been shown to be a valuable tool in mTBI and SRC assessment.[10,17,32] Recent evidence suggests that repetitive sub-concussive head impacts are associated with changes in NPC, and adolescents with receded NPC following concussion exhibit gait-related deficits .[30,31] A VOMS tool to assess vestibular and ocular motor deficits following SRC utilizes NPC as one of its domains, and an NPC distance ≥ 5 cm resulted in a 34% increase in accurately diagnosing a concussion.[10]

The common cutoff value for an abnormal NPC used as a SRC diagnostic measure includes either ≥5 cm or ≥6 cm.[10,15,25,26,33] The source of the recommended cutoffs is derived from normative data research in either schoolchildren (5-12 yrs) or various adult populations (22-37 yrs) with ≥5 cm as the most commonly used cutoff.[28,34,35] VOMS authors also recommend utilizing a cutoff value of ≥5 cm to define an abnormal NPC.[10] Various ranges of NPC exist within the data across multiple populations ranging from 5-15 cm.[20,34,36,37] Other factors affecting NPC values include target type, meaning the target (pen tip, letter target, drawn line) in which the subject is instructed to focus, and the location of the "*zero measure point*," which is the point from which the NPC is measured when the participant reports diplopia (double vision).[10,20,28,34–36] The common points for the "*zero measure*" are the "center of the forehead at the level of the brow,"[28,35] the "bridge of the nose just below the brow,"[23,34] the lateral corner of the eye,[36,38] or the "tip of the nose," which is utilized in VOMS' NPC measure.[10]

In addition to different "*zero measure points*," the instrument and method of the procedure varies between the VOMS NPC assessment and common clinical NPC assessments.[10,31,35] VOMS uses a tongue depressor with a letter target as the patient holds the target "at arm's length and slowly brings it toward the tip of their nose," with the NPC distance measured "in cm between target and the tip of nose."[10] Clinical assessment of NPC is commonly performed with an accommodative ruler, also with a letter target, placed above the nose at the brow between the two eyes or, in some cases, placed on the upper lip, with the examiner moving the target at a speed of approximately 1-2 cm/s.[28,31,35] There has been no investigation on differences in NPC values between different instrument methods (tongue depressor, accommodative ruler).

The primary purpose of this study was to determine if instrument method (tongue depressor or accommodative ruler) influences NPC values in high school athletes. Based on variability in NPC values when assessed from different zero measure point landmarks (brow between eyes, nose, upper lip) in previously reported data, we hypothesized high school athletes to have different NPC values between the use of a tongue depressor measured from the tip of the nose and an accommodative ruler measured from the brow just above the nose between the eyes.[28,34–36] The secondary purpose was to assess whether a difference exists in NPC values between contact and limited or non-contact sport type athletes. Based on reports, collegiate athletes have not displayed significant differences between sport type for various baseline measures, but high school athletes have demonstrated difference between sport type on neuropsychological test performance.[39–41] Therefore, we hypothesized high school contact sport athletes would have different NPC values compared to limited and non-contact sport athletes.

Chapter 2

METHODS

2.1 Participants

Near point of convergence (NPC) measurements were collected on 201 high school student-athletes (Table 1) during the 2017-2018 academic year. Participants were recruited from a local Delaware high school and ranged in age from 14-18. Participants were excluded from the study if they reported a history of vertigo, accommodative dysfunction (problem sustaining prolonged near focus), any self-reported neurological disorder, and any metabolic, vestibular, vision disorders, or other conditions that would impair NPC performance. Participants signed an IRB approved assent form, following approved parental consent, or an informed consent form if above the age of 18 (Appendix A).

Consent forms were sent out to participants in the fall (August), winter (December), and spring (March) preseasons. Following consent and exclusion criteria, 68 subjects were from fall sports (football, field hockey, boys' soccer, volleyball), 38 subjects were from winter sports (boys'/girls' basketball, wrestling), and 95 subjects were from spring sports (boys'/girls' lacrosse, girls' soccer, baseball, softball, track & field). Participants completed a health history questionnaire (Appendix B) that included demographic information and vision specific questions prior to their testing session. Teams were tested individually separate from other sports and testing sessions occurred in preseason on a practice or non-scrimmage day prior to practice.

2.2 Procedures

Near Point of Convergence Tongue Depressor (NPC-TD) Measure

The NPC measures the distance of the subject's ability to view a near target without double vision. The examiner was seated in front of the patient, who was also seated, and observed their eye movement during this test. Corrective lenses in the form of contact lenses and glasses were worn as needed. The subject focused on a small target letter ***"T"*** (font size 14) taped to the tip of a tongue depressor at arm's length and slowly brought it toward the tip of their nose (Figure 1). The subject was encouraged to try to keep the target single and instructed to stop moving the target when they saw two distinct images. Blurring of the image was ignored. The distance in centimeters between target and the tip of the nose was measured with a tape measure and recorded. If a subject did not report diplopia (double vision), the point at which the subject had an outward or inward deviation of one eye was recorded as the NPC value. If a subject did not report diplopia or have a deviation before the tongue depressor reached the nose, the NPC value was recorded a 0. A total of three NPC measures were taken and then averaged to determine the final NPC-TD value.

Near Point of Convergence Accommodative Rule (NPC-AR) Measure

An accommodative ruler (Bernell Incorp. Mishawaka, IN) was used to assess the NPC-AR measure (Figure 2). The patient was seated in front of the examiner, who may have also been seated, and observed the patient's eye movement during this test. Corrective lenses in the form of contact lenses and glasses were worn as needed. The accommodative ruler was placed to rest on the participant's brow just above the nose between the eyes. Participants were instructed to focus on a small target letter ***"T"*** (font size 14; same target as above) attached to the accommodative ruler as it was moved down the ruler at a rate of approximately 1-2 cm/s by the examiner. The subject was encouraged to try to keep the target single and instructed to verbalize when they saw two distinct images. Blurring of the image was ignored. If a subject verbalizes diplopia, target movement on the accommodative ruler was stopped by the examiner, and the distance in centimeters marked on the side of the accommodative ruler was recorded as the NPC value. If subject did not report diplopia (double vision), the point at which the subject had an outward or inward deviation of one eye was recorded as the NPC value. If a subject did not report diplopia or have a deviation before the target reaches a stop, the NPC value was recorded a 1. One centimeter was the minimum possible value for each measurement following previous accommodative ruler measure protocols.[28,34] Since the instrument was placed on the participant's brow, a value of 0 could never occur because the true zero measure point was invisible to the eyes. A total of three NPC measures were taken and then averaged to determine the final NPC-TD value.

2.3 Data & Statistical Analysis

A paired samples *t*-test was used to analyze differences in NPC-TD and NPC-AR values for all participants. For the secondary purpose, participants were separated into contact and limited/non-contact sport type groups. Contact sport types included basketball, field hockey, football, lacrosse, soccer, and wrestling; limited/non-contact sport types included baseball, cross country, softball, volleyball, and track & field.[42] Athletes participating in both contact and limited/non-contact sport types were placed in the contact sport group to minimize contact sport experience affecting the limited/non-contact group. Participants were additionally separated into potential concussion history and no or unrecognized concussion history. Potential concussion history included participants reporting 1 or more concussion injury and participants answering "yes" to the question, “have you ever been hit in the head and ‘knocked silly,’ ‘seen stars,’ knocked unconscious, or lost your memory?” from the health history questionnaire (Appendix B). Lastly, participants were separated by age into <17 years and ≥17 years.

Because a significant difference was determined between NPC-TD and NPC-AR procedures, an independent samples *t*-test was used to analyze differences in both NPC-TD and NPC-AR for all subgroups between contact and limited/non-contact sport type athletes, suspected concussion history and no concussion history, and between participants <17 years and ≥17 years. Descriptive statistics (including mean ± standard deviation, median, mode) were collected on all participant NPC-TD and NPC-AR values. A cumulative frequency at the 85th percentile was calculated for the NPC-TD and NPC-AR values, following a similar criterion of previous NPC normative publications to compare reports.[28,34,35] All data were analyzed with an alpha level set at $P \leq 0.05$.

Chapter 3

RESULTS

Descriptive statistics (Table 1) included mean, median, mode, and cumulative frequencies at the 85^{th} percentile. 44 participants had either history of 1 concussion or had ever been hit in the head and "knocked silly," "seen stars," knocked unconscious, or lost memory, 4 participants with a history of 2 concussions, and 4 participants with a history of 3 or more concussions. 85% of all NPC-TD values (Figure 3) were less than 4.8 cm and 85% of all NPC-AR values (Figure 4) were less than 5.3 cm.

There was a significant difference between NPC-TD (2.0±2.8cm) and NPC-AR (2.8±2.7cm) values (Table 2, Figure 5), $t(200)=5.85$, $p<0.001$. Due to significant differences between NPC-TD and NPC-AR methods, independent *t*-tests were performed on both methods for each subgroup (sport type, concussion history, age). There was a significant difference between contact and limited/non-contact groups (Table 3, Figure 6) with NPC-TD, $t(199)=4.01$, $p<0.001$, and NPC-AR, $t(199)=2.71$, $p=0.004$. There was a significant difference between concussion history and no concussion history (Table 4, Figure 7) with NPC-TD, $t(199)=2.50$, $p=0.010$, but not NPC-AR, $t(199)=1.60$, $p=0.094$. There was a significant difference between participants <17 years old and participants ≥17 years old (Table 5, Figure 8) with NPC-TD, $t(199)=2.47$, $p<0.001$, and NPC-AR, $t(199)=2.09$, $p=0.003$.

Chapter 4

DISCUSSION

Our results indicate a significant difference between NPC-TD and NPC-AR instrumentation methods in this high school student-athlete sample. Various reports exist recognizing the value of NPC in assessing convergence deficits following SRC, and throughout the recovery process potentially aiding in return to play decisions post-injury.[10,26,43] In addition, NPC has an association with long term effects following injury such as gait-related deficits, and a potential indicator of convergence disruption following sub-concussive impacts.[22,30,31] However, our results indicate that the procedure and instrument utilized in the measure affect recorded NPC values and support the use of consistent methods when assessing NPC in both a clinical and research environment. Modifiable methods for NPC can include instrument (tongue depressor, accommodative ruler), zero measure point (brow between eyes, tip of the nose, lateral corner of the eye), target type (letter, finger/pen tip, drawn line), and initiator of target movement (subject or examiner).[10,20,28,31,35,36,38]

An 85th percentile cumulative frequency was performed to compare to NPC normative data. In our high school aged population, 85% of all student-athletes had an NPC value <4.8cm with NPC-TD and <5.3cm with NPC-AR. Previous evidence with an accommodative ruler, following the same criterion, reports 85% of elementary school children populations had NPC-AR values <6cm[28] and <4.7cm,[34] and 85% of an adult population had NPC-AR values <4.5cm,[35] which are all similar to our results. When comparing to other NPC-TD value means, our results (2.0±2.8cm) fall within range of other reported NPC-TD means in youth athletes (1.5±2.6cm),[44] healthy adolescent controls (1.9±3.2cm,[10] 3.3±2.0cm),[22] and collegiate athletes at baseline (2.16±2.76cm).[45] Alternatively, when comparing to other NPC-AR value means (measuring from the brow), our results (2.8±2.7cm) fall within range of other reported NPC-AR means in elementary schoolchildren (3.26±2.59cm, 4.09±2.41cm, 4.26±3.40cm),[28] and healthy adults (2.49±1.74cm).[35] While other NPC data exist in literature, these reports differ either on instrument or zero measure point from our methods.[30,31,34,36,38,43]

As we hypothesized, both NPC-TD and NPC-AR values were significantly different between contact sport athletes and limited/non-contact sport athletes, which lends support to the growing body of evidence suggesting sub-concussive head impacts affect changes in NPC.[30,31] Neuroimaging data suggest the ocular motor system is acutely affected by sub-concussive head impacts.[30,46,47] Specifically in rugby players following a full contact game, differences between pre-game and post-game scans led the authors to conclude that even acute exposure to sub-concussive trauma demonstrates the ability to alter functional connectivity.[46] In college football players, a sustained increase in NPC throughout a season, associated with higher frequencies and magnitudes of impacts, highlighted the vulnerability of the ocular motor system to repetitive sub-concussive impacts.[30] Specific to children aged 8-16 years, those with concussion have visual processing deficits up to 12 weeks post-injury compared to healthy matched controls.[48] Potential effects from sub-concussive impacts and injury coupled with data that 40-55% of high school athletes do not report their concussion, convergence deficits may exist in these contact sport populations without any symptomatic indicator to the clinician.[7,49]

In addition, NPC-TD and NPC-AR values were significantly different between participants ≥17 years old and participants <17 years old. We chose this age cut-point because previous literature typically measures up to 17 years when examining an NPC change throughout age.[50,51] These results indicate an age effect on NPC when utilizing these methods, whereas current evidence is conflicting on whether NPC values improve or worsen with age.[50,51] One study concluded that NPC increases by 0.24 cm per year between ages 2-17, while a more recent study reported no significant change in NPC over time with only a .3 cm mean increase over 10 years.[50,51] Additionally, two normative reports with similar methods to the current study, using an accommodative ruler, had conflicting conclusions on the effect of age on NPC with their elementary schoolchildren populations.[28,34] Therefore, while our study indicates an age effect, perhaps this is because we examined athletes, and experience in sport may play a role.

