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ORIGINAL RESEARCH

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Reliability of two dissociating tests of phoria in artificially created phoria in normal adults

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Abstract

Background: The ability of physical therapists (PTs) to accurately identify and reliably measure phoria/tropia is critical in the differential diagnosis of individuals with acute vestibular syndrome and concussion/mild traumatic brain injury.

Objectives: To determine if PTs may reliably measure phoria and to determine the reliability of two dissociating tests of phoria, the prism neutralized Maddox rod test and modified Thorington method, in normal adults with artificially created phoria.

Methods: Thirty adults (mean age 24.87 ± 4.74 years) were randomly assigned to wear trial lenses (1, 2, 4, or 6 pd prism left, plain glass right) to create phoria. In sitting and supine, phoria was measured using prism neutralized Maddox rod test and modified Thorington method. Mean, SD, and range of first neutral endpoint were calculated for each examiner. Percentage of trials in agreement (≤ 2 and 4 pd); comparisons within the linear mixed effects regression model; and inter-rater reliability between examiners was calculated with the intra-class correlation coefficient (ICC).

Results: Participants underwent 20 measurements by each examiner. Trial agreement between examiners was 74% (range 13%-100%) in horizontal and 91% (range 63%-100%) in vertical plane. Maddox rod test had significantly different means between two examiners ($P < .05$). Modified Thorington test had no significant difference. The Maddox rod test had a significant examiner main effect, examiner 2 always scored lower. Inter-rater correlation coefficient for each test was significant at level of $P < .01$ (ICC ≥ 0.67 ≤ 0.94) except for modified Thorington test in supine, horizontal plane with $P < .05$ (ICC ≥ 0.38).

Conclusion: PTs may reliably measure artificially created phorias using prism neutralized Maddox rod test and modified Thorington method.

KEYWORDS
dissociative test, ocular misalignment test, phoria test, skew deviation, vertical diplopia

1 | INTRODUCTION

In normal individuals, when the head is tilted laterally in the roll plane the otolith-ocular reflexes control head-eye posture. The utricular-otolith pathway generates a skew deviation (ipsilateral eye elevates and contralateral eye depresses relative to the side of the head tilt) and an ocular counter-roll (conjugate, torsional eye rotations opposite to the head tilt) to maintain alignment of the vertical axes of the head and eye with earth vertical.[1] This triad—head tilt, skew deviation, and ocular counter-roll—is called the physiological ocular tilt reaction (OTR).

A unilateral lesion to the utricular-otolith pathway will result in tonic imbalance causing an internal misperception of vertical.[2] In an attempt to realign to the misperception, a partial or complete pathological OTR is generated. Relative to the side of the lesion, an ipsiversive head tilt occurs with an acute unilateral peripheral vestibular or central pontomedullary lesion and a contraversive head tilt with an acute central pontomesencephalic lesion.[1,2] The head tilt further causes misalignment of the vertical visual axis, resulting in vertical strabismus or double vision. Relative to the head tilt, the ipsilateral eye depresses, and contralateral eye elevates creating a pathological skew deviation and the superior pole of both eyes rotate ipsilateral creating an abnormal ocular torsion.[1,2]

The magnitude of the head tilt and skew deviation is critical to distinguish between a peripheral or central acute vestibular syndrome (AVS).[3] AVS is characterized by sudden onset of persistent vertigo lasting more than 24 hours, associated with nausea, vomiting, and head motion intolerance.[4] The most common cause of AVS is a unilateral peripheral vestibular lesion—vestibular neuritis, but in 27% of cases, it may be due to a central vestibular lesion—stroke.[5] A targeted examination using the HINTS-Plus protocol (Head-Impulse, Nystagmus, Test of Skew, sudden onset unilateral hearing loss) is useful in distinguishing between the two.[4,6] The cover test is used to measure skew. A small amplitude skew suggests peripheral AVS and large amplitude skew suggests central AVS.[6-8] Large amplitude skew >3.3° (5.8 pd) is a potential stroke indicator (specificity of 98.1% and sensitivity of 8.3%).[9] When nystagmus is present in AVS, a skew of <3° is not detected by the human eye.[9] Within the first 72 hours of symptoms, the presence of a large amplitude skew is more sensitive than an early magnetic resonance imaging (MRI) or diffuse weighted imaging MRI in detecting central AVS with no other associated neurologic signs.[6]

The magnitude of misalignment is independent of eye position but is dependent on head position.[3] In individuals with chronic skew deviation due to brainstem or cerebellar lesions, changing the orientation of the head from upright to recumbent supine changes the orientation of the utricle from the earth-horizontal plane to the earth-vertical plane leading to a saturation or reduction in the overall activity of the reflex.[10] This results in a 74% decrease in magnitude of vertical misalignment of the visual axis.[10]

The prism neutralized Maddox rod test and modified Thorington method are used to measure misalignment of the visual axis with both phoria and tropia. Phoria is deviation of the eyes from neutral position when not fixating on a target or when fusion is broken and tropia is deviation of the eyes from neutral position with binocular vision.[11] Heterophoria is a horizontal or vertical misalignment. The magnitude of phoria/tropia is described in prism diopters (pd, Δ), 1 pd equaling 1 cm deviation at 1 m (Figure 1A). Two prism diopter is the smallest magnitude of eye movement a practitioner can detect without the use of special equipment.[12] Normal accommodation can occur with horizontal heterophoria measuring 0-4 pd.[11,13] Test-retest reliability of experts measuring heterophoria with prism neutralizing Maddox rod test is good (ICC > 0.90) in individuals with strabismus.[11] The modified Thorington test is considered to have one of the highest rates of repeatability and reliability.[11,14] Test-retest reliability of measurement of skew has not been determined.

