Accommodation to an Isolated Light Emitting Diode (LED) Target

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Abstract

Steady-state accommodative responses to a standard white LED light were compared to a high contrast reduced Snellen chart with normal room illumination under binocular and monocular viewing conditions. These responses were also compared to a diffuse transilluminator beam. Targets were presented at 2m, 0.5m, and 0.25m test distances, and the accommodative responses were objectively assessed. During the LED and transilluminator presentations, the room illumination was extinguished, and the subjects focused upon the center of the light. The Snellen chart was viewed under normal room illumination. Subjects focused on a 20/30 word at 0.5m and 0.25m and on the 20/150 word at 2m. For all conditions, there was no statistical difference in the mean accommodative response at each stimulus level. However, for all conditions, the individual accommodative responses to the LED and the transilluminator beam were consistently less accurate and more variable than found for the Snellen chart. An LED light or a transilluminator beam would be an adequate stimulus to drive the overall steady-state accommodative response under similar viewing conditions, although not as optimally as the Snellen chart.

Key Words

accommodative stimuli, ocular accommodation, proximal accommodation, Snellen chart, transilluminator beam target, vergence accommodation, white LED target

INTRODUCTION

Accommodation refers to the ability to alter the dioptric power of the crystalline lens of the human eye to focus and maintain high resolution of the retinal image on a target of interest.[1] This process occurs under a wide range of viewing conditions. It involves: optical, sensory, motor, perceptual, cognitive, pharmacological, and biomechanical aspects**.** Consequently, it represents a complex neurological control process. The accommodative system has four components: blur, vergence, proximal, and tonic**.** Under normal binocular viewing conditions, these components act in concert and in a non-linearly manner to produce the aggregate response.[2]

Numerous laboratory investigations have been conducted to evaluate the relative accuracy of the steady-state accommodative response using a wide array of targets. A spectrum of stimulus attributes such as size, color, contrast, spatial frequency, chromatic aberration, and luminance have been found to influence the steady-state accommodative response. Nevertheless, there has been shown to be maintenance of relatively good accuracy over a wide range of target conditions.[1]

With advancing imaging technology, several non-invasive measurement techniques have evolved to study vision-related brain functions. These include: positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and magneto-encephalography.[3] More specifically, the neural basis of visuomotor actions imaged using fMRI technology is an ever increasing topic of interest in the field of visual neuroscience.

These neuroimaging techniques have frequently employed light emitting diodes (LEDs) as visual stimuli.[4,5] For example, a recent PET study used LEDs that varied in physical distance to study the human accommodative/vergence neural network.[5] LED lights have also been used as fixation targets in numerous visually-guided motor studies,[6] presumably providing some degree of accommodative guidance. In addition, LEDs have been used as fixational targets in several oculomotor studies that assessed accommodation and vergence.[7,8] LEDs were used as targets in several ocular and brain imaging studies. These studies assessed accommodation and related oculomotor aspects and raised a question of particular interest; namely, would a relatively diffuse light source, such as an LED, lacking in apparent detail, comprise an effective accommodative stimulus (AS) when viewed in isolation? Such testing of accommodative accuracy and overall responsivity has not been conducted previously.

The present study evaluated monocular and binocular steady-state accommodative responses (AR) to an isolated white LED in an otherwise totally darkened room**.** Further, the study compared its responsivity to a high contrast Snellen chart under normal room illumination, considered to be the "gold standard" AS.[1] In addition, the responses were compared with a diffuse transilluminator beam that has been reported to be a poor AS.[9,10]