Lastly, a significant difference between participants with potential history of concussion and with no or unrecognized history of concussion was only discovered with the NPC-TD method and not when using NPC-AR. An increase in NPC has been demonstrated in military populations with blast-induced mild traumatic brain injury and among athletes post-concussion.[10,32] Concussion history affecting NPC values is also supported by the growing body of evidence suggesting that post-concussion, athletes are more prone to injury compared to non-concussed athletes potentially indicating specific system deficits may linger well after an athlete is asymptomatic and returns to play.[52–54] Additionally, this may indicate that standard concussion assessment methods are not sensitive enough in identifying long term deficits and even if the patient is asymptomatic, a dysfunction may still exist furthering the need to identify a definitive time point for physiological recovery following concussion.[47,54,55] Significant difference with NPC-TD, but a lack of difference in NPC-AR may be explained by the NPC-AR method having a consistent, strong reliability (ICC: 0.89-0.98),[26,31,56] and the NPC-TD method reportedly having a less than optimal reliability in collegiate athletes (Kappa: 0.51),[45] potentially affecting the final NPC value because it is averaged across 3 trials.[10]

Limitations did exist within this study. Only one local public high school was used for student-athlete participants, and this alone is not representative of the entire high school aged student-athlete population. Because our study followed previously placed protocols for NPC-TD[10] and NPC-AR,[28] it resulted in different zero measure points for each instrument and different letter target movement, with the participant moving the target in NPC-TD values and the examiner moving the target in NPC-AR values. Groups separated by sport type, concussion history, and age were also not numerically matched in independent group testing because a large portion of the athletes utilized in this study played both contact and limited/non-contact sports, most athletes lack a history of concussion or simply do not report, and typically only senior high school athletes are aged 17 or older. Lastly, NPC is not the only assessment available for detecting convergence deficits and full orthoptic measures were not performed in this study because the equipment and personnel required to undergo such measures were not feasibly available in a high school setting.[57]

4.1 Conclusion

NPC, with either instrument used in this study, is easy to perform and quickly measured. Our data indicates a difference between using a tongue depressor and an accommodative ruler. Future research should analyze reliability differences between each instrument, including location of zero measure point, target type, and between target movement by participant or examiner. It is also worth investigating which set of procedures more accurately identifies convergence deficits post-concussion and throughout the recovery phase. Determining post-concussion NPC values with precise and consistent methods will allow clinicians to more accurately identify convergence deficits following injury and give the option of utilizing either a tongue depressor or accommodative ruler.

Chapter 5

LEGEND

Figure 1: Near point of convergence tongue depressor (NPC-TD) procedure.

Figure 2: Near point of convergence accommodative ruler (NPC-AR) procedure.

Table 1: Participant demographics and NPC descriptive statistics.

Number of Participants		201
Males/Females		126/75
Mean Age (yrs)		15.7 ± 1.2
Mean Height (cm)		170.5 ± 10.0
Mean Mass (kg)		69.9 ± 16.2
Concussion History N	**0**	149
	1[a]	44
	2	4
	≥3	4
NPC-TD[b] (cm)	**$\bar{x}$[d]**	2.0±2.8
	med[d]	0.67
	mo[d]	0.0
NPC-AR[c] (cm)	**$\bar{x}$[d]**	2.8±2.7
	med[d]	1.17
	mo[d]	1.0
NPC-TD[b] (cm) 85% Frequency		4.8 cm
NPC-AR[c] (cm) 85% Frequency		5.3 cm

[a] Includes athletes that have ever been hit in the head and “knocked silly,” “seen stars,” knocked unconscious, lost memory

[b] Near Point of Convergence with Tongue Depressor (NPC-TD) averaged across 3 trials

[c] Near Point of Convergence with Accommodative Rule (NPC-AR) averaged across 3 trials

[d] Mean ($\bar{x}$), median (med), and mode (mo)

Figure 3: Cumulative frequency histogram on NPC-TD values representing the total sum of the recorded value in the sample. For example, 103 participants recorded an NPC-TD value between 0 and 0.67 cm indicated by the histogram below

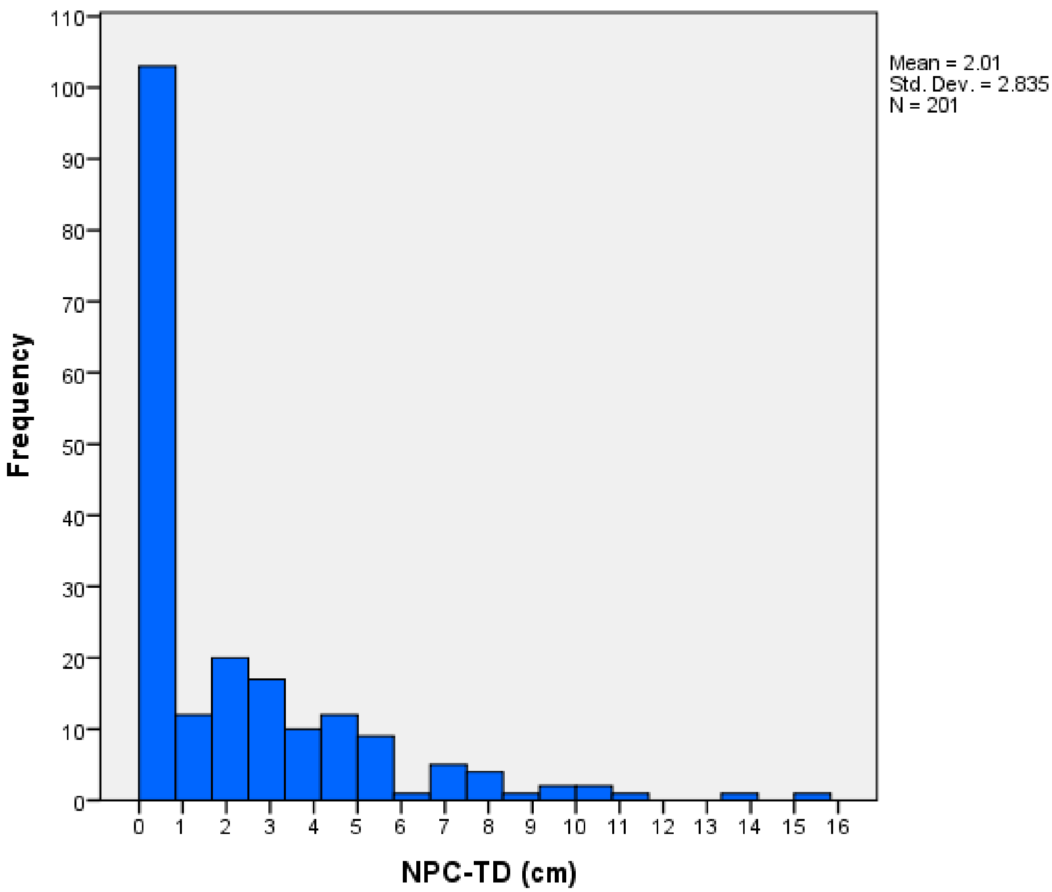

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Figure 4: Cumulative frequency histogram on NPC-AR values representing the total sum of the recorded value in the sample. For example, 104 participants recorded an NPC-TD value between 1 and 1.67 cm indicated by the histogram below.

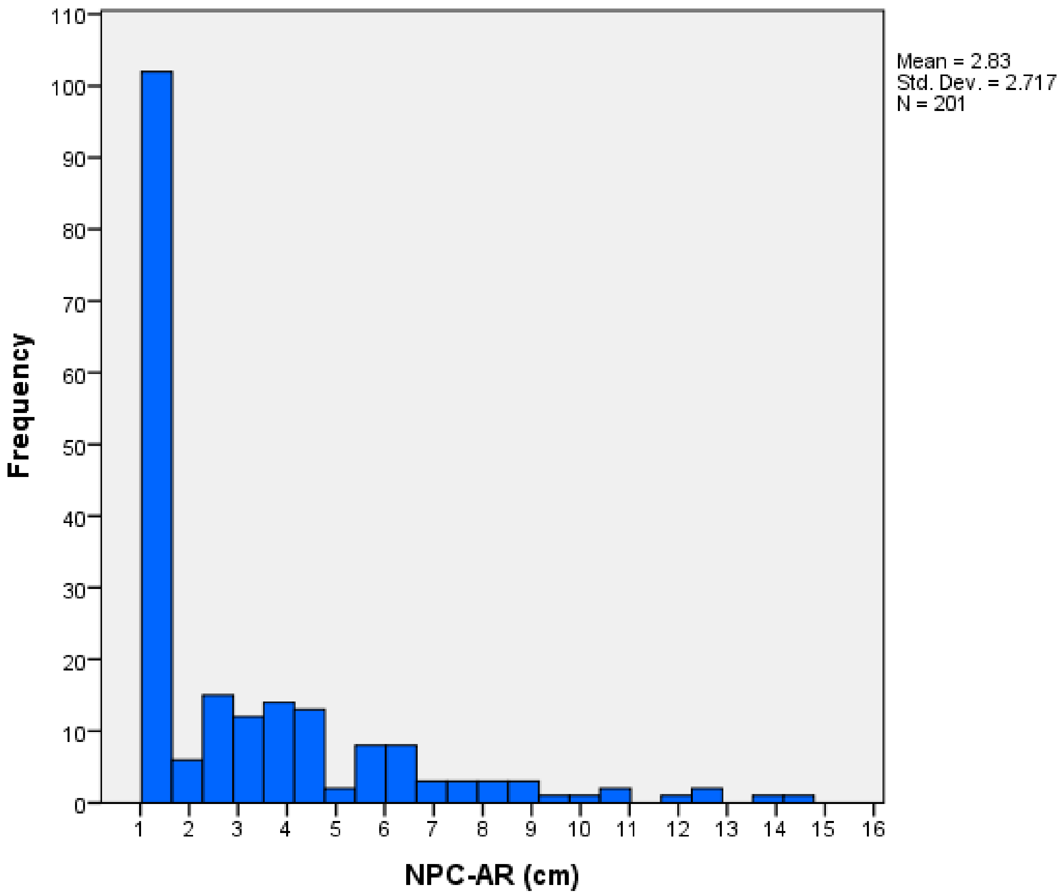

Table 2: Paired samples *t*-test on NPC-TD and NPC-AR values.

