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A novel approach using a polarized nonius test to evaluate the near point of convergence

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KEYWORDS
Polarized Nonius test; near point of convergence; vergence; convergence insufficiency symptom survey

Abstract
Purpose: This study aims to evaluate the efficacy of a new method for measuring the near point of convergence (NPC) using a Nonius polarized target stimulus, comparing its sensitivity in detecting convergence ability to that of traditional approaches.
Methods: In this prospective study, 65 participants underwent near point of convergence (NPC) measurements using three methods: an accommodative target (NPC1), a penlight with a red filter (NPC2), and a Nonius polarized target (NPC3). Participants also completed the Convergence Insufficiency Symptom Survey (CISS). Statistical analyses, including repeated-measures ANOVA and Spearman's correlation, were conducted to assess differences among the methods.
Results: The Nonius method demonstrated a median break point of 8.37 cm, significantly higher than the other methods, NPC1: 6.63 cm, and NPC2: 7.17 cm. Sensitivity for detecting CI symptoms was 92.6 % for the NPC3, which outperformed NPC1 (77.8 %) and NPC2 (74.1 %). NPC3 exhibited low specificity (7.4 %). Correlations between NPC measurements and CISS scores were weak and nonsignificant, though the strongest correlation was observed for NPC3
Conclusion: The Nonius polarized target method shows benefits compared to traditional methods in measuring NPC. This study provides a more sensitive method to measure convergence ability, reducing variability across clinical settings, and enhancing the reliability of assessments in both research and practice.

Introduction

The near point of convergence (NPC) is a fundamental measurement of the visual system that determines the closest near point at which an individual can maintain binocular

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single vision.[1,2] NPC measurement play a crucial role in visual function assessment and is particularly important for diagnosing convergence insufficiency (CI).[2] However, a comprehensive diagnosis of CI also involves additional clinical evaluations, including assessments of exophoria at both distance and near, as well as measurements of positive fusional vergence.[3] CI is the most common visual dysfunction,[4] with a prevalence ranging from 3.43 % to 10.3 %.[5] The most effective treatment for CI is the office−based vergence/accommodative therapy procedure.[6]

The process of measuring NPC is determined by observing the patient's ability to keep both eyes aligned on a target, such that it is gradually moved (at about 1 to 2 cm/s) closer to the eye. The most common method to measure NPC involves using an accommodative target with letters of visual acuity of 20/40,[7] which is moved toward the patient until double is reported, or the examiner observes a break in binocular fusion. This method is called the push-up method with an accommodative target, and is considered the gold-standard. An alternative method is using a penlight instead of letters as a target. In this case, a red filter is placed in front of one eye, and the penlight is moved toward the patient reports diplopia (two lights).[4] For both methods, after determining the break point, the examiner moves the target back to the initial position. The examiner then observes the patient's ability to regain single binocular vision as the target is moved away from the nose, which is the recovery point.[2]

Discrepancies regarding the clinical cut-off values for the NPC,[2,3,8] and the targets used,[2,9] have been addressed in the literature. For children, some studies have observed that the normative value of the NPC with an accommodative target is $<$5 cm,[10] others have indicated that should be 6 cm for the break, and 10 cm for the recovery point,[11] and others have concluded 8 cm for the break point using a pencil as stimulus.[12] For young adults the normative values should be approximately 10 cm for break, and for presbyopic adults, the NPC is higher than 13 cm using a column of letters as the stimulus,[8] or 14 cm using a pencil or the examiner's index finger.[13] To summarize, for the adult population, both accommodative and penlight and red filter methods, have an established cut-off of break and recovery points at 5 cm and 7 cm, respectively.[2,6] Hence, having an NPC break point $>$6 cm is a sign of CI.[14,15]

The Convergence Insufficiency Symptom Survey (CISS) is a self-reported survey that assesses the severity of symptoms associated with CI.[16] The maximum score on the CISS is 60 points, as the survey consists of 15 symptom-related questions, each rated from 1 to 5, where 1 means "never" and 5 means "always".[4] The CISS is a validated instrument for quantifying symptoms for both adults and children.[17] The normative values of the CISS survey are 16 or lower for children and 21 or lower for adults, with higher scores indicating likelihood of convergence insufficiency.[18] However, other authors have identified the CISS as not sensitive to CI.[19] This may be because CISS symptoms can reflect a range of visual discomfort beyond just receded NPC, including accommodative issues, asthenopia, and other binocular vision dysfunctions. In addition, the method used to measure NPC may contribute to this discrepancy.

