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Validation of the PowerRef 3 for Measuring Accommodation: Comparison With the Grand Seiko WAM-5500A Autorefractor

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Purpose: This validation study examines the PowerRef 3 as a method for measuring accommodation objectively. We assess agreement with refractive measurements obtained simultaneously by the Grand Seiko WAM-5500A autorefractor.

Methods: Refractive measurements were recorded simultaneously using the PowerRef 3 and WAM-5500A in 32 noncyclopleged participants aged 15 to 46 years. Accommodative states were recorded for 10 seconds at six accommodative demands (5 diopters [D], 4 D, 3 D, 2.5 D, 2 D, and 0 D) while participants fixated a high-contrast Maltese cross. WAM-5500A measurements were converted to power in the vertical meridian for comparison with PowerRef 3 data. Dioptric difference values were computed, and agreement was assessed using Bland-Altman plots with 95% limits of agreement (LOA) and intraclass correlation coefficient analyses.

Results: The mean absolute dioptric differences measured 0.14 D or less across accommodative demands. Analyses showed an excellent intraclass correlation coefficient across the tested demands (0.93). Bland–Altman plots indicated a bias of −0.02 D with 95% LOA of −1.03 D to 0.99 D. The 95% LOA was smallest for the 3 D demand (−0.71 D to 0.64 D), and largest at 5 D demand (−1.51 D to 1.30 D).

Conclusions: The mean dioptric differences between the PowerRef 3 and WAM-5500A autorefractor were small and not clinically significant. While some variability in agreement was observed depending on the tested demand, the PowerRef 3 demonstrated good agreement with the WAM-5500A.

Translational Relevance: The PowerRef 3 may be used to obtain objective measures of accommodation both monocularly and binocularly and provides a more flexible method, especially in pediatric populations.

Introduction

Accommodation is the change in the refractive power of the eye to match the changes in accommodative demand of a target. For instance, when a target demand changes from far (i.e., optical infinity) to near, the eye must increase its refractive power to bring the target of regard into focus. Accurate measures of the accommodative response are critical for the detection, treatment, and management of accommodative disorders and provides insight into clinically significant refractive errors such as myopia,[1,2] moderate or high hyperopia,[3] accommodative esotropia,[4] or presbyopia.[5] In addition, accurate measures of accommodation are required by researchers who study the underlying mechanisms of the accommodative system and need to quantify accommodative responses.[6–11]

Clinical measures of accommodation are often obtained using subjective methods, whereby outcomes are based on either the clinician's judgement (i.e., measure of accommodative accuracy using dynamic retinoscopy[12]) or the patient's report (i.e., measure of accommodative amplitude using the push-up method[11]). In research settings, however, objective measurements of accommodation are usually preferred to avoid potential subjective bias and to increase reproducibility. In recent years, Grand Seiko autorefractors (Rexxam Co. Ltd., Japan) have become the gold standard in obtaining objective measures of static accommodation.[13–15] The Grand Seiko can capture a wide range of refractive states (±22 diopter [D] sphere and ±10 D cylinder in 0.01/0.12/0.25 D steps) with corresponding pupil size (≥2.3 mm),[16] and its binocular open-view design allows for stimulus presentations at any desired distance. The autorefractor can be used in static mode, capturing a refractive state during a single measurement, or dynamic mode, capturing continuous data at 5 Hz[16] or 6 Hz[17] (grandseiko.com). Clinical and research instruments that objectively measure accommodation must be validated to be used as reliable and accurate measuring techniques. Grand Seiko autorefractors have been shown to have excellent agreement with subjective refraction across a wide range of refractive errors under cycloplegic conditions,[15,16,18–21] making the Grand Seiko an excellent instrument to objectively measure the refractive state of the eye in older children and adults. However, given that the Grand Seiko requires individuals to keep still by placing their head in a chin and forehead rest, this method is challenging to use in infants and young children. The instrument housing is also located just centimeters away from the eyes, which is often intimidating to young children. Furthermore, the Grand Seiko autorefractor only obtains refractive measures monocularly and cannot simultaneously track eye position. This factor makes assessing interactions between the accommodative and vergence systems[22] without the use of additional measurement instruments impossible.[23] Researchers are also limited in conducting essential data quality control checks using eye position, such as validating that a participant fixated a given stimulus during recording.

Eccentric photorefraction (hereafter, photorefraction) is an alternative methodology for obtaining objective measures of accommodation.[24] Photorefraction measures the optical defocus of the eye by emitting infrared (IR) light, which reflects from the retina back to the source and thereby creates a luminance gradient profile of the pupil.[24] Although the operating range for refractive measurements and pupil sizes is smaller than those of the Grand Seiko (e.g., −7.00 D to +5.00 D in 0.01 D steps in the vertical meridian, and 3.0 mm to 8.0 mm in 0.1 mm steps, respectively; Plusoptix, Nuremberg, Germany), this range is common for testing accommodation and refractive errors beyond this range are uncommon in infants, children, and adults.[25–28] Commercially available photorefraction instruments are typically positioned at a distant point from the individual (commonly at 1 m) and allow for small head movements.[29] Additionally, binocular measures of eye gaze position can be recorded via Purkinje image tracking,[29,30] making it possible to study accommodation and vergence systems simultaneously.

Previous validation studies of commercially available photorefraction instruments—the first- and second-generation PowerRefractor (Multichannel Systems, Nuremberg, Germany) and PowerRef II (Plusoptix)—consistently found a similar performance in measuring refractive states compared with other autorefractors and subjective refraction.[21,29,31–36] Choi et al.[29] (2000) found comparable refractive measures between the original PowerRefractor and the Nidek AR800 autorefractor, and the PowerRefractor differed from subjective refraction by mean absolute dioptric values of 0.593 D for sphere and 0.399 D for cylinder. Compared with subjective refraction, the PowerRefractor performed better than the Nidek AR800 when measuring the magnitude and axis of astigmatism. However, the performance of the PowerRefractor/PowerRef II has also been found to have variable results when assessing validity during accommodation. Aldaba et al.[21] (2015) found comparable refractive measurements between the PowerRef II and the WAM-5500 autorefractor (Rexxam Co. Ltd., Japan) for accommodative demands of 2.50 D (0.08 ± 0.32 D); however, significant differences in refractive values were identified for 5 D demands (−0.32 ± 0.48 D). Such variability can be expected, given that refractive states are more variable at higher accommodative demands,[37–39] and the measurements in Aldaba et al. (2015) were taken sequentially rather than simultaneously. Other validation studies to date also obtained refractive measures using different instruments one after the other, creating variability in the data not only due to changes in refractive states between measurements (particularly at higher accommodative demands), but also associated position changes of the participant between recordings.

