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# Real-Time Objective Measurement of Accommodation While Reading

## **Description**

**Purpose:** To determine the feasibility of collecting accurate, continuous accommodative data during reading.

**Methods:** Real-time accommodative measures were measured on nine subjects (5 female, 4 male) under three conditions while accommodative measurements were collected at 5 Hz with the Grand Seiko WAM-5500 open-field autorefractor. The first two conditions tested ability of the auto-refractor to measure accommodative response with peripheral gaze: one with distant targets and the other with near targets. The third condition involved reading from an electronically-presented text.

**Results:** Accommodative response, allowing for expected accommodative lag, was measured within 0.25 D of expected clinical values during reading in a 3-line vertical, 15-degree horizontal window.

**Conclusions:** Within the 15° visual angle range, open-field autorefraction is able to accurately measure the real-time accommodative response to within 0.25 D.

## **Disciplines**

Optometry

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# Real-Time Objective Measurement of Accommodation While Reading

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## 5 Abstract

*Purpose:* To determine the feasibility of collecting accurate, continuous accommodative data during reading. *Methods:* Real-time accommodative measures were measured on nine subjects (5 female, 4 male) under three conditions while accommodative measurements were collected at 5 Hz with the Grand Seiko WAM-5500 open-field autorefractor. The first two conditions tested ability of the auto-refractor to measure accommodative response with peripheral gaze: one with distant targets and the other with  
10 near targets. The third condition involved reading from an electronically-presented text.

*Results:* Accommodative response, allowing for expected accommodative lag, was measured within 0.25 D of expected clinical values during reading in a 3-line vertical, 15-degree horizontal window. *Conclusions:* Within the 15° visual angle range, open-field autorefraction is able to accurately measure the real-time accommodative response to within 0.25 D.

15 **Keywords:** accommodation, autorefraction

## Introduction

In younger patients, visual complaints related to accommodation are common.<sup>1</sup> Frontal headaches, intermittent blur, and  
20 asthenopia are a few of many classic symptoms experienced by patients with accommodative disorders.<sup>2</sup>

Standard clinical tests of accommodative function, such as amplitude, facility, lag testing, and positive and negative relative accommodation often enable an accurate diagnosis of the accommodative disorder.<sup>3</sup> However, none of these tests measures or demonstrates the accommodative response while performing a near task, such as reading. Dynamic retinoscopy performed while a patient is reading from a card is the current optometric test that comes closest to measuring accommodative response during  
25 reading. However, this test is very technique-sensitive, difficult to continuously quantify, and the reading environment is quite different than normal. If repeatable, real-time measurements of accommodative response are potentially useful, either directly in patient care or as a comparison test, for patient diagnosis and management.<sup>4</sup>

The open-field autorefractor has potential to enable real-time measurement of accommodation while reading.<sup>5</sup> An “open-field” autorefractor is distinguished by the fact that the patient views objects in real-space when the refractive measurement is made.  
30 This is accomplished by having the patient view free space through a beam splitter, the optical path for measuring refractive error is in the other path and not visible to the patient. The instrument measures the location of eye focus: i.e. the distant refractive error if the patient views a distant target and the location of accommodative focus if the patient views a near target.<sup>6</sup> The first commercially available open-field autorefractor was the Canon R-1.<sup>7</sup> The Grand Seiko WAM 5000 series are more advanced instruments still in production, and can measure the eye focus objectively at 5 Hz. When fitted with a continuous text target on a  
35 reading rod, it performs similarly to the fused crossed cylinder test, but provides continuous objective measurements and a more normal reading environment.<sup>8</sup>

We are unaware of previous studies that measure accommodation dynamically during the reading task. Our intention here is to examine the ability of the WAM-5500 to provide meaningful measures of accommodative response during typical reading. Since reading requires that the eye move across a page of text, a primary concern is potential inaccuracy caused by off-axis  
40 measurements.<sup>9</sup> We tested the ability of the instrument to make off-axis measurements and to measure accommodation during the reading process.