Therefore, for this study we investigated a new method to evaluate the NPC with a Nonius stimulus polarized target, based on a stimulus similar to fixation disparity.[20] Fixation disparity refers to a small disagreement between the alignment of the two eyes.[21] We hypothesise that using this method might be more sensitive to measure the convergence ability at near, and detect CI symptoms than the accommodative target test or the penlight test, because the Nonius polarized test presents different images to each eye, each eye sees a line, and can detect possible central suppressions.[22] When the dichoptic lines are aligned, they form stimulating pairs of corresponding retinal points in the two eyes. Although ocular accommodation is naturally engaged during binocular fixation of a near target, as occurs in typical visual tasks,[22] we hypothesize that the use of polarized lines helps reduce excessive accommodative stimulation. This, in turn, may minimize accommodative bias and improve the accuracy of convergence measurements by allowing for a more precise assessment of subjective misalignment of the visual axes during ocular convergence.

In this study, we aimed to compare the results of two gold-standard methods for evaluating the near point of convergence (NPC) with those obtained using a new testing approach. Additionally, we investigated the potential advantages of this new method in measuring NPC and its effectiveness in detecting visual symptoms, as assessed using the Convergence Insufficiency Symptom Survey (CISS) survey.

Material and methods

Participants

In this prospective cross-sectional study, all participants were informed about the nature of the study, and signed a written informed consent before any measurements were taken. This study was approved by the Institutional Review Board of the UPC and followed the tenets of the Declaration of Helsinki. Participants were unfamiliar with the NPC measurement procedures. All patients wore their habitual refractive correction during the experiment. Inclusion criteria were: visual acuity $\geq$20/20 in both eyes at distance and near, and stereopsis $\leq$70 arcsec, measured with Random Stereoacuity Test (Vision Assessment Corporation, Elk Grove Village, IL, USA). While 60 s of arc is often considered the threshold for normal stereoacuity, we chose a slightly more lenient cut-off to include individuals with near-normal stereopsis. This approach was intended to improve the generalizability of our findings while still ensuring functionally adequate depth perception among participants.

Material and procedures

Before the NPC procedure, patients answered the validated Spanish version of the CISS.[23] Amplitude of accommodation was measured monocularly in the right eye using the Donders push-up method and the Royal Air Force rule (RAF).[25] A 0.7 decimal visual acuity (equivalent to approximately 20/30 Snellen) was required, and participants were asked to fixate a line of 5 letters at this acuity level. The target was slowly moved toward the participant until the first sustained blur was reported. Three measurements were taken for each eye, and the average value was used for analysis. The NPC was measured with three different methods

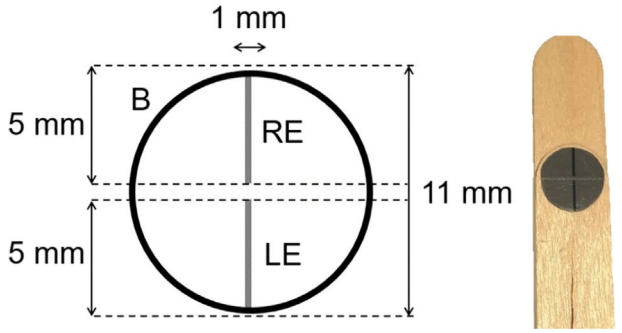

Fig. 1 Left: Representation of the Nonius Linear Polarized Stimulus. *B*, binocular viewing; RE, right eye; LE, left eye. Right: Photograph of the stimulus created for this study.

on the same day. Tests were presented in a random order to avoid vergence adaptation, with a five-minute break point between measurements to minimise fatigue. One of the methods for measuring the NPC (NPC1) used an accommodative target with a column of letters of 20/30 visual acuity. The second method used a penlight and a red filter over the right eye (NPC2). The third and new method used the Nonius stimulus polarized target (NPC3) and required participants to wear polarizing filter glasses. Nonius lines are a pair of polarized vertical lines in which one line is seen with the right eye, and the other one with the left eye (Fig. 1). Before starting this test, all participants saw both fixation lines. Participants were asked to report the first moment when the vertical lines lost their vertical alignment.

