# Real-Time Objective Measurement of Accommodation While Reading

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## Abstract

***Purpose:*** *In the clinical care of functional vision disorders, dynamic retinoscopy such as Monocular Estimate Method has been the mainstay for objective measurement of the accommodative response. It is valuable, fast and widely available. Dynamic retinoscopy however does not allow for quantified measures of accommodation by inexperienced clinicians or technicians. Automated, objective methods for performing simple clinical tests like book retinoscopy would be most useful, if only real-world targets like continuous text could be included. This study was aimed at determining the feasibility of collecting automated, continuous accommodative data during reading.*

***Methods:*** *Real-time accommodative measurements were measured on nine subjects under three conditions while accommodative measurements were collected at 5Hz with the Grand Seiko WAM-5500 open-field autorefractor. The first two conditions tested the ability of the autorefractor to measure accommodative response using peripheral gaze: with distant and near targets. The third condition involved reading from the 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 15º visual angle range, open-field autorefraction is able to accurately measure the real-time accommodative response to within 0.25 D. Although there are dynamic fluctuations in the accommodative response during reading, measured accommodative lag increases with demand and is consistent with the literature on dynamic retinoscopy. Open-field autorefraction has the potential to demonstrate accommodative dysfunction when used in real-time mode.*

## Key Words

*accommodation, autorefraction, dynamic retinoscopy, Grand Seiko WAM-5500*

Visual complaints related to accommodation are common.[1] Frontal headaches, intermittent blur, and asthenopia are a few of many classic symptoms experienced by patients with accommodative disorders.[2] 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.[3] However, none of these tests measures or demonstrates the accommodative response while performing a near task, such as reading. Dynamic retinoscopy, such as the Monocular Estimate Method (MEM) performed while a patient is reading from a card, is the current optometric test that comes closest to measuring accommodative response during reading.[4,5] However, this test is very technique-sensitive, difficult to continuously quantify, and the reading environment is quite different than normal. If they are repeatable, real-time measurements of accommodative response are potentially useful for patient diagnosis and management.[6]

The open-field autorefractor has the potential to enable real-time measurement of accommodation while reading.[7] An “open-field” autorefractor is distinguished by the fact that the patient views objects in real-space when the refractive measurement is made. This is accomplished by having the patient view free space through a beam splitter; the optical path for measuring refractive status is in the other path and not visible to the patient. The instrument measures the location of eye focus: i.e. the distant refractive status if the patient views a distant target and the location of accommodative focus if the patient views a near target.[8] The first commercially available open-field autorefractor was the Canon R-1.[9] The Grand Seiko WAM 5000 series, a more advanced instrument, can measure the eye focus objectively at 5 Hz. When fitted with a continuous text target on a reading rod, it performs similarly to the fused crossed cylinder test but provides continuous objective measurements and a more normal reading environment.[8]

We are unaware of previous studies that measure accommodation dynamically during the reading task. Although the Grand Seiko WAM-5500 is now the gold standard for measuring transient accommodative effects, these measurements are inevitably done before and after the reading task is complete.[10] This study endeavors to examine the ability of the WAM-5500 to provide meaningful measures of accommodative response during typical reading. Because reading requires that the eye move across a page of text, a primary concern is potential inaccuracy caused by off-axis measurements.[11] The purpose of the study was to assess 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; mean age, 26 years). Ages spanned from 20 to 38. All wore the proper spectacle or contact lens prescriptions, if applicable, for this study. Those with functional or pathological vision problems, especially those affecting accommodation, were excluded from the study. This included, but was not limited to, patients with presbyopia and accommodative insufficiency.

### Apparatus

A Grand Seiko WAM-5500 open-field autorefractor was used to measure accommodation and pupil size at a sampling rate of 5 Hz. These are standard measures for this instrument, which has replaced the old standard, the discontinued Canon Autoref R-1 Refractometer.[12-15] Data were automatically recorded to an Excel file on a computer connected to the WAM-5500 via a serial cable using WCS-1 data collection software provided with the autorefractor.

Three display devices were used to display text stimuli: a 15" liquid crystal (LCD) display Dell 1505FP LCD (1024 x 768 screen resolution, 60 Hz), a handheld smart phone (HP iPAQ hw6945, 3" thin-film transistor (TFT) backlight light-emitting diode (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 an LCD screen, readily to be compared to the desktop LCD, yet can be mounted to a reading rod for measurements nearer than 50 cm. The smartphone was controlled with a wireless keyboard used for text scrolling during the reading test.