The ability of physical therapists (PTs) to accurately identify and reliably measure phoria/tropia is critical in the differential diagnosis of individuals with AVS,[6] rehabilitation of uncompensated unilateral peripheral vestibular dysfunction,[15] and management of concussion/mild traumatic brain injury.[16] The purpose of this study is to determine if PTs may reliably measure phoria in short sitting and recumbent supine and to determine the reliability of two dissociating tests of phoria, the prism neutralized Maddox rod test and modified Thorington method, in normal adults with artificially created phoria.

2 | METHODS

2.1 | Study population

Thirty participants were recruited as a sample of convenience from the Midwestern University, Downers Grove, IL community in October-November 2017. Each subject underwent a comprehensive history, neurological screen, and neuro-otological examination including alternating cover test (ACT), prism neutralized Maddox rod test, prism neutralized modified Thorington method, and videonystagmography. Subjects were included if they had a history of normal vision and full neck motion. Subjects were excluded if they had a spontaneous nystagmus or history of diplopia, prior strabismus surgery, or inability to follow directions or communicate effectively.

This study was performed in accordance with the guidelines of the 1964 Declaration of Helsinki and was approved by the Institutional Review Board for Human Subjects, Midwestern University—Downers Grove (2976). Written consent was obtained from each person prior to the study.

2.2 | Study protocol

All participant testing was completed in a single session and in the same environment between testers. Participants were randomly assigned by computerized random number generation to trial lenses

