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## Comparing Autorefractors for Measurement of Accommodation
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| Abstract: | Purpose:<br>To compare the static and dynamic accommodative responses measured with the WAM-5500 and the PowerRef-11 autorefractors.<br><br>Methods:<br>The dynamic and static monocular accommodative responses were measured with the WAM-5500 and the PowerRef-11 instruments in thirty pre-presbyopic patients (23.66 ± 3.19 years). The spherical equivalent was measured at 0.00, 2.50 and 5.00 diopters (D) of accommodative stimulation for the static measurements. The subjective refraction was also determined. Dynamic accommodation was measured for abrupt changes of stimulus vergence of 2.00D. Mean and peak velocities of accommodation and disaccommodation were evaluated. For the PowerRef-11, dynamic measurements were calculated for sampling frequencies of 5 and 25 Hz.<br><br>Results:<br>For far distance static results, the differences between subjective and WAM-5500 measurements were of 0.07 ± 0.21D (p = 0.093) and between the subjective and the PowerRef-11 were of 0.70 ± 0.47D (p = 0.001). The difference in the response measured with both instruments was of 0.08 ± 0.32D (p = 0.194) for 2.50D and -0.32 ± 0.48D (p = 0.001) for 5.00D of stimulation. For the dynamic mode, the PowerRef-11 at 25 Hz measured faster mean and peak velocities of accommodation and disaccommodation than the WAM-5500, with statisically significant (p<0.05) differences of 0.68 ± 1.01, 0.67 ± 0.98, 1.26 ± 1.19 and 1.42 ± 1.53D/s, respectively. With a sampling frequency of 5 Hz for the PowerRef-11, these differences, statisically significant (p<0.05), were reduced to 0.52 ± 0.90, 0.49 ± 0.91, 0.83 ± 1.07 and 0.83 ± 1.31D/s, respectively. |

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| | Conclusions:<br>There is good agreement between subjective refraction and WAM-5500 measurements. 1n contrast, the PowerRef-11 produced more hyperopic results. There were no differences among instruments at 2.50D of static stimulation; however, differences were found at 5.00D. 1n the dynamic measurements, the PowerRef-11 measured faster velocities, partly due to the difference in the sampling frequency. |

Accommodation, defined as the dioptric change of the crystalline lens of the eye,[1] enables people to obtain clear images at different distances. Presbyopia, the progressive loss of amplitude of accommodation with age,[2] has been widely investigated since it eventually affects the whole population. Accommodation measurements can be indicative of different diseases affecting the accommodative system[3] and also the binocular vision.[4] Additionally, in the past few years there has been an increasing interest in restoration of accommodation,[5] i. e., the techniques that increase accommodative ability in people with presbyopia by means of intraocular lenses and surgical treatments. To quantify the real effect of these techniques, precise measurements of the accomodation are necessary.

The measurements of accommodation can be divided into static and dynamic. In static measurements accommodation is measured under different stimulus conditions. The most commonly used static measurement is amplitude of accommodation, where total/maximal accommodation is evaluated. Other static measurements are the accommodative-stimulus response curve and lag of accommodation. In all these cases, the basis of the measurement is the degree of accommodation under specific conditions. In dynamic measurements, the accommodative response is evaluated through time. Although in clinical practice they are less common than static measurements, dynamic measurements such as accommodative flexibility are widely used. Other dynamic measurements such as accommodative velocity, latency and response time are currently laboratory based and still not typically applied to clinical work.

Static and dynamic accommodation can be measured with subjective and objective techniques. Subjective techniques have a tendency to overestimate the accommodative response.[6] To circumvent the dependence on the participant's response, objective measurements such as retinoscopy,[7] autorefraction,[8] aberrometry[8] and double-pass systems[9] are being increasingly used.

Dynamic retinoscopy is the objective technique most commonly used in clinical practice.[7] However, it is difficult to perform and it can be considered partially subjective as it is dependent on the examiner. An automatic alternative is photorefraction,[10,11] based on the same principle as dynamic retinoscopy but where the examiner does not determine the neutral point. There was a commercial instrument based on this principle (PowerRefractor, Plusoptix) previously validated[12] but no longer available in the market. The PowerRef-II is the successor of the PowerRefractor, based on the same principle, and its usefullness for static and dynamic accommodation measurements has been demostrated;[13] it has become a reference instrument in accommodation measurements as shown by its use in several research studies.[13-15]

Autorefraction is also widely used in research accommodation measurements. Indeed, a great number of autorefractors based on different principles are available on the market. Seidemann *et al*.[16] highlighted the great variability of results when measuring accommodation with different autorefractors, which can be explained by the different principles on which they are based and by other factors such as the accommodative stimulus. The Canon Autoref R-1,[17] an open-field autorefractometer that can simulate natural vision conditions, became widely used in research accommodation measurements and produced several studies on different aspects of accommodation.[18-21] While the Canon Autoref R-1 is no longer in the market, new open-field autorefractometers such as the Grand Seiko WAM-5500[22] or Shin-Nippon NVision-K 5001 (also branded as the Grand Seiko WR-5100K)[23] are now commercially available. The Grand Seiko WAM-5500 is now a reference instrument in the study of accommodation.[24-26]

The main goal of this study is to compare the static and dynamic accommodative measurements obtained with the PowerRef-II and the Grand Seiko WAM-5500. These instruments are two of the most widely used in research to assess the accommodative response. To our knowledge, no previous studies that compare these two instruments have been published.

## Material and Methods

### Subjects

This prospective study was conducted on healthy young adults recruited from the staff and students of the Polytechnic University of Catalonia (UPC). The research was conducted according to the tenets established by the Declaration of Helsinki: all subjects gave their written informed consent after receiving a written and verbal explanation of the nature of the study, and the study was approved by the Hospital Mutua de Terrassa Ethics Committee.