### 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

Subjects sat in a comfortable chair behind the WAM-5500. Chair and chin rest height 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.

To examine how sensitive the 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. Subjects were asked to look at a series of 12-point Tahoma letters in a straight-ahead position, 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. Data were collected for 30 seconds for each viewing distance.

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° to 15° at distance of 50 cm. A red fixation dot was also presented

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

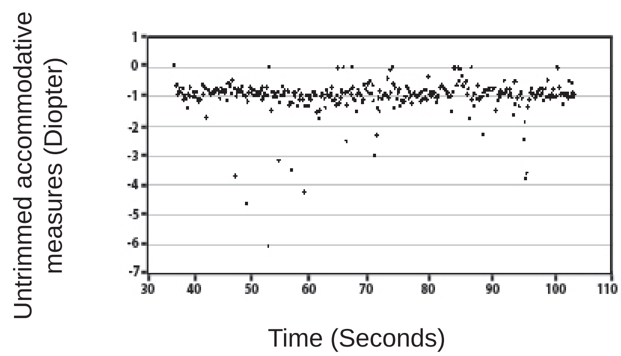



*Figure 1b. Raw Grand Seiko accommodative data after trimming to 2 SD*

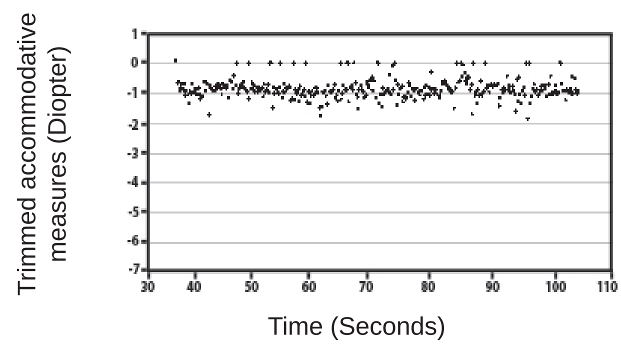



*Figure 1c. Raw Grand Seiko accommodative example showing the nature of fluctuation from accommodative focus measures; data derived from a different study, in which the subjects read words presented only in primary gaze.*

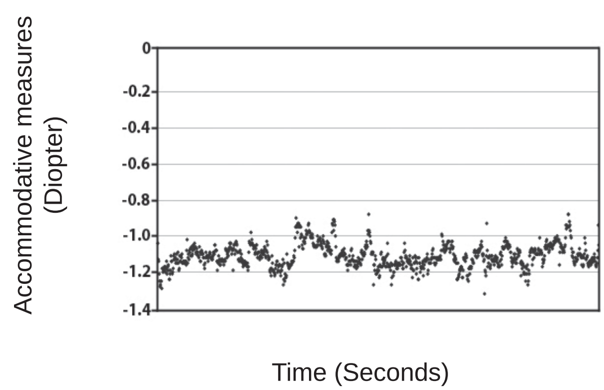


*Figure 2: Accommodative response of primary gaze at various viewing distances. The bars are showing 84% confidence interval of the measures. Non-overlapping bars were significant at p < 0.05.*

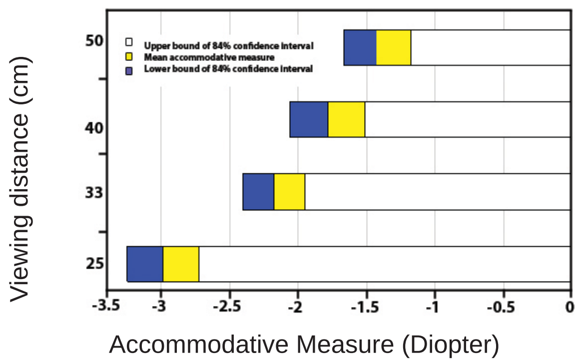
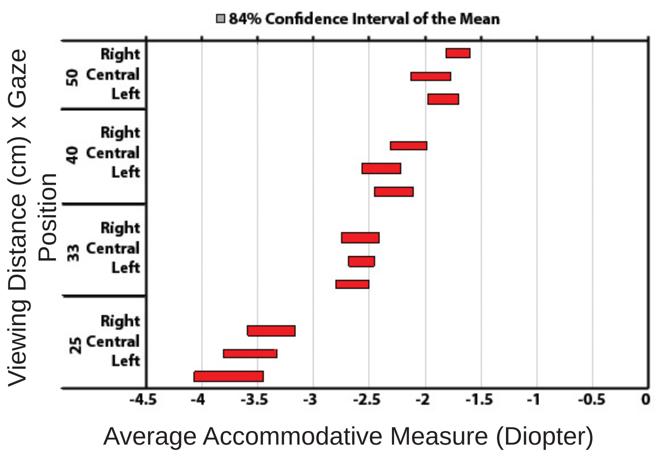



*Figure 3: Accommodative response across eccentric visual angles at various viewing distances*




at the primary gaze position, right under the middle (0°) letter. 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 series of 30-second measures were made with the iPAQ on the WAM-5500 reading rod.