A third-generation PowerRef 3 (Plusoptix) is now available commercially. The PowerRef 3 provides binocular measurements of refractive state (in the vertical meridian), pupil size, and eye position at 50 Hz—the highest sampling rate currently available for commercial photorefraction. Because the PowerRef 3 has not yet been validated as an instrument for accommodative measures, the aim of this study was to investigate the agreement between the PowerRef 3 and the gold standard Grand Seiko WAM-5500A autorefractor by obtaining refractive measurements simultaneously.

Methods

Participants

Participants 13 to less than 50 years were recruited from Akron Children Hospital's faculty and staff, as well as the local community. Participants were included if they were emmetropic or were wearing contact lenses and had normal vision, per report. Participants were excluded from the study if they wore spectacles due to interference with the experimental set-up (see Experimental Set-up). The purpose of the study was to collect a range of accommodative response magnitudes in which to compare the two instruments, thus participants were not evaluated for accommodative abilities prior to enrollment. Although demographic information was not collected, most of the included participants were White. The study was conducted in accordance with the Declaration of Helsinki and was approved by Akron Children Hospital's Institutional Review Board for the protection of human subjects. Adult participants (≥18 years) provided written informed consent before the study. Minors (<18 years) provided assent, and their accompanying caregiver gave written permission for the minor to participate in the study.

Instrumentation

Measures of the refractive state of the eye were obtained simultaneously by the PowerRef 3 and the Grand Seiko WAM-5500 Advanced (WAM-5500A) at various accommodative demands. The PowerRef 3 (Plusoptix) requires the optical path length between the instrument's camera and the participant's eyes to be 1 m (±5 cm). IR light is emitted from the instrument to create a luminance gradient profile in the pupil, which indicates myopic, emmetropic, or hyperopic refractive states of the eye in the vertical meridian.[24] The PowerRef 3 measures the refractive state of the eye in the vertical meridian (refractive range of −7.00 D to +5.00 D in 0.01 D steps), pupil size (3.0 mm to 8.0 mm in 0.1 mm steps), and eye position using Purkinje image eye tracking. The PowerRef 3 records in dynamic (i.e., continuous) mode only, at a sampling rate of 50 Hz. Measures may be obtained either monocularly or binocularly. Detailed methods of eccentric photorefraction are described elsewhere.[24,40]

The WAM-5500A measures refractive states by emitting an IR ring-light and recording the reflection from the retina. Detailed methods describing Grand Seiko autorefraction are found elsewhere.[18] The WAM-5500A can be used in either static or dynamic mode. In static mode, refractive measurements are recorded in terms of sphere (±22 D), cylinder (±10 D), and axis (0° to 180°), with pupil size ranging from 2.3 mm to 8.0 mm (in 0.1 mm steps).[16] In dynamic mode, refractive states are collected in spherical equivalent notation (sphere + $\frac{1}{2}$ cylinder) at a sampling rate of 6 Hz. While the WAM-5500A allows binocular viewing of a stimulus, the measures of refractive state are obtained monocularly.

Because the PowerRef 3 only records in dynamic mode, and the current study aimed to record refractive states from both instruments simultaneously, the PowerRef 3 and WAM-5500A were used in their respective dynamic modes. Given that refractive states from the WAM-5500A are recorded in spherical equivalent when used in dynamic mode, we obtained additional, separate measurements in static mode from the WAM-5500A. This allowed conversion from the spherical equivalent values obtained in dynamic mode to power in the vertical meridian, thereby providing refractive values that could be compared with the PowerRef 3 measurements (see Data Processing for details).

Experimental Set-up

The experimental set-up is visualized in Figure 1. Participants were asked to place their head in the chin and forehead rest of the WAM-5500A and to fixate a high-contrast Maltese cross (2 cm in diameter), which was displayed on an iPod Touch (Apple Inc., Cupertino, CA; 1136 × 640 resolution) using Keynote presentation software (Apple Inc.). Participants viewed the Maltese cross monocularly in primary gaze with their right eye. The left eye was covered using an opaque occluder throughout testing. The iPod was placed on the near-point rod of the WAM-5500A at five discrete near-viewing distances: 20 cm, 25 cm, 33 cm, 40 cm, and 50 cm, corresponding with accommodative demands of 5 D, 4 D, 3 D, 2.5 D, and 2 D, respectively. In a separate condition, participants monocularly viewed a printed star-shaped distance stimulus (14 cm in diameter) with a centered dot to hold fixation (2 cm in diameter) at 3 m.

Simultaneous measures of the refractive state were obtained monocularly in the right eye using the PowerRef 3 and the WAM-5500A. To allow concurrent recordings, a 2 cm × 3 cm 50T/50R beam splitter (i.e., transmits 50% of near-IR light, reflects 50% of near-IR light) was placed between the participant's right eye and the WAM-5500A (approximately 1 cm from the cornea) at a 45° angle in a custom-built holder attached to the forehead rest (Fig. 1). The beam splitter allowed the participant to view the stimulus while passing the

