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ORIGINAL ARTICLE

Comparing clinical measures of near point of convergence and accommodation from the lateral canthus and browline in a paediatric and adolescent population

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Abstract

Purpose: Clinicians measure the near point of convergence (NPC) and the amplitude of accommodation (AA) from the spectacle plane, the bridge of the nose or the lateral canthus when assessing visual function. These values are compared to standard clinical criteria to diagnose vergence and accommodation deficits, despite varying reference points. This prospective study explored measuring relative to the spectacle plane and from the lateral canthus for NPC and monocular AA, and the resulting clinical implications of diagnosing visual deficits.

Methods: Participants were seen by a single clinician for an eye examination. NPC was measured from the forehead and the lateral canthus of the right eye. Monocular AA was measured from the brow and the lateral canthus. Differences between measurements were analysed using non-parametric statistical tests including Wilcoxon Signed Rank, as well as linear regression and a linear mixed effects model to adjust for inter-eye correlation and repeated measures. Chi-square tests were used to assess differences in rates of abnormal findings.

Results: Data were collected from 70 participants (53% female, median age 13 [11–15] years). On average, measuring NPC from the lateral canthus yielded a value 1.8 cm higher than measuring from the forehead. Measuring AA from the lateral canthus resulted in an average difference of 1.5 cm compared to measuring from the brow. A total of 39% and 76% of subjects failed NPC compared to clinical norms when measured from the forehead or the lateral canthus, respectively, while 7% and 40% failed AA when measured from the brow or the lateral canthus, respectively.

Conclusion: With the variable anatomy of the eye, it is imperative to account for the measurement point when assessing visual function. Measuring from the lateral canthus greatly increased the failure rates for NPC and AA compared with measuring from the forehead and brow, respectively.

KEYWORDS
accommodative amplitude, adolescent, binocular vision, near point of convergence, paediatrics

INTRODUCTION

The near point of convergence (NPC) and accommodative amplitude (AA) are important clinical measures used to diagnose non-strabismic binocular vision disorders.[1] A receded or abnormal, near point of convergence can be indicative of convergence insufficiency, while a reduced AA can be the single factor determining a diagnosis of accommodative insufficiency.[1–3] Increasingly, these tests are utilised by non-vision care providers to screen for vision deficits following concussion; both tests have been shown to be abnormal at higher rates in concussed adolescents, while reduced AA has been a predictor of prolonged concussion recovery time.[4,5]

The NPC is tested by slowly bringing a target closer to the observer's eyes and measuring to the point where they subjectively report that the target doubles or splits in two, or when the clinician objectively observes one eye drift out. This measurement represents the maximum point of binocular fusion.[1] Monocular AA is measured using several different methods in clinical practice. A common method is the "push-up" technique, where the examiner slowly brings the target toward the eye and then measures where the patient reports the first slight, sustained blur.[1,6] This point quantifies the eye's maximum ability to focus on an object at near.[1] In children and adolescents, these tests are particularly important as convergence and accommodation can impact reading ability, concentration and performance in school.[7–9]

Despite their subjective nature, the relative ease and interpretability of these two tests have led to their frequent utilisation in vision examinations.[1] For paediatric patients, a near point of convergence ≥6 cm is considered abnormal, a criterion established through cohort studies of school-age children.[10] Amplitude of accommodation is typically compared to Hofstetter's formulae a series of equations that determine age-appropriate accommodation values.[3,11] A value less than age-expected might be considered abnormal, though studies have shown that Hofstetter's formulae, might provide inaccurate predictions for expected accommodation in children and adolescents.[12]