In the final condition, the subject read 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). This font size was one of two available on the smartphone, and subtended the same visual angle as the larger desktop monitor font due to distance magnification. A pilot test was conducted to be sure that the accommodative measures derived from the edges of the small text window of the iPAQ were no different from the measures obtained in primary gaze. At the four testing distances the edges of the line of text required eccentric gazes of +/- 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. Then the dot was removed and the text was revealed for continuous reading.

## RESULTS

### Statistical Analysis

Trimming to two standard deviations above and below the mean eliminated outlying data for each subject and testing condition. This is a standard statistical procedure for noisy data when the reason for the noise is explainable, in this case, with blinks. Figure 1 shows the comparison of data before and after trimming.

SPSS® general linear model within subject analysis of variance (ANOVA) was used for analysis. Graphs were constructed to compare the means using confidence intervals constructed such that non-overlapping intervals were significantly different at an unadjusted p<0.05. This was accomplished by constructing the 84$^{th}$ percent confidence interval around each mean.[16] In constructing this confidence interval, the standard error (SE) for a single mean was estimated using the standard error of the differences (SED) in the following formula: SE = SED/(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 between the non-overlapping confidence intervals and the t-tests (F (3, 21) = 132.594, p < 0.0001).

### Sensitivity of Primary-Gaze Accommodative Measures to Viewing Distance

The first test measured the sensitivity of Grand Seiko to different viewing distances while looking straight ahead at the target. The expected accommodative demand is -2.0 D at viewing distance of 50 cm, and increases stepwise as viewing distance decreased to 40 cm, 33 cm, and 25 cm.

ANOVA demonstrated a significant effect of viewing distance on the accommodative response. Within-subjects comparison identified a significant linear trend. Pairwise comparisons show significant difference among the five viewing distances. Figure 2 illustrates the estimated mean accommodative response at the four viewing distances. This result suggests that the measures are sensitive to the change of viewing distance.

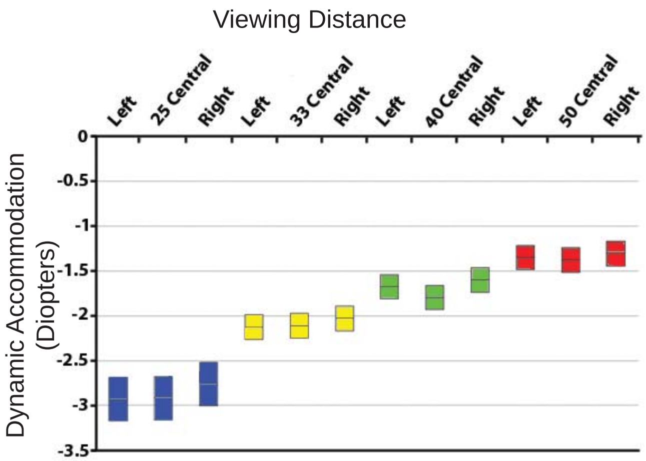
### Accommodative Measures Across Eccentric Distances and Viewing Distances

Figure 3 shows the consistency of accommodative measures across eccentricity at 50 cm. 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 (F(1.847, 12.931) = 0.515, p = 0.596). This suggests that Grand Seiko measurements are stable at least within 15° from the central fixation point; however, the result of no significant difference may be due to the small sample size. Further investigation is needed to refine the horizontal boundary of the Grand Seiko measures.

### Accommodative Measures During Reading

Accommodative response is presumed only to be dependent on working distance. However, off-axis measures of ac-

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




commodative response in secondary gaze may make accurate determination difficult. Therefore a pilot test was conducted to examine the consistency of the Grand Seiko measurements 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 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 particular test visual angle (Figure 4).

A significant effect of viewing distance on the average measure of the continuous accommodative recordings 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 shows the average accommodation and its variation at the tested distance.

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 that there is no systematic deviation from identity across all viewing distances.