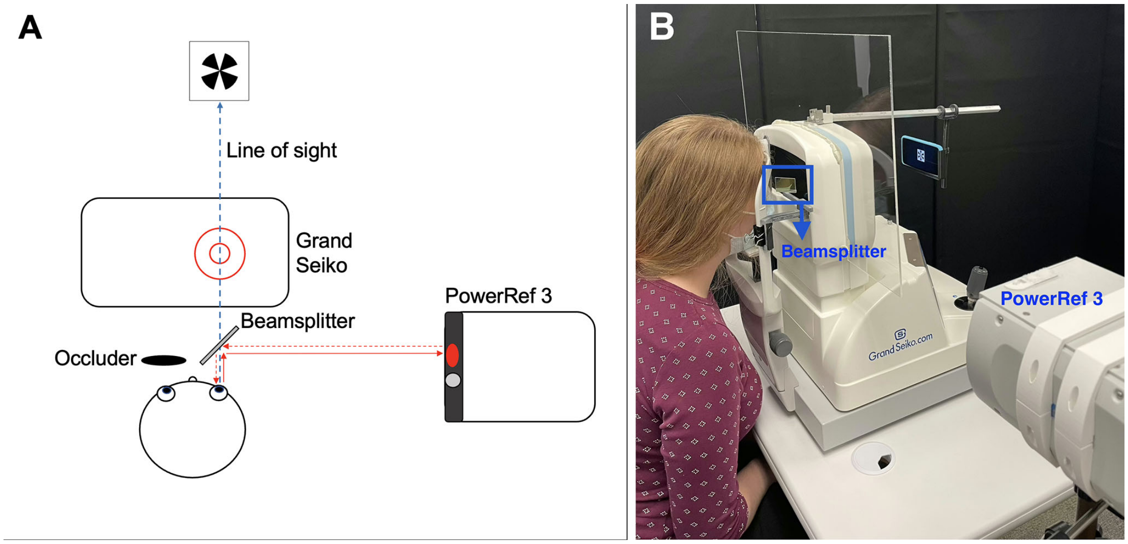

Figure 1. (**A**) Schematic of the instrumentation set-up for simultaneous measures between the PowerRef 3 and WAM-5500A. A beam splitter was placed in front of the participant's right eye at a 45° angle using a custom-built apparatus attached to the WAM-5500A forehead rest. The beam splitter reflected IR light from the PowerRef 3 while allowing the IR light from the WAM-5500A and any visible light to pass through. The PowerRef 3 was located 90° temporally from the participant's right eye such that the optical path length from the PowerRef 3 to the right eye measured 1 m. A Maltese cross stimulus was placed at 20 cm, 25 cm, 33 cm, 40 cm, and 50 cm on the WAM-5500A near-point rod. (**B**) Participant sitting in the experimental set-up.

emitted IR light from the WAM-5500A to the right eye. The PowerRef 3 was positioned 90° to the right of the participant, and the emitted IR light was reflected to the participant's eye via the beam splitter (Fig. 1).

Procedures

After providing written consent and assent, participants completed monocular visual acuity testing both at distance (ATS eETDRS[41]) and at near (ATS4 Near Acuity Test[42]) in their habitual viewing state (i.e., no correction or contact lenses if worn). Participants were required to have visual acuity of 0.1 logarithm of the minimum angle of resolution (logMAR; 20/25 Snellen equivalent) or better in the right eye (i.e., the fixating eye in this study), both at distance and near to further participate in the study. Eligible participants then proceeded with the main experiment involving simultaneous WAM-5500 and PowerRef 3 recordings. The PowerRef 3 was preprogrammed to measure refractive states for 10 seconds, starting from the moment when the examiner (TLR) manually initiated recording via mouse-click. The WAM-5500A was used in dynamic mode and manually started and stopped via the autorefractor's control button by the same experienced examiner (TLR). Data from the PowerRef 3 and WAM-5500A were collected simultaneously by the examiner pressing the control buttons of each instrument at the same time (the PowerRef 3 was started using the examiners right index finger and the WAM-5500-A was started using the examiner's left index finger). If the examiner experienced proprioceptive feedback that the two instruments were not started at the same time, the trial was discarded and another trial was obtained. Once the measurement began, the examiner monitored the PowerRef 3 display screen until the 10-second recording automatically stopped, at which point the examiner stopped the WAM-5500A recording. The offset between the recording stops of the PowerRef 3 and the WAM-5500A was less than 1 second. The accommodative response at each stimulus distance (5 D, 4 D, 3 D, 2.5 D, 2 D, and 0 D) was measured once. Each measurement recorded accommodative responses simultaneously from the PowerRef 3 and WAM-5500A for 10 seconds. The testing order of accommodative demands was randomized across participants.

Separately, each participant also underwent an individual lens calibration[22,35,40] of the right eye (plano to +4 D in 1 D steps[9]) using the PowerRef 3 to obtain more accurate accommodative measurements. The lens calibration was conducted in a separate experimental set-up to allow binocular recordings using only the PowerRef 3, whereby the eye being calibrated was covered by an opaque IR filter (Kodak 89B Wratten) while the participant's fellow eye fixated a distance letter at 3 m.[9] Calibration data was collected for 10 seconds at each lens power.

Data Processing

Data processing involved three steps: filtering, calibrating, and data transformation to allow direct comparisons of refractive measurements from the PowerRef 3 and WAM-5500A. Data from the PowerRef 3 were filtered offline to remove measurements known to be outside the working range of the PowerRef 3 or physiologically unlikely. Specifically, data were removed if refractive values were less than −6.00 D or greater than +4.00 D,[29] the pupil size was less than 4 mm[29] or greater than 8 mm, and gaze position was outside ±10° horizontal or ±5° vertical to eliminate erroneous measures from peripheral refraction[43] and as recommended by the manufacturer for the first-generation PowerRefractor. In addition, values were removed if the change in refractive measures between two consecutive data points was more than 10 D/s[44] to account for fluctuations secondary to blinks. To allow for comparisons between the two instruments, data from the WAM-5500A were filtered offline using the same criteria as for the PowerRef 3, with the exception of pupil size because the WAM-5500A does not consistently provide pupil size in the dynamic mode. Additionally, one data point before and after a period of missing data were removed from the WAM-5500A measurements to avoid contamination by blinks.

Next, lens calibration was applied to the filtered PowerRef 3 data. Specifically, the anisometropic difference in refractive measures of each eye was calculated for each trial lens power (plano to +4 D in 1 D steps). The resulting linear (line) function was generated, and applied to the refractive measurements from the PowerRef 3.[40]

The PowerRef 3 outputs refractive states in the vertical meridian, whereas the WAM-5500A autorefractor outputs values as spherical equivalent when used in dynamic mode. To allow data comparisons between the two instruments, spherical equivalent values from the WAM-5500A were transformed to represent the power in the vertical meridian. Such transformations require measures of sphere, cylinder, and axis, which can be obtained by the WAM-5500A when used in static mode. Thus, five additional static measures were therefore collected at each accommodative demand (5 D, 4 D, 3 D, 2.5 D, 2 D, and 0 D), converted to power vectors to obtain mean spherical equivalent, J_0, and J_{45} values, and back-transformed to spherocylindrical notation.[45] Separately for each accommodative demand, the mean cylinder power obtained from the static recording and the known spherical equivalent collected in dynamic mode during the main experiment were substituted into Equation 1 to calculate the sphere power.

$$Spherical\ equivalent = Sphere + \frac{1}{2}Cylinder. \qquad (1)$$

The resulting sphere power (*sphere*), along with the mean static cylinder power (*cylinder*) and the mean static axis value (α), were then substituted into Equation 2 to calculate power in the vertical meridian. Equation 2 states 90 degrees to represent the desired vertical meridian.

$$\begin{aligned} &Power\ in\ vertical\ meridian \\ &= Sphere + Cylinder * sin^2(90 - \alpha) \qquad (2) \end{aligned}$$

Data Analysis

The refractive measures in the vertical meridian (from the PowerRef 3 readings, and the converted WAM-5500A readings; see *Data Processing*) were averaged across the 10-second trial period for each instrument at each accommodative demand. The difference in values between the two instruments were then calculated at each demand by subtracting the mean refractive measurement of the PowerRef 3 from the mean refractive measurement of the WAM-5500A. Difference values close to zero would suggest closer agreement between the two instruments, whereas values larger or smaller than zero would indicate that the WAM-5500A recorded larger or smaller refractive states, respectively, than the PowerRef 3.