There are inconsistencies in clinical instruction and research methodology as to the reference point of measurement for these two tests. Examiners variously measure from the forehead, the brow, the lateral canthus or the bridge of the nose (Table 1). The differences between measurement tools contribute to these varying reference points and the ability to adjust between measurement styles; for example, Royal Air Force (RAF) rulers are designed to rest on a patient's cheek and cannot test closer than 5.5 cm from the spectacle plane.[13] Although these differing zero points might have negligible differences in a clinical setting, failing to account for them can affect the reported prevalence of oculomotor deficits. Hayes et al. measured the NPC from the centre of the forehead at brow level to establish the 6 cm cut-off.[10] Hofstetter's formulae are based on datasets from Duane and Donders; Duane used the spectacle plane as his point of reference, and assumed it to lie 13–14 mm in front of the cornea, while Donders measured from the nodal point, and assumed to be 7 mm behind the vertex of the cornea.[11] Table 1 summarises a number of studies that have assessed NPC and/or AA in a paediatric population, as well as the point of reference and cut-off criteria used to illustrate the variability in measurements.

The objectives of this study were: (1) to determine the difference between NPC measurements using the forehead and the lateral canthus as reference points; (2) to determine the difference between AA measurements using the brow and the lateral canthus as reference points and (3) to understand how these differences might impact the prevalence of binocular vision deficits.

Key points

- Both the near point of convergence and accommodative amplitude are measured from varying reference points. This can reduce the interpretability of study findings and lead to misdiagnosis of non-strabismic binocular vision deficits.
- This study quantified the differences between measuring from the lateral canthus and the browline for near point of convergence and accommodative amplitude in a paediatric and adolescent population.
- The findings support increased reporting of the measurement point in study methodologies and establishing a universal reference point for normative data.

METHODS

Data were collected from participants seen by a single clinician for possible visual function deficits or a regular eye examination. Participants were not excluded for pre-existing binocular vision diagnoses. Boston Children's Hospital Institutional Review Board approved the research protocol. Written assent was obtained from participants and written informed consent was obtained from their parent or guardian.

Participants were seated in an examination chair and instructed to sit up straight. The examiner monitored and corrected patient movement and head tilt. NPC was measured once to the nearest 0.5 cm from the middle of the browline on the forehead using a near point rule (Oculomotor Assessment Tool, Gulden Ophthalmics, guldenophthalmics.com/product/oculomotor-assessment-tool-omat/) and a ruler was used to measure from the lateral canthus of the right eye to the same target position. Monocular AA was measured once from one or both eyes using the same method from both the brow and the lateral canthus. All measurements were taken by the same examiner.

NPC measures were compared to established clinical criteria (≥6 cm) to determine abnormal values. AA measures were compared to the age-expected AA calculated from Hofstetter's minimum formula (15 – (0.25 × age) – 2D).

The distance between the lateral canthus and the midpoint of the forehead along the browline and midpoint of the brow was estimated for each participant by calculating the square root of the sum of squared differences for their corresponding measurements (Figure 3). This calculated estimate of "lateral canthus to browline width" was used to examine trends in how face morphology might impact the magnitude of the difference when measuring from different reference points.

Statistical analysis was completed using R Statistical Software (version 4.3.1, r-project.org). Differences

TABLE 1 Summary of studies measuring near point of convergence and accommodative amplitude in paediatric and adolescent populations, as well as their measurement reference point, reported findings and diagnostic criteria (cut-off).