## DISCUSSION

Accommodative dysfunction is an established cause of discomfort with near work, yet is difficult to measure after the completion of the asthenopia-inducing task.[17] This gap between symptom-inducing tasks and the direct measurement of the visual system dysfunction has traditionally been addressed with dynamic retinoscopy. Dynamic retinoscopy techniques such as MEM, bell, and book retinoscopy are extremely valuable in the hands of the experienced clinician. However, they require practiced skill and are limited in the number of data points they can collect. What is needed is a

*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.*

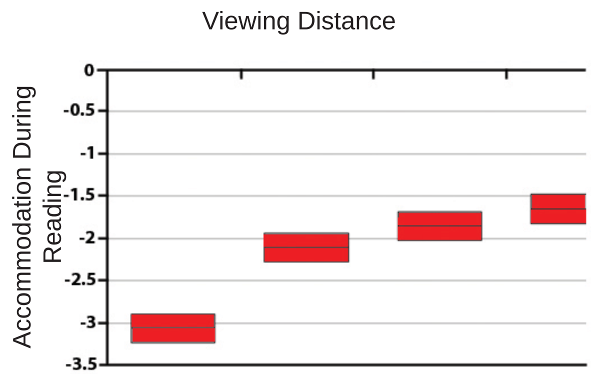
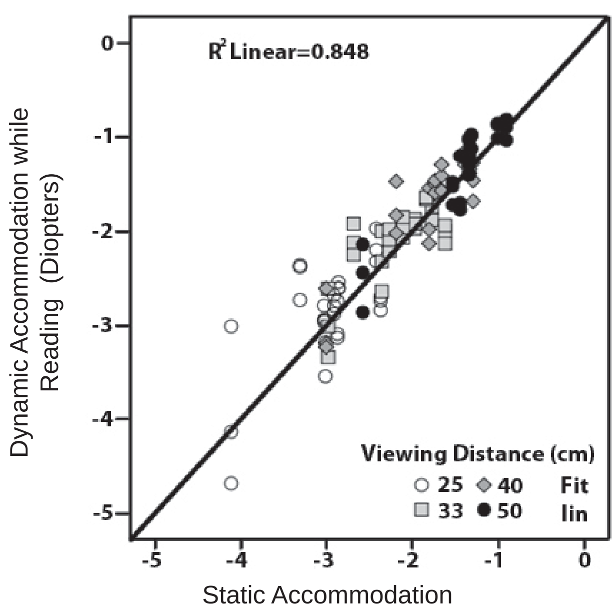



*Figure 6. The relationship between static accommodation at baseline and dynamic accommodation while reading. The line in the chart is the line of identity for reference rather than the regression line.*




continuous way to measure the accommodative response during reading of continuous text.

Open-field autorefraction can address this need. The Grand Seiko WAM-5500 autorefractor can be used to measure the accommodative response and pupil size up to five times per second. What was previously unknown is that the WAM-5500 can also be used effectively while the patient reads actual continuous text, like a book, within certain parameters. The visual angle data shows that measures conducted at ±15º of primary gaze are within 0.25D of baseline in all but one subject. This seems to demonstrate that off-axis effects are minimal when using this instrument. Accommodative lag shows a regular increase with closer working distances, as expected from dynamic retinoscopy.

Not every working distance is measurable with open-field autorefraction. Gaze fixation and reading test analysis proved useful in this regard. 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 tolerant of off axis viewing at ±7.5º. Within this angular limit, it is shown that the WAM-5500 will likely perform accurately at 33 cm, 40 cm, and 50 cm. Beyond that, dynamic retinoscopy like the MEM technique will need to be used.

Other limitations of this technique include vertical window size (limited to 2-3 text lines due to upper lid interference with the Grand Seiko), and most notably, lack of proprioceptive input. This latter drawback is shared with many other traditional techniques used to measure visual performance at near, including any that use the reading rod that attaches to the phoropter in much the same way it does to the Grand Seiko. The fact that the patient cannot localize the reading material by holding it may simulate symptoms experienced during the use of a desktop computer. However, when symptoms exist for patients for whom proprioception is a factor (such as those reading hard copy, using a tablet display or electronic reader), open-field autorefraction cannot replace classic near visual stress measurement techniques, such as book retinoscopy.

## CONCLUSIONS

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.

Although open-field autorefraction will never replace dynamic retinoscopy in the hands of an experienced clinician, it has certain advantages. For use in research, continuous accommodative and pupil measures can be obtained with minimal operator training. For clinical use, open-field autorefraction allows for accommodative amplitudes to be measured objectively for the first time. Lastly, this study showed the use of a handheld video display instead of static near cards holds great promise to simulate modern accommodative demands and hold patient interest.

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