To assess the agreement between the PowerRef 3 and WAM-5500A and examine any bias in measurements, Bland-Altman plots were generated along with the 95% limits of agreement (LOA). In addition, intraclass correlation coefficients (ICCs) were computed based on a two-way mixed-effects model to assess absolute agreement, with coefficients classified as moderate (0.50–0.75), good (0.75–0.90), or excellent (>0.90).[46] To determine whether any detected bias was constant or changes with the magnitude of refractive states, additional linear regressions were conducted separately for each accommodative demand as well as for all accommodative demands combined. Data analysis was performed using R (Version 4.1.2; R Core Team, Vienna, Austria).

Results

Thirty-two participants (26 female, 6 male) aged 15 to 46 years (median, 22 years; interquartile range, 10 years) took part in the study. Thirty

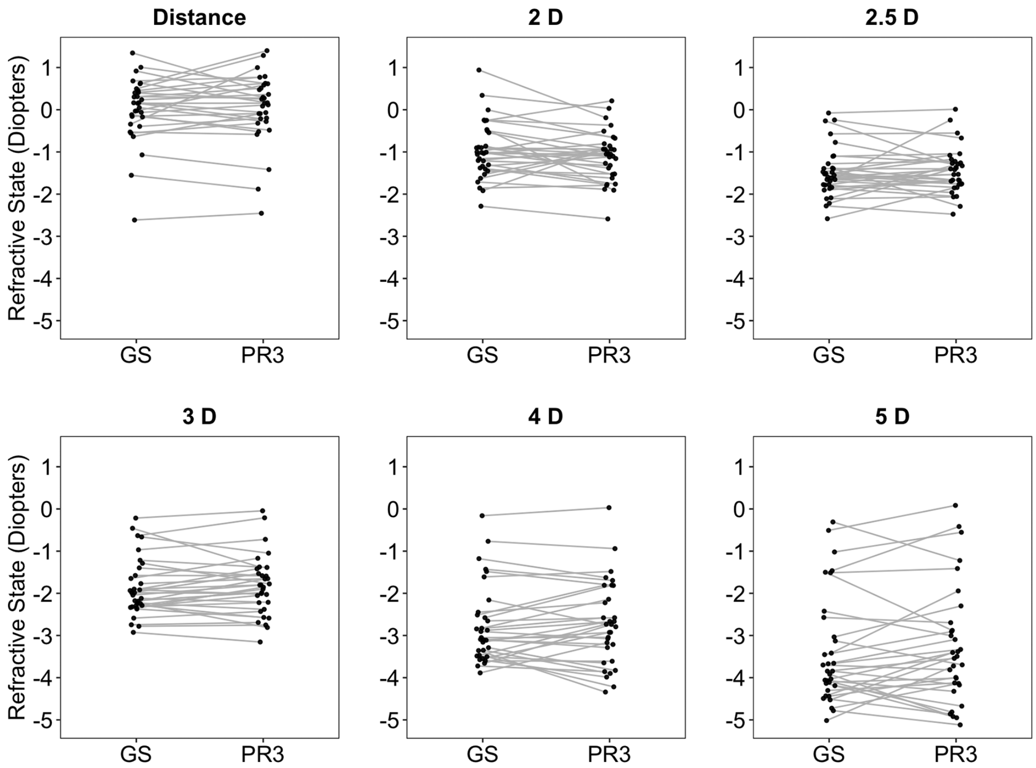

Figure 2. Mean refractive states at each accommodative demand measured by the Grand Seiko WAM-5500A (GS) and PowerRef 3 (PR3). Connecting lines indicate paired measurement samples.

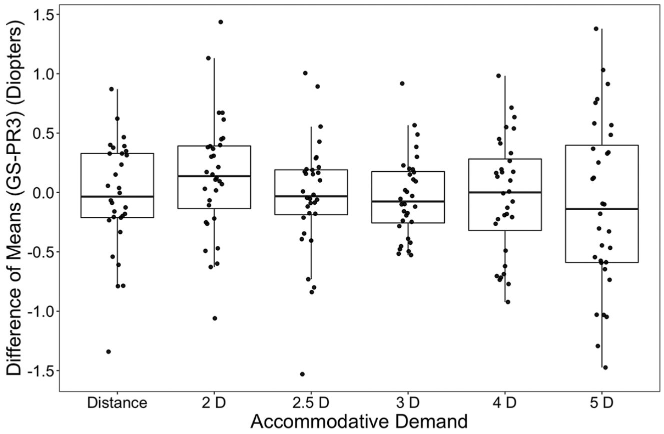

Figure 3. Differences in mean refractive states for each accommodative demand, whereby measures from the PowerRef 3 (PR3) are subtracted from those obtained by the Grand Seiko (GS) WAM-5500A.

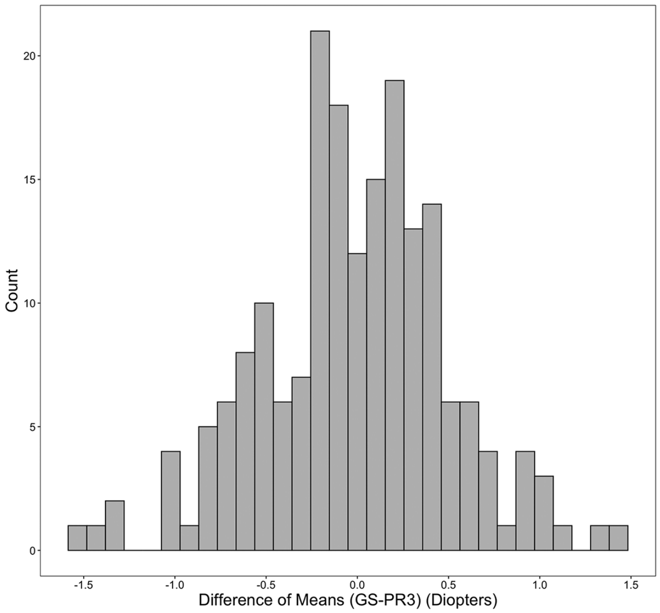

Figure 4. Frequency distribution of the differences in means across all accommodative demands.

participants provided data for all six conditions (accommodative demands), and two individuals completed five conditions. Refractive measurements from the PowerRef 3 and the WAM-5500A are visualized in Figure 2 at each accommodative demand. Figures 3 and 4 further show the distribution of the differences in mean refractive states to visualize descriptively the agreement between the two instruments.