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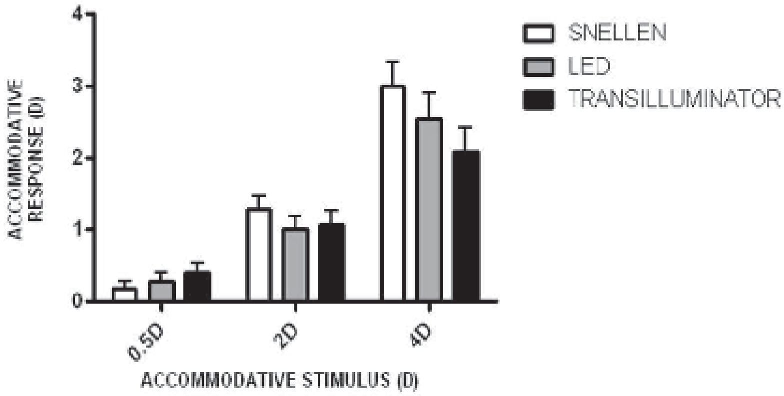

Figure 1: Mean (+1SEM) monocular accommodative responses for 3 different targets at 3 stimulus magnitudes.

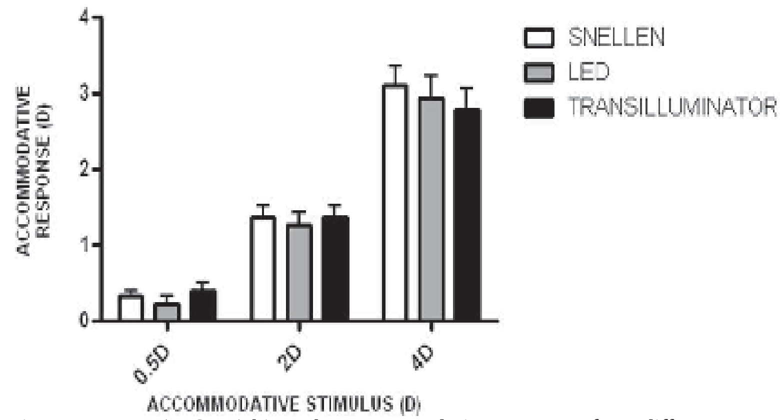

Figure 2: Mean (+1SEM) binocular accommodative responses for 3 different targets at 3 stimulus magnitudes.

METHODS

Subjects

Sixteen visually-asymptomatic, young-adults were recruited from the student population of the SUNY, State College of Optometry. Ages ranged from 22 to 31 years, with a mean of 26.2, ± one standard error of the mean (SEM) of ± 1 year. The subjects denied having been diagnosed with any binocular dysfunction. None had systemic, ocular, or neurological disease, nor were they taking any drugs or medications that would adversely affect accommodation. Many had some degree of experience in vision experiments. Subjects included emmetropes (n=4) and myopes (n=12). Emmetropes had a spherical equivalent refractive range of +0.50 D to -0.50 D, with a mean ±SEM of -0.25 ± 0.37 D. Myopes had a spherical equivalent refractive range of -0.50 D to -6.50 D, with a mean ±SEM of -3.75 ± 1.75 D. Astigmatism was ≤ 1.00D. All had 20/20 or better Snellen visual acuity in the distance and near in each eye with either their current spectacle or contact lens prescription. Informed consent was obtained from each subject after the nature of the study was explained. The research followed the tenets of the Declaration of Helsinki and was approved by the College's Internal Review Board.

Instrumentation

Static ARs were objectively measured using a commercially-available, open-field, infrared autorefractor.[a] The instrument's measurement range is from –22.00 to +22.00 D sphere with an apparent resolution of 0.01 D, from 0 to 10.00 D cylinder with a resolution of 0.01 D, and from 0 to 180º cylinder with a resolution of 1º. Based on the manufacturer's specification, it has ±0.25 D accuracy when measured between +10.00 and –10.00 D range. In the static mode, the instrument samples the accommodative state in 70 milliseconds.