## Methods

### *Subjects*

Nine subjects participated in the study (5 females, 4 males). Ages spanned from 20 to 38. All wore the proper spectacle or contact  
45 lens prescriptions, if any, for this study.

## *Apparatus*

A Grand Seiko WAM-5500 open-field autorefractor was used to measure accommodation and pupil size at a sampling rate of 5 Hz. Data were automatically recorded to an Excel file on a PC connected to the WAM-5500 via a serial cable using WCS-1 data collection software provided with the autorefractor.

5 Three display devices were used to display text stimuli: a 15" LCD display Dell 1505FP LCD, 1024 x 768 screen resolution, 60 Hz), a handheld smart phone (HP iPAQ hw6945, 3" TFT backlight LED display, 240 x 240 screen resolution, 5.4 cm wide x 5.4 cm high), and hardcopy paper (regular letter-size printing paper). The Hp iPAQ was chosen because it has a LCD screen, readily to be compared to the desktop LCD, yet can be mounted to a reading rod for measurements nearer than 50 cm. It was connected wireless keyboard used for text scrolling during the reading test.

## 10 *Materials*

Tahoma font was used throughout the study, as it is the default font used in the iPAQ. All stimuli were located in front of the WAM-5500 for viewing through the window of the autorefractor.

## *Procedures*

15 Subjects sat in a comfortable chair behind a WAM-5500. Chair height and chin rest were adjusted to individual comfort. Room lighting was kept constant across all testing and was provided entirely by fluorescent fixtures typical of an office setting. All measurements were made on the subject's right eye; the left eye was occluded unless otherwise noted.

Each subject was tested in three conditions: Primary gaze position, Eccentric gaze positions at 50 cm, and reading over a small screen.

20 To examine how sensitive Grand-Seiko autorefractor is to accommodative demand caused by viewing distance, measures of accommodative focus of primary gaze position at different viewing distances were obtained. Subject was asked to look a series of 12-point Tahoma letters in fovea at distance of 4.75 m (far gaze position), followed by near gaze at distance of 25, 33, 40, and 50 cm (near gaze positions). The letters were presented in the mode of Power point slide show. Latin-square randomization was used to determine the testing order of near distances across. Data were collected for 30 seconds for each viewing distance.

25 The eccentric gaze measures were to compare accommodative measures at different eccentric distances. Seven uppercase letters (A to G, in 12-point Tahoma) were displayed on the LCD at every five degrees of horizontal gaze from  $-15^{\circ}$  to  $15^{\circ}$  at distance of 50 cm. A red fixation dot was also presented at the primary gaze position, right under the middle ( $0^{\circ}$ ) letter D. The subject was asked to focus at the fixation dot until a stable measure was obtained and then to shift their focus to a specific letter called out by the experimenter, without moving their head, for 30 seconds. The procedure was repeated for all seven targets and their testing order was determined by Latin square. A similar a series of 30-second measures were made with the iPAQ on the WAM-5500  
30 reading rod.

In the final condition the subject read a text at the same four distances (25, 33, 40, and 50 cm) for 90 seconds each. The text (*Emma*, by Jane Austen) was presented in 9-point Tahoma font on the iPAQ window (5.4 cm wide x 5.4 cm high). A pilot test was conducted to be sure that the accommodative measures derived from the edges of the small text window of the iPAQ was no  
35 different from the measures obtained in primary gaze. At the four testing distances the edges of the line of text required eccentric gazes of  $\pm 5$ , 10, and 15 degrees. Subjects scrolled the text using a wireless keyboard and were instructed to remain within one vertical line of baseline to minimize eyelid interference. At the beginning of each reading distance, the subject was asked to focus at a central dot until obtaining a stable measurement and then the dot was removed and the text reveal for continuous reading.