NPC-TD[a] & NPC-AR[b]		
Number of Participants		201
Males/Females		126/75
NPC Means	**NPC-TD**	2.0±2.8 cm
	NPC-AR	2.8±2.7 cm
Mean Difference		0.82 ± 1.98 cm
t		5.85
95% CI	**Lower**	0.54
	Upper	1.09
Sig. (2-tailed)		<0.001
	Correlation	0.75
	Cohen's *d*	0.41

[a] Near Point of Convergence with Tongue Depressor (NPC-TD) averaged across 3 trials
[b] Near Point of Convergence with Accommodative Rule (NPC-AR) averaged across 3 trials

Figure 5: Box plot of results for NPC values between NPC-TD and NPC-AR methods. The whiskers represent the data range, the box indicates the 95% confidence interval and the black line within the box indicates the median value. The markers display outliers that were removed from the box plot.

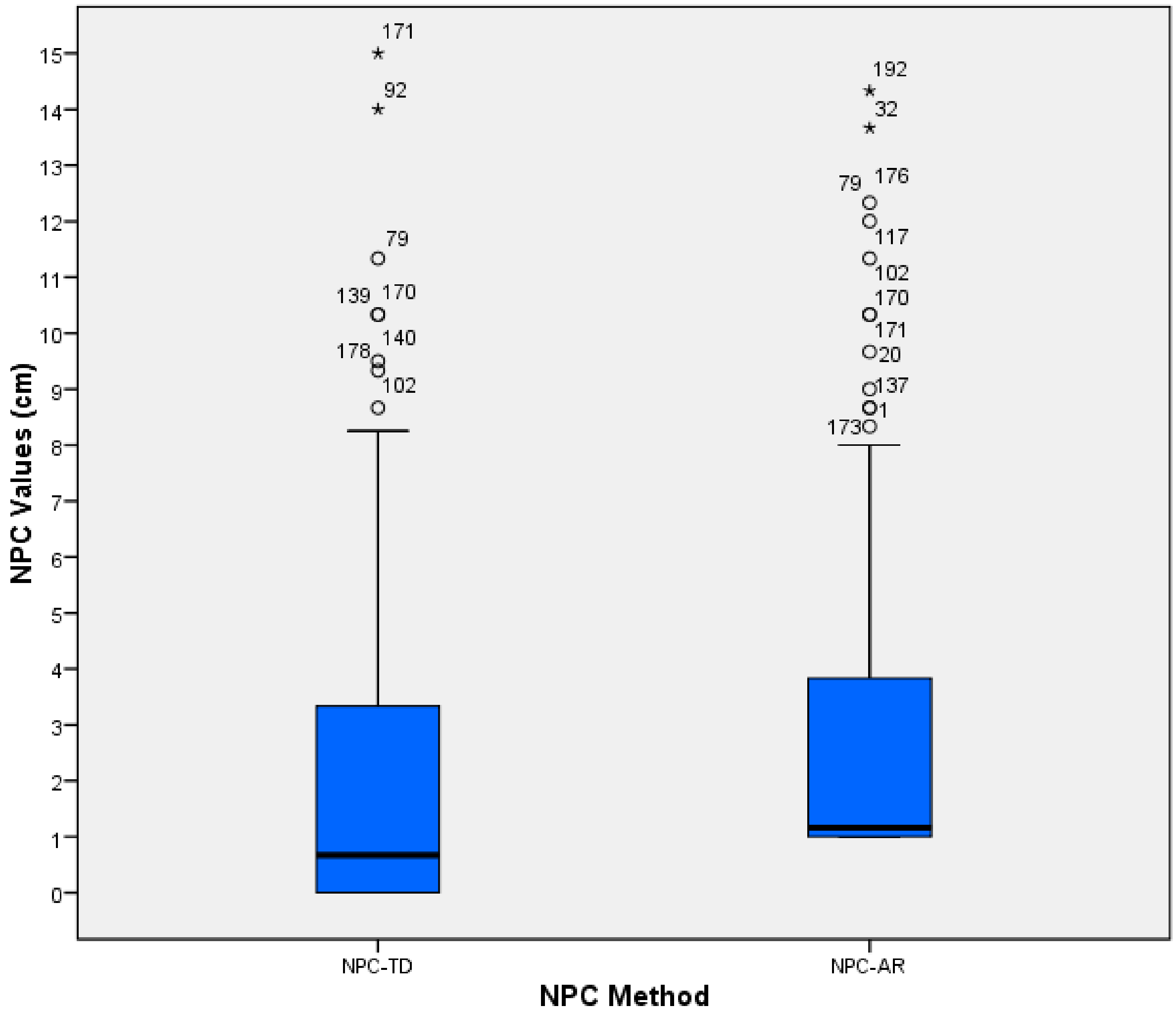

Table 3: Independent samples *t*-test on contact and limited/non-contact (NC) groups.

	NPC-TD[a]		**NPC-AR**[b]	
Sport Type	Contact	Limited/NC	Contact	Limited/NC
N	149	52	149	52
Mean (cm)	2.47±3.06	0.71±1.36	3.13±2.82	1.97±2.21
F	25.28		8.54	
t	4.01		2.71	
Sig.	<0.001		0.004	
Mean Difference	1.77 cm		1.17 cm	
95% CI Lower	0.89		0.32	
95% CI Upper	2.63		2.01	
Cohen's *d*	0.74		0.46	

[a] Near Point of Convergence with Tongue Depressor (NPC-TD) averaged across 3 trials
[b] Near Point of Convergence with Accommodative Rule (NPC-AR) averaged across 3 trials

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Figure 6: Box plot of results for NPC values between subjects participating in contact and limited/non-contact sport separated by NPC method. Each pair of boxes is separated with values from the NPC-TD and NPC-AR methods. The whiskers represent the data range, the box indicates the 95% confidence interval and the black line within the box indicates the median value. The markers display outliers that were removed from the box plot.

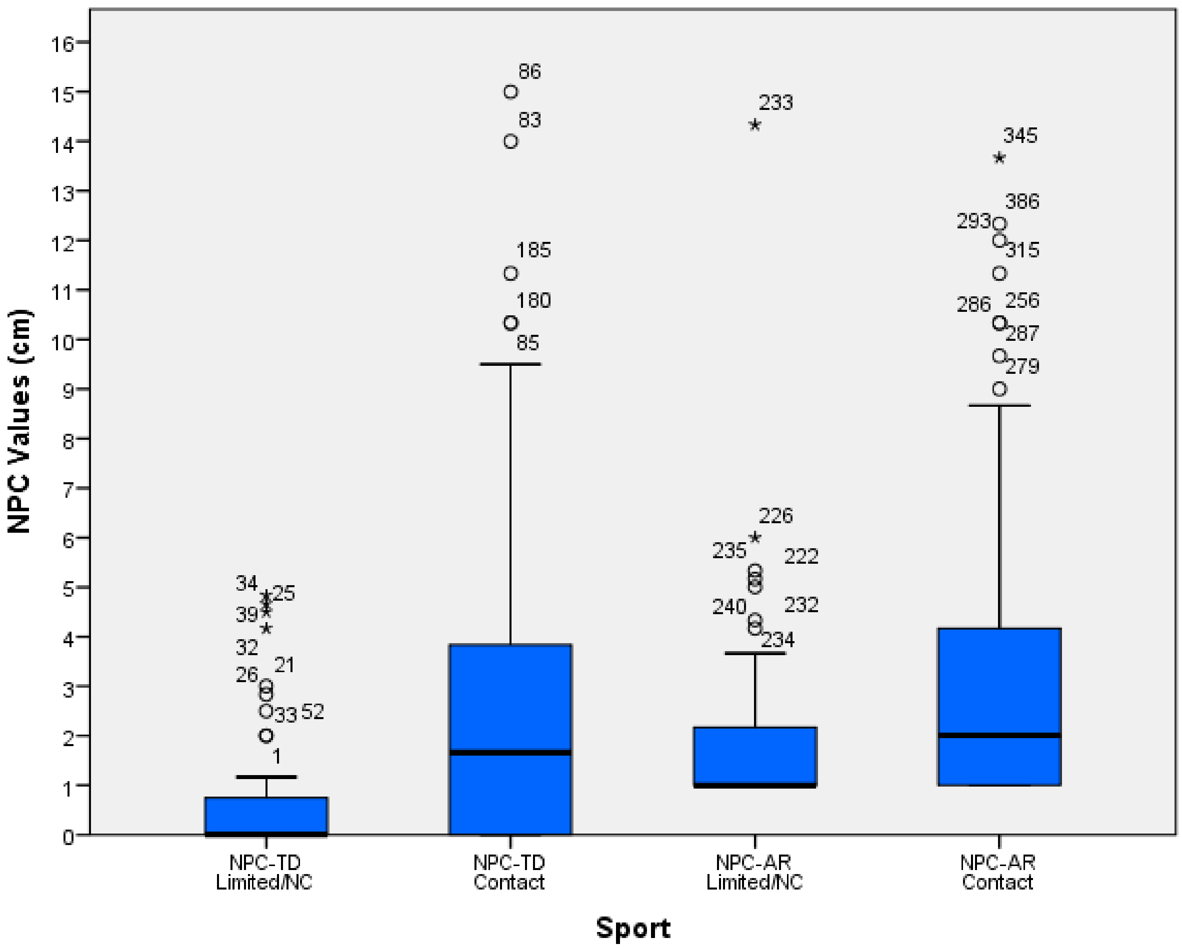


Table 4: Independent samples *t*-test on concussion and no concussion history groups.

		NPC-TD[a]		**NPC-AR**[b]	
Concussion History		Yes	No	Yes	No
N		52	149	52	149
Mean (cm)		2.85±3.64	1.72±2.44	3.34±3.03	2.64±2.58
F		6.84		2.83	
t		2.50		1.60	
Sig.		0.010		0.094	
Mean Difference		1.13 cm		0.70 cm	
95% CI	**Lower**	0.23		-0.16	
	Upper	2.01		1.55	
Cohen's *d*		0.36		0.25	

[a] Near Point of Convergence with Tongue Depressor (NPC-TD) averaged across 3 trials
[b] Near Point of Convergence with Accommodative Rule (NPC-AR) averaged across 3 trials

Figure 7: Box plot of results for NPC values between subjects with and without concussion history separated by NPC method. Each pair of boxes is separated with values from the NPC-TD and NPC-AR methods. The whiskers represent the data range, the box indicates the 95% confidence interval and the black line within the box indicates the median value. The markers display outliers that were removed from the box plot.