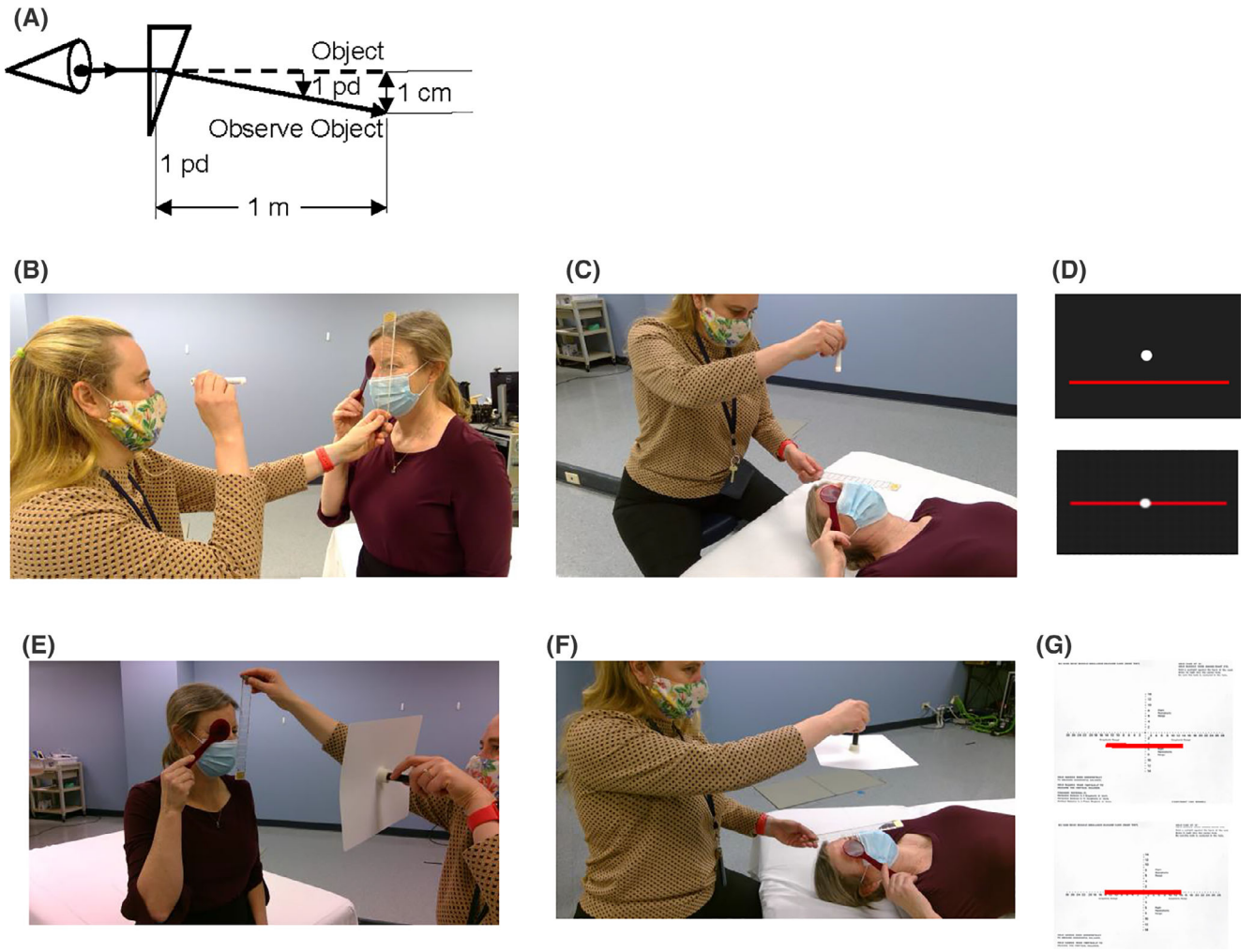

FIGURE 1 Prism diopter (A). Prism is a wedge-shaped piece of refracting material that changes the direction of light without changing its focus. Prism is measured in units called prism diopters (pd). 1 pd creates a deviation of 1 cm at 1 m. Prism neutralized Maddox rod test in sitting (B) and recumbent supine (C) position. A Maddox rod is a red lens composed of a parallel series of strong cylinders, through which a point of light is viewed as a red line (D). It is used to measure the magnitude of phoria/tropia. By convention, the Maddox rod is always placed in front of the right eye with the groves facing out. The individual will see a line through the right eye. The direction of the visualized line will be perpendicular to the cylinder axis. The penlight is shined 18 cm away from the bridge of the nose. The light will be seen by the individual's left eye. Observes red line with right eye and light with left eye (D). The individual is asked where the light falls in relation to the red line. The light should be aligned directly on top of the red line (D, bottom). If the light deviates from the line (D, top), the deviation is neutralized with prisms by changing the direction of light without changing its focus (D, bottom). A prism bar is positioned in front of the left eye in the frontal plane. The strength of the prism is incrementally increased until the deviation is neutralized (no further movement of the eye is observed) and the light is aligned on top of the line (D, bottom). A pair of prism bars corrects horizontal and vertical misalignment. The practitioner notes the diopters required to first neutralize the deviation—first neutral. To measure the deviation in the horizontal plane the Maddox rod "grooves" are horizontal, and the individual will see a vertical line through the right eye. To measure in the vertical plane, the Maddox rod "grooves" are vertical, and the individual will see a horizontal line through the right eye. Prism neutralized modified Thorington method in sitting (E) and recumbent supine position (F). The Thorington card (BC/1209 N [MIM] Muscle Imbalance Measure Card) contains a cartesian coordinate system. The coordinate points on the X and Y axes are numbered consecutively 0-10 on a tangent scale, each division calibrated 1 pd at a viewing distance of 40 cm. "0" contains an aperture located centrally. The near card is positioned 40 cm from the bridge of the individual's nose. The light from a penlight is shown through the aperture. The Maddox rod by convention is placed in front of the right eye, either oriented horizontally or vertically. The individual is asked to look at and keep the numbers in focus/clear to control accommodation. Observe red line with right eye and light/grid with left eye (G). The individual will see a red line with the right eye and the light, graph, and numbers with the left eye. This red line is either horizontal or vertical depending on the orientation of the Maddox rod. The individual reports the number and location the red line intercepts the horizontal and vertical axis. The red line should be aligned directly onto the light at coordinate zero. If the red line deviates from coordinate zero on the Y axis there is a vertical deviation (G top) or on the X axis there is a horizontal deviation

TABLE 1 Congruency of measurement between examiners

		Horizontal mean absolute agreement *n* (%)				Vertical mean absolute agreement *n* (%)			
		Maddox rod test		Modified Thorington method		Maddox rod test		Modified Thorington method	
pd	Sample size	Sitting	Supine	Sitting	Supine	Sitting	Supine	Sitting	Supine
≤2 pd difference									
1	7	5 (71)	5 (71)	6 (86)	4 (57)	7 (100)	7 (100)	7 (100)	7 (100)
2	7	5 (71)	4 (57)	7 (100)	6 (86)	7 (100)	6 (86)	6 (86)	7 (100)
4	8	5 (63)	4 (50)	4 (50)	4 (50)	7 (88)	7 (88)	7 (88)	5 (63)
6	8	1 (13)	5 (63)	4 (50)	3 (38)	6 (75)	6 (75)	7 (88)	7 (88)
<4 pd difference									
1	7	5 (71)	5 (71)	7 (100)	7 (100)	7 (100)	7 (100)	7 (100)	7 (100)
2	7	6 (86)	6 (86)	7 (100)	7 (100)	7 (100)	7 (100)	7 (100)	7 (100)
4	8	6 (75)	5 (50)	6 (75)	5 (50)	8 (100)	8 (100)	8 (100)	7 (88)
6	8	3 (38)	6 (75)	6 (75)	4 (50)	7 (88)	7 (88)	8 (100)	8 (100)

Notes: Congruency was defined as mean absolute difference in measurement between examiners of ≤2 pd and ≤4 pd. Number and percentage of agreement of trials in horizontal and vertical plane with mean absolute agreement between examiner 1 and 2 for prism neutralized Maddox rod test (far vision) and modified Thorington method (near vision) in sitting and recumbent supine position.