The criteria for inclusion were best spectacle-corrected visual acuity of 0.00 logMAR or better, and no history of any ocular condition, surgery and/or pharmacological treatment. Patients wearing spectacles were excluded to avoid interferences generated by the reflex of the lens. Consequently, only emmetropic and contact lens wearers were included.

After excluding three subjects who did not fit the inclusion criteria in terms of visual acuity, thirty subjects, fourteen male and sixteen female, were enrolled in the study. The mean age (± standard deviation [SD]) of the population was 23.66 ± 3.19 years (range: 20 to 32 years). The mean uncorrected visual acuity was 0.49 ± 0.65 logMAR (range: 1.30 to −0.08), and the mean best spectacle-corrected visual acuity was −0.02 ± 0.03 logMAR (range: 0.00 to −0.08). The mean spherical refractive error was -1.15 ± 1.65 dioptres (D) (range: −6.00 to +1.00 D), and the mean cylindrical refraction was −0.40 ± 0.38 D (range: 0.00 to −1.00 D).

**Instrumentation and set-up**

*PowerRef-II*. The PowerRef-II is an instrument based on infrared retinoscopy. It is used for the automatic determination of the sphere, cylinder and spherical equivalents in the refractive state of the eye. The measurable spherical refraction ranges from +5.00 to −7.00 D and the pupil diameter from 3 to 8 mm, with the best results obtained in pupils larger than 4 mm.[13] The PowerRef-II obtains dynamic refractive state measurements at a sampling frequency of 25 Hz. This instrument allows open-field fixation, that can simulate natural vision conditions for accommodative measurements; it can also perform simultaneous binocular measurements.

*WAM-5500*. The Grand Seiko WAM-5500 is an open-field autorefractor which projects a ringlight and measures its deformation after reflection from the retina through the optics of the eye in order to calculate the refractive state of the eye for the sphere, cylinder and spherical equivalents. The measurable range of spherical refraction is ±22.00 D, the minimum pupil diameter is 2.3 mm[22] and the vertex distance can be adjusted. It can measure the refractive state in static and dynamic modes at a frequency of 5 Hz connecting the autorefractor to a computer. The WAM-5500 allows binocular accommodative stimulation, but the measurements are monocular.

*Setup*. The setup for the measurements with the PowerRef-II and WAM-5500 is shown in Figure 1 *a* and *b*, respectively. A fixation target was shown at adjustable distance in both instruments. In order to simulate the open-field viewing conditions of the WAM-5500 with the PowerRef-II (Figure 1a) a hot mirror was used, as previously done by Jainta *et al.*[13] The patient was placed in a chinrest and the total distance from the PowerRef-II to the patient's pupil plane was 1 m. In the PowerRef-II configuration, the hot mirror was at 50mm from the pupil's plane and the field of view was 28º. When using the WAM-5500, the instrument was at 50mm from the patient's pupil plane and the (vertical) field of view was 32º.

## Measurement procedure

All measurements were performed by the same experienced examiner. Measurements were carried out in only one eye: due to the configuration setup, the left eye was chosen in all cases. The right eye was occluded. Subjects wore contact lenses with their best refractive correction or no correction in emmetropes.

Firstly, an optometric examination was performed. The refractive state was measured by means of streak retinoscopy and subjective refraction, with the endpoint criteria of minimum negative lens power to maximize visual acuity. Uncorrected visual acuity and best-spectacle-corrected visual acuity were also evaluated. Accommodation was evaluated measuring the amplitude of accommodation by means of the Sheard or negative lens method and the accommodative facility using ±2.00 D flippers.

After the optometric examination, accommodation was measured with both instruments. For each instrument, first the static and next the dynamic accommodation were measured. The sequence of the instruments was randomly chosen for each patient to avoid a learning effect on the results. For all measurements the vertex distance of the WAM-5500 was set at 0 mm, since the subjects wore contact lenses or no correction. Measurements with both instruments were performed on-axis, controlling the centration with the cameras from the instruments. The illumination of the room was the same for all participants (350 lux) and the pupil diameter obtained with this illumination for far vision was 5.29±0.68mm.

*Static measurements*. The mean spherical equivalent of five consecutive measurements was obtained for three accommodative stimulations: 0.00, 2.50 and 5.00 D. Measurements started from the far stimulation (0.00D) and ended at near (5.00D). Accommodative response was determined as the absolute value of the spherical equivalent difference between the near distance (2.50 or 5.00 D) minus the far distance (0.00 D).

*Dynamic measurements*. For dynamic accommodative response measurements, the accomodative stimulus changed from 1.00 to 3.00 D in 2.00 D steps. Two fixation targets were used to obtain abrupt changes with the accommodative stimulus: one at 1.00 m (1.00 D of stimulation) and the second at 0.33 m (3.00 D of stimulation). The test at 0.33 m was connected to a motor and appeared and disappeared in 64ms. The period of the cycle was of ten seconds, and six cycles were repeated for each patient with a total duration of sixty seconds, as shown in Figure 2. The spherical equivalent was measured and exported to a computer, where it was divided in six parts (each one corresponding to a cycle) and the mean step response was calculated. From the mean response, the mean accommodation and disaccomodation velocity and the velocity peaks of accommodation and disaccommodation were calculated as other authors have previously described and demonstrated.[27] The amplitude of the response is calculated as the maximum difference in the step response. The mean accommodation and disaccommodation velocities are calculated as the absolute value of the dioptric change divided by the time over the interval 10-90% of the total step, 80% of the absolute value. The peaks of accommodation and disaccommodation velocities are calculated as the absolute value of the maximum dioptric change per time unit. Due to sampling frequency differences between both instruments, dynamic calculations obtained with the PowerRef-II were recalculated to reduce its sampling frequency from 25 to 5 Hz. The data obtained from the measurements were thus filtered, taking into account just one value of every five.