Table 1. Statistical Values for Comparisons of Refractive Measurements Between the WAM-5500A and PowerRef 3

	Mean Difference in D (SD)	ICC (95% CI)	95% LOA (Lower, Upper)
Distance	−0.03 (0.47)	0.84 (0.69–0.92)	(−0.95, 0.89)
2 D	0.14 (0.50)	0.68 (0.44–0.83)	(−0.85, 1.13)
2.5 D	−0.04 (0.49)	0.63 (0.36–0.80)	(−1.00, 0.92)
3 D	−0.04 (0.34)	0.88 (0.77–0.94)	(−0.71, 0.64)
4 D	−0.03 (0.49)	0.87 (0.76–0.94)	(−1.00, 0.93)
5 D	−0.11 (0.72)	0.86 (0.73–0.93)	(−1.51, 1.30)
All demands	−0.02 (0.51)	0.93 (0.91–0.95)	(−1.03, 0.99)

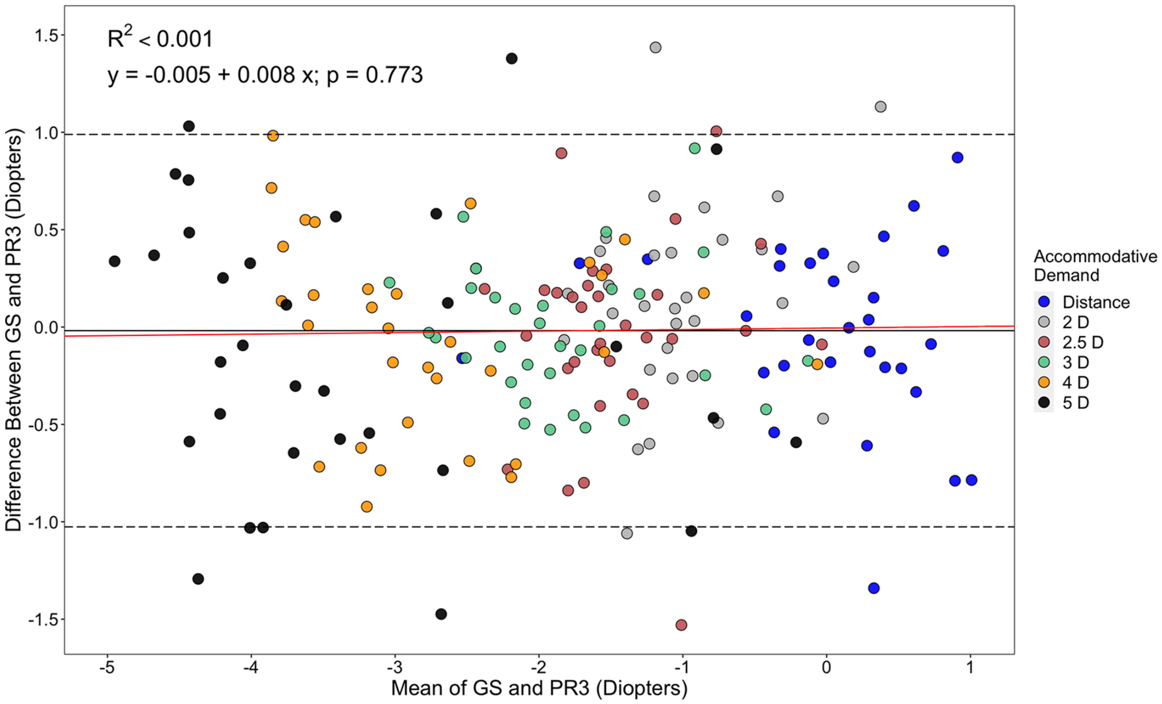

Figure 5. Bland–Altman plot for each accommodative demand. Dashed lines represent the 95% LOA across accommodative demands, and the black solid line represents the overall bias (−0.02). Red line indicates linear regression using points from all accommodative demands.

For each accommodative demand, the differences in refractive measurements were also averaged across participants, with the descriptive statistics summarized in Table 1. The differences were normally distributed, with mean absolute differences measuring 0.14 D or less across all accommodative demands, and 0.04 D or less for four of six conditions (i.e., 2.5 D, 3 D, 4 D, and 0 D) (Table 1).

ICC analyses showed moderate to good agreement (range, 0.63–0.88) between the PowerRef 3 and WAM-5500A (see Table 1 for ICC values) for each individual demand and excellent ICC when collapsing across all accommodative demands (0.93). The agreement between the PowerRef 3 and WAM-5500A is shown using Bland–Altman plots collapsed across accommodative demands (Fig. 5) and separately for each demand (Fig. 6). No bias for one instrument to measure a greater response than the other was found across the range of accommodative responses (−0.02 D). The lower and upper 95% LOAs were 1.00 D or less for four of six accommodative demands (see Table 1). The 95% LOA was smallest for the 3 D demand (95% LOA of −0.71 D to 0.64 D), and largest for the 5 D demand (95% LOA of −1.51 D to 1.30 D). Collapsed across accommodative demands, the 95% LOA was roughly within ±1.00 D (95% LOA of −1.03 D to 0.99 D).

The Bland–Altman plot (Fig. 5) indicated that the difference in refractive measurements obtained by the WAM-5500A versus the PowerRef 3 did not