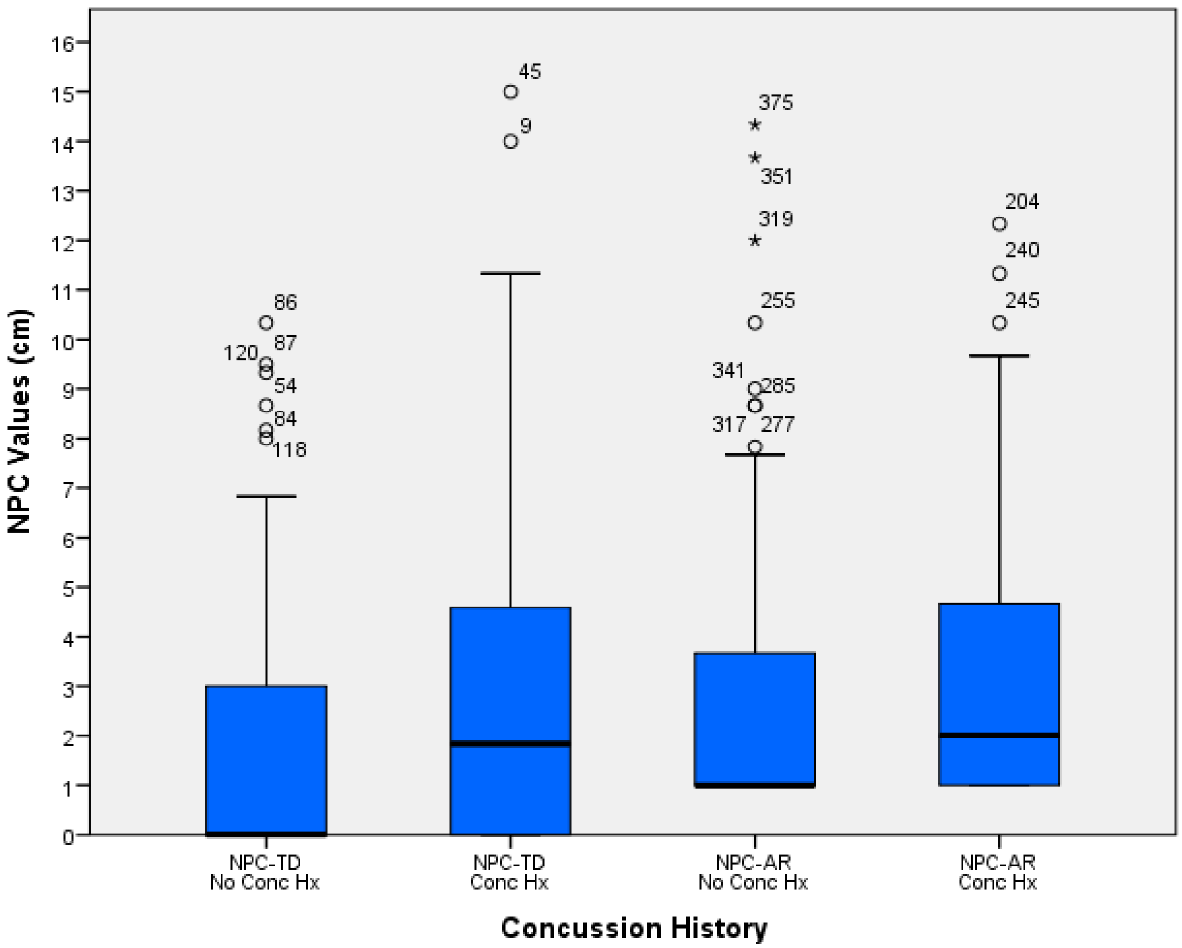
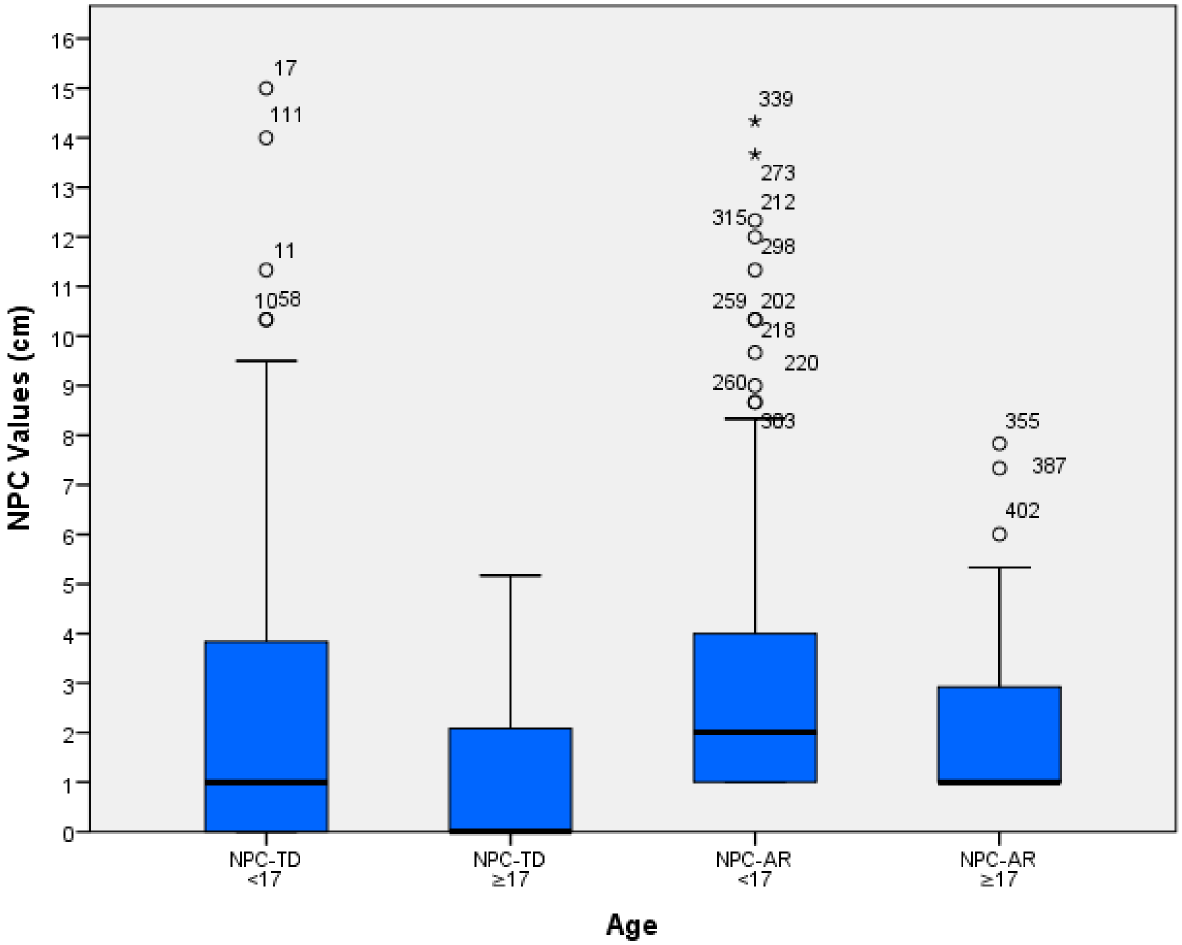


Table 5: Independent samples *t*-test on age groups (<17 and ≥17 years old).

	NPC-TD[a]		NPC-AR[b]	
Age	<17	≥17	<17	≥17
N	149	52	149	52
Mean (cm)	2.30±3.10	1.20±1.66	3.06±2.94	2.16±1.78
F	13.78		8.78	
t	2.47		2.09	
Sig.	<0.001		0.003	
Mean Difference	1.11 cm		0.91 cm	
95% CI Lower	0.22		0.05	
95% CI Upper	2.00		1.76	
Cohen's *d*	0.44		0.37	

[a] Near Point of Convergence with Tongue Depressor (NPC-TD) averaged across 3 trials
[b] Near Point of Convergence with Accommodative Rule (NPC-AR) averaged across 3 trials

Figure 8: Box plot of results for NPC values between subjects <17 years old and ≥17 years old separated by NPC method. Each pair of boxes is separated with values from the NPC-TD and NPC-AR methods. The whiskers represent the data range, the box indicates the 95% confidence interval and the black line within the box indicates the median value. The markers display outliers that were removed from the box plot.



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Appendix A

CONSENT FORMS (INFORMED, PARENTAL, ASSENT)

A.1 Informed Consent Form

University of Delaware
Informed Consent Form

Title of Project: Near Point of Convergence and Tandem Gait in High School Athletes

Principal Investigator (s): William "Wes" Sellars

Other Investigators: Thomas W. Kaminski, PhD.

You are being asked to participate in a research study. This form tells you about the study including its purpose, what you will be asked to do if you decide to participate, and any risks and benefits of being in the study. Please read the information below and ask the research team questions about anything we have not made clear before you decide whether to participate. Your participation is voluntary and you can refuse to participate or withdraw at any time without penalty or loss of benefits to which you are otherwise entitled. If you decide to participate, you will be asked to sign this form and a copy will be given to you to keep for your reference.

WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to collect normative data on near point of convergence (NPC) (vision testing) and tandem gait/walking (TG) in high school athletes. Secondly, we are looking to see if there is a difference in NPC between ball and non-ball sport athletes.

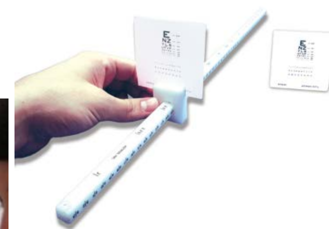
WHY ARE YOU BEING ASKED TO PARTICIPATE?

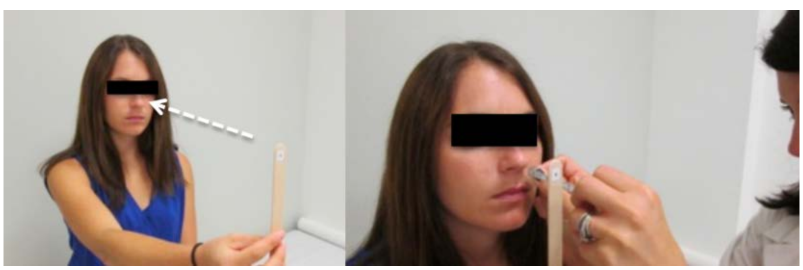
You are being asked to participate because you are a current member of a Hodgson Vocational Technical High School sport team. You can/will be excluded if you have a history of dizziness, accommodative dysfunction (problem sustaining prolonged near focus), any self-reported neurological disorder, current lower extremity orthopedic injury, and/or metabolic, vestibular, vision disorders, or other conditions that would impair walking and/or NPC performance. You will be removed from the study if you, for any reason, are no longer part of a Hodgson Vocational Technical High School sport team, or if you request to be removed from the study. There will be approximately 250 high school athletes participating in the study.

WHAT WILL YOU BE ASKED TO DO?

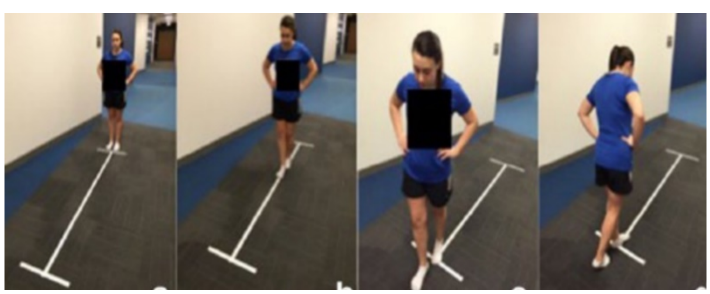
Prior to the start of the season, you will be asked to do a pre-season test session at Hodgson Vocational Technical High School. First, you will be asked to complete a health history questionnaire; immediately following completion of the form you will take part in the vision and walking tests. The total test time is 10 minutes.

The NPC measures your ability to focus on a small object without seeing double. You will be seated with the examiner in front of you. You will focus on a small letter "T" target on the tip of a tongue blade at arm's length and slowly brings it toward the tip of your nose. You are instructed to stop moving the target when you have double vision (see 2 of the letter "T"). Blurring of the image is to be ignored. The distance between the tongue blade and the tip of the nose is measured with a tape measure and recorded. You will complete a total of 3 trials. A second set of 3 trials will be performed as described above, with an accommodative ruler (below right) measured from the center of the forehead at the level of the brow.





For the TG trials you will be instructed to stand behind the starting line with feet together and, in response to a "start" command, walk with alternating heel-to-toe gait, in a forward direction, along the tape line on the floor as quickly as possible. Once you reach the end of the line, you turn around and return to the starting line with the same heel-to-toe gait pattern (pictured right). We will do this a total of 4 times.



WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

There are minimal risks associated with this study and these risks are no greater than the everyday activities of daily living. There is limited risk during the TG testing. It is possible you could trip or fall during the testing. However, at least one member of the investigative team will be in close proximity to you at all times to ensure a fall will not occur.

WHAT ARE THE POTENTIAL BENEFITS?

You will likely receive no direct benefit for participating in this study, however you will be provided your results, once calculated, if you so request. The results of this study will improve the understanding of NPC and TG measurements in high school athletes.

WHAT IF NEW INFORMATION BECOMES AVAILABLE ABOUT THE STUDY?

During the course, we may find more information that could be important to you. This may include information that may cause you to change your mind about participating in the study. We will notify you as soon as possible if any new information becomes available.

HOW WILL CONFIDENTIALITY BE MAINTAINED?

If you choose to participate in this study, you can be assured your information is kept confidential. For this study, you will be identified only by your subject number. Records of this information will be kept on electronic file, available only to those directly associated with the research. This consent form will be the only document with your name and personal information. This consent form and data collected will be stored for three years. The consent form will be locked in a file cabinet in the Athletic Training Research Lab (Room 160 of the Human Performance Laboratory). No personal information will be shared when the results of this study are reported.

Your research records may be viewed by the University of Delaware Institutional Review Board, but the confidentiality of your records will be protected to the extent permitted by law.

Data will be destroyed at the conclusion of the study and after data analysis, interpretation, and dissemination are complete, the physical and paper records will be destroyed by shredding these records.

WILL THERE BE ANY COSTS RELATED TO THE RESEARCH?

There will be no costs related to your participation in this study.

WILL THERE BE ANY COMPENSATION FOR PARTICIPATION?

You **WILL NOT** receive any money for your participation in this study.

WHAT IF YOU ARE INJURED DURING YOUR PARTICIPATION IN THE STUDY?

If you are injured during research procedures, which are separate from athletic participation, you will be offered first aid at no cost to you. If you need additional medical treatment, the cost of this treatment will be your responsibility or that of your third-party payer (for example, your health insurance). By signing this document you are not waiving any rights that you may have if injury was the result of negligence of the university or its investigators.

DO YOU HAVE TO TAKE PART IN THIS STUDY?

Taking part in this research study is entirely voluntary. You do not have to participate in this research. If you choose to take part, you have the right to stop at any time. If you decide not to participate or if you decide to stop taking part in the research at a later date, there will be no penalty or loss of benefits to which you are otherwise entitled. Your refusal will not influence current or future relationships with the University of Delaware, Hodgson Vocational Technical High School, your sport team or coaching staff, playing time/opportunities, or the sports medicine staff. Your refusal will not affect your participation in your sport at Hodgson Vocational Technical High School or your grades in your classes.

WHO SHOULD YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?

If you have any questions about this study, please contact the Principal Investigator or Advisor:

Principal Investigator - William "Wes" Sellars @ sellars@udel.edu or 904-536–3971

Advisor – Thomas W. Kaminski @ kaminski@udel.edu or 302-831-6402

If you have any questions or concerns about your rights as a research participant, you may contact the University of Delaware Institutional Review Board at 302-831-2137.

Your signature on this form means that: 1) you are at least 18 years old; 2) you have read and understand the information given in this form; 3) you have asked any questions you have about the research and those questions have been answered to your satisfaction; 4) you accept the terms in the form and volunteer to participate in the study. You will be given a copy of this form to keep.

______________________	______________________	__________
Printed Name of Participant	Signature of Participant	Date
______________________	______________________	__________
Person Obtaining Consent	Signature of Person Obtaining Consent	Date

A.2 Parental Permission Form

University of Delaware
Parental Permission for Participation in a Research Study

Title of Project: Near Point of Convergence and Tandem Gait in High School Athletes

Principal Investigator (s): William "Wes" Sellars (graduate student) in the Department of Kinesiology and Applied Physiology, Thomas W. Kaminski, PhD (professor) in the Department of Kinesiology and Applied Physiology.

Your child is being asked to participate in a research study. This form is designed to tell you about the study including its purpose, what your child will do if you allow them to participate, and any risks and benefits of being in the study. Please read the information below and feel free to ask the research team questions about anything you do not understand before you decide whether or not to allow your child to participate. Your child's participation is completely voluntary and you or your child can refuse to participate or withdraw at any time without penalty or loss of benefits to which you are otherwise entitled. If you decide to allow your child to participate, you will be asked to sign this form and a copy will be given to you for your records. If your child turns 18 during the study, but prior to the last testing session, he will need to re-consent as an adult by filling out an informed consent form.

WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to collect normative data on near point of convergence (NPC) (vision testing) and tandem gait/walking (TG) in high school athletes. Secondly, we are looking to see if there is a difference in NPC between ball and non-ball sport athletes.

WHY ARE YOU BEING ASKED TO PARTICIPATE?

Your child is being being asked to participate because they are a current member of a Hodgson Vocational Technical High School sport team. They can/will be excluded if they have a history of dizziness, accommodative dysfunction (problem sustaining prolonged near focus), any self-reported neurological disorder, current lower extremity orthopedic injury, and/or metabolic, vestibular, vision disorders, or other conditions that would impair walking and/or NPC performance. They will be removed from the study if for any reason, are no longer part of a Hodgson Vocational Technical High School sport team, or if they or you request to be removed from the study. There will be approximately 250 high school athletes participating in the study.

WHAT WILL YOU BE ASKED TO DO?

Prior to the start of the season, your child will be asked to do a pre-season test session at Hodgson Vocational Technical High School. First, they will be asked to complete a health history questionnaire; immediately following completion of the form they'll take part in the vision and walking tests. The total test time is 10 minutes.

A.3 Child Assent Form

University of Delaware
Child Assent Form for Youth Ages 14-17

Your parent(s) has/have given permission for you to take part in a research study for the University of Delaware. But first, we want to tell you all about it so you can decide if you want to be a part of it. If you do not understand, please ask questions. You can choose to be in the study, not be in the study, or take more time to decide.

WHAT IS THE NAME OF THIS STUDY?

Near Point of Convergence and Tandem Gait in High School Athletes

WHO IS IN CHARGE OF THIS STUDY?

William “Wes” Sellars (graduate student), Dr. Thomas W. Kaminski, PhD (advisor).

WHAT IS THE STUDY ABOUT?

You are invited to take part in a research study to collect normative data on near point of convergence (NPC) (vision testing) and tandem gait (TG; walking testing) in high school athletes. Secondly, we are looking to see if there is a difference in NPC between ball and non-ball sport athletes.

WHY ARE YOU BEING ASKED TO PARTICIPATE?

You are being asked to participate because you are a current member of a Hodgson Vocational Technical High School sport team. You can/will be excluded if you have a history of dizziness, accommodative dysfunction (problem sustaining near focus with your eyes or switching focus quickly between near and far objects), any self-reported neurological disorder, current lower extremity orthopedic injury, and/or metabolic, vestibular (significant and/or diagnosed problems with balance), vision disorders, or other conditions that would impair walking and/or NPC (near vision) performance. You will be removed from the study if you, for any reason, are no longer part of a Hodgson Vocational Technical High School sport team, or if you request to be removed from the study. There will be approximately 250 high school athletes participating in the study.

WHAT WILL YOU BE ASKED TO DO?

Prior to the start of the season, you will be asked to do a pre-season test session at Hodgson Vocational Technical High School. First, you will be asked to complete a health history questionnaire; immediately following completion of the form you will take part in the vision and walking tests. The total test time is 10 minutes.

Appendix B

HEALTH HISTORY QUESTIONNAIRE

Please answer the following questions as honestly as possible. Your answers will remain confidential and will **NOT** be shared with anyone.

Subject ID ________________________ Date: _____ / _____ / _______

Gender: M / F Age: _______

Height: _______ Weight: _______

Year in School: FR SO JR SR Sport: ________________

Please answer the following questions about your injury history;

1. Have you ever suffered a concussion? YES NO

   If yes, when was your last concussion? _________

   If yes, how many concussions have you suffered? _______

2. Have you ever been hit in the head and "knocked silly," "seen stars," knocked unconscious, or lost your memory? YES NO

   If yes, how many times has this happened? _____

3. Do you wear corrective lenses (glasses, contacts, etc.)? YES NO

   If yes, are you wearing them currently? YES NO

4. Do you have a history of dizziness? YES NO

5. Do you have any problems with focusing on near objects? YES NO

6. Do you have history of any neurological disorders, metabolic, vestibular, or vision disorders? YES NO

7. Do you have any history of motion sickness? YES NO

   If Yes, please explain: ____

8. Do you currently have a lower extremity injury? YES NO

   If yes, please explain: ____

9. Are you currently taking any medication which affects your balance or cognitive (thinking)? YES NO

Appendix C

SPECIFIC AIMS

C.1 Specific Aim 1: To determine if instrument method (tongue depressor or accommodative ruler) influences NPC values in high school athletes.

C.2 Hypothesis 1: High School athletes will have different NPC values between the use of a tongue depressor measured from the tip of the nose and an accommodative ruler measured from the brow just above the nose between the eyes. Evidence suggests this difference will exist based on variability in NPC values when assessed from different zero measure point landmarks (brow between eyes, nose, upper lip) in previously reported data.[28,34–36]

C.3 Specific Aim 2: To assess whether a difference exists in NPC values between contact and limited or non-contact sport type athletes.

C.4 Hypothesis 2: High school contact sport athletes will have increased (worse) NPC values compared to limited and non-contact sport athletes. Based on reports, collegiate athletes have not displayed significant differences between sport type for various baseline measures, but high school athletes have shown statistical significance between sport type on neuropsychological test performance, and this evidence suggests a difference will occur between these two groups.[39–41]

Appendix D

BACKGROUND AND SIGNIFICANCE

D.1 Introduction

Sport-related concussions (SRC) are a prevalent injury in high school athletes and are continuously gaining attention in our society.[1,9,58,59] Athletic trainers face a challenging task of recognizing and diagnosing a concussion.[6,8,9,59] SRC present with a large array symptoms and impairments that requires a multifaceted approach to diagnosis.[8–10,12,13,60] In recent literature, the need to assess the vestibular and ocular motor systems following a concussion has been suggested.[9,10,13–15,21,24,26,33,61,62]

A Vestibular/Ocular Motor Screening (VOMS) tool was recently developed to assess vestibular and ocular motor impairments and symptoms after SRC.[10] The VOMS consists of assessments in 5 domains: smooth pursuit, horizontal and vertical saccades, convergence, horizontal vestibular ocular reflex, and visual motion sensitivity. [10] This clinical screening tool, in multiple studies, has shown to be valid and reliable.[10,14,24,33,63]

NPC, measured as part of the VOMS domains, is used to assess convergence insufficiency. Data exist with recommendations for NPC cutoff points to diagnose an insufficiency,[28,34–36] however, a cutoff point for the athletic population, specifically high school aged athletes, has yet to be determined.[34–37,64]

D.2 Sport-Related Concussion

It is estimated that approximately 4.1 million boys and girls in the United States participate in organized youth sport programs and high school athletics, and an estimated

1.6-3.8 million SRC occur annually.[1,6,58,59,65] Concussions are a complicated injury thought to include a combination of metabolic, physiological, and microstructural injuries to the brain.[3,4,66] Simply, an SRC is a traumatic brain injury induced by biomechanical forces.[4]