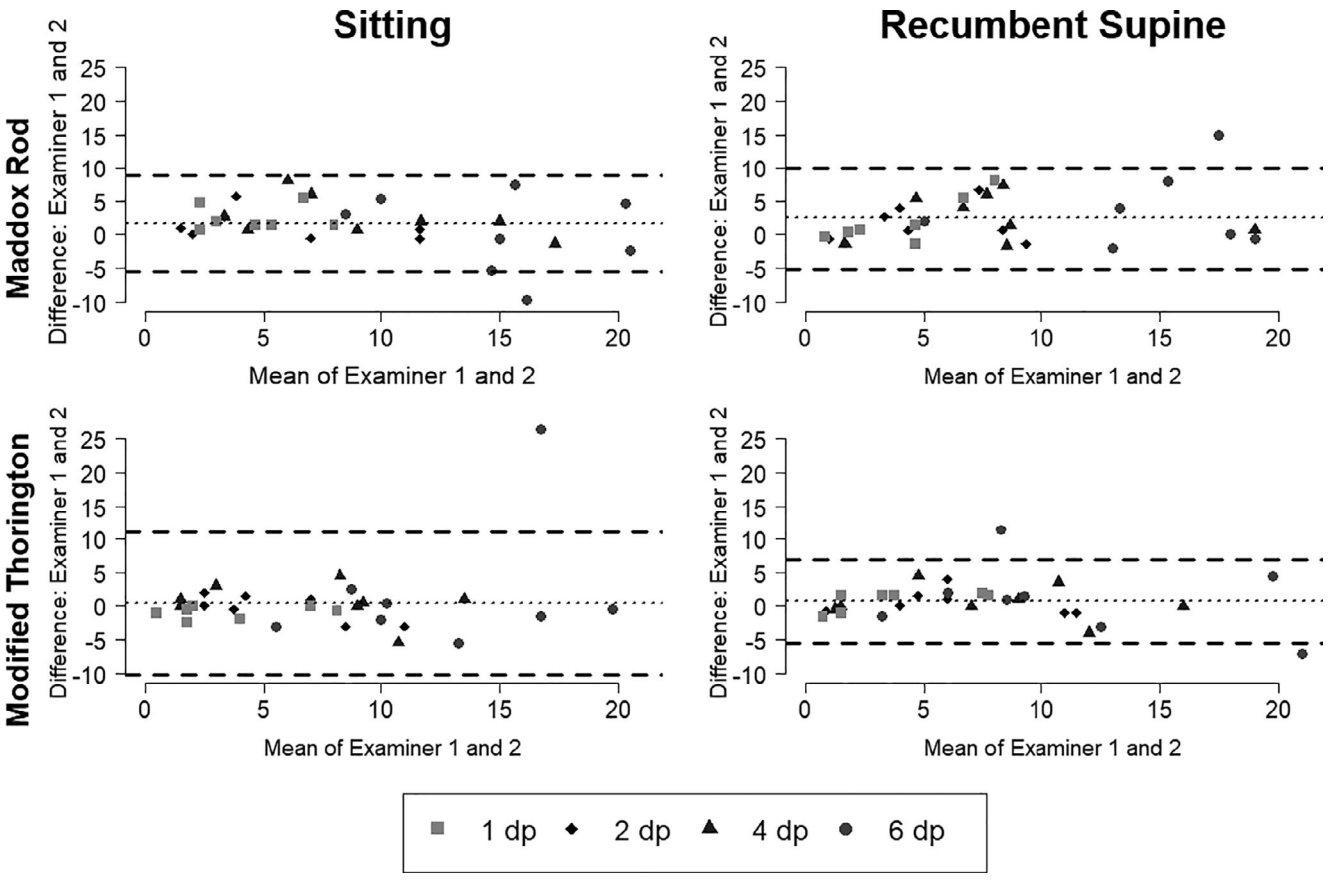

FIGURE 2 Difference vs mean plots of interexaminer repeatability of horizontal plane measurements to describe agreement for each lens, position, and dissociating test of phoria. For each participant, the mean deviation in the horizontal plane measured by examiner 1 and 2 were plotted against the average difference in examiner 1 and 2 in a Bland-Altman plot to describe agreement for sitting and recumbent supine position and dissociating test of phoria—Maddox rod test and modified Thorington method. The solid line represents the averaged signed difference of the measurements between examiner 1 and examiner 2 using first neutral endpoints. The dotted lines indicate ±2 SD, or the 95% limits of agreement