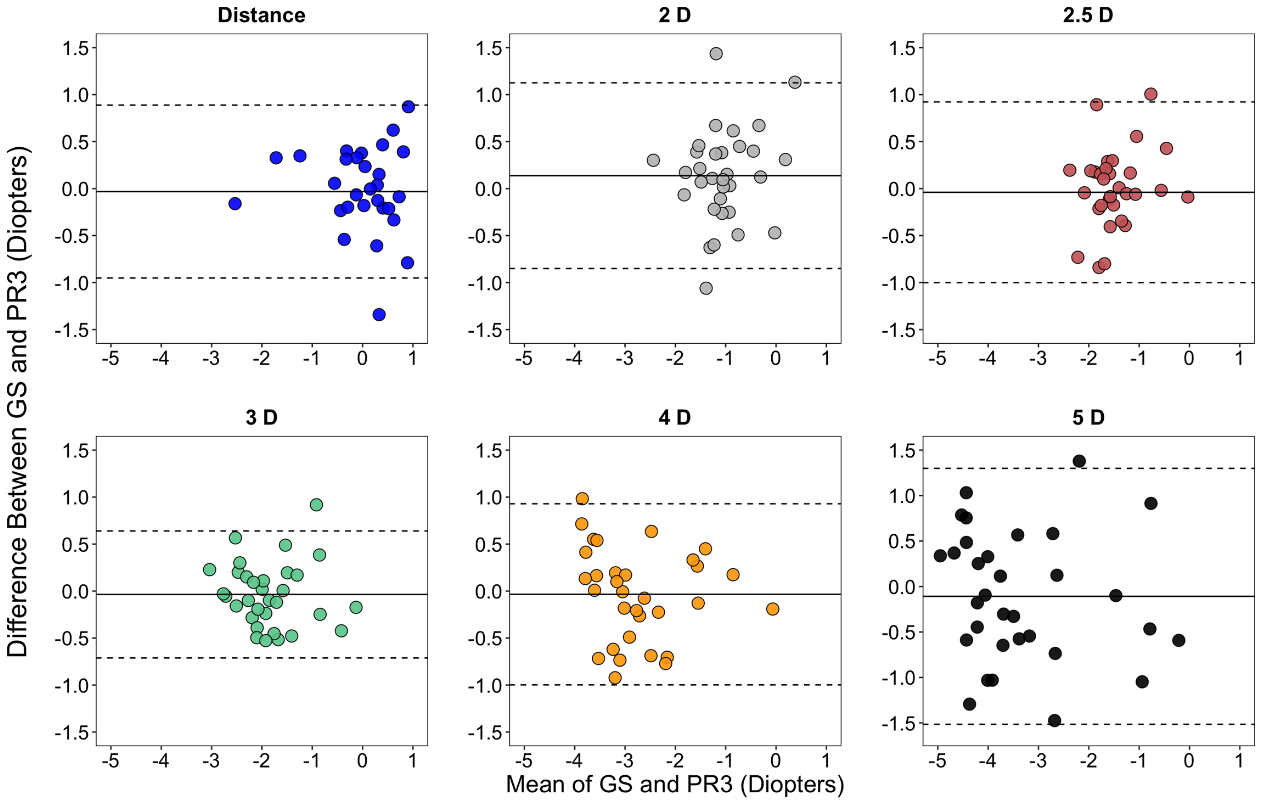

Figure 6. Bland–Altman plots separately for each accommodative demand. Dashed lines represent the 95% LOA, the black solid line represents the bias.

differ systematically across accommodative demands. Additional linear regression analyses were performed at each demand as well as collapsed all to determine if the differences between the two instruments were associated with the magnitude of accommodation (here, the mean refractive measurement of the WAM-5500A and PowerRef 3). A significant linear relationship was not observed for any accommodative demand

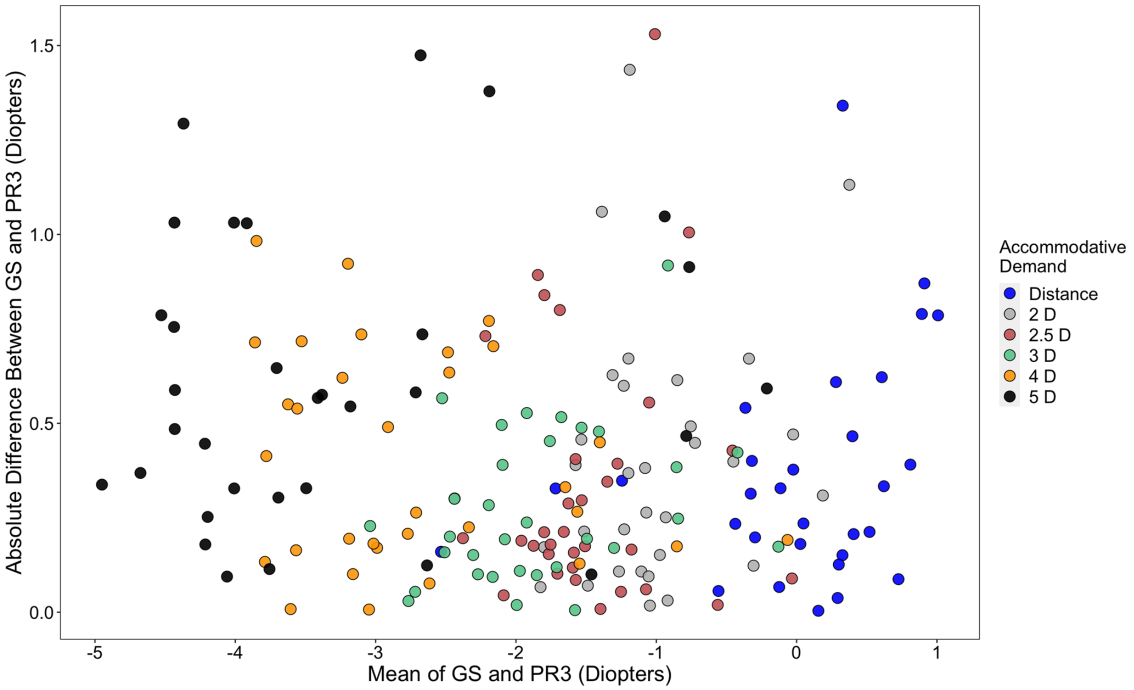

Figure 7. Bland–Altman plot using absolute difference values.

(5 D: $R^2 = 0.015$, $P = 0.498$; 4 D: $R^2 = 0.020$, $P = 0.439$; 3 D: $R^2 = 0.001$, $P = 0.777$; 2.5 D: $R^2 = 0.010$, $P = 0.588$; 2 D: $R^2 = 0.031$, $P = 0.332$; distance: $R^2 = 0.017$, $P = 0.491$), nor when collapsing all ($R^2 = 0.001$, $P = 0.773$) (see Figure 5).

Given that a distribution of difference values symmetrical about zero could mask any linear relationships with magnitude of accommodation, additional linear regression analyses using absolute difference values were performed (see Fig. 7). Regression analyses did not reveal any significant relationships between absolute differences and the mean of refractive measurements for any accommodative demand (5 D: $R^2 = 0.021$, $P = 0.424$; 4 D: $R^2 = 0.049$, $P = 0.224$; 3 D: $R^2 = 0.091$, $P = 0.093$; 2.5 D: $R^2 = 0.003$, $P = 0.764$; 2 D: $R^2 = 0.052$, $P = 0.208$; distance: $R^2 = 0.097$, $P = 0.095$), nor across all demands ($R^2 = 0.008$, $P = 0.227$).