## **Results**

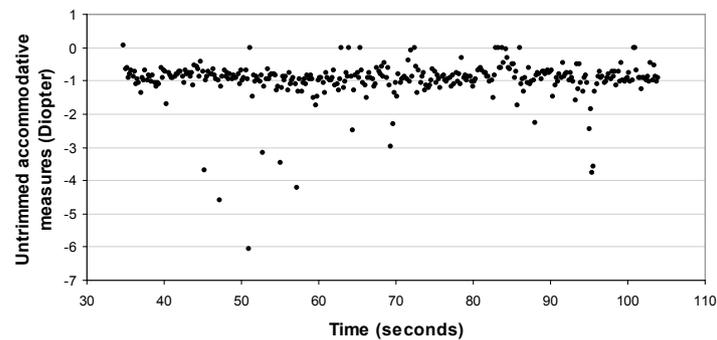
### *Statistical analysis*

40 Trimming to three standard deviations above and below the mean eliminated outlying data for each subject and testing condition. Figure 1 shows the comparison of data before and after trimming.

SPSS Repeated measures analysis of variance was used for analysis. Graphs were constructed to compare the means using confidence intervals constructed such that non-overlapping confidence intervals were significantly different at an unadjusted  $p < 0.05$ . This was accomplished by constructing the 84<sup>th</sup> percent confidence interval around each mean.<sup>10</sup> In constructing this confidence interval the standard error for a single mean (SE) was estimated using the standard error of the differences (SED) in the following formula:  $SE = SED / (\text{square root of } 2)$  with degrees of freedom equal to  $n-1$ . The standard error of the differences between means was taken from the least squared difference t-test (SPSS version 17; SPSS Inc. Chicago, Ill) yielding identical tests of significance.

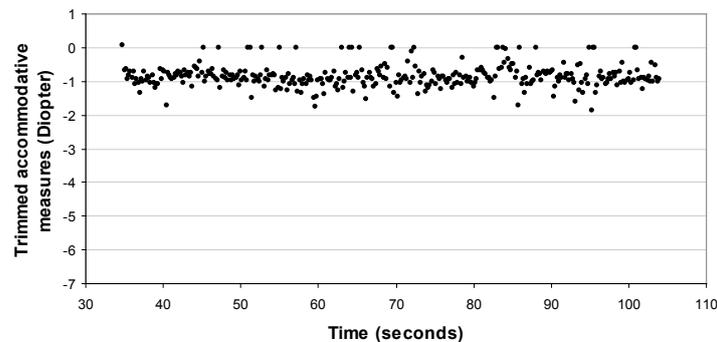
10

(a)



**Figure 1a. Raw Grand Seiko accommodative data (a) before trimming to 2 SD**

(b)

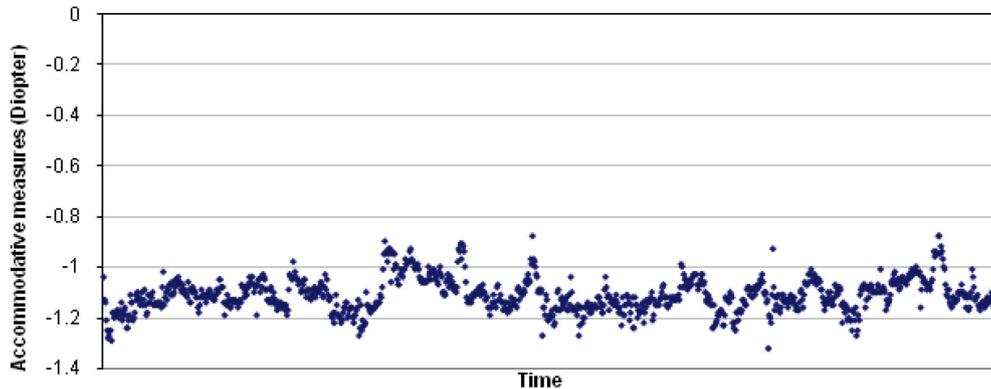


15

**Figure 1b. Raw Grand Seiko accommodative data after trimming to 2 SD**

20

(c)