**Statistics**

The static accommodative response measured with both instruments was compared with different methods, according to McAlinden *et al.* [28]. Firstly, the mean difference among instruments was calculated. A Bland and Altman analysis[29] was subsequently performed to study the agreement between instruments. This method plots the mean difference against the mean value and the corresponding limits of agreement, defined as 1.96 times the standard deviation of the mean difference, within which 95% of the differences between measurements are expected to lie. To evaluate if there was any tendency in the differences to vary in any systematic manner over the range of measurements, the Pearson correlation coefficient and its significance were also used in the Bland and Altman plot. Finally, the Kolmogorov-Smirnov test was used to evaluate the normal distribution of all variables and a paired sample test was carried out to analyse if there were significant differences between the accommodative response measurements obtained with the two instruments.

In relation to dynamic accommodative response measurements, the comparison procedure was similar to the static measurements: mean difference, limits of agreement, Bland and Altman plot and paired sample test after evaluating the normality by means of Kolmogorov-Smirnov test. Due to the large number of variables analysed (mean and peak velocities of accommodation and disaccommodation), in each Bland and Altman graph mean and peak absolute velocities were represented together.

Statistical analysis was performed using commercial SPSS software for Windows (version 17.0, SPSS, Chicago, IL). A *p* value of 0.05 was considered significant.

# Results

## Static accommodation

The results for far refraction of the spherical equivalent, where subjective refraction was compared with both objective techniques (WAM-5500 and PowerRef-II), are summarized in Table 1. The mean difference is calculated as the objective refraction obtained with the WAM-5500 or the PowerRef-II minus the subjective refraction. Thus, in objective measurements positive values correspond to more hyperopic results. The WAM-5500 produced little differences with the subjective refraction and no statistically significant differences, whereas with the PowerRef-II objective refraction was 0.70 D more positive than subjective refraction, the limits of agreement were double that of the WAM-5500 and statistically significant differences were found. In both cases the Kolmogorov-Smirnov test proved the normal distribution of the variables.

The static accommodative responses obtained with the WAM-5500 and the PowerRef-II were compared by pairs for the accommodative stimulations of 2.50 D and 5.00 D; results are shown in Table 2. The mean difference is calculated as the response of the WAM-5500 minus the PowerRef-II. Thus, positive values correspond to higher accommodative responses with the WAM-5500. The mean difference between instruments was close to zero at 2.50 D of stimulation; in contrast, higher accommodative response values were obtained with the PowerRef-II for the 5.00 D stimulation. The Bland and Altman plot is shown in figure 3 for accommodative stimulations of 2.50 and 5.00D, with Pearson correlation coefficients of -0.499 ($p=0.005$) and -0.712 ($p<0.001$) respectively. Finally, after confirming the normal distribution of the values, the *t* test showed no differences at 2.50 D of stimulation but significant differences for 5.00 D.

**Dynamic accommodation**

With regard to the mean velocity of accommodation and disaccommodation, the results for the WAM-5500 were 1.60 ± 0.41 D/s and 1.47 ± 0.44 D/s; for the PowerRef-II at 25 Hz, 2.29 ± 1.03 D/s and 2.14 ± 0.96 D/s; and for the PowerRef-II at 5 Hz, 2.13 ± 0.92 D/s and 1.96 ± 87 D/s. In Table 3, the comparison among the WAM-5500, the PowerRef-II at 25 Hz and the PowerRef-II at 5 Hz is shown as the mean difference, limits of agreement and *t* test performed after confirming the normal distribution of the variables. In the mean difference, positive results correspond to faster velocities with the first instrument compared, i.e., when comparing the PowerRef-II at 25 Hz versus the PowerRef-II at 5 Hz the mean difference is 0.16 D/s, thus the PowerRef-II measures faster velocities at 25 Hz than at 5 Hz. The mean velocity measured with the WAM-5500 was slower than the mean velocity measured with the PowerRef-II for both 5 Hz and 25 Hz. When comparing the mean velocity at 5 Hz and 25 Hz, faster velocities were obtained with the higher frequency. There were statistically significant differences in all the comparisons.

The mean peak of accommodation and disaccommodation velocities for the WAM-5500 were 2.35 ± 0.54 D/s and 2.32 ± 0.62 D/s; for the PowerRef-II at 25 Hz, 3.61 ± 1.21 D/s and 3.74 ± 1.45 D/s; and for the PowerRef-II at 5 Hz, 3.18 ± 1.06 D/s and 3.15 ± 1.18 D/s. In Table 3, the comparison among the WAM-5500, the PowerRef-II at 25 Hz and the PowerRef-II at 5 Hz is shown as the mean difference, limits of agreement and *t* test performed after confirming the normal distribution of the variables. The peak velocity measured with the WAM-5500 was slower than that measured with the PowerRef-II for both 5 Hz and 25 Hz. When comparing the peak velocity at 5 Hz and 25 Hz, faster velocities were measured with the higher frequency. There were statistically significant differences in all comparisons.

Bland and Altman graph, figure 4, summarizes the results for dynamic accommodative response. Figure 4 *a* shows the mean (crosshair) and peak (diamond) absolute value of the acccommodation and disaccommodation velocities when comparing the WAM-5500 with the PowerRef-II at 25Hz, where negative values in the difference (ordinate) correspond to higher velocities measured with the PowerRef-II. The Pearson correlation coefficient for this case was -0.676 ($p$<0.001). The figure 4 b plots the mean (crosshair) and peak (diamond) absolute velocities comparison for the PowerRef-II at 25Hz and 5Hz, where positive values in the difference (ordinate) correspond to higher velocities measured with the PowerRef-II at 25Hz. The Pearson correlation coefficient for this case was -0.694 ($p$<0.001).