Study	Reference point	Average	Cut-off
Near point of convergence (break point)			
Hayes et al. (1998)[10] • *6th grade cohort*	Centre of forehead	4.26 ± 3.40 cm	>6 cm
Von Noorden and Campos (2002)[14]	Bridge of nose or plane of centres of rotation of the eye	N.R.	8–10 cm
Maples et al. (2007)[15] • *Age 9 cohort*	Bridge of nose	3.30 ± 4.17 cm	>5 cm
Convergence Insufficiency Treatment Trial (2008)[16]	Centre of forehead	14.3 ± 7.6 cm	≥6 cm
Abraham et al. (2015)[17]	Lateral canthus	6.3 ± 2.8 cm	N.R.
Ostadimoghaddam et al. (2016)[18]	Lateral canthus or spectacle plane	6.95 ± 3.87 cm	N.R.
Hussaindeen et al. (2017)[19]	Centre of forehead	3 ± 3 cm	≥6 cm
Hashemi et al. (2018)[20]	Lateral canthus or spectacle plane	8 cm	N.R.
Hassan et al. (2018)[21]	Lateral canthus or spectacle plane	N.R.	≥8 cm
Ma et al. (2019)[22]	RAF Ruler	5.1 ± 2.4 cm	≥6 cm
Wajuihian et al. (2019)[23]	RAF Ruler	6.88 ± 2.88 cm	≥7.5 cm
Accommodative amplitude (blur point)			
Hussaindeen et al. (2017)[19] • *7–10 age group* • *11–17 age group*	Centre of forehead (binocular)	13 ± 3 D 11 ± 2 D	N.R.
Hashemi et al. (2017)[24]	Bridge of nose	11.53 ± 3.02 D	Hofstetter's formula
Hashemi et al. (2018)[12]	Spectacle plane	14.4 D	N.R.
Ma et al. (2019)	N.R.	12 ± 2.47 D	Hofstetter's formula
Near point of convergence in the setting of concussion/sports medicine			
Mucha et al. (2014)[25] • *Control cohort*	Tip of nose	1.9 ± 3.2 cm	≥6 cm
Pearce et al. (2015)[26] • *Concussed cohort*	Tip of nose	6.23 ± 8.08 cm	>5 cm
Kawata et al. (2016)[27] • *Control cohort*	Upper lip	5.5 ± 2.0 cm	9.5–10 cm
Storey et al. (2017)[28] • *Concussed cohort*	N.R.	9 cm	>6 cm

Abbreviation: N.R., not reported.

between measurements were analysed using non-parametric statistical tests including Wilcoxon Signed Rank, as well as linear regression and a linear mixed effects model to adjust for inter-eye correlation and repeated measures. Chi-square tests were used to assess differences in rates of abnormal findings using the different reference points. Categorical data are reported as a frequency (percentage) and continuous data as median and interquartile range (IQR).

RESULTS

Seventy participants were enrolled (53% female, median age 13 years [11–15 years]). Participant demographics are reported in Table 2. NPC measurements, monocular AA values from the right eye and monocular AA values from the left eye were obtained from 54, 60 and 57 subjects, respectively (Table 3, Figure 1).

TABLE 2 Participant demographics.

N	70 (53% female)
Age (years)	13 [11–15]
Race (self-reported)	47% White 34% Asian 7% Black 11% Other

On average, measuring NPC from the lateral canthus yielded a 1.8 cm (95% CI 1.7–2.0 cm; $p < 0.0001$) higher value than measuring from the forehead (Figure 1b). Measuring AA from the lateral canthus yielded a measurement that was on average 1.5 cm (95% CI 1.4–1.7 cm; $p < 0.0001$) higher than from the brow after adjusting for

TABLE 3 Measurements from the browline and lateral canthus. AA, accommodative amplitude; NPC, near point of convergence; OD, right eye; OS, left eye.

	N	Browline	Lateral canthus	*p*-Value
NPC	54	5 [4.0–6.5] cm	7 [6–8] cm	$p < 0.0001$
AA OD	60	8.5 [7.4–10] cm	9.5 [9–11] cm	$p < 0.0001$
		11.8 [10–13.6] D	10.5 [9.1–11.1] D	$p < 0.0001$
AA OS	57	8.5 [7.5–9.5] cm	10 [9–11.5] cm	$p < 0.0001$
		11.8 [10.5–13.3] D	10 [8.7–11.1] D	$p < 0.0001$

Note: Continuous data are reported as median and interquartile range (IQR). AA is reported in cm and dioptres (D). Browline and lateral canthus measures were compared using Wilcoxon Signed Rank tests.

inter-eye correlation. This translated to an average difference of 1.9 D (95% CI 1.7–2.2 cm; $p < 0.0001$) between the lateral canthus and brow for the AA measurements (Figure 1b).