Discussion

The current study examined agreement of accommodative measurements obtained by the Grand Seiko WAM-5500A and the PowerRef 3 in individuals aged 15 to 46 years. Our results demonstrate good agreement for accommodative demands 0 D to 5 D when using the methods presented in the current study. The largest mean (absolute) differences between the WAM-5500A and PowerRef 3 were observed for the 2 D (0.14 D) and 5 D (−0.11 D) demands; the remaining accommodative demands resulted in difference values close to zero, validating accommodative measurements obtained by the PowerRef 3. Although the PowerRef 3 overall measured slightly more myopic than the WAM-5500A (difference of −0.02 D), the magnitude of this bias is negligible and not clinically meaningful. Bland–Altman plots and ICC analyses confirmed agreement between the two instruments. The 95% LOA for all demands combined further demonstrated limits within an acceptable range of approximately ±1 D, accompanied by excellent agreement between instruments based on ICC analyses (ICC = 0.93).

The differences in refractive measurement between the WAM-5500A and PowerRef 3 are comparable to or even smaller than the differences reported in previous studies comparing the WAM-5500A (or older Grand Seiko autorefractors) to other acceptable measures of refractive states of the eye, including dynamic retinoscopy or subjective refraction (see Table 2). McClelland and Saunders[12] (2003) compared the Grand Seiko SRW-5000 autorefractor with dynamic retinoscopy and found a mean spherical equivalent difference of 0.06 D (*SD* = 0.51 D) at a 4 D accommodative demand, which is comparable with the present mean difference (vertical meridian) of −0.03 D (*SD* = 0.49 D). Antona et al.[47] (2009) compared the Grand Seiko SRW-5000 autorefractor with both the Nott and monocular estimate method retinoscopy methods and found mean differences of −0.13 D (*SD* = 0.50 D) and −0.31 D (*SD* = 0.50 D), respectively, for a 2.5 D demand. In addition to dynamic retinoscopy, accommodative measures obtained using Grand Seiko autorefractors have also been compared with subjective refraction. Choong et al.[48] (2006), for instance, compared the Grand Seiko WR-5100K with subjective refraction and identified a mean difference of −0.2 D (*SD* = 0.51 D) for distant targets, along with a 95% LOA of −1.2 D to 0.8 D. Our findings are consistent with a mean difference of −0.03 D (*SD* = 0.47 D) and a 95% LOA of −0.95 D to 0.89 D, and suggest better agreement between the WAM-5500A when comparing to the PowerRef 3. Altogether, the PowerRef 3 showed comparable performance to accepted methods of accommodative measurement when using a Grand Seiko autorefractor as a reference method.

To our knowledge, only two studies compared refractive measurements from a Grand Seiko autorefractor with those obtained using photorefraction in noncyclopleged participants. Hunt et al.[34] (2003) collected accommodative measures in 150 adults aged 18 to 37 years using both the SRW-5000 autorefractor and the first-generation PowerRefractor and identified a mean spherical equivalent difference of −0.20 D (*SD* = 0.72 D) for distant targets. Although this represents a much larger dioptric difference compared with the present findings (−0.03 D at distance), it should be noted that participants in Hunt et al. (2003) were measured on each instrument sequentially rather than simultaneously, introducing the potential for higher variability. Given that refractive measurements using photorefraction are often obtained when the eye is in an accommodative state, studies employing various accommodative demands are of relevance when validating instruments. Only one study compared refractive measures from the Grand Seiko autorefractor to photorefraction when participants' eyes were in an accommodative state. Aldaba et al.[21] (2015) compared the WAM-5500 with the PowerRef II and found a mean difference of 0.08 D (*SD* = 0.32 D; 95% LOA of −0.55 D to 0.71 D) for a 2.5 D demand, and a mean difference of −0.32 D (*SD* = 0.48 D; 95% LOA of −1.26 D to 0.62 D) for a 5 D demand. Although the mean difference at 2.5 D is comparable with the present findings (−0.04 D), Aldaba et al. (2015) obtained a greater (absolute) difference for the higher 5 D demand than in the current study (−0.11 D). Nonetheless, the greater discrepancy between the two instruments in Aldaba et al. (2015) could partly be accounted by the sequential data collection, which may have a greater effect on measurement variability at higher accommodative demands, 'as greater demands have been shown to have greater variability.'[49] With respect to the 95% LOA, Aldaba et al. (2015) obtained smaller limit ranges for both the 2.5 D and 5 D demands compared with the current findings. Several reasons could explain the larger limit ranges found in the present study; for example, our participant pool may have had greater variability in refractive errors, which could potentially affect measurement accuracy depending on the instrument used (further details are provided elsewhere in this article). Another source of variability could be due to the required conversion from refractive measurement in spherical equivalent to vertical meridian for the present WAM-5500A data using additional, static autorefractor measurements (see Data Processing). The conversion method assumed that cylinder power and axis collected during static WAM-5500A measurements remained constant for dynamic recording (see Equations 1 and 2),[50] and static measures were collected at each tested accommodative demand to determine cylinder power and axis with greater accuracy. Aldaba et al. (2015) did not report how conversions were applied (comparisons were conducted using spherical equivalent), but it nevertheless raises the possibility that the present conversion approach may have introduced additional variability.

Although the PowerRef 3 demonstrated good agreement with the WAM-5500A, the 5 D accommodative demand showed much greater variability in agreement (95% LOA of −1.51 D to 1.30 D) (see also Figs. 2 and 3). Because refractive states in this study were collected simultaneously, this cannot be explained by any accommodative changes between measurements. However, greater variability in agreement at high accommodative demands is not specific to comparisons with the PowerRef 3. McClelland and Saunders (2003) tested individuals at 4 D, 6 D, and 10 D demands using both the Grand Seiko SRW-5000 autorefractor and dynamic retinoscopy and found increasingly greater discrepancies and variability in refractive measurements at higher accommodative demands (mean spherical equivalent differences of 0.06 D, 0.15 D, and 0.17 D, for 4 D, 6 D, and 10 D demands, respectively) (see Table 2). Aboumourad and Anderson[55] (2019) also compared refractive measurements from the WAM-5500 against dynamic retinoscopy at various accommodative demands between 2.5 D and 30 D and obtained a wide limit range (95% LOA of −1.87 D to 1.92 D), likely owing to the inclusion of several high demands. The greater variability in agreement at the 5 D demand in the current study is therefore consistent with previous studies comparing a Grand Seiko autorefractor at high demands to another clinically accepted measurement method of accommodation.