SRC affects the autonomic nervous system and the control of both cerebral blood flow and cardiac rhythm, and has been described as a "neurometabolic cascade of events that involves bioenergetic challenges, cytoskeletal and axonal alterations, impairments in neurotransmission, vulnerability to delayed cell death and chronic dysfunction."[3,66] SRC may be caused by a direct or indirect blow to the body with an impulsive force transmitted to the head accompanied by a rapid onset of neurological impairment with clinical symptoms reflecting a functional disturbance rather than a structural injury.[1,3,4]

Epidemiological data further supports the prevalence and need for recognition of SRC.[1,2,4,6,58,59,65,67–69] In a study involving 17,549 collegiate and high school football players, the overall incidence of concussion at all levels was reported at a rate of 5.1% with the greatest incidence at the high school level at a rate of 5.6%.[59] The same study reported that players who sustained one concussion in a season were three times more likely to sustain a second concussion in the same season compared with uninjured players, supporting the notion that correct and accurate identification of this injury is paramount. [59] A similar study with a total of 2,385 high school and college football players reported an overall concussion rate of 3.8% in both groups.[69]

In a study examining concussion epidemiology across 100 high schools and 180 colleges, concussions represented 8.9% of all high school athletic injuries and 5.8% of all collegiate athletic injuries, with injury rates of 0.23 and 0.43 concussions per 1,000 athletic exposures in high school and college, respectively.[5] The Centers for Disease

Control reported during 2001-2009 that 6.5% of 2,651,581 children 19 and younger were treated annually for sports or recreation-related traumatic brain injury.[68] A clinical review of several studies on pediatric SRC stated that some athletes fail to report concussions altogether, further urging the need to prevent recurrent injuries with reliable assessment and management techniques.[1]

One study investigating the epidemiology of concussions in high school athletes across 20 sports determined an injury rate of 2.5 concussions per 10,000 athlete exposures.[6] The study also discovered that more than half of all high school students participated in sports during the school year. Finally, across all sports, the data showed concussions made up 13.2% of the 14,635 injuries reported.[6] A report from 2015 examined the incidence of concussion in athletes participating in youth, high school, and collegiate American football.[58] It was discovered that concussion injury rate was higher than knee sprains or fractures in high school football. At the high school football level, the injury rate of concussions was 2.01 per 1,000 athlete exposures.[58]

Regarding high school athletes, an epidemiological study was performed across 147 high schools over the course of 3 years reporting an overall SRC rate of 3.89 per 10,000 athlete exposures.[2] High school athletes tend to lack knowledge of concussions as well as underreport their injury.[7,70] Underreporting of concussion among high school athletes is as high as 55% with females more likely to report a SRC.[7,70] The top reasons for not reporting a concussion were they did not recognize the symptoms as serious (46.2% of athletes) and did not want to lose playing time (36.5% of athletes).[70] In addition, the most commonly unidentified symptoms by high school athletes in association with concussion were sleep difficulties, difficulties with concentrating, and behavioral changes.[7]

SRC are prevalent in youth sports, with higher incidence rates occurring in high school athletics.[1,2,9,58,59,68,69] With more than half of all high school students participating in sports, SRC representing 5.6-13.2% of all injuries, and rates ranging from .23-.39 per 1,000 athlete exposures, awareness and recognition of SRC is continuously increasing.[2,6,59] The concern and growing attention revolving around these injuries support the need for reliable and valid screening tools to assist the clinician in diagnosing SRC. Due to the complicated and multifaceted presentation of SRC, the use of multiple diagnostic tools to more accurately assess the injury is needed.[3,4,8–10,12–15,21,24,26,33,60–62,71]

D.3 Current Diagnostic Tools for Concussion

Currently, there is not a *"gold-standard"* testing method that can identify all individuals with SRC.[9] There are numerous diagnostic tools used to assess SRC with the most effective approach is to combine the methods together as an assessment battery to clinically diagnose the injury.[4,8,9,13,60,72–74] It is recommended to record a baseline of these assessments to compare to should an athlete suffer a SRC.[4,8,73,75] Diagnostic tools most commonly used include a self-reported symptom checklist, the Standardized Assessment of Concussion (SAC), Balance Error Scoring System (BESS), and the Immediate Post-concussion Assessment Cognitive Test (ImPACT) or other neurocognitive assessment.[4,8,9,72] Recently introduced and researched tools include the King-Devick Test (K-D), a Clinical Reaction Time test, and the Vestibular/Ocular Motor Screening (VOMS) assessment.[10–12] Also worth nothing is the Sport Concussion Assessment Tool—5th Edition (SCAT5) that includes a 22-item symptom checklist, SAC, and a modified BESS, and "currently represents the most well-established and rigorously developed instrument available for sideline assessment".[4,9]

Self-reporting SRC symptom checklists are widely-used and have value in concussion assessment.[8,73,75] Several symptom scales are available to clinicians such as the Concussion Symptom Inventory, Graded Symptom Checklist (GSC), or Post-Concussive Symptom Score (PCSS); with number of symptoms assessed ranging between 7 and 24 items.[73,75] Specifically, the GSC and PCSS have shown to have a sensitivity and specificity ranging from 64-89% and 91-100%, respectively.[75] A potential issue with symptom checklists is they rely on the athlete honestly self-reporting, and multiple studies have shown that athletes often hide symptoms to return-to-play.[7,70,76]

The SAC is a brief evaluation of cognitive function including questions of orientation, working memory, concentration, and remote memory.[4,75] In 2002, a study involving 2,385 high school and collegiate athletes reported 95.6% of all injured subjects had lower SAC scores at time of injury.[69] However, SAC impairment was no longer detected 48 hours or 90 days post-injury. [69] While, it has been shown less effective farther than 48 hours from injury, the SAC has shown to record impairment in some SRC otherwise missed by different assessments, thus indicating its value.[69,76]

The BESS is a balance test assessing errors made in different stances (double leg, single leg, tandem) on firm and foam surfaces.[12,77] Athletes are required to undergo each trial for 20 seconds, with a point added for each error, with the maximum score for each trial to be 10 errors and 60 errors the maximum score of all trials combined. [12,77] The BESS has shown to be limited by great variability in scoring within and between raters.[76,77] In 2009, ICC for total BESS score for intra-rater and inter-rater was reported as 0.74 and 0.57, respectively, with the study stating none of the total BESS scores reached the set threshold of 0.75 for good reliability.[77]

The most commonly used neurocognitive testing tool, the ImPACT, is a computerized test with assessments of verbal memory, visual memory, visual motor speed, reaction time, impulse control, and cognitive efficiency index.[78] In 2007, a study examining the sensitivity of a concussion assessment battery reported ImPACT to have a sensitivity of 62.5% within 24 hours of injury. However, when combined with the ImPACT symptom inventory, a sensitivity of 79.2% was reported.[8] A recent meta-analysis on ImPACT and self-reported symptoms indicated a larger effect size for self-reported symptoms than ImPACT within 1 week of injury, and comparable effect sizes after 1 week, with the authors stating, "if the athlete reports symptoms within 1 week of injury, administering a cognitive test does not appear to offer additional information to the clinician."[78]

The King-Devick Test (K-D) is a quick assessment of rapid number naming that requires vision and saccadic eye movements.[12] In a sample of 30 collegiate athletes with a SRC, K-D differences from baseline to post-injury showed worsening in 79% of the athletes. [12] The K-D has demonstrated reliability and an association with ImPACT visual motor speed score.[12,79] However, the K-D only measures saccadic eye function, is highly susceptible to a practice effect, and does not include any vestibular component.[14]

More recently, a measurement of Clinical Reaction Time (CRT) in which the examiner drops, at various assigned delays, an 80 cm measuring stick with a weighted rubber disk affixed to one end that is then caught by the subject as quickly as possible.[11] This tool has shown to be useful in ruling-out a SRC injury, as evident in the reporting of a 93% specificity. [11] Another more recently developed tool assessing vestibular and ocular motor system deficits is the Vestibular/Ocular Motor Screening (VOMS), which will be discussed in more detail in its labeled section.[10]

Individually, there is no one tool that can identify all concussions, but literature has shown a strong sensitivity when combining multiple assessment tools.[4,8,9,12,71,73] While there are a myriad of options available to clinicians for concussion assessment, none of the commonly used assessments screen for vestibular and/or ocular motor deficits.[9,10,73,74] One could argue the need for a test of these system's deficits be included in a common assessment battery, and it has, therefore, been recently recommended that a vestibular and ocular motor assessment be performed following a SRC.[4,10,13,66,74] Vestibular and ocular motor impairments occur in approximately 60% of athletes following SRC, indicating the need for assessment of these systems.[10] An understanding of these systems and deficits associated with SRC is important in order to improve concussion recognition in patients suffering these impairments.

D.4 Vestibular and Ocular Motor Systems

The vestibular system involves 2 functional aspects, the vestibulo-spinal reflex (VSR) regulating postural stability and the vestibulo-ocular reflex (VOR) integrating movement of the head and vision. Together they play a role in balance control, gaze stabilization, and posture.[14,33,80] The vestibular system is integrated with visual, proprioceptive and other extra-vestibular information that combine leading to a sense of motion.[80]

Afferent fibers of the vestibular component carry signals from the receptor cells to the vestibular nuclei, and the central neurons of the nuclei then project to the neural structures that control eye movements, posture, and balance. The two types of afferent fibers are regular and irregular. Regular afferents are twice as sensitive and transmit double the information about head motion than the irregular afferents. [80] To simplify, regular afferents provide the detailed information about head movements, whereas irregular afferents act as event detectors at high frequences of movement and are more sensitive to acceleration of head movement. [80]

Central neurons in the vestibular system can be separated into two main categories of vestibulo-ocular reflex (VOR) neurons and posture or self-motion neurons. The VOR neurons comprise a three-neuron arc in which vestibular nerve afferents project to central neurons in the vestibular nuclei which project to extraocular motor neurons. Two main subtypes of the VOR neurons are the position-vestibular-pause (PVP) neurons and vestibular-only (VO) neurons. The PVP neurons carry signals during passive head rotations and eye movements, while the VO neurons receive direct input from the vestibular nerve without projecting to ocular motor structures or contributing to VOR. The VO neurons project to the spinal cord and are thought to mediate vestibulo-spinal reflex (VSR). Therefore, while PVP mediate the VOR, stabilize gaze and ensure clear vision during daily activities, the VO plays a crucial role in ensuring postural equilibrium. [80]

The VOR produces compensatory eye movements of equal and opposite magnitude to head rotations to stabilize the visual axis relative to space which assists in maintaining stable gaze. The VOR may be our fastest behavior with eye movements generated at a latency of 5-6 ms in response to head movement. VOR stabilizes gaze faster than would be possible with the most rapid visually evoked eye movements and shows remarkable compensatory gain as well as minimal phase lag over the physiological relevant range of head motions. [80] VOR accomplishes this by relying on vestibular inputs, not on visual information, to generate these compensatory eye movements to stabilize vision during rapid movement. [80]

Head motion is often made to redirect our visual axis (gaze) voluntarily, which can be rapid (gaze shifts) or slow (gaze pursuits). A coordinated sequence of eye and head movements are made toward the target of interest. Interestingly, during this shift or pursuit, the VOR is suppressed because if it were intact during these voluntary gaze shifts, it would command an eye movement in the opposite direction. Therefore, it is compensatory when the goal is to stabilize gaze, but suppressed when the goal is to redirect gaze. [80]

The vestibulo-spinal reflexes (VSR) play an important role in active and passive head motion by coordinating head and neck movement with the trunk and body to maintain the head in an upright position. The VSR is comprised of vestibular afferents that project to the vestibular nuclei which then project to spinal motor neurons. Within the VSR, VO neurons actively respond to passive head movements, but are attenuated during active head movements, indicating the VSR is suppressed during voluntary head movements. This is due to the VSR mainly being responsible to selectively adjust postural tone in response to movement that the brain does not expect. When working together, the VOR and VSR function to ensure stable gaze and posture as well as the processing of self-motion information for higher-order functions. [80] The separation of the vestibulo-ocular and vestibulo-spinal subsystems further implicates the need for an assessment of the vestibular system separate from postural or balance tests.[14,74,80,81]