In all three methods, the stimulus was placed at a starting distance of 40 cm in the midline in front of the participant. The target was then moved, employing the RAF rule,[24] at a slow constant speed, 1 cm/s, towards the patient. When the subject reported diplopia in NPC1, double vision in NPC2, or a loss of vertical alignment in NPC3, the break point in centimeters was noted. Then, the direction was reversed, and the stimulus was moved away from the participant until they experienced single vision again (in NPC1 and NPC2) or a recovery of vertical alignment in NPC3, which was recorded as the recovery point. This procedure was executed identically in all three techniques, and repeated three consecutive times for each method. The mean of these three measurements determined the break and recovery points for the NPC in each technique. The same optometrist performed all the measurements to minimize potential human bias in the methodology. All measurements were conducted in the same room under consistent lighting conditions.

Statistical analysis

Statistical analyses were conducted using IBM SPSS version 27.0 for Windows. The normality of all variables was assessed using the Shapiro-Wilk test. For data with a non-parametric distribution ($p < 0.05$), the median and inter-quartile range (IQR) were reported. A repeated-measures ANOVA was conducted to compare the means between different methods, applying Mauchly's test for sphericity. If Mauchly's test indicated a violation of sphericity ($p < 0.05$), the Greenhouse-Geisser correction was applied. The relationships among the results from different tests were evaluated using Spearman's correlation coefficients for non-parametric data and Pearson's correlation for parametric data. Sensitivity, specificity, and ROC analyses were performed using SPSS.

Results

A total of 65 participants were included in the study. Table 1 shows the demographic and descriptive characteristics of the participants for age, stereoacuity, CISS values, and amplitude of accommodation. The dataset associated with this project is available at the following link: https://osf.io/y6a7b/?view_only=16b7cbdc9d0a4882aa8e56df80670f0a.

A significant strong correlation was found between both eyes for amplitude of accommodation, rho(65)=0.96, $p < 0.0001$. Descriptive values for the different methods evaluating the NPC are detailed in Table 2.

The ANOVA of repeated measures revealed a significant statistical difference between the three methods in the break, F(2128)=14.38, $p < 0.001$, η_p^2=0.184, and in the recovery point values, F(2128)=15.26, $p < 0.001$, η_p^2=0.193. Pairwise comparison using Bonferroni's correction yielded a significant difference between break point values for NPC1 and NPC3, $p < 0.001$, NPC2 and NPC3, $p = 0.002$, but not within NPC1 and NPC2, $p = 0.256$. For recovery point values, the pairwise comparison revealed significant statistical differences between NPC1 and NPC3, $p < 0.001$, NPC2 and NPC3, $p = 0.005$, and NPC1 with NPC2, $p = 0.050$ (Fig. 2).

Normality test using Shapiro-Wilk revealed that NPC1 break point and CISS score values passed normality test, $p = 0.073$, $p = 0.377$, respectively, but not for NPC2 and

Table 1 Demographic and descriptive data of the participants.

	Age		Stereoacuity		CISS		AA	
	Male	Female	Male	Female	Male	Female	Male	Female
Sample	22	43	22	43	22	43	22	43
Mean	20.86	20.16	28.68	38.20	15.63	13.76	11.61	11.45
Std. Deviation	3.49	4.35	12.79	19.39	8.19	6.38	2.44	1.60
Minimum	13.00	12.00	15.00	16.00	1.00	4.00	8.00	9.00
Maximum	26.00	30.00	60.00	120.00	33.00	26.00	17.50	15.50

Stereoacuity in arcsec, CISS, convergence insufficiency symptom survey; AA, amplitude of accommodation in sphere diopters (D).

Table 2 Descriptive values for the different methods evaluating the NPC.