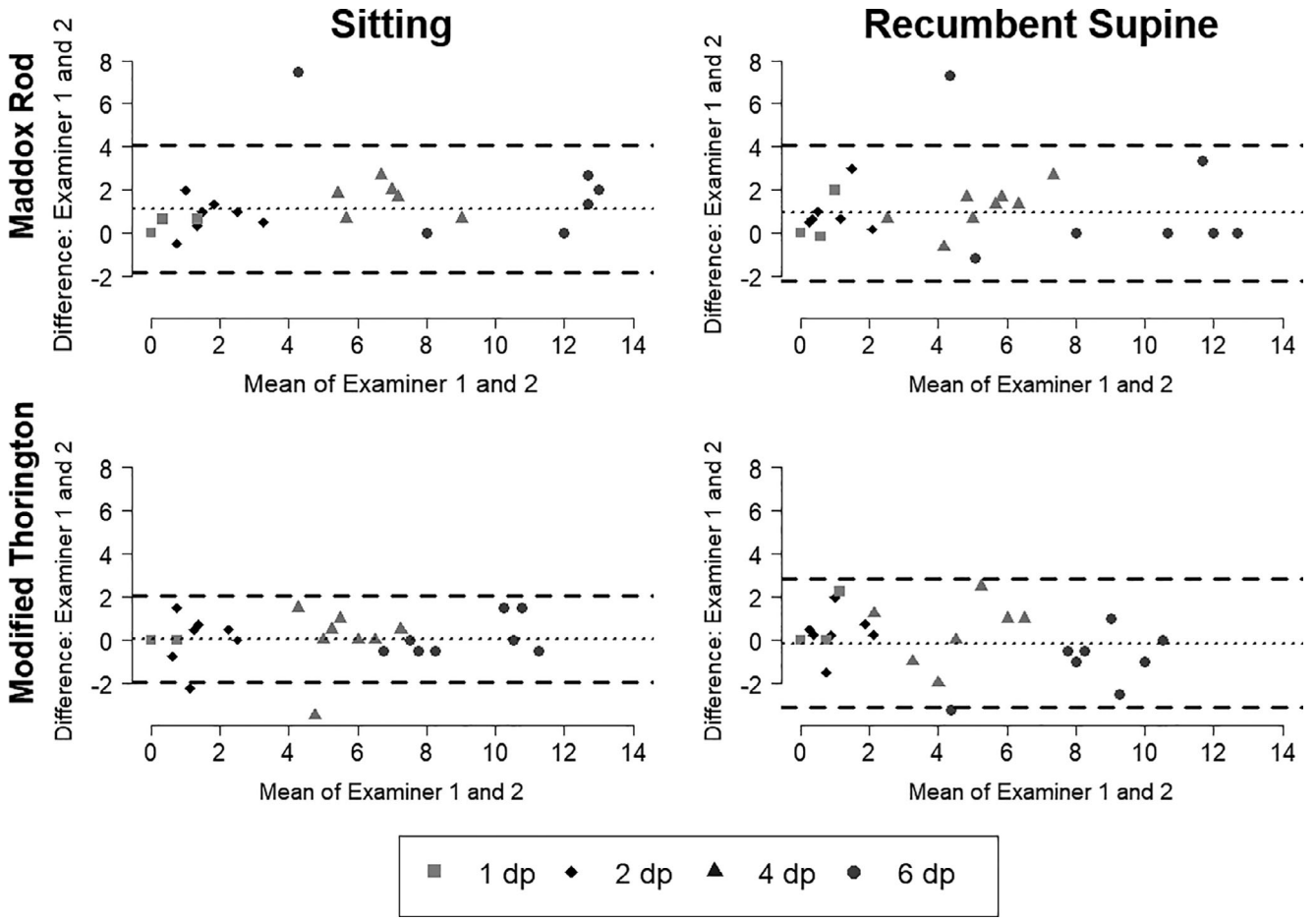

FIGURE 3 Difference vs mean plots of interexaminer repeatability of vertical plane measurements to describe agreement for each lens, position, and dissociating test of phoria. For each participant, the mean deviation in the vertical plane measured by examiner 1 and 2 were plotted against the difference in examiner 1 and 2 in a Bland-Altman plot to describe agreement for sitting and recumbent supine position and dissociating test of phoria—Maddox rod test and modified Thorington method. The solid line represents the averaged signed difference of the measurements between examiner 1 and examiner 2 using first neutral endpoints. The dotted lines indicate ±2 SD, or the 95% limits of agreement

that created artificially acquired phoria—misalignment of the visual axis both skew deviation and heterophoria. Trial lenses were fabricated with a 1, 2, 4, or 6 diopter monocular prism on the left side and plain glass on the right side. Each participant was examined by two different examiners (JH: LG), with randomization of the order of the first examiner. One examiner was a licensed PT, the other was a physical therapy student. Examiners and participants were blinded to trial lenses. With the participant in short sitting wearing the trial lenses, examiners observed eye alignment with the ACT. In sitting and recumbent supine, distant phoria was measured using the prism neutralized Maddox rod test (Figure 1B,C) and near phoria using the prism neutralized modified Thorington method (Figure 1E,F) (Thorington card BC/1209 N [MIM] Muscle Imbalance Measure Card). Each test was conducted by each examiner in sitting and supine recumbent positions. For each position horizontal and then vertical deviations were measured.

A total of 20 measurements were taken per individual—3 measurements Maddox rod test and 2 measurements modified Thorington method in each position and plane.

2.3 | Primary outcome measure

The primary outcome measured was first neutralization of endpoint, the use of prism to correct eye deviation in the horizontal and vertical plane. There are multiple endpoints which can be recorded when neutralizing eye deviation with prisms: first neutral, high neutral, reversal, and any midpoint value. First neutral is found by adding prism to correct deviation of the axis until no movement of the eye is observed. If further prism is added, there is a neutral range where no movement of the eye is observed, the upper limit called high neutral. The reversal point is identified when prism is added just beyond the upper limit of neutral and an opposite movement of the eye is elicited. Most literature proposes using first neutral as the endpoint; however, there is no standard agreement.[17] High inter/intraexaminer reliability for congruency of measurement ≤0.5 pd was found with experienced examiners measuring heterophoria with ACT using either first neutral or reversal prism endpoint.[17] A difference of ≤2 pd was considered clinical agreement in this study, the smallest eye movement an examiner can detect.[12]

TABLE 2 For each test and position, mean, SD, and range were calculated for each examiner