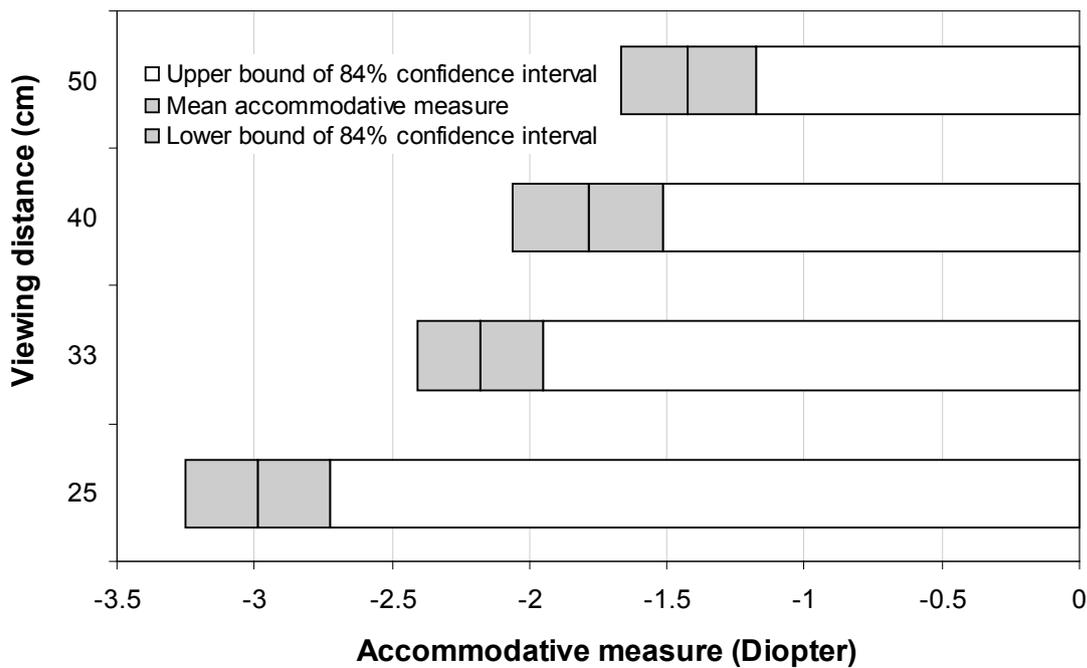


**Figure 1c. Raw Grand Seiko accommodative example showing the nature of fluctuation from accommodative focus measures; data derived from a different study, in which the subjects read words presented only in primary gaze.**

5 *Sensitivity of primary-gaze accommodative measures to viewing distance*

The first test measured the sensitivity of Grand-Seiko measure to different viewing distances at foveal vision (i.e., looking straight ahead at the target). The expected accommodative demand is -2.0 Diopter at viewing distance of 50 cm, and increases by -0.5 Diopter per step as viewing distance decreased to 40 cm, 33 cm, and 25 cm.