When measured from the forehead, 21 participants (39%) had an abnormal NPC (≥6 cm). Note that participants were not excluded based on pre-existing binocular vision issues. However, 41 participants (76%) had a NPC ≥6 cm when measured from the lateral canthus ($p < 0.0001$). When measuring from the brow, only four participants (7%) had abnormal AA (using Hofstetter's minimum formula) in their right eye, whereas 24 (40%) participants had abnormal right eye AA measures when using the lateral canthus as the reference point ($p < 0.0001$). These rates were similar in the left eye, with five (9%) and 26 (46%) participants having abnormal AA measures when measured from the brow or the lateral canthus, respectively ($p < 0.0001$) (Figure 2).

When considering possible anatomical differences due to the demographic characteristics of the participants, we used a calculated estimate of the distance between the lateral canthus and the brow reference point ("lateral canthus to browline width"), as this is fixed for each participant and determined by facial morphology (Figure 3a,b). On average, a 1 cm increase in this lateral canthus to browline width difference between the lateral canthus and the forehead corresponded to a 0.64 cm (95% CI 0.58–0.69 cm; $p < 0.0001$) difference between NPC measurements when controlling for the browline measurement. The median lateral canthus to browline width for the NPC cohort was 4.8 cm (IQR [3.9–5.5 cm]). There were no significant differences in NPC lateral canthus to browline width due to age or sex (age: $p = 0.37$, sex: $p = 0.19$) in the NPC cohort.

For AA, a 1 cm increase in lateral canthus to browline width corresponded to a 0.51 cm (95% CI 0.50–0.53, $p < 0.0001$) greater difference between AA measurements, controlling for the AA brow measurement and inter-eye correlation. The median lateral canthus to browline width for the AA cohort was 5.1 cm (IQR [4.6–6.0 cm]). There were no significant differences in lateral canthus to browline width due to age or sex (age: $p = 0.06$; sex: $p = 0.86$).

DISCUSSION

The primary purpose of this study was to quantify the differences in NPC and AA measurements when using the lateral canthus and the browline as reference points. Measuring NPC from the lateral canthus led to a 1.8 cm greater value (i.e., more receded) compared with measuring from the forehead. For AA, measuring from the lateral canthus increased the measurement on average by 1.5 cm, corresponding to a 1.9 D reduction compared with measurements from the brow for this cohort. Of note, since dioptres are a non-linear scale, this 1.5 cm difference would have led to a larger dioptric difference if the sample had high baseline AA values, and conversely a smaller difference in individuals with lower AA measurements. For example, if the same 1.5 cm difference resulted from values of 7.5 cm (13.3 D) and 9 cm (11.1 D) from the brow and lateral canthus, respectively, then this would result in a 2.2 D difference. However, if the respective values were 9.5 cm (10.5 D) and 11 cm (9.1 D), then the dioptric difference would only be 1.4 D.

The secondary purpose of this study was to illustrate how measuring from the lateral canthus without adjusting cut-off criteria could impact the reported prevalence of binocular vision deficits. Although the present study cohort was partially comprised of patients with pre-existing binocular vision diagnoses and thus would have a higher frequency of test failure, we found that the rates of abnormal measures increased significantly when comparing lateral canthus measurements to commonly used clinical criteria. For NPC, test failure increased from 39% to 76% when measuring from the lateral canthus. For AA, failure rates increased from 7% to 40% when measuring from the lateral canthus of the right eye. These data illustrate how measuring from the lateral canthus can lead to a reduced prevalence of clinical test failures if cut-off criteria are not adjusted to account for the reference point.

In considering anatomical differences that could be influenced by factors like age and sex, we found that an increase in the calculated distance between the browline reference point and the lateral canthus for a given patient was correlated with a larger difference between measurements when controlling for the browline measurement. This analysis was limited by the small sample size and served only as an estimate, as it did not account for the depth of the lateral canthus relative to the browline. However, this analysis illustrates the problem with varying reference points: since the measurements were taken from the same target position, a larger width between the lateral canthus and the midline of the brow or forehead and a greater depth of the lateral canthus relative to the brow would lead to a larger difference between the two measurements for a given target distance. Further, our analysis demonstrated the variation in facial morphology in a paediatric and adolescent population with the range in lateral canthus to browline widths.