	Maddox rod test			Modified Thorington method		
Trial lens pd	Examiner 1 (pd)	Examiner 2 (pd)	*P* values	Examiner 1 (pd)	Examiner 2 (pd)	*P* values
Horizontal deviation—first prism neutral endpoint						
Sitting						
1	5.8 ± 2.5 (2–10)	3.4 ± 2.3 (0-10)	.10	3.4 + 3.4 (0-8)	4.7 + 3.4 (1-10)	.53
2	6.5 ± 3.9 (2-14)	5.2 ± 4.7 (1-14)	.38	6.3 + 3.4 (2-12)	6.3 + 4.2 (2-14)	.99
4	10.5 ± 4.5 (4-18)	7.9 ± 5.9 (2-20)	.06	8.5 + 5.0 (2-16)	7.3 + 5.4 (1-14)	.51
6	15.3 ± 4.7 (8-25)	15.0 ± 5.8 (6-25)	.83	14.8 + 8.1 (4-30)	12.6 + 7.2 (6-25)	.27
Recumbent supine						
1	5.1 ± 4.0 (0-12)	3.1 ± 1.6 (1-6)	.20	5.3 ± 4.4 (0-12)	3.7 ± 2.6(1–8)	.46
2	6.29 ± 3.3 (0-12)	4.5 ± 3.1 (1-10)	.25	7.1 ± 4.5 (0-14)	6.6 ± 4.6 (2-14)	.59
4	9.5 ± 5.4 (1-20)	6.8 ± 5.2 (1-20)	.07	9.6 ± 5.8 (1-16)	9 ± 6.8 (2-10)	.75
6	16.6 ± 5.9 (6-30)	13.4 ± 5.2 (4-20)	.03*	15.6 ± 9.1 (2-30)	12.3 ± 9.6 (2-30)	.10
Vertical deviation—first prism neutral endpoint						
Sitting						
1	0.33 ± 0.63 (0-2)	0.14 ± 0.36 (0-1)	.73	0.14 ± 0.38 (0-1)	0.14 ± 0.38 (0-1)	.99
2	2.1 ± 0.95 (0.5-4)	1.3 ± 0.90 (6-10)	.15	1.9 ± 1.3 (0-3.5)	1.6 ± 1.2 (0-3.5)	.63
4	7.7 ± 1.1 (6-10)	6.0 ± 1.3 (3.5-10)	.00**	6.4 ± 2.2 (3-10)	6.8 ± 1.2 (5-8)	.50
6	10.7 ± 2.8 (8-14)	9.0 ± 3.8 (0.5-12)	.00**	10.8 ± 3.0 (8-14)	10.0 ± 2.4 (8-14)	.19
Recumbent supine						
1	0.36 ± 0.78 (0-3)	0.095 ± 0.26 (0-1)	.68	0.4 ± 0.79 (0-2)	0.1 ± 0.38 (0-1)	.69
2	1.4 ± 0.87 (0-3)	0.40 ± 0.73 (0-2)	.12	1.3 ± 1.1 (0-3)	1.0 ± 1 (0-2)	.69
4	5.8 ± 1.9 (2.5-10)	4.6 ± 1.2 (1.5-6)	.06	5.4 ± 2.1 (3-8)	5.4 ± 2.6 (1-10)	.92
6	9.6 ± 3.0 (3.5-14)	8.5 ± 3.8 (0.5-14)	.05	9.3 ± 2.8 (4-12)	9.6 ± 2.1 (7-12)	.57

Note: Comparisons within the linear mixed effects model to determine if first prism neutral endpoint significantly differed between examiner 1 and 2.
*Significant at a level of .05.
**Significant at a level of .01.

2.4 | Statistical analysis

Descriptive statistics were used to present the demographic data and results of the cover tests. The congruency of measurement between examiners, defined as the percentage of trials in agreement by ≤2 pd and ≤4 pd, was calculated. Absolute mean differences, SD, and range of first prism neutral endpoint were calculated for each examiner, dissociating test of phoria, test position (sitting and recumbent supine), trial lenses, and plane of deviation (horizontal and vertical). For each participant, the mean horizontal and vertical deviation measured by examiner 1 and 2 were plotted against the difference in examiner 1 and 2 in a Bland-Altman plot to describe agreement, for each position and dissociating test of phoria.

Linear mixed regression models were used to determine whether there is a difference in the mean absolute differences of first prism neutral endpoint by examiner and trial lens. The subject ID was included in the model as a random effect and comparisons were done comparing the examiners for each dissociating test of phoria, position, trial lenses, and plane of deviation. Statistical significance was assessed at the .05 level.

The intraclass correlation coefficient (ICC) was estimated for the first prism neutral endpoint for each test position, dissociating test of phoria, and plane of deviation using a two-way random effects model, absolute agreement, average measures, and ICC analysis. The ICC (95% confidence intervals) was calculated using the IBM statistics software SPSS Statistics Version 22 (Chicago, Illinois). The magnitude of the ICC was interpreted according to criterion levels of reliability: (1) less than 0.50 poor reliability, (2) 0.50 ICC < 0.75 moderate reliability, and (3) greater than and equal to 0.75 good reliability.[18]

3 | RESULTS

3.1 | Participant demographic data

All 30 participants completed the study and no adverse events occurred. The mean age of the participants was 24.87 ± 4.74 (range 23-30) years; 23 participants were female (77%). Significant medical history includes pre-existing phoria or tropia (n = 3) identified by