The ocular motor system includes the versional, vergence, and accommodative systems. These systems work in conjunction with the vestibular system to maintain visual stability and scanning capabilities.[14,17] Versional ocular motility involves a conjugate movement of the 2 eyes including movements of fixation, saccades, and pursuits.[17] The premotor neural components include frontal eye fields, supplemental eye fields, parietal area, right prefrontal cortex, and right posterior parietal cortex. [17] Vergence ocular motility involves a disjunctive movement of both eyes, convergence and divergence. Premotor neural components in the brainstem are located 1-2mm dorsal and dorsolateral to the nucleus of the oculomotor nerve. There are three types of vergence cells; tonic, burst, and burst-tonic. Tonic cells are involved with changes in vergence angle, burst with changes in vergence velocity, and burst-tonic respond to combined angle and velocity. [17] To elicit convergence at the peripheral level, a decreased stimulation to the bilateral abducens nerves and increased stimulation to the oculomotor nerves must take place. [17]

Accommodation is the ability to focus visually, whether it’s a single target or transitioning from near to far or vice versa. [17] The innervation for the accommodation system is comprised of premotor and cortical neural components. The premotor component is the autonomic nervous system (ANS), with the parasympathetic system initiating the accommodative response and the sympathetic system assisting in maintaining. Input is received and processed from the ANS, carried to the oculomotor nerve, and the motor fibers then travel to the ciliary muscle to produce a change in accommodation. [17] All three of these ocular motor system subdivisions are susceptible to diffuse axonal injury. [17]

The vestibular and ocular motor systems are often a part of the most common and debilitating symptoms that can occur following mild traumatic brain injury (mTBI) and SRC.[14–16,33,61,66,82,83] Vestibular and ocular motor alterations following a SRC can result in symptoms including imbalance, vertigo, dizziness, blurred vision, difficulty focusing, difficulty reading, difficulty tracking, double vision, loss of vision, photophobia, and/or impairment of the following: pupillary reflex, accommodation, convergence, pursuit, saccades, and vestibulo-ocular reflex (VOR).[14–16,83] Vestibular and ocular motor dysfunction may also lead to visual motion sensitivity (VMS), which refers to a heightened awareness of normal visual stimuli due to an inability to centrally integrate visual and vestibular information. Symptoms often include dizziness, vertigo, nausea, or disequilibrium in busy environments.[14]

A retrospective analysis of 160 individuals with a TBI reported that 90% had an ocular motor dysfunction, 56.3% of which had convergence insufficiency and vergence problems.[17] Dizziness, a vestibular/ocular motor symptom, may involve vertigo or illusion of movement, feeling of faint, or psychophysiologic symptoms.[74] In a sample of 107 high school students, on-field dizziness was associated with a 6.34 odds ratio of increased risk of a protracted recovery with the authors suggesting specific tests be used for dizziness rather than using postural or balance deficits as an indicator. [74]

In a sample of 101 adolescent patients (mean age 14.2), 28.6% with an acute SRC and 62.5% with post-concussion syndrome (PCS) exhibited vestibulo-ocular dysfunction (VOD). VOD was a significant risk factor for the development of PCS in the pediatric cohort.[61] A study examining concussed athletes against healthy controls reported approximately 45% of the athletes experienced abnormal NPC distances indicating convergence insufficiency.[10] In light of multiple symptoms indicating dysfunction of vestibular and/or ocular motor systems following concussion, a brief clinical screening tool for these systems following a SRC was recently developed.[10]

D.5 Vestibular/Ocular Motor Screening (VOMS)

Recent literature has recognized the need to assess vestibular and ocular motor systems following a concussion.[4,9,10,12–15,21,24,26,33,60–62,66,73,74,81,84] Previous literature has stated that nearly 30% of concussed athletes report visual problems during the first week after the injury.[10] A vestibular/ocular motor screening (VOMS) tool to assess impairments and symptoms following SRC was recently developed. [10] The VOMS consists of assessments in 5 domains: smooth pursuit, horizontal and vertical saccades, NPC, vestibular-ocular reflex, and visual motion sensitivity. [10] Equipment needed for the screening is a tape measure (cm), metronome, and a target with a 14-point font print, usually in the form of a ***"T"*** or ***"X"*** taped on the surface of a tongue depressor. Baseline symptoms of headache, dizziness, nausea, and fogginess are recorded on a 0-10 scale. The individual test domains are then performed with another recording of headache, dizziness, nausea and fogginess on the same scale following each test. [10]

1. Smooth pursuits: test the ability to follow a slowly moving target (Figure 1). Patient and examiner are seated with the examiner holding a fingertip 3 ft. from the patient. The patient maintains focus on the target as the examiner moves the target smoothly in the horizontal direction 1.5 ft. to the right and 1.5 ft. to the left of midline, and then repeated moving the target smoothly and slowly in the vertical direction 1.5 ft. above and 1.5 ft. below midline.

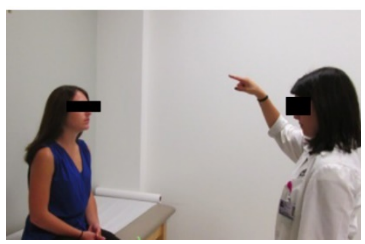


Figure 1. Smooth Pursuits[10]

2. Saccades: test the ability of the eyes to move quickly between targets (Figure 2). For horizontal saccades, the examiner holds two fingertips horizontally 3 ft. from the patient, 1.5 ft. to the right and left of midline; for vertical, the examiner holds two fingertips vertically 3 ft. from the patient, and 1.5 ft. to the right and left of midline. The patient is instructed to move their eyes as quickly as possible from point to point for each individual test. [10]

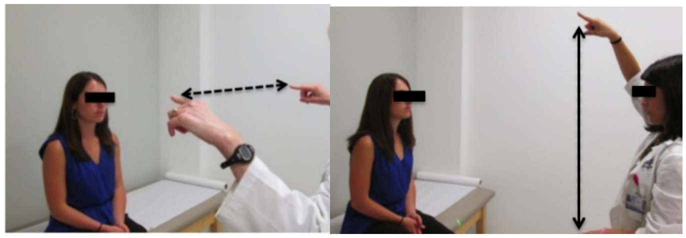


Figure 2. Saccades (Horizontal and Vertical)[10]

3. NPC: measures the ability to view a near target without double vision (Figure 3). With the patient seated, the examiner observes their eye movement during the test. The patient focuses on a small target (approx. 14-point font) at arm's length slowly bringing it toward the tip of their nose and instructed to stop moving it when they see two distinct images or when the examiner observes an outward deviation of one eye. Blurring is ignored. The distance in cm. between target and tip of the nose is the measured NPC, and is recorded in addition to the routine symptom recording. [10] An abnormal NPC is ≥ 5 cm from the tip of the nose. [10,35]

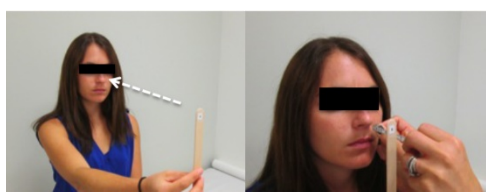


Figure 3. NPC[10]

4. Vestibular-Ocular Reflex (VOR): assesses the ability to stabilize vision as the head moves (Figure 4). The examiner holds a target approximately 14-point font size 3 ft. in front of the patient in midline. The patient is asked to rotate their head horizontally while maintaining focus on the target for horizontal VOR (Figure 2c), and then repeated with the patient moving their head vertically for vertical VOR.[10]

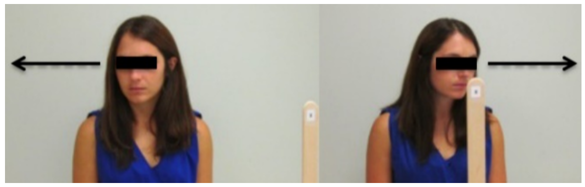


Figure 4. VOR[10]

5. Visual Motion Sensitivity (VMS): assesses the ability to inhibit vestibular-induced eye movements using vision (Figure 5). The patient is standing with feet shoulder width apart holding their arm outstretched and focusing on their thumb. Maintaining focus on their thumb, the patient rotates, together as a unit, their head, eyes, and trunk at a speed of 50 beats/min.[10]

Figure 5. VMS[10]

To examine internal consistency and validity of VOMS after SRC, the VOMS was administered to 64 patients (13.9±2.5 yr.; 36 male/28 female), seen approximately 5.5±4.0 days after a SRC, and 78 controls (12.9±1.6 yr.; 57 male/21 female).[10] Data indicated that the internal consistency of VOMS total symptom score and the NPC distance was high (Cronbach $\alpha = .92$), and that it could distinguish concussed from non-concussed athletes. Combining VOR, VMS, and NPC distance ≥5 cm yielded a positive prediction rate of 0.89, when controlling for age. The authors concluded that, "cutoff scores ≥2 total symptoms after any VOMS item or an NPC distance ≥5 cm resulted in high rates (96% and 84%) of identifying concussions".[10]

Multiple studies since the implementation of the VOMS tool have demonstrated it to be reliable and valid.[14,24,33,63] A recent study, analyzing validity and reliability of

VOMS, had 105 healthy adolescents (15.4±1.2 yr.; 53 male/52 female) complete the VOMS, BESS, and K-D tests, with a subsample of 21 adolescents (15.5±1.2 yr.; 16 male/5 female) completing the VOMS twice to assess reliability.[33] No significant relationships resulted between VOMS and BESS or K-D scores, and VOMS items demonstrated agreement in scores between testing trials; leading the authors to conclude that VOMS did not provoke common vestibular symptoms and obtains unique measures of vestibular function, other than what is captured by BESS or K-D, with good reliability.[33]

In a sample of 263 NCAA Division I athletes (19.85±1.35 yr.; 166 male/97 female), internal consistency of the VOMS was high (Cronbach $\alpha=0.97$) with 89% of the athletes scoring below cutoff levels (score of ≥2 for any individual VOMS symptom, NPC distance ≥5cm).[24] Another study examining sex differences in VOMS after SRC reported females to have greater vestibular ocular reflex (VOR) scores when compared with males, with a VOR cutoff score of ≥3 identifying female subjects at 68% sensitivity and 72% specificity.[81] Findings from these studies continue to reinforce the need for multiple tools and a comprehensive assessment approach to SRC.[24]

D.6 Near Point of Convergence

NPC is defined as the point of intersection of the lines of sight when the eyes are maximally converged. It is a clinical measure used to diagnose convergence insufficiency and is often included as a test procedure for vision screenings.[21,23,28,85–87] Convergence insufficiency (CI) is a binocular disorder in which the eyes do not work well at near fixation.[27] Three components of CI include 1) abnormal NPC, 2) near point exophoria (outward deviation of an eye at near), and 3) decreased fusional amplitudes at near fixation, which means a decrease in strength of convergence indicated by an inability to maintain convergence without fatigue.[27] Symptoms of CI include headache, eyestrain, double vision, blurred vision, excessive tiredness when reading, complaints of the words moving on a page, and constant adjustment of the distance of the object to see and read better.[23,27,86,88] Prevalence of CI has been reported to range from 0.1% to 13% depending on the population, with specific ranges of 2.25% to 8.3% in adolescents, 8% to 13% in ages of 9 to 13 years, and 7.7% in a sample of university students.[85,88–91]