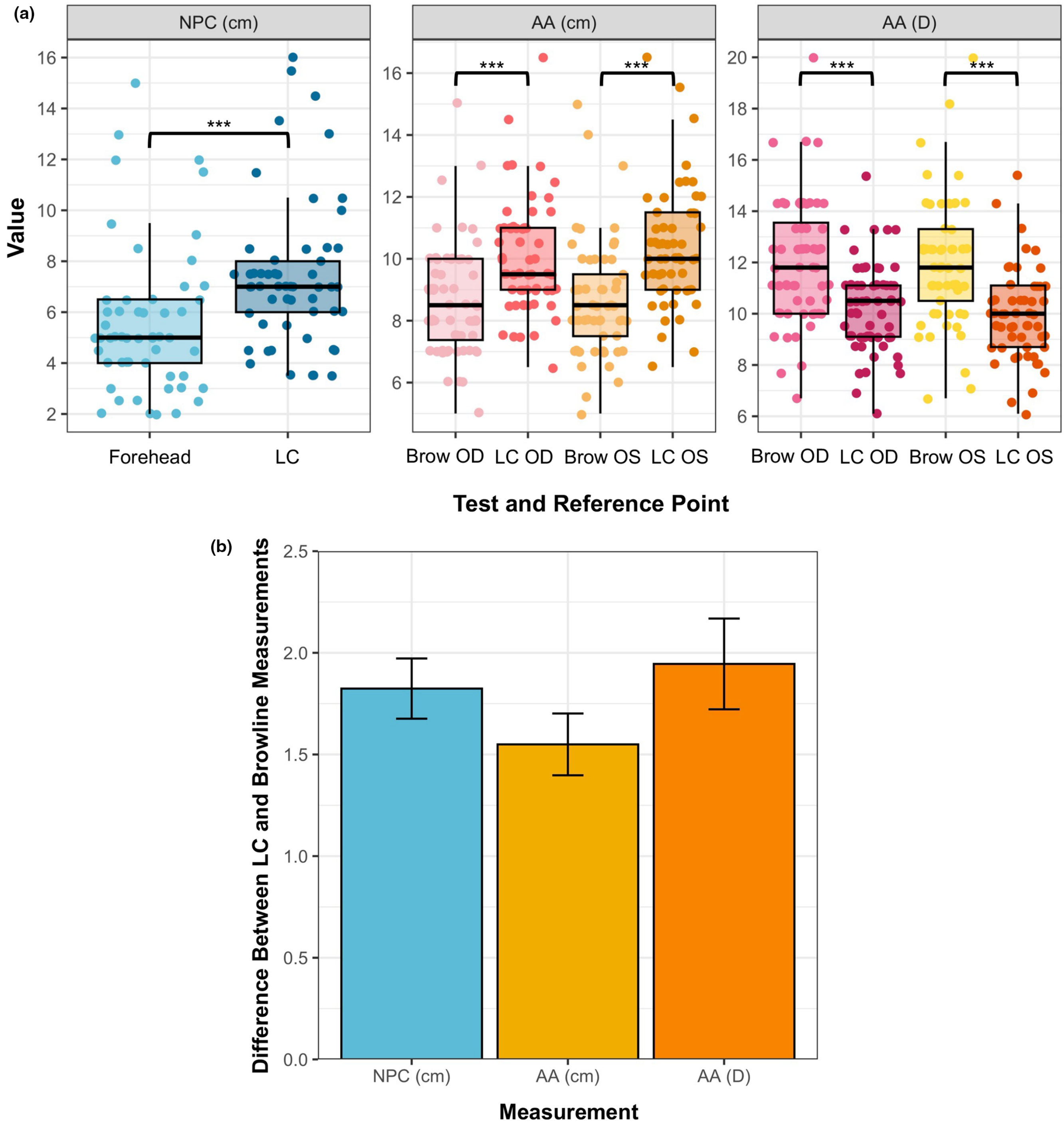

FIGURE 1 (a) Comparison of near point of convergence (NPC) measurements from the middle of the forehead and lateral canthus (LC—cm) and monocular amplitude of accommodation (AA) measures from the browline and lateral canthus (cm and dioptres (D)). Individual measures are displayed as points. Box plots describe the median, 25th and 75th percentiles (the box), with the tails representing all other data. Horizontal brackets represent significant Wilcoxon-Signed Rank differences. OD, right eye; OS, left eye. ***$p < 0.001$. (b) Mean difference between lateral canthus (LC) and forehead or browline measurements for near point of convergence (NPC—cm) and monocular amplitude of accommodation (AA in cm or dioptres (D)), adjusted for inter-eye correlations and repeated measures. Error bars represent 95% confidence intervals.

The objective of this study was not to determine which reference point represents a "better" method of measuring NPC or AA, but rather to quantify the difference between the reference points. These findings support increased reporting of the measurement reference point when describing NPC and AA tests, thus improving data interpretability and comparability across studies. Another application of the findings is to modify the cut-off criteria when measuring from the lateral canthus (i.e., NPC failure ≥8 cm and AA failure < Hofstetter's predicted amplitude – 4 D), although a larger cohort is required to generate this normative data.