	NPC1		NPC2		NPC3	
	Break	Recovery	Break	Recovery	Break	Recovery
Median	6.63	7.87	7.17	8.67	8.37	9.70
IQR	(5.50,8.43)	(6.05,9.62)	(5.17,8.83)	(6.68,10.58)	(7.17,9.71)	(8.40,11.49)
Min to Max	3.00 to 13.47	4.93 to 15.17	3.00 to 14.00	4.00 to 16.83	3.00 to 16.70	5.00 to 17.20
Mean, SD	6.76 (2.34)	8.02 (2.34)	7.33 (2.76)	8.90 (2.89)	8.40 (2.28)	9.89 (2.37)

NPC1 corresponds to the measurements taken with an accommodative target, NPC2 with a penlight and a red filter over the right eye, and NPC3 using the novel Nonius stimulus polarized target. All values are in cm. In order to provide a summary of central tendency and variability, data for break and recovery points are also presented as mean and standard deviation (SD).

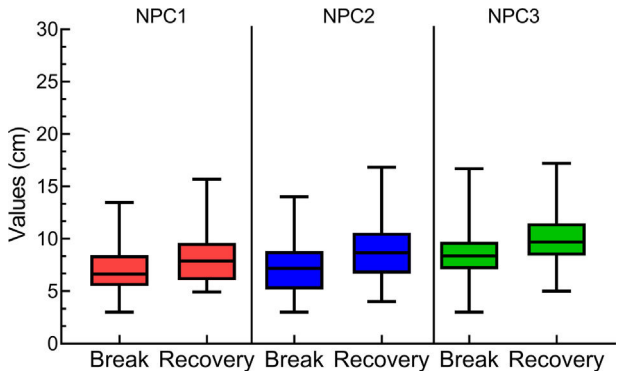

Fig. 2 Box-plots for all the data points (values in cm) between all three methods used in this study. NPC1= measurement with an accommodative target, NPC2= penlight and a red filter over the right eye, and NPC3= novel Nonius stimulus polarized target.

NPC3, $p < 0.001$. The Pearson correlation analysis revealed a non-significant correlation between the break points for NPC1 and CISS survey variables, r(65)=0.07, $p = 0.834$. Spearman's correlations with NPC2 and CISS were rho(65)=0.07, $p = 0.571$, and NPC3 with CISS, rho(65)=0.16, $p = 0.189$ (Fig. 3). Recovery point values were not normally distributed (Shapiro-Wilk test) for NPC1, $p = 0.004$, but normally distributed for NPC2, $p = 0.085$, and NPC3, $p = 0.543$. The correlation between recovery point values and CISS was not statistically significant for NPC1, rho(65)=0.02, $p = 0.875$, NPC2, r(65)=0.06,$p = 0.608$, and NPC3, r(65)=0.17, $p = 0.157$.

The correlations within break point values between three of the NPC methods were statistically significant between NPC1 and NPC2, rho(65)=0.49, $p < 0.001$, NPC1 and NPC3, rho(65)=0.48, $p < 0.001$, and NPC2 with NPC3, rho(65) =0.47, $p = 0.002$.

In addition, the relationship between NPC1, NPC2, and NPC3 and the right eye's amplitude of accommodation values was analyzed, and the Spearman's correlation for NPC1, NPC2 and NPC3 was, rho = 0.14, $p = 0.257$, rho = −0.04, $p = 0.760$, and rho = 0.02, $p = 0.872$, respectively. The relationship between NPC1, NPC2, and NPC3 and the stereopsis values was also examined. Spearman's correlations revealed that stereopsis showed a weak, non-significant negative correlation with NPC1 (rho=−0.18, $p = 0.140$) and weak, non-significant positive correlations with NPC2 (rho=0.13, $p = 0.297$) and NPC3 (rho=0.23, $p = 0.065$).

Sensitivity and specificity of the NPC1, NPC2 and NPC3 break point values were calculated for the CISS scores. The cut-off between normal and abnormal values in NPC breaking points was 6 cm, with values >6 cm were considered positive or altered. In line with the criteria used in previous research,[2] a CISS score ≥16 was set as the cut-off. Sensitivity for NPC1 was 77.8 %, and specificity 22.2 %. For NPC2 the sensitivity was 74.1 % and 25.9 %, and for NPC3 was 92.6 % and 7.4 %, respectively. The results are summarized in Table 3.