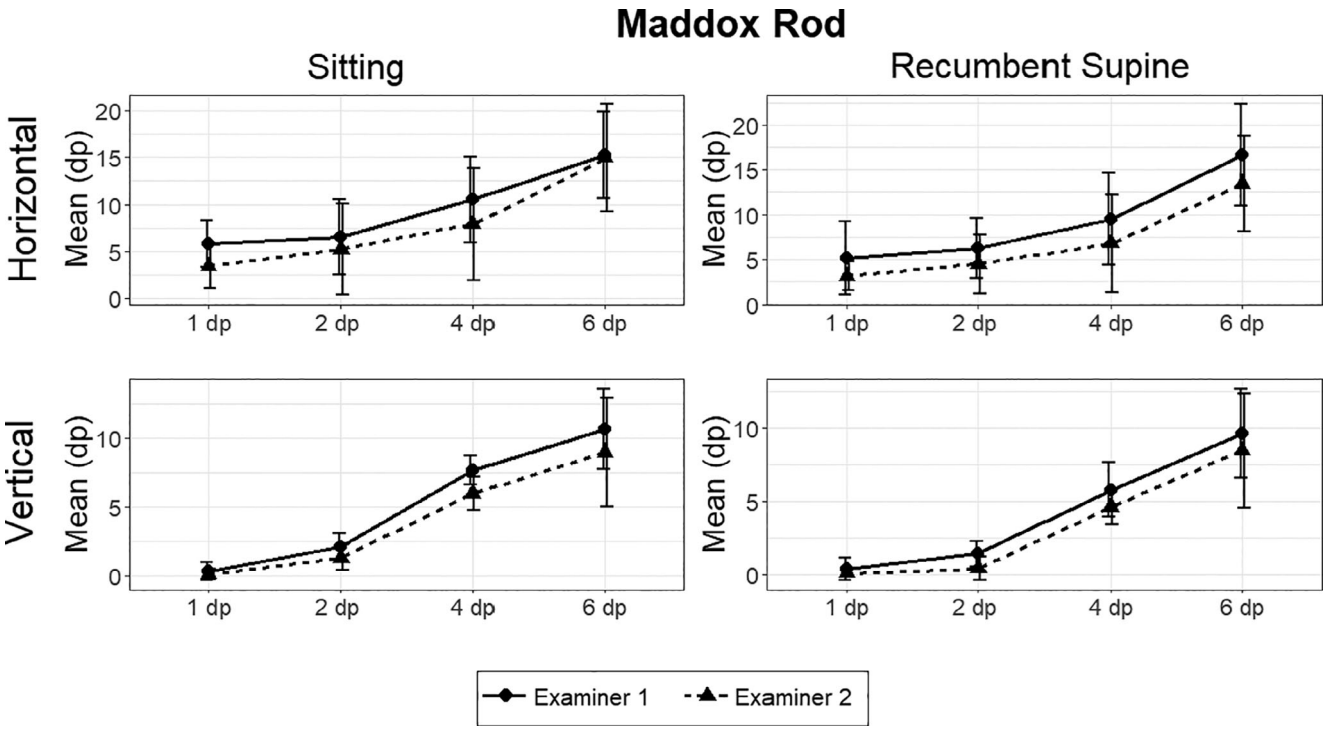

FIGURE 4 Difference in the mean absolute differences of first prism neutral endpoint by examiner and trial lens for the prism neutralized Maddox rod test. Comparisons were made by examiner, position, trial lenses, and horizontal and vertical plane of deviation. Statistical significance at the .05 level. The error bars represent +1 SD

prism neutralized Maddox rod test, myopia (n = 7), astigmatism (n = 5), concussion (n = 8), and migraines (n = 8).

3.2 | Congruency of measurement of ocular alignment between examiners

Participants noted diplopia while wearing the prism lens. Each participant underwent 20 measurements by each examiner for a total of 1200 measurements in the study. The percentage of trials in agreement of ≤2 pd between examiners occurred in 73% (range 13%-100%) of measurements in the horizontal plane and 89% (range 63%-100%) of measurements in the vertical plane. The percentage of trials in agreement of ≤4 pd between examiners occurred in 74% (range 38%-100%) of measurements in the horizontal plane and 92% (range 88%-100%) of measurements in the vertical plane. Congruency was greater in the vertical plane than horizontal plane. Table 1 shows the percentage of trials in agreement between examiner 1 and 2 in the horizontal and vertical plane for each dissociating test of phoria, position, and trial lens.

3.3 | Reliability

The mean absolute differences of first prism neutral endpoint for the difference in examiner 1 and examiner 2 was plotted against the average of examiner 1 and 2 in a Bland Altman plot for each participant, position, and dissociated test of phoria (Figure 2 horizontal deviation: Figure 3 vertical deviation) to illustrate agreement and repeatability of measurement for magnitude of acquired phoria. The mean absolute differences of first prism neutral endpoint, SD, and ranges along with the results and significance of the comparisons within the linear mixed effects regression model are found in Table 2 for each dissociating test of phoria and position. In the linear mixed effects regression model, the Maddox rod test had a significant examiner main effect, indicating that examiner 2 scored lower regardless of trial lens for horizontal sitting ($\beta = -1.6$, $P = 0.02$), horizontal recumbent supine ($\beta = -2.5$, $P < .01$), vertical sitting ($\beta = -1.1$, $P < .01$), and vertical recumbent supine ($\beta = -0.92$, $P < .01$) (Figure 4, Maddox rod test). There were no differences in examiners for the Thorington method across all trial lenses.

Inter-rater reliability was calculated for first neutral prism endpoints for each dissociating test of phoria, position, and plane of deviation (Figures 2 and 3). The inter-rater correlation coefficient for each test was statistically significant at a level of $P < .01$ (ICC > .67 < .94) except for the modified Thorington method in supine, horizontal plane with a $P < .05$ (ICC > .38). All had good consistency except for modified Thorington method in the supine, horizontal plane which demonstrated poor consistency.