Symptoms of CI are similar to those following a SRC, and recent literature has reported CI to be a common ocular complication following SRC and mild traumatic brain injury (mTBI).[10,15,17,21–23,25,26,38,64,88] Prevalence of CI is markedly higher following SRC and mTBI than in the general population, with reported ranges of 23-42% in the United States Military, and 24-62% in pediatric and adolescent populations.[10,15,17,21,88] The NPC measure is often used to identify CI in the general population and is the primary tool in identifying convergence deficits following SRC.[10,15,21–23,25,26,28,30,34,35,38,88]

The NPC measure is often used as the sole means of diagnosing CI and has proven to be reliable for both the general population and those who have suffered a SRC.[20,26,28–31,34,56] An early study assessing the reliability of the NPC measure in a group of 98 subjects aged 20-79 reported a Pearson r value of +0.934 comparing findings taken the first day to that of the second day.[29] A more recent report in a sample of 20 fifth and sixth graders (10.8±0.34 yr.), with two examiners testing, resulted in high intra-examiner and inter-examiner reliabilities, with ICC's ranging from 0.86 to 0.98.[56] Three trials of NPC assessment were collected in a group of 78 athletes (14.31±2.77 yr.) following a SRC, resulting in high internal consistency across NPC measurements, with ICC's ranging from 0.95-0.98.[26]

In addition, NPC and other vergence anomalies have not been reported to be significantly different between males and females.[50,85,92–94] In a sample of 453 fifth and sixth graders (11.3±0.6 yr.; 50.3% male/49.7% female), gender was not associated with CI classification, including NPC measures.[92] This report was also consistent with those involving elementary schoolchildren and South African adolescent populations.[50,85,94] However, females have shown to have an earlier development of full convergence in infancy (13.0 vs. 14.2 weeks) than males.[95] Conflicting literature exists on whether or not age has an effect on NPC.[38,50,51,96] One study concluded that NPC increases by a rate of 0.24 cm per year between the ages of 2-17, while a more recent study assessing NPC once a year for 10 years in 114 subjects (10.6±1.4 yr. at time of first assessment) reported no significant change in NPC over time with only a .3 cm mean increase over 10 years.[50,51]

Analysis of NPC between athletes and the general population, or between athletes of different sports is lacking in the literature, but there is some evidence that suggests athletes have superior visuomotor skills.[97–103] Professional baseball players and Olympic athletes in soccer and softball have superior visual and stereo acuity (depth perception, or ability to detect differences in distance between objects) with speculation that, "in sports such as soccer, baseball, and softball, athletes do require acute depth perception abilities to judge the three-dimensional position of the ball as it approaches the athlete."[100,101] Similarly, 51 softball and baseball players (14.2 yr.) had a superior stereo acuity compared to 52 non-ball players (13.8 yr.) of the same age range.[97] Interestingly, a pair of studies which include NPC as a measure of comparison between athletes and non-athletes reported athletes to have superior visuomotor skills, but also a worse NPC value.[98,102] In a population 86 Chinese athletes (21.7±1.4 yr.) in interceptive sports (tennis, baseball, volleyball, badminton, basketball) had a NPC mean of 6.6 cm compared to 60 non-athletes (21.3±0.9 yr.) with a NPC mean of 3.8 cm (t=4.65, p<0.001).[98] However, the non-athlete group was made up of 60 Chinese optometry students potentially affecting the significance, and the increase in means compared to other literature could be because a value of 1 was recorded if no diplopia was reported when the target reached the nose, instead of a value of 0, as in VOMS and other NPC data.[98] In a population in Malaysia, 107 athletes (14.8±1.0 yr.) had a NPC mean of 5.9±3.6 cm compared to 107 non-athletes (15.0±1.0 yr.) with a NPC mean of 3.8±3.4 cm (t=4.39, p<0.001).[102] Unfortunately, details of the participants in each group are not present in the article, and groups are simply separated by athletes from a "Sports School" and non-athletes from a "National Secondary School".[102] Evidence for NPC comparisons between sport has yet to be determined in an American high school population, where a competitive culture exists, unlike other areas of the world.

NPC has recently been shown to be a useful assessment in concussion diagnosis.[9,10,14,22–26,30,64] In preliminary VOMS findings, mean NPC distance across three trials was significantly greater in the concussed group (5.9±7.7 cm) than the control group (1.9±3.2 cm). Additionally, when controlling for age, a combination of VOR, VMS, and NPC distance resulted in a positive prediction rate of 0.89 for identifying SRC.[10] In a retrospective cohort of 275 concussed pediatric patients aged 5 to 18, 67 (24%) presented with abnormal NPC (>6 cm).[25] Another study examining 100 adolescents (14.5 yr.) with a SRC diagnosed 49% with CI.[21] Additionally, in a group of 33 concussed participants, those with a receded NPC walked with a significantly slower average walking speed during single-task and dual-task gait when compared with controls, while concussed participants with a normal NPC did not display the same deficits, indicating that convergence deficits following SRC may be related to motor system dysfunction.[22] Lastly, in a population of 247 patients aged 5-18 years with a prolonged concussion recovery, 62% had an abnormal NPC thought to be associated with prolonged symptoms and poorer school outcomes.[15]

Most literature utilizing NPC as a concussion diagnostic measure defines an abnormal NPC as a measure of ≥5 cm or a measure of ≥6 cm.[10,15,22–26,33,61,79,82,104] This cutoff point is often cited from one of two articles establishing normative data for NPC measures.[28,35] The first, from Hayes et al. in 1998, established age-related normative values in 297 schoolchildren in kindergarten, third, and sixth grades.[28] Values between grades were 3.3±2.6 cm for kindergarten, 4.1±2.4 cm for third graders, and 4.3±3.4 cm for sixth graders, with significant difference only between kindergarten and sixth graders. While there was a mean difference between groups, at least 85% of the measurements in all three samples were 6 cm or less, leading to the authors suggesting a clinical cutoff value of 6 cm.[28]

In 2003, Scheiman et al. established a normative database for NPC in 175 adults with normal binocular vision (24.9 yr., range 22-37 yr.).[35] This study also assessed NPC with three different targets (accommodative target, a penlight, and a penlight with red and green glasses), with which they reported no significant difference between NPC measures with various methods. The mean NPC in the healthy adults ranged from 2.06-2.49 cm (±1.74-2.11 cm).[35] In this population, 85% of subjects had an NPC of 4.5 cm or less with all targets, but the authors suggested rounding the clinical cutoff value to 5 cm.[35]

While these are the most often cited articles for NPC cutoff values, literature exists with various ranges of normative values across different populations.[33,34,36–38,96] In 539 school children in first through third grades, 85% had an NPC of 4.7 cm or less leading to the authors supporting the previously suggested cutoff value of 5 cm.[34,35] A study from India establishing normative data in three cohorts of 50 separated by ages of 10-18 years, 19-27 years, and 28-35 years reported means of 6.3±2.8 cm, 8±3.39 cm, and 8.33±3.16, respectively, while also concluding that NPC values increase with age.[36] In a separate Indian sample of 637 school children (age range of 7-17 years), the mean of NPC was 3±3 cm with an accommodation target and 7±5 cm with a penlight, further concluding that the method used to measure NPC affects the value.[37]

When examining the literature, an interesting aspect of the normative data publications is that they use various points of measurement for the *"zero measure"*, which is the point from which the NPC is measured when the participant reports diplopia.[23,28,34–36,38] The common points for the *"zero measure"* are the "center of the forehead at the level of the brow,"[28,35] the "bridge of the nose just below the brow,"[23,34] and the lateral canthus, or lateral corner of the eye.[36,38] However, in VOMS literature, and other recent articles signifying the value of NPC as a concussion identifier, use the "tip of the nose" as the *"zero measure"*, when specified.[10,22,24,26,33] Interestingly, the VOMS cutoff is based off of Scheiman et al., which measures, in centimeters, from the center of the forehead, as opposed to the tip of the nose.[10,35] Therefore, a more accurate clinical cutoff is needed based on the use of a tongue depressor with the *"zero measure"* as the tip of the nose, instead of the common points of the center of the forehead, bridge of the nose, or lateral corner of the eye, which are used in ophthalmology literature.[23,28,34–36,38]

Although only few articles determine a cutoff based on an 85% metric, comparisons can still be made among varying normative data values between articles with reported means. Reported means, as well as demographics of the population, are presented below.

As previously mentioned, measures of NPC are also potentially affected by the target type, meaning the target in which the subject is instructed to focus.[20,35,37] Various target types used include a penlight, a black line on a white card, pen or pencil tip, fingertip, and/or letters.[20] In 637 children, a significant difference was reported between the use of an accommodative target and a penlight with red filter when assessing NPC with means of 3±3 cm and 7±5 cm, respectively.[37] A study determining if target type influences NPC in a sample of 39 young adults (23.6±3.1 yr.) resulted in a significant NPC difference between a letter target and both a drawn line and pen tip targets.[20]

Summary of reported NPC values

Author	Year	Age	N	NPC (Mean)	Clinical Cutoff Recommendation
Hayes et al.[28]	1998	Kindergarten	100	3.3±2.6 cm	6 cm
Hayes et al.[28]	1998	Third Grade	89	4.1±2.4 cm	6 cm
Hayes et al.[28]	1998	Sixth Grade	100	4.3±3.4 cm	6 cm
Scheiman et al.[35]	2003	24.9 yrs	175	2.1-2.5 cm	5 cm
Maples et al.[34]	2007	6-9 yrs	539	4.2±3.4 cm	5 cm
Mucha et al.[10]	2014	12.9±1.6 yrs	78	1.9±3.2 cm	N/A
Abraham et al.[36]	2015	10-35 yrs	150	6.3-8.3 cm	N/A
Hussaindeen et al.[37]	2016	7-17 yrs	637	3±3 cm (AT)[a] 7±5 cm (PLR)[a]	N/A
Kontos et al.[24]	2016	19.85±1.35 yrs	263	2.1±2.9 cm	N/A
Yekta et al.[96]	2016	5.1±0.63 yrs	3701	5.1 cm	N/A
Ostadimoghaddam et al.[38]	2017	10-19 yrs	N/A	6.9±3.9 cm	N/A

[a] Means reported using Accommodative Target (AT) or Penlight with red filter (PLR)

D.7 Conclusion

SRC are complex injuries with a multitude of deficits, including vestibular and ocular motor symptoms.[9,10,13,60] VOMS has shown promise as a reliable tool in recognizing these deficits, with NPC as a strong component.[10,22,26,33] However, factors affecting NPC values include target type, meaning the target (pen tip, letter target, drawn line) in which the subject is instructed to focus, and the location of the "*zero measure point*," which is the point from which the NPC is measured when the participant reports diplopia (double vision).[10,20,28,34–36] In addition to different "*zero measure points*," the instrument and method of the procedure varies between VOMS' NPC assessment and common clinical NPC assessments.[10,31,35] VOMS uses a tongue depressor with a letter target as the patient holds the target "at arm's length and slowly brings it toward the tip of their nose," with the NPC distance measured "in cm between target and the tip of nose."[10] There has been no investigation on differences in NPC values between different instrument methods (tongue depressor, accommodative ruler). Therefore, the primary purpose of this study is to determine if instrument method (tongue depressor or accommodative ruler) influences NPC values in high school athletes.

Appendix E

PERMISSION LETTER

Athletic Training Education Program
Human Performance Laboratory
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541 South College Avenue
Newark, DE 19716
302-831-6402

Photographic Release Form

I hereby grant the Athletic Training Research Laboratory and its research staff the royalty-free rights to publish photographs (digital images) of me in any publications, presentations, media-releases, etc…. in which I appear as a model, subject, and/or patient. I understand that any figure in which I appear may be modified.

Alexandra Davisson
Printed Name

Alex Davisson
Signature

Date: 2/12/18