## Discussion

The WAM-5500 and the PowerRef-II are two of the most widely used instruments to investigate the accommodative response of the eye. This study compared the results of static and dynamic accommodation measurements when using these two instruments.

Firstly, the results of refraction obtained by means of the two objective instruments (WAM-5500 and PowerRef-II) were compared with subjective refraction. The results showed a good agreement between the subjective and the WAM-5500 refraction, with a mean difference close to zero (0.07 D), relatively narrow limits of agreement [0.48,-0.34] and no statistically significant differences. In contrast, with the PowerRef-II the mean difference with subjective measurements was high (0.70 D), the limits of agreement were wider [1.62,-0.22] and statistically significant differences were found. In a previous study[22] evaluating the WAM-5500, a good agreement between subjective and autorefractometer refraction was obtained, with a mean difference of 0.04 ± 0.41 D and no statistically significant differences ($p$ = 0.21). On the other hand, the PowerRef-II tends to produce more hyperopic results, as shown in this study. Specifically, when comparing the PowerRef-II and subjective refraction, Jainta *et al.*[13] found statistically significant differences of +0.63 D, Choi *et al.*[12] of +0.59 D for the sphere, Gekeler *et al.*[30] of +0.41 D for the sphere and Hunt *et al.*[31] of +0.05 D. When compared with other objectives measurements, the PowerRef-II also showed more hyperopic results: Abrahamsson *et al*.[32] found a difference of +0.42 D using an autorefractometer and streak retinoscopy, Jainta *et al*.[13] of +0.59 D using an autorefractometer, Seidemann *et al*.[16] of +1.08 D using streak retinoscopy and Gekeler *et al*.[30] of +0.43 D for the sphere using an autorefractometer. The only exception to this trend of more hyperopic results in PowerRef-II refraction are the results of Hunt *et al.*[31] comparing the PowerRefractor with an autorefractometer, with a difference of −0.20 D for the sphere. The subjective refraction data in the study of Hunt *et al.* showed a high standard deviation, and the first version of the instrument was used (the PowerRefractor, as opposed to the PowerRef-II), which could explain the differences. Regarding the limits of agreement, the WAM-5500 also shows better concordance with the subjective refraction than the PowerRef-II.While in the WAM-5500 the limits of agreement with subjective refraction were between ±0.50, these limits increased by more than double with the Power-Ref-II. Overall, our results agree with previous studies that obtained a refraction with the WAM-5500 closer to the subjective and a more hyperopic PowerRef-II refraction.

When studying the static accommodative response measured by means of the WAM-5500 and the PowerRef-II at 2.50 D of stimulation, small (0.08 D), non-significant differences between instruments were found. On the other hand, when increasing the accommodative stimulation to 5.00 D, the differences increased to 0.32 D (highest accommodative response measured with the PowerRef-II) and became statistically significant. The Bland and Altman plot clearly shows the enlargement of the differences between the WAM-5500 and PowerRef-II instruments as the accommodation increases. In a previous article on the effect of phenylephrine on accommodation,[33] a similar effect was found to a 4D stimulus. Similarly, Jainta *et al*.[13] found that the slope of the accommodative response as a function of the stimulation was significantly higher for the PowerRef-II (slope of 0.99) compared with the Canon R-1 (slope of 0.88), i.e., the PowerRef-II measures higher accommodative responses. In order to verify this finding, a small study was carried out in two eyes with the accommodation paralyzed with tropicamide.[34] The accommodative response was measured with both instruments with eyes wearing contact lenses of powers from 0.00 to 5.00 D in 1.00 D steps, a procedure similar to that used by other authors for calibration purposes.[24] Contact lenses, and not trial lenses, were used to avoid reflexes in the instruments. Contact lenses were fitted with the centration controlled, and time to adaptation prior to measurements was allowed. Figure 5 shows the results for the PowerRef-II and WAM-5500, where the PowerRef-II measures higher accommodative responses. The slope difference among instruments (0.05) is consistent with the data obtained in the whole population for 2.50 D and 5.00 D stimulations, since the slope difference would predict an accommodative response difference of 0.12 D at 2.50 D of stimulation (difference measured in patients: 0.08 D) and 0.25 D at 5.00 D of stimulation (difference measured in patients: 0.32 D). The WAM-5500 autorefractor is essentially the same as the WR-5100K and Nvision-K5100 autorefractors for the static mode[23,24]. Thus the conclusions for the static measurements (refraction and accommodation) can be extended to these two autorefractors (WR-5100K and Nvision-K5100).

With regard to the dynamic accommodation and disaccommodation mean and peak velocities, our results were in the same range as those obtained by Heron *et al.*,[27] but slower than those obtained by other authors.[35-37] This could be due to the method used to calculate the velocity. As previously mentioned, we used the method proposed by Heron *et al.*, whereas different methods were used by the other authors.

When comparing the WAM-5500 and the PowerRef-II at a sampling frequency of 25 Hz, the results obtained with the PowerRef-II were faster and the differences were statistically significant (Table 3); a negative difference corresponds to faster velocities measured with the PowerRef-II, since the difference is calculated as the results of the WAM-5500 minus results from PowerRef-II. If the differences shown in Table 3 are shown in percentage (considering the WAM-5500 value as reference), there was a difference in mean velocity of 44% (43% for accommodation and 45% for disaccommodation), and for the peak velocity of 57% (53% for accommodation and 61% for disaccommodation). In the Bland and Altman plot, figure 4 *a*, it can be clearly seen the increasing difference between the WAM-5500 and the

PowerRef-II as faster velocities are measured, with a statistically significant correlation of -0.676. The differences in our study were significant, probably due to the differences between the measurement principles of the instruments and/or to the sampling frequency (5 times slower in the WAM-5500 than in the PowerRef-II).