4 | DISCUSSION

This study reveals that PTs may reliably measure phoria using the prism neutralized Maddox rod test and modified Thorington method

in sitting and supine recumbent positions in normal adults with artificially created phoria. On average, 26% of all measurements in the horizontal plane were incongruent. Variability may be due to the individual's ability to use accommodation to correct for retinal disparity in the horizontal plane and fatigue of the eye muscles to accommodate. The variable prism bar adjustments may have caused the fusional feedback loop to be open, and therefore no need for the ocular motor system to keep the vergence angle stable under open-loop conditions.[19] There was no disparity error signal because fusionable contours were absent causing instability in the vergence angle.[19] On average, 9% of all measurements in the vertical plane were incongruent. The two examiners were within agreement for both tests of phoria in sitting and supine recumbent position in the vertical and horizontal plane. The Maddox rod test had significantly different means between the two examiners for horizontal, recumbent supine, 6 pd and for vertical, sitting, 4 pd and 6 pd. In the Maddox rod test, examiner 2 scored lower regardless of trial lens for horizontal sitting, horizontal recumbent supine, vertical sitting, and vertical recumbent supine. In part, this may be due to differences in technique between examiners. Examiner 1 identified multiple endpoints (first neutral, high neutral, and reversal point) before determining first neutral. Examiner 2 only identified first neutral. The increase in number of adjustments made by examiner 1 may have increased instability in the vergence angle. In part, this may also be due to differences in incremental measurement of the two sets of prism bars used and complexity of controlling retinal disparity in the horizontal plane. The modified Thorington method had no significantly different means. A near Thorington card was used that enabled accommodation to assist with correction of retinal disparity creating increased stability in measurement. Although there was a statistically significant difference in means between examiners using the Maddox rod test the difference is not clinically significant and did not affect the correlation. Between examiners, both tests had significant correlations in each position. Based on the results, no conclusion may be made on the difference in agreement between evaluators using the Maddox rod test or modified Thorington method.

The dissociating tests of phoria used in this study may be reliably performed by PTs to identify and measure misalignment of the visual axis to assist in the differential diagnosis of vertigo/dizziness. A targeted examination using the HINTS-Plus protocol (Head-Impulse, Nystagmus, Test of Skew, sudden onset unilateral hearing loss) is useful in distinguishing between peripheral and central causes of AVS[4,6] with a large magnitude skew of >5.8 pd being associated with central AVS.[9] The dissociating tests of phoria may be used to assist with identifying and measuring the magnitude of deviation to assist with the clinical decision to refer to the appropriate practitioner for timely and appropriate management.

Pre-existing binocular vision abnormality may be a potential risk factor for partial resolution of symptoms following vestibular rehabilitation.[15,20] Abnormalities include reduced stereopsis, double vision at near fixation, or abnormal head posture with a reduced field of binocular single vision. Early recognition of pre-existing binocular vision abnormalities by PTs may facilitate referral to appropriate clinicians such as optometry, ophthalmology, or neurology. Early management of unrecognized binocular vision abnormalities may optimize functional outcomes[21] and reduce costs by reducing number of treatment sessions.

The physical therapy evaluation and treatment after concussion/mild traumatic brain injury Clinical Practice Guidelines developed by the Academies of Orthopaedic and Neurologic Physical Therapy of the American Physical Therapy Association recommends that PTs should examine ocular alignment in individuals with a history of concussion.[16] Following a concussion, individuals have varying symptoms. The individuals' symptoms may be clustered into categories—vestibular, oculomotor, cognitive, post-traumatic migraine, cervical, and anxiety/mood.[22,23] Using a profiling model to target ongoing symptoms and impairments may help clinicians to provide targeted therapy interventions. Emerging evidence suggests that there is a correlation between ocular and vestibular abnormalities and convergence insufficiency in postconcussion syndrome.[24] Reliable measurement of ocular alignment would enable monitoring through the recovery process and identification of skew and large heterophorias to refer to the appropriate clinician for optimal management. A reduction of skew in the supine recumbent position may assist with the differential diagnosis of trochlear nerve palsy vs a unilateral utricular-otolithic pathway lesion.

Our study had several limitations. A disparity between examiners was created because the increment of measurement varied between prism bar sets. One set measured in ½ pd and the other in 1 pd. The processing of retinal disparity is of greater complexity in the horizontal plane compared to the vertical plane, which may be associated with the variability in measurement in the horizontal plane. Variability within and between dissociated tests of phoria may have occurred because accommodation was allowed for the prism neutralized modified Thorington method and not allowed for the prism neutralized Maddox rod test. The measurements were performed on healthy individuals with a phoria artificially created with glasses, as opposed to measuring an individual who had a natural phoria. A 6 pd prism resulted in phorias of 20-30 pd. An individual's ability to reduce artificially created phoria was variable. Some individuals reported actively converging to reduce deviation whereas others relaxed and allowed eyes to deviate. The individuals' response was not predictable. Therefore, the variability of measurement within the horizontal plane may be due to variability in the individual's ability to reduce retinal disparity and fatigue. The oculomotor system did not need to keep vergence stable because the fusional feedback loop was in open feedback conditions.[19] The vertical and horizontal phoria tests were not randomized which may have controlled for a possible adaptation response. Adaptation maintains the open-loop vergence in a wide range.[19] For an individual, test prisms have to be worn at least 10 minutes to evaluate whether or not prism adaptation saturates.[25] In individuals, prism adaptation saturation was not tested. Lastly, there may have been a learning curve for the participants associated with the testing, becoming familiar with the methods with the first tester, then moving on to the second tester.

Further studies need to be performed to determine the magnitude of the misalignment of the visual axis that suggests referral to a specialist. The magnitude of misalignment acceptable may vary based

on horizontal or vertical plane, pre-existing or acquired misalignment, and cause.

5 | CONCLUSION

Maddox rod test had significantly different means between two examiners ($P < .05$). The difference is not clinically significant and did not affect the correlation. Modified Thorington method had no significant difference. These dissociating tests of phoria may reliably be used by PTs in the clinic to screen for large, acquired phorias/tropias for referral to the appropriate specialist - optometrist, ophthalmologist, or neurologist.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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