The current study suggests that the PowerRef 3 may serve as an appropriate method to measure refractive states within the demands tested. Our study included older children and adults as participants, who can provide the high-quality data that facilitates the interpretation of validation studies. Given the suitability of the PowerRef 3 for use in infants and young children, future work should nevertheless also examine instrument performance in younger populations. This is especially important since the PowerRef 3 is limited by pupil size and infants can present with smaller pupils than older children and adults.[51] Smaller pupil sizes can indicate a larger depth of focus,[52] which in turn could impact refractive measurements and agreement between instruments. However, this impact of depth of focus typically diminishes for pupil sizes greater than 4 mm.[52] Because the data points included for analysis from the PowerRef 3 were associated with pupil sizes of greater than 4 mm, it is unlikely that the present findings on agreement between instruments were affected. However, because the PowerRef 3 requires a pupil size of greater than 4 mm, a practical challenge may remain when using the instrument in individuals with smaller pupils. An additional limitation in the generalizability of the current study findings relates to the range of variables that potentially impact measurement accuracy between instruments, for example, refractive error, participant group, the instrument's refraction range, or participants' aberrations. The PowerRefractor was previously found to be less precise in measuring refractive error for individuals with high hyperopia,[36] and the PowerRef II showed less accuracy in detecting significant hyperopia.[53] This difference could have resulted from individuals accommodating through their hyperopia during measurements because they were not cyclopleged, making the use of the PowerRef 3 and its predecessors potentially less accurate as a screening tool for detecting hyperopic refractive error. Participants in the current study were required to have a (corrected) visual acuity of 0.1 logMAR (20/25 Snellen equivalent), but refractive error was not obtained, and future investigations should examine the influence of refractive error on agreement. Last, most participants in the present study were White; future validation studies are, therefore, required to examine whether current findings are generalizable to individuals from different racial or ethnic backgrounds with varying retinal pigmentation, which can affect the reflection of IR light from the retina.[54]

Table 2. Papers Comparing a Grand Seiko Autorefractor to Acceptable Methods Measuring Accommodation (Subjective Refraction and Dynamic Retinoscopy)

Study (Authors, Year)	Participant Group	Methods of Measurement	Demand	Mean Refractive Error (Range)	Mean Dioptric Difference (SD)	LOA (in D)	Cyclo
Aldaba et al. (2015)[21]	30 adults (20–32 years)	WAM-5500 vs subjective refraction	Distance	Subjective refraction: −1.15 (−6.00 to +1.00)	SE: 0.07 (0.21)	SE: (−0.34, 0.48)	No
Sheppard & Davies (2010)[16]	75 adults (18–69 years; mean, 25 ± 9 years)	WAM-5500 vs subjective refraction	Distance	Subjective refraction: −1.25 (−6.38 to +4.88)	SE: −0.01 (0.38) SC: 0.04 (0.41)	SE: (−0.75, 0.73)[a] SC: (−0.76, 0.84)[a]	No
Cleary et al. (2009)[19]	50 adults (18–68 years; mean, 35 years)	WR-5100K vs subjective refraction	Distance[b]	Subjective refraction: −0.49 (−6.25 to +3.625)	SE: 0.03 (0.55) SC: 0.004 (0.56)	SE: (−1.05, 1.12) SC: (−1.08, 1.09)	No
Choong et al. (2006)[48]	117 children (7–12 years)	WR-5100K vs subjective refraction	Distance	WR-5100K Non-cyclo: −0.79 (SD = 2.4) Cyclo: −0.44 (SD = 2.48) Subjective refraction Non-cyclo: −0.62 (SD = 2.51) Cyclo: −0.37 (SD = 2.61)	SE (non-cyclo): −0.2 (0.51); SE (cyclo): −0.1 (0.59)	SE (non-cyclo): (−1.2, 0.8); SE (cyclo): (−1.2, 1.1)	Both[c]
Mallen et al. (2001)[13]	100 adults (18–58 years; mean, 24 ± 8 years)	SRW-5000 vs subjective refraction	Distance	Subjective refraction: −1.60 (−15.00 to +6.50)	SE: 0.16 (0.44) SC: 0.15 (0.46)	SE: (−0.70, 1.02)[a] SC: (−0.75, 1.05)[a]	No
Davies et al. (2003)[18]	99 adults (18–60 years; mean, 23 ± 7 years)	WR-5100K vs subjective refraction	Distance	Subjective refraction: −1.71 (−8.25 to +7.25)	SE: 0.14 (0.35) SC: 0.18 (0.35)	SE: (−0.55, 0.83)[a] SC: (−0.51, 0.87)[a]	No
Antona et al. (2009)[47]	61 adults (18–32 years)	SRW-5000 vs Nott retinoscopy SRW-5000 vs monocular estimate method retinoscopy	2.5 D 2.5 D	N/A	SE: −0.13 (0.50) SE: −0.31 (0.50)	SE: (−0.89, 0.73) SE: (−1.29, 0.67)	No
Aboumourad & Anderson (2019)[55]	95 individuals (5–60 years; mean, 32 ± 16 years)	WAM-5100 vs dynamic retinoscopy	Amplitude of accommodation (2.5–30.0 D)	N/A	SE: 0.02 (0.97)	SE: (−1.87, 1.92)	No
McClelland & Saunders (2003)[12]	36/38 individuals (6–43 years; mean, 24 ± 10 years)	SRW-5000 vs dynamic retinoscopy	4 D 6 D 10 D	Sphere: −6.88 to +2.75	SE: 0.06 (0.51) SE: 0.15 (0.58) SE: 0.17 (0.79)	SE: (−0.94, 1.06)[a] SE: (−0.99, 1.29)[a] SE: (−1.38, 1.72)[a]	No
Kuo et al. (2020)[56]	308 children (6–17 years)	WR-5100K vs Retinoscopy	Distance	Cycloplegic Retinoscopy: Right eye: −1.23 (SD = 1.98) Left eye: −1.08 (SD = 2.02)	SE (non-cyclo): 0.05 (0.31); SE (cyclo): 0.29 (0.39)	SE (non-cyclo): (−0.56, 0.66)[a]; SE (cyclo): (−0.47, 1.05)[a]	Both[c]

SD, standard deviation; Cyclo, whether cycloplegic (vs noncycloplegic) refraction was performed.

The mean refractive error and mean dioptric differences represent mean spherical equivalent (SE) or mean spherical component (SC).

[a] Calculated using reported mean dioptric difference and corresponding standard deviation.

[b] Subjective refraction performed at 6 meters, WR-5100K measures obtained using a +5 D Badal lens system to simulate infinite distance target.

[c] Measured both before and after cycloplegia.

In conclusion, the observed measurement differences between the instruments in this study were small, on average, across the tested accommodative demands. We conclude that the PowerRef 3 demonstrated good agreement with the Grand Seiko WAM-5500A autorefractor and represents an appropriate instrument to measure accommodative states objectively.

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