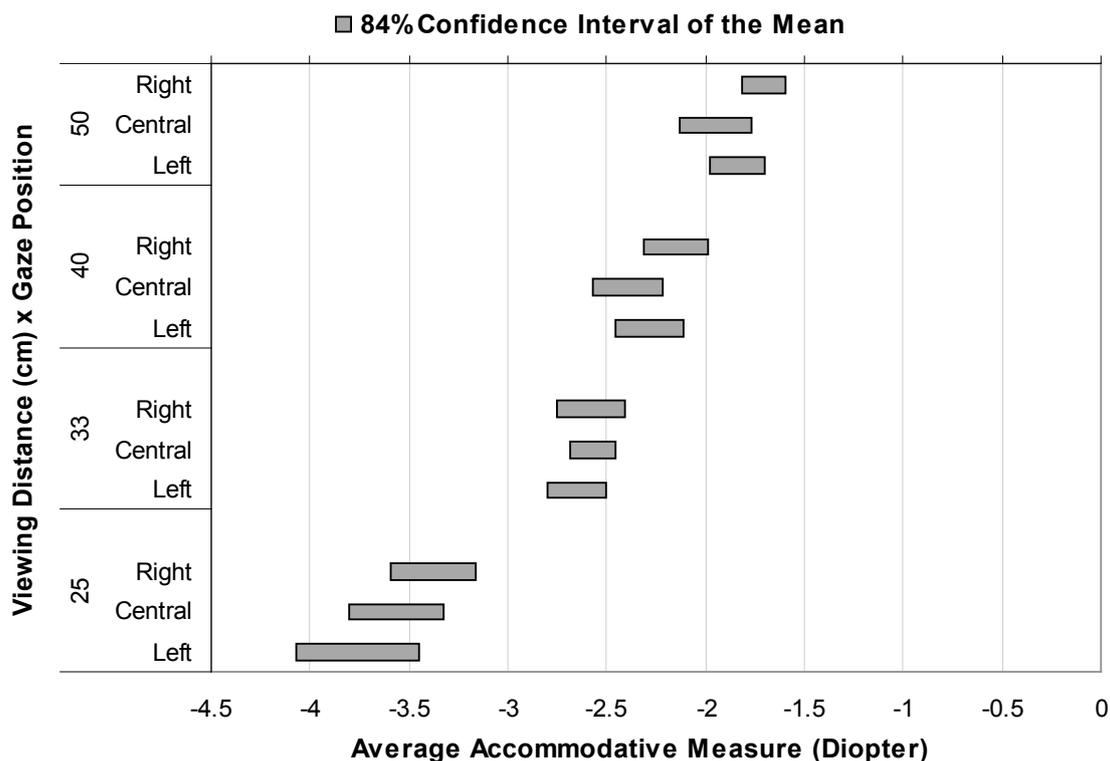
10 Using SPSS Repeated Measure ANOVA, a significant effect of viewing distance on accommodative measures was found. Within-subjects Contrasts showed significant linear and quadratic trends. Pairwise comparisons show significant difference between all pairs of measures from the five viewing distances. Figure 2 shows the estimated mean accommodative measure at the four viewing distances. This result suggests that the measures are sensitive to the change of viewing distance.



**Figure 2: Accommodative response of primary gaze at various viewing distances. The bars are showing 84% confidence interval of the measures. Non-overlapping bars were significant at  $p < 0.05$ .**

### *Accommodative measures across eccentric distances and viewing distances*

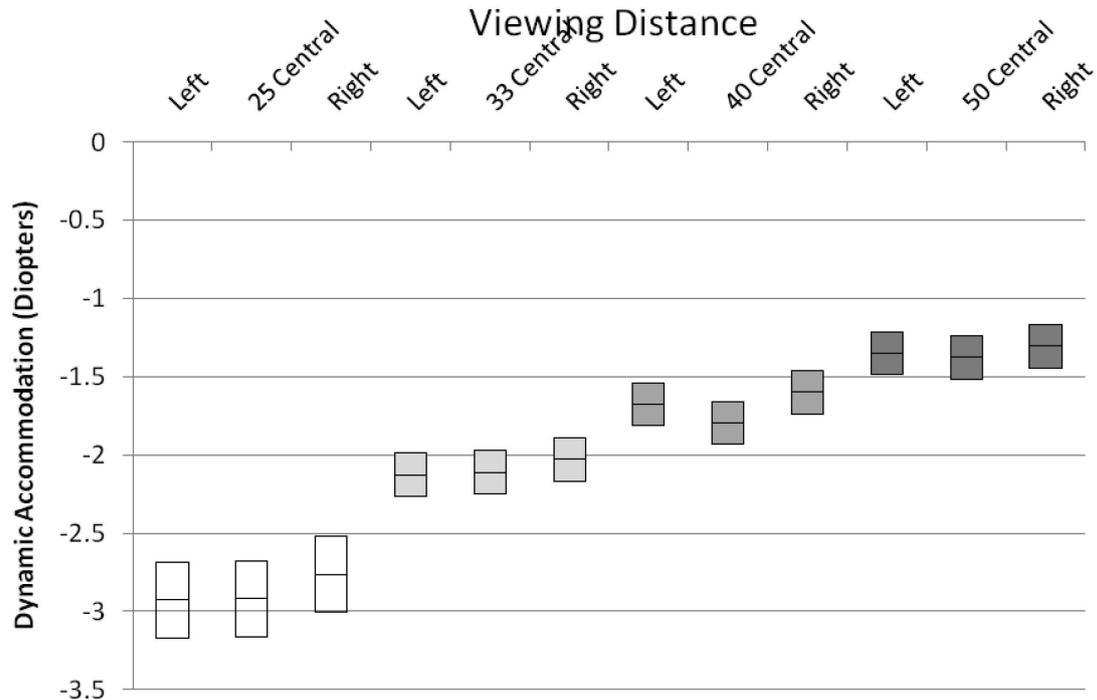
Figure 3 shows the consistency of accommodative measures across eccentricity at 50 cm. Repeated ANOVA shows no significant effect of visual angle on the accommodative measures, suggesting that, at 50 cm, there is no significant difference between measures 15° on either side of the primary gaze. This suggests that Grand-Seiko measure is stable at least within 15° from the central fixation point; however, the result of no significant difference may result from the small sample sizes (nine participants). Further investigation is needed to refine the horizontal boundary of the Grand-Seiko measures.