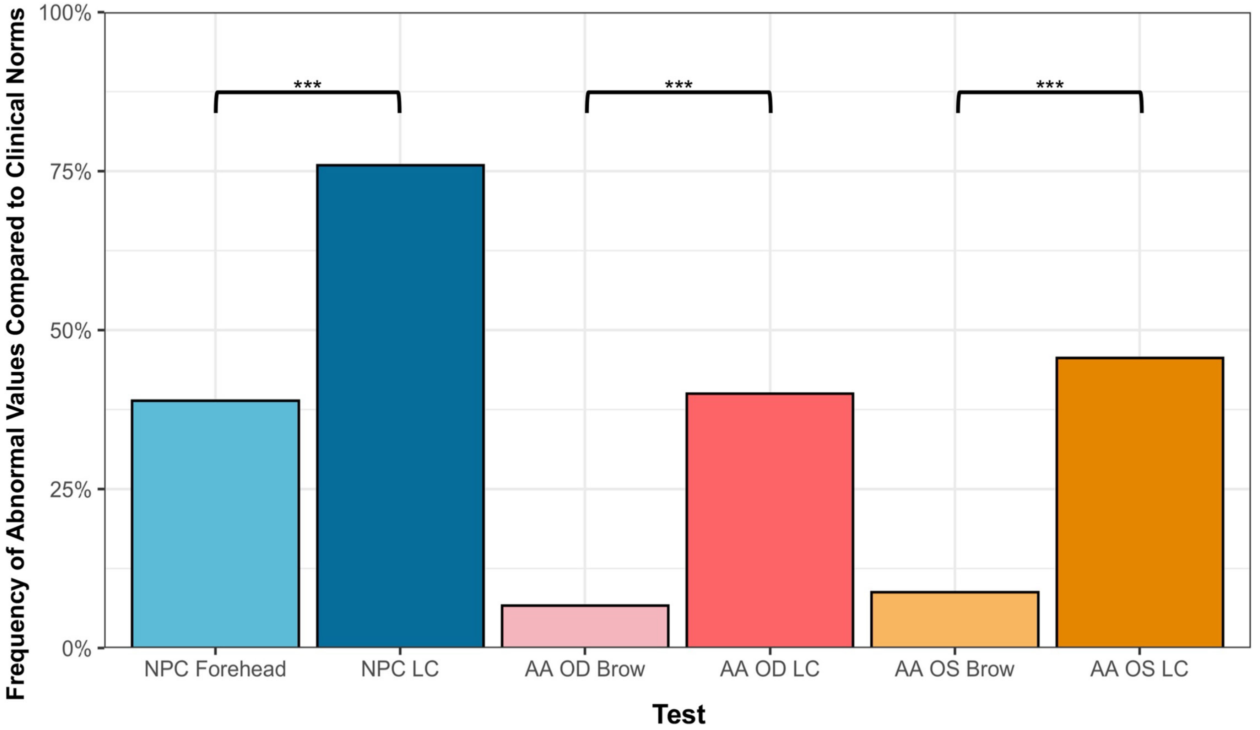

FIGURE 2 Rates of abnormal findings when measurements were compared to clinical norms (≥6 cm for the near point of convergence (NPC) and Hofstetter's minimum formula for monocular amplitude of accommodation (AA)). Brackets represent a significant chi-square difference. LC, lateral canthus; OD, right eye; OS, left eye. ***$p < 0.001$.

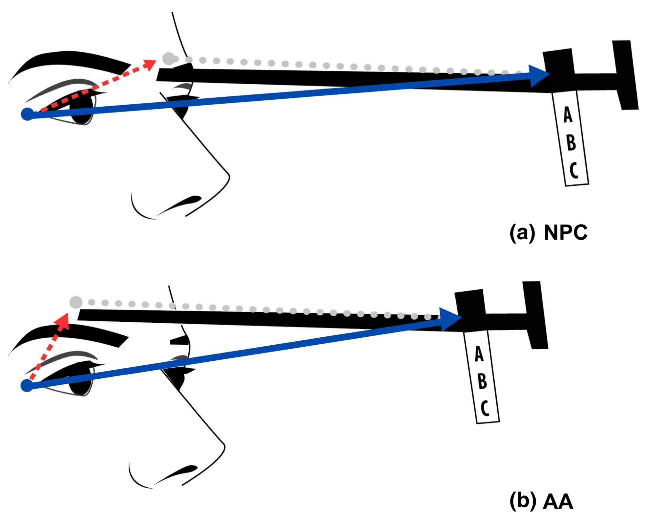

FIGURE 3 (a) The dotted grey arrow represents near point of convergence (NPC) measurements from the forehead, the blue arrow represents NPC measurements from the lateral canthus and the red arrow represents the calculated estimate of "lateral canthus to browline width" (the distance between the reference points). (b) The dotted grey arrow represents amplitude of accommodation (AA) measurements from the browline, the blue arrow represents AA measurements from the lateral canthus and the red arrow represents the calculated estimate of "lateral canthus to browline width" (the distance between the reference points).

A more holistic solution to the difference identified here could be the standardisation of a reference point. As shown in Table 1, NPC is increasingly being utilised outside of optometry clinics and in the setting of sports medicine to screen for and study concussions.[25,28,29] Establishing a universal reference point with corresponding normative data could impact the sensitivity and specificity of this test as a screening tool. Using the forehead and brow as zero points is immediately possible, as the established cut-off criteria were generated using these methods. A second advantage is that these points are similar to the spectacle plane, which is commonly used as a zero point if a patient is wearing an optical correction. However, Wallace et al. suggested that the benefit of using the lateral canthus as a reference point is it that might be less morphologically variable.[30] By generating clinical norms for measurements from the lateral canthus, they may be readily applicable to a more diverse patient population.

AUTHOR CONTRIBUTIONS

Sophia Marusic: Data curation (lead); formal analysis (lead); investigation (supporting); project administration (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **Neerali Vyas:** Data curation (supporting); project administration (supporting); writing – review and editing (supporting). **Carissa H. Wu:** Project administration (supporting); visualization (supporting); writing – review and editing (supporting). **Aparna Raghuram:** Conceptualization (lead); funding acquisition (lead); investigation (lead); methodology (lead); resources (lead); writing – original draft (supporting); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The datasets generated and analysed in this study are not publicly available due to patient privacy considerations.

PATIENT CONSENT STATEMENT

Prior to participating in the study, participants gave their written assent and their parent or guardian gave written informed consent.

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