In order to study if the instruments caused the differences, the sampling frequency of the PowerRef-II was reduced from 25 Hz to 5 Hz, which is the sampling frequency of the WAM-5500. In the comparison of results obtained with the WAM-5500 and the PowerRef-II at 5 Hz shown in Table 3, the differences were smaller in relation to the previous comparison, but still statistically significant. PowerRef-II at 5 Hz measured faster velocities than the WAM-5500. Specifically in percentages, the differences for the mean velocity were of 33.5% (33% for accommodation and 34% for disaccommodation) and for the peak velocity of 35.5% (35% for accommodation and 36% for disaccommodation). On the other hand, to study the impact of sampling frequency, the results obtained with the PowerRef-II at 25 Hz and 5 Hz were compared and statistically significant differences in all cases were again obtained (Table 3), though smaller than previously. If the data is shown in percentages, the differences for the mean velocity were of 10.5% (10% for accommodation and 11% for disaccommodation) and of 22% (18% for accommodation and 24% for disaccommodation) for the peak velocity. In the Bland and Altman graph, figure 4 *b,* it can be seen that greater differences in velocities are measured as the velocity increases, with a statistically significant correlation coefficient of -0.694. In comparison with the figure 4 *a*, the slope of the regression line is less, highlighting the lower impact of the sampling frequency in comparison with the effect of the instrument difference.

From the comparison of dynamic results, it can be concluded that there are substantial differences among these instruments. The error or difference between the WAM-5500 and the PowerRef-II under normal conditions (25 Hz) was 44% for the mean velocity and 57% for the peak velocity. The differences due to the instruments (WAM-5500 vs. PowerRef-II at 5 Hz) induce an error of 33.5% and 35.5% for the mean and peak velocities, respectively. The error attributable to the sampling frequency (PowerRef-II 25 Hz *vs.* PowerRef-II 5 Hz) is of 10.5% and 22% for the mean and peak velocities.

To summarize, it can be concluded that when comparing both instruments for far vision refraction, the WAM-5500 is closer to the subjective refraction than the PowerRef-II. In static accommodation, there are differences among instruments, not significant at low accommodative stimulations (2.50 D) but significant at higher stimulations (5.00 D). With regard to dynamic accommodation, the differences between the WAM-5500 and the PowerRef-II can be mainly attributed to the instrument, but also to the sampling frequency at which measurements are taken.

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## FIGURE LEGENDS:

Figure 1. Setup for the static and dynamic accommodative response measurements. *a*) The setup for the PowerRef-II with a fixation target (FT) at adjustable distance (d) seen through a hot mirror (HM). *b*) The setup for the WAM-5500 with a fixation target (FT) at adjustable distance (d).

Figure 2. Example of dynamic accommodative stimulation (black solid line) and response (red dots) through time (*t*) (D: Dioptres; s: seconds).

Figure 3. Bland and Altman plots comparing the accommodative response (AR) measured with the WAM-5500 (WAM) and the PowerRef-II (PR) for accommodative stimulations (AS) of 2.50 (crosshair) and 5.00D (diamond). Dashed lines indicate the 95% limits of agreement and dotted lines the mean value. Dash-dotted lines indicate the regression line.

Figure 4. Bland and Altman plots comparing the mean (crosshair) and peak (diamond) absolute value of the acccommodation and disaccommodation velocities (v). a) WAM-5500 (WAM) versus PowerRef-II at 25Hz (PR25), b) PowerRef-II at 25Hz (PR25) versus PowerRef-II at 5Hz (PR5). Dashed lines indicate the 95% limits of agreement and dotted lines the mean value. Dash-dotted lines indicate the regression line.

Figure 5. Accommodative response measured with the PowerRef-II and WAM-5500 in accommodation cyclopleged eyes wearing contact lenses of known

power (theoretical power) (D: dioptres). Dashed lines indicate the regression line and dotted line indicates the line of equality.

Table 1.

| | Mean difference ± sd (D) | 95% Limit of Agreement (D) | Paired sample *t* test (*p*) |
|---|---|---|---|
| $Rx_{WAM} - Rx_{Subj}$ | 0.07 ± 0.21 | [0.48,-0.34] | 0.093** |
| $Rx_{PR} - Rx_{Subj}$ | 0.70 ± 0.47 | [1.62,-0.22] | < 0.001 |

** No significant differences

Table 1. Comparison of refraction (Rx) when measured subjectively (Subj) and objectively using the WAM-5500 (WAM) and the PowerRef-II (PR). The mean difference (± SD), 95% limits of agreement and the paired sample *t* test results are shown (D: dioptres).

Table 2.

| | AS (D) | Mean difference±sd (D) | 95% Limit of Agreement (D) | Paired sample *t* test (*p*) |
|---|---|---|---|---|
| $AR_{WAM}$- $AR_{PR}$ | 2.50 | 0.08±0.32 | [0.71,-0.55] | 0.194** |
| | 5.00 | -0.32±0.48 | [0.62,-1.26] | 0.001 |

** No significant differences

Table 2. Comparison of accommodative response (AR) measurements using the WAM-5500 (WAM) and the PowerRef-II (PR). For the two accommodative stimulations (AS), the mean difference (± SD) between instruments, 95% limits of agreement and the paired sample *t* test results are shown (D: dioptres).