**Figure 3: Accommodative response across eccentric visual angles at various viewing distances**

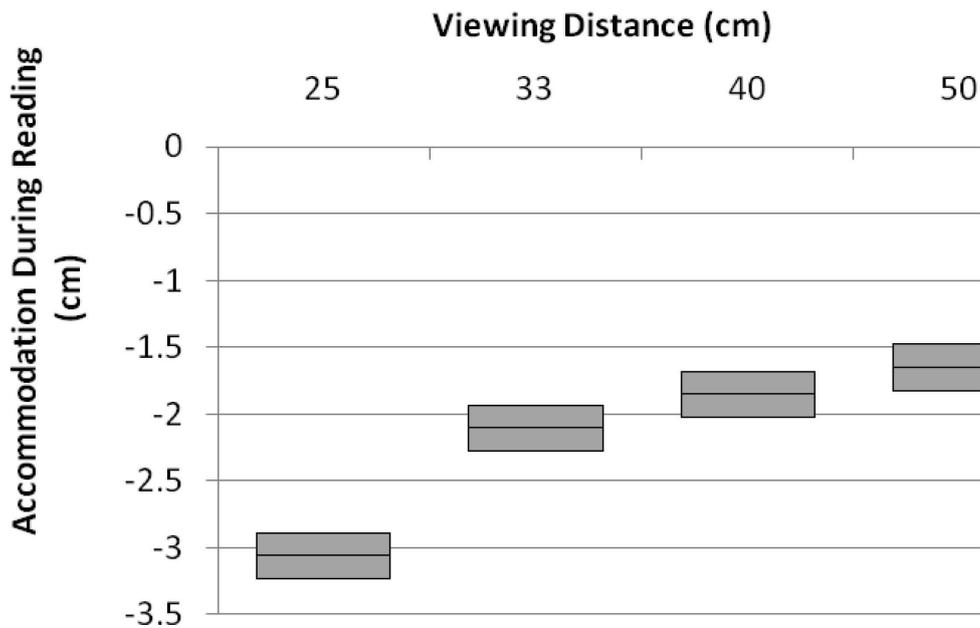
### *Accommodative measures during dynamic reading*

Accommodative response is presumed to only be dependent on working distance. However, off-axis measures of accommodative response in secondary gaze may make accurate determination difficult. Therefore a pilot test was conducted to examine the consistency of the Grand-Seiko measures within a small display region from four viewing distances (50, 40, 33, and 25 cm). The display region was selected to match the screen size of the iPAQ, which was used to display the reading text. A two-way Repeated ANOVA shows significant main effect of viewing distance ( $F(3, 21) = 132.594, p < 0.0001$ ) but no significant effect of gaze position ( $F(2, 14) = 1.259, p = 0.314$ ) nor their interaction ( $F(1.847, 12.931) = 0.515, p = 0.596$ ), suggesting that derived accommodative measures were responsive to the change of viewing distance but were consistent within a testing visual angle.