Discussion

This study aimed to determine whether a new test based on a Nonius stimulus-polarized target can be more sensitive in measuring the near point of convergence (NPC) and determining convergence insufficiency symptoms, evaluated using

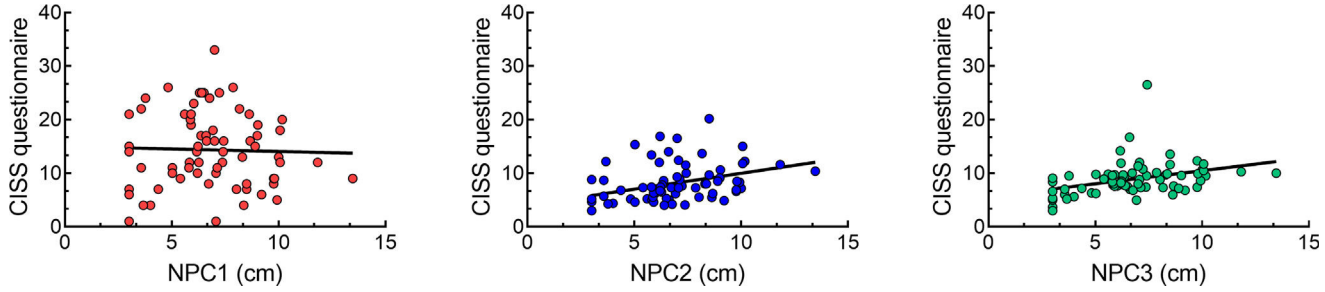

Fig. 3 Correlation plots between the CISS score and break point values for the three NPC methods used. NPC1 corresponds to the measurement with an accommodative target, NPC2 with a penlight and a red filter over the right eye, and NPC3 using the novel Nonius stimulus polarized target.

Table 3 Sensitivity and Specificity percentages for the three methods evaluated.

	Sensitivity	Specificity
NPC1	77.8 %	22.2 %
NPC2	74.1 %	25.9 %
NPC3	92.6 %	7.40 %

the CISS survey. In addition, this test was compared with gold-standard methods for evaluating NPC.

Our results indicate that the values obtained using this new test differ from those obtained with the gold-standard methods. It was observed that the break point values were higher with the red filter and with the penlight than with the accommodative stimulus, in agreement with previous literature.[3,4] Some studies show that NPC measured with an accommodative target often results in a closer convergence break point because it involves both convergence and accommodation employed at the same time,[1,2] suggesting that NPC measured with the accommodative target produces more accurate results in adult populations with normal accommodation.[9,13] In the present study, the NPC break and recovery points values were the highest when measured with the nonius lines, in comparison with the accommodative and penlight methods. In the case of NPC3, the values reported for break and recovery points are higher for the three methods than for the other three methods. We believe that this is caused by the fact that it is easier to detect the first misaligned point with Nonius, rather than detecting blur using the accommodative or red filter and penlight.

The results of this study align with previous studies showing that the accommodative target generally produces lower NPC values than other methods.[3,4] For instance, some research indicates that the normative NPC values for children should be <5 cm,[10] whereas our adult population showed a higher median break point, which may reflect differences in age-related visual function. The higher median break point for the Nonius method (NPC3) suggests that this new technique may yield higher convergence demands, potentially due to the nature of the stimulus that requires a more precise alignment of the visual axes. Moreover, our findings regarding the recovery point also revealed notable differences. Traditionally, the penlight and red-filter method has been considered more effective than accommodative stimuli for detecting a receded near point of convergence (NPC), as it introduces a dissociative element that reduces accommodative cues. Interestingly, our findings suggest that the Nonius method measures an even more receded NPC than both the accommodative and penlight methods. This may be attributed to the higher sensory demand imposed by the Nonius task, which not only challenges the visual system more intensely but also incorporates anti-suppression and Nonius stimuli. As a result, this method can provide a more reliable and precise assessment of convergence ability by minimizing the influence of compensatory mechanisms like suppression.