Table 3.

| | | WAM – PR 25 Hz | WAM - PR 5 Hz | PR 25 Hz - PR 5 Hz |
|---|---|---|---|---|
| $V^{A}_{mean}$ (D/s) | Mean difference | −0.68 ± 1.01 | −0.52 ± 0.90 | 0.16 ± 0.15 |
| | 95% LoA | [1.30,-1.65] | [1.24,-1.38] | [0.45,0.02] |
| | *t* test | 0.003 | 0.009 | 0.000 |
| $V^{D}_{mean}$ (D/s) | Mean difference | −0.67 ± 0.98 | −0.49 ± 0.91 | 0.17 ± 0.17 |
| | 95% LoA | [1.25,-1.65] | [1.29,-1.36] | [0.50,0.01] |
| | *t* test | 0.003 | 0.014 | 0.000 |
| $V^{A}_{peak}$ (D/s) | Mean difference | −1.26 ± 1.19 | −0.83 ± 1.07 | 0.43 ± 0.30 |
| | 95% LoA | [1.07,-2.40] | [1.27,-1.86] | [1.02,0.14] |
| | *t* test | 0.000 | 0.001 | 0.000 |
| $V^{D}_{peak}$ (D/s) | Mean difference | −1.42 ± 1.53 | −0.83 ± 1.31 | 0.59 ± 0.46 |
| | 95% LoA | [1.58,-2.89] | [1.74,2.09] | [1.49,0.15] |
| | *t* test | 0.000 | 0.005 | 0.000 |

Table 3. Comparison in terms of mean difference (± SD), 95% limits of agreement (LoA) and the paired sample *t* test of mean accommodative ($V^{A}_{mean}$) and disaccommodative ($V^{D}_{mean}$) velocity and peak accommodative ($V^{A}_{peak}$) and disaccommodative velocity ($V^{D}_{peak}$) measurements using the WAM-5500 (WAM) and the PowerRef-II at 25 Hz (PR 25 Hz) or 5 Hz (PR 5 Hz) sampling frequency (D: dioptres).