**Figure 4: Accommodative Response as a Function of Working Distance and Position of Gaze.**

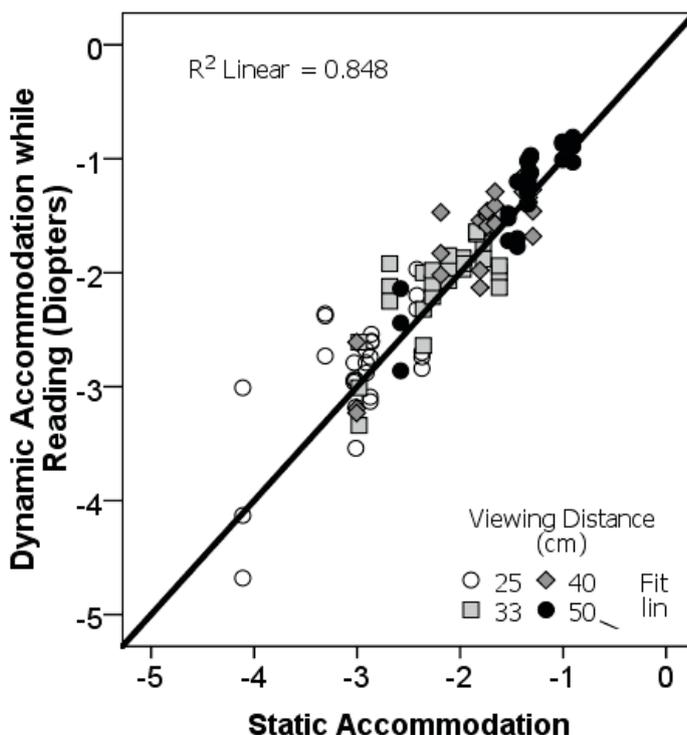
Repeated ANOVA was used to analyze the effects of the Viewing distance on the average measure of the continuous accommodative recordings. Significant effect of viewing distance was obtained ( $F(1.410, 9.873) = 61.649, p < 0.0001$ ). Within-subject contrast shows significant linear ( $p < 0.0001$ ) and quadratic trends ( $p = 0.0158$ ). Pairwise comparisons indicate significant differences of accommodative measures between all four viewing distances. Figure 5 showed the average accommodation and its variation at the tested distance.



**Figure 5: Mean accommodative response as a function of viewing distance during reading. Notice the increased accommodative lag with closer working distance is very linear.**

Figure 6 illustrates the relationship between static accommodations while staring at a fixation point with dynamic accommodation while reading. The graph includes points with left, center, and right gazes during reading compared to the single fixation point static accommodation. The line of unity in the figure illustrates there is no systematic deviation from identity across all viewing distances.

5



**Figure 6. The relationship between static accommodation at baseline and dynamic accommodation while reading. The line in the chart is the line of identity for reference rather than the regression line.**

## Discussion

10 The Grand Seiko WAM-5500 autorefractor can be used to measure the accommodative response at 5 Hz. The visual angle data show that measures conducted at  $\pm 15^\circ$  of primary gaze are within 0.25D of baseline in most subjects. Accommodative lag shows a regular increase with closer working distances.

The gaze fixation analysis proved useful as well; it shows limits on working distance for accurate data recording. In each of the three greater distances ( $>25$  cm), the data remained stable left and right of primary gaze, indicating that the WAM-5500 was 15 tolerant of off axis viewing at  $\pm 7.5^\circ$ . Within this angular limit, it is shown that the WAM-5500 will likely perform accurately at 33 cm, 40 cm, and 50 cm.

The reading test analysis confirms the conclusions reached in the previous paragraph: data can be collected at distances of greater than 33 cm.

## Conclusions

20 The Grand Seiko WAM-5500 appears to be an accurate tool for quantifying accommodation in both static and dynamic modes. By conducting this study, limits and boundaries have been created that will allow this instrument to be used in future studies.

The diagnosis of clinical entities like accommodative insufficiency would benefit greatly from an objective measure of the accommodative response during reading. Under the conditions outlined in this study, the Grand Seiko WAM-5500 can obtain this information. It is a step forward in allowing clinicians to help make better diagnoses based on objective accommodative measures.

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## Notes and references

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