The Nonius method (NPC3), although not statistically significant, showed the highest correlation with the CISS survey but with less variability compared with NPC1 (accommodative stimulus) and NPC2 (red filter + penlight). Borsting et al.[16] and Rouse et al.[17] found a higher correlation between CISS and abnormal NPC values in both children and adults. Moreover, other studies have found a relationship between higher NPC values and higher CISS scores.[25]

However, the specificity and diagnostic value of the CISS has been recently questioned. Horan et al.[19] found no significant difference in CISS scores between CI and normal binocular vision patients, suggesting that this survey may not be specific to CI. Similarly, Horwood et al. (2014) reported that many young adults with high CISS scores did not have CI, while some with CI were asymptomatic. This study concluded that using the CISS for CI screening is not recommended in young adults.[26] Bade et al.[27] found no significant relationship between the severity of CI clinical signs and symptom levels measured by CISS in children with symptomatic CI. These findings suggest that although the Nonius method did not show statistically significant differences, it's stronger, rather non-significant, correlation with CISS scores and lower variability highlight its potential clinical relevance. The method's design, which incorporates anti-suppression elements and dissociative stimuli, may offer a more accurate reflection of patients' functional visual difficulties.

Based on the results of this study, a more challenging stimulus using polarized Nonius stimulus yields significantly less variability with CISS scores in their correlation. When comparing the sensitivities between the three methods, our study found that the Nonius method (NPC3) had a sensitivity of 92.60 %, significantly higher than the accommodative target (NPC1) at 77.80 % and the penlight method (NPC2) at 74.10 %. This new method using polarized Nonius lines has both oculomotor and sensory components,[22] which could be the cause of having a higher sensitivity. Its ability to present a more demanding and precise alignment task helps uncover subtle convergence deficits that might be missed by less sensitive tools, such as the accommodative target or penlight method. As such, the Nonius method provides a more robust and clinically valuable approach for evaluating convergence performance, supporting its integration into routine clinical assessments where precise detection of convergence issues is critical, particularly because its combined oculomotor and sensory demands reduce the likelihood of compensatory mechanisms like suppression, thereby revealing deficits that may go undetected with traditional methods. This dissociation may reveal latent deviations or instabilities that can be compensated under normal viewing conditions.[28] However, due to this artificial dissociation, the test has a low specificity, reported at only 10.6 %, which means that it often identifies receded near point of convergence even in individuals without higher visual symptoms (based on CISS survey).

Therefore, although the polarized Nonius test has advantages for measuring NPC, it should not be used in isolation. It is essential to confirm any findings with additional, more specific tests to establish an accurate diagnosis and avoid misclassifying normal individuals as having binocular vision disorders.

This study has several limitations, including a relatively small and homogeneous sample consisting primarily of young adults, which may limit the generalizability of the findings. Additionally, the reliance on subjective reporting for break and recovery points, along with the use of a controlled testing environment, may introduce variability. The choice of examination instruments and techniques also influences the

results—for instance, some studies have found that using an RAF rule can lead to a more receded NPC.[9,29] Moreover, the results obtained with the Nonius stimulus serve as a baseline representation of individuals with normal binocular vision. It would be valuable to replicate these procedures in populations with convergence insufficiency and paediatric groups to better understand the method's broader applicability.

Clinicians should employ a multimodal approach to the near point of convergence assessment, recognizing that different measurement methods yield different normative values. In addition to monitoring subjective visual symptoms, it is essential to incorporate a broader battery of binocular and accommodative tests to ensure an accurate diagnosis of visual dysfunction. For example, vergence facility and near-fusional vergence ranges can provide critical information about a patient's binocular coordination that may not be captured through NPC testing alone.[1] Recent research emphasizes that subjective assessments, such as the monocular subjective push-up test, may not reliably reflect objective accommodative function, particularly in children and young adults, highlighting the importance of integrating objective measures when available.[30] Future studies should continue to refine diagnostic protocols by examining the interplay between subjective symptoms and objective clinical markers, with the goal of establishing more reliable, evidence-based standards for binocular vision assessment.

Conclusions

The Nonius polarized target method offers significant advantages over traditional approaches for measuring NPC, particularly due to its reduced variability and improved suppression control. The significant differences in median break and recovery points between the two gold-standard methods underscore the importance of selecting the appropriate technique to ensure accurate clinical outcomes.

Conflicts of interest

The authors have no conflicts of interest to declare.

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