Figure 1A-B finalKAZ



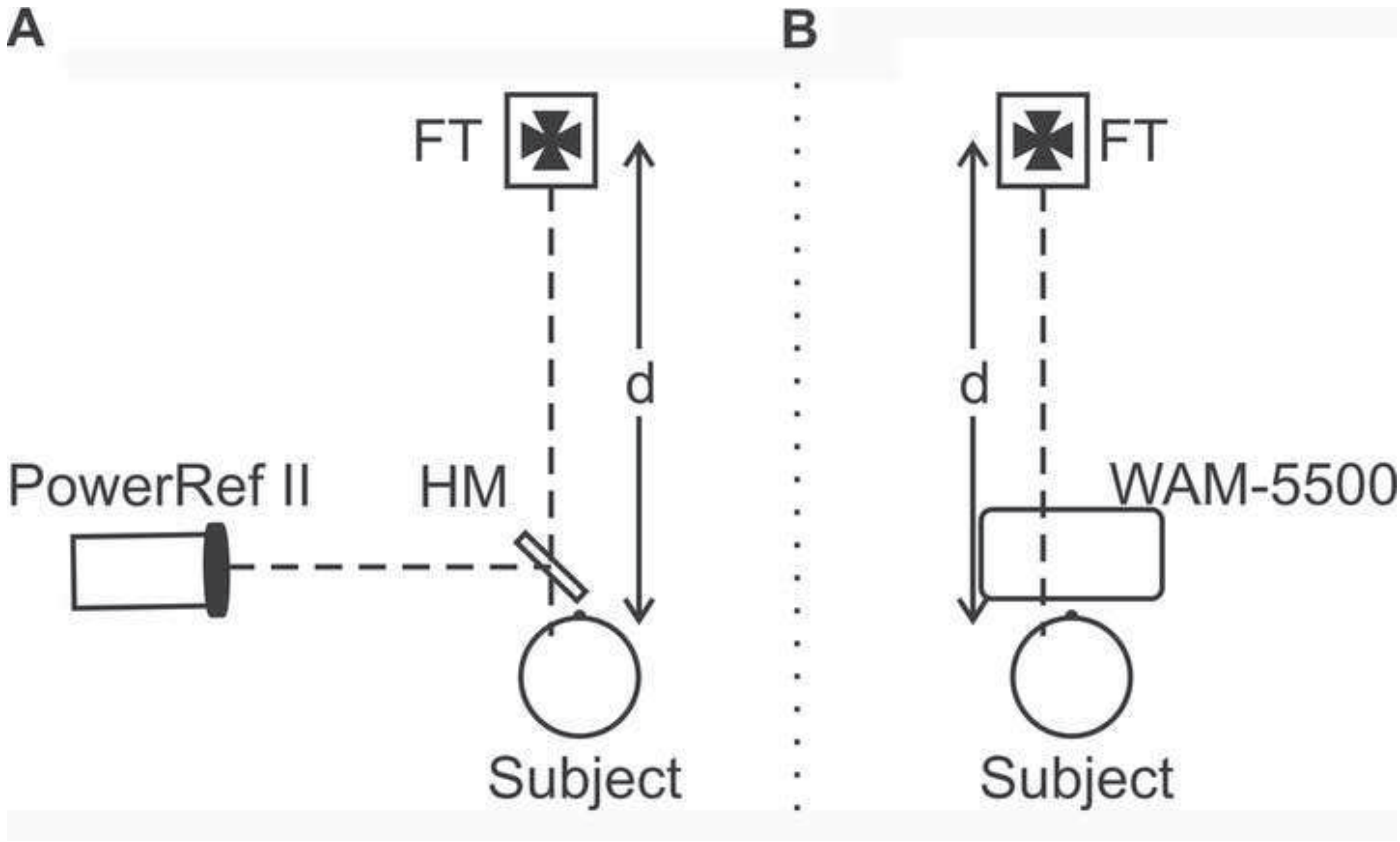

Figure 2 RGB finalKAZ


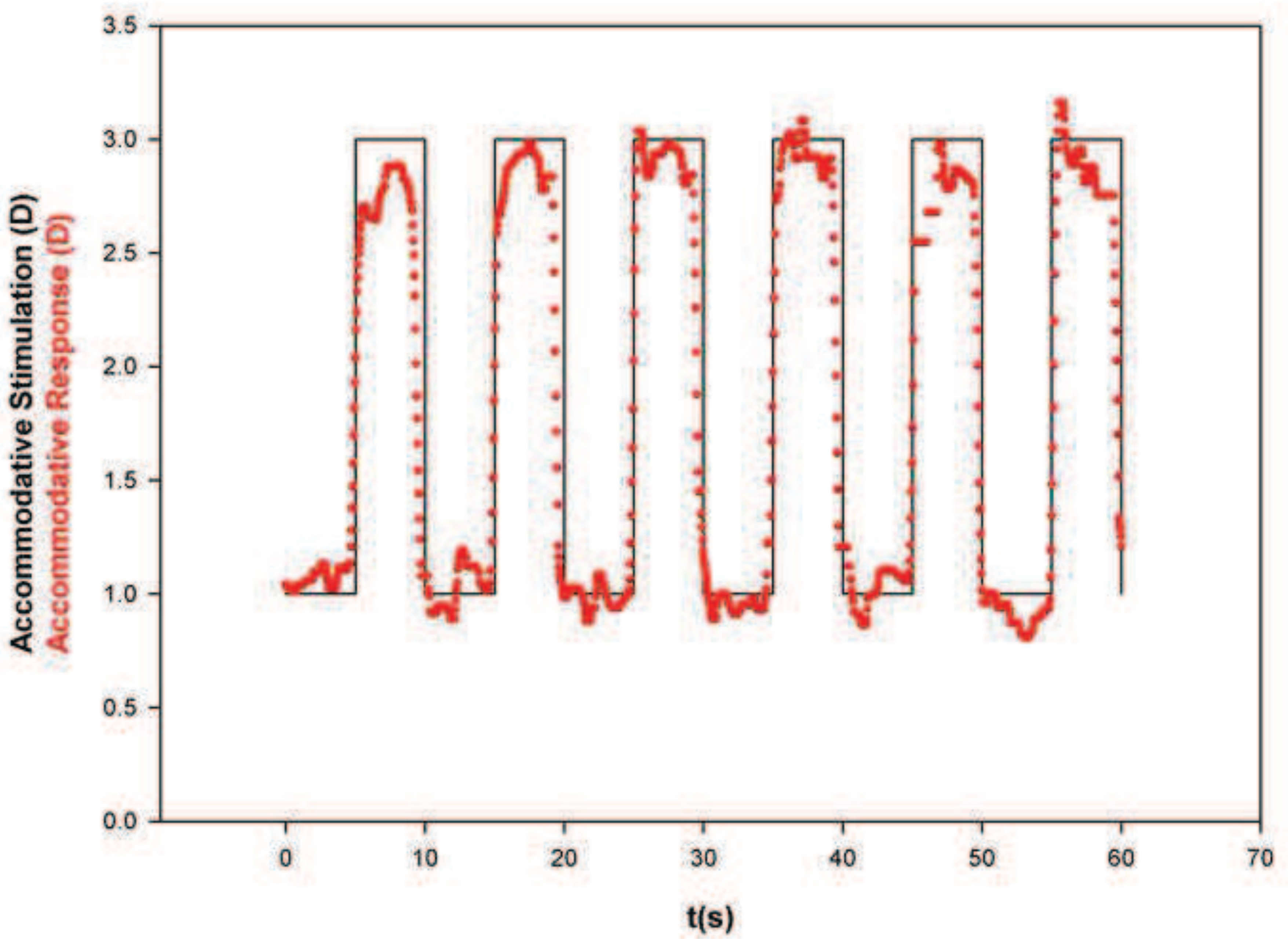

Figure 3 RGB finalKAZ
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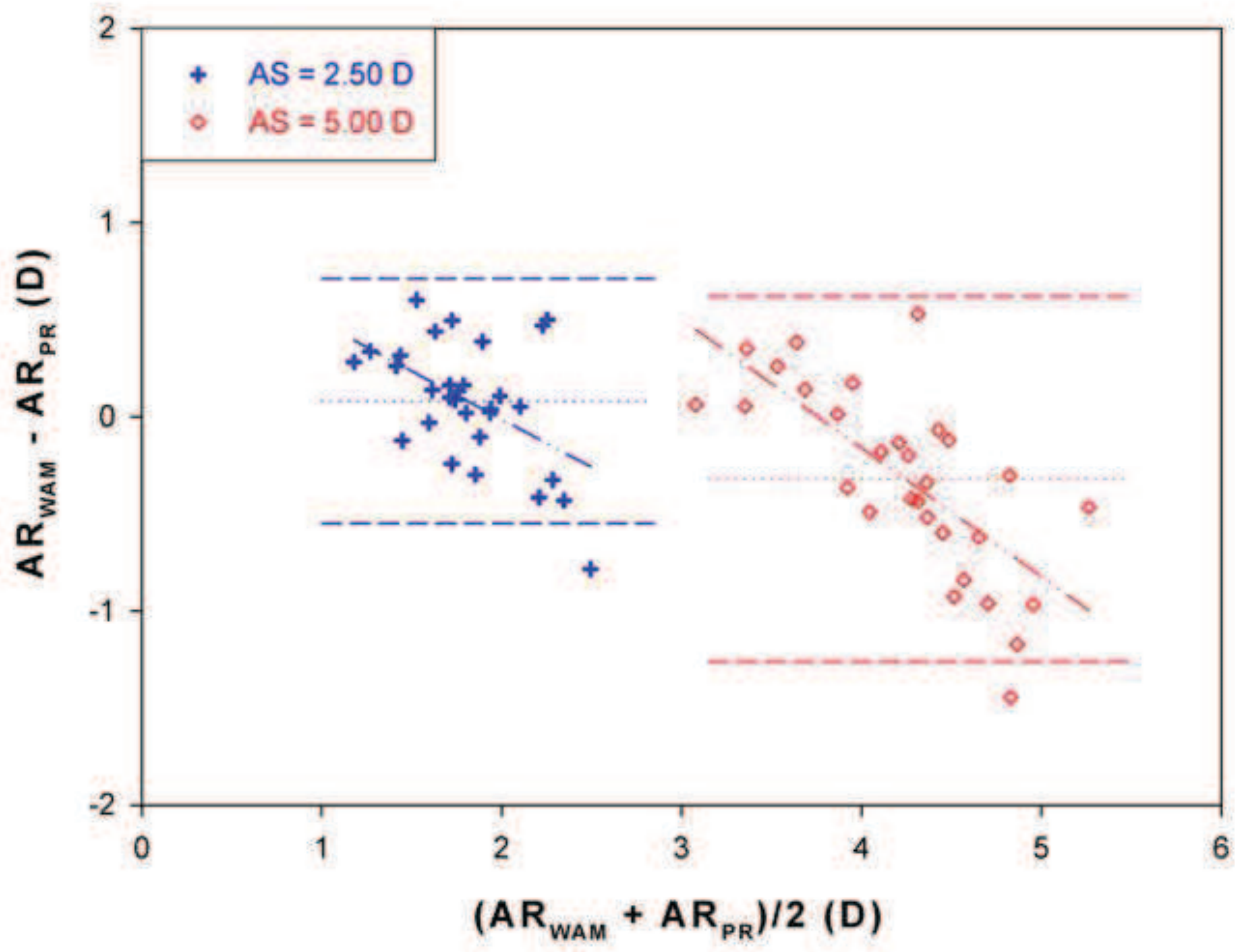

Figure 4A-B RGB finalKAZ



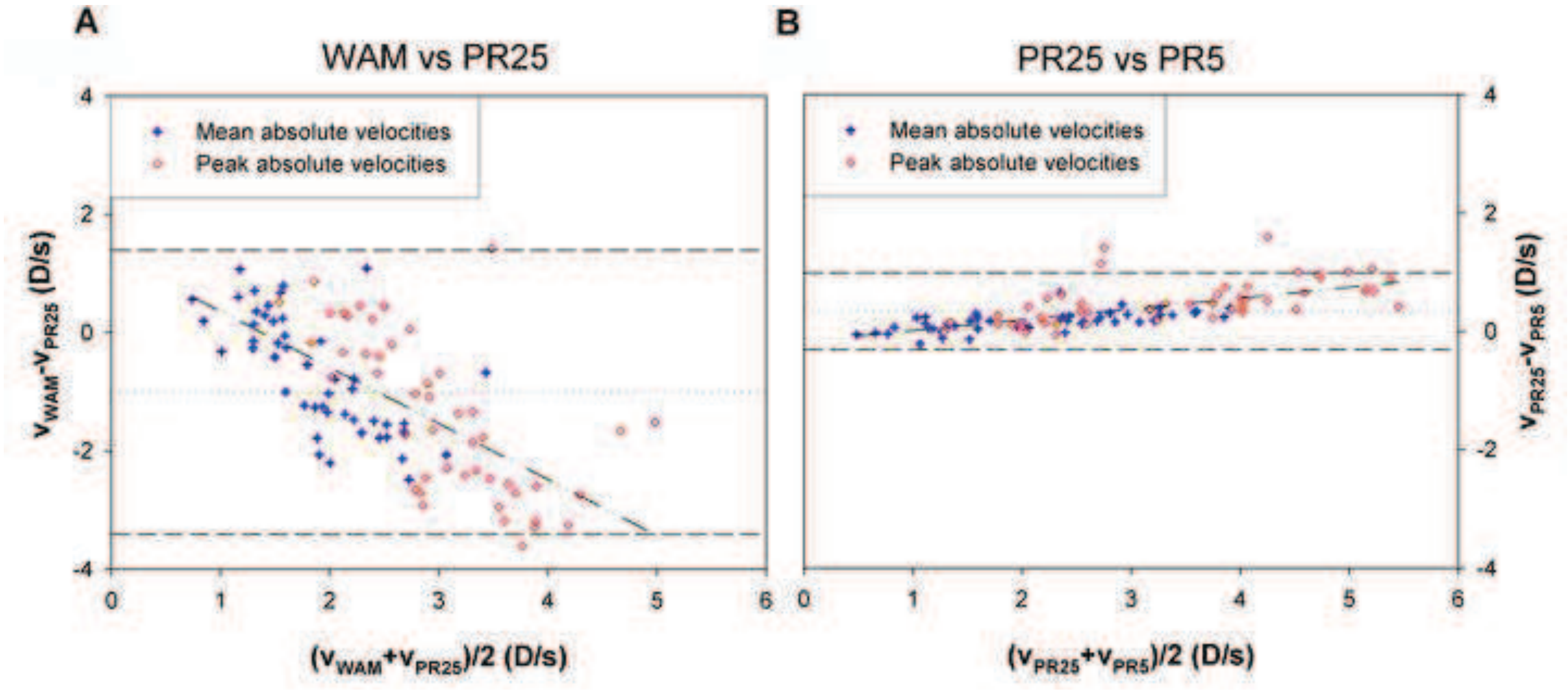

Figure 5 RGB reformattedKAZ
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