Test targets

Three different targets were used: a high contrast (>90%) reduced Snellen chart whose luminance was 35 cd/m^2; a 4mm diameter white LED (460-555 nm)[b] whose luminance was 50 cd/m^2; and a standard ophthalmic transilluminator beam (3.5V halogen fiber-optic transilluminator)[c] with a 3mm diameter and 200 cd/m^2 luminance. Targets were presented at 2m, 0.5m, and 0.25m, corresponding to AS levels of 0.50 D, 2.00 D, and 4.00 D, respectively. At 2m, 0.5m, and 0.25m, the visual angle subtended by the LED was 0.11, 0.46, and 1.15 degrees, respectively, and the visual angle subtended by the transilluminator beam was 0.08, 0.34, and 0.86 degrees, respectively. At 2m, 0.5m, and 0.25m, the visual angle subtended by the word on Snellen chart was 0.57, 0.23, and 0.14 degrees, respectively. A white LED light was chosen over a monochromatic LED light**.** Accommodation to monochromatic light has been reported to be less accurate than accommodation to a full spectrum white light target. This is because of the absence of ocular longitudinal chromatic aberration with the monochromatic light.[11] The latter factor is a major directional cue for accommodation.[1]

Test procedure

Subjects sat comfortably with their head and chin in the head/chin rest of the autorefractor. Stimulus presentation was counterbalanced. During the LED and transilluminator presentations, subjects were asked to focus upon the center of the light. With the room lights completely extinguished, the only source of light in the test room was from either the LED or transilluminator test stimuli viewed against an empty background. The light from the auto-refractor's screen was masked using black matte cloth to avoid any external source of light. The Snellen chart was viewed under normal room illumination. Subjects fixated a 20/30 word at 0.5m and 0.25m and a 20/150 word at 2m. They were instructed to "keep the target in focus." Steady-state AR were measured under binocular viewing conditions in all 16 subjects, and also under monocular viewing conditions (with the left eye completely patched) in nine of the 16 subjects (two emmetropes and seven myopes). Monocular and binocular viewing conditions were randomized for the nine subjects, and both conditions were completed on the same day. The autorefractor was aligned with the right eye, and 10 measurements were obtained. For each target, viewing condition and AS, the AR was the average (spherical equivalent) of 10 measurements. The astigmatic component did not vary significantly (≤0.25D) between the 10 measures in each subject.

RESULTS

Table 1 shows the group mean (+1SEM) AR under monocular and binocular conditions for the three different target conditions at the three different AS levels. Figures 1 and 2 present the results at each AS level under monocular and binocular viewing conditions, respectively. A two-

Table 1 showing mean (+1SEM) accommodative response (top) and mean (+1SEM) lag (bottom *Italicized*) for monocular and binocular conditions for 3 different targets at 3 stimulus magnitudes. S-Snellen; L-LED; T-Transilluminator

	0.5D			2D			4D		
	S	**L**	**T**	**S**	**L**	**T**	**S**	**L**	**T**
Accommodative response **Monocular**	0.19(0.1)	0.28(0.12)	0.41(0.13)	1.28(0.19)	1.01(0.19)	1.07(0.19)	3.01(0.33)	2.55(0.35)	2.08(0.35)
Lag	*0.31(0.1)*	*0.21(0.13)*	*0.08(0.13)*	*0.71(0.14)*	*0.99(0.11)*	*0.92(0.12)*	*0.98(0.18)*	*1.44(0.18)*	*1.91(0.25)*
Accommodative response **BInocular**	0.32(0.09)	0.23(0.09)	0.40(0.1)	1.37(0.15)	1.31(0.15)	1.37(0.16)	3.11(0.25)	2.95(0.28)	2.78(0.29)
Lag	*0.18(0.07)*	*0.26(0.11)*	*0.09(0.1)*	*0.62(0.09)*	*0.68(0.07)*	*0.62(0.1)*	*0.88(0.11)*	*1.04(0.09)*	*1.21(0.16)*

way, repeated-measures analysis of variance (ANOVA) with factors of target type (Snellen, LED and transilluminator) and viewing condition (monocular and binocular) was performed at each AS level. At the 4D stimulus level, no significant effect was found among the target types (F [2, 48] = 1.61; p= 0.21) or viewing condition (F [1, 48] = 1.41; p = 0.24). Interaction effects were not significant (F [2, 48] = 0.33; p = 0.71). Similarly, at the 2D stimulus level, there was no significant effect among the target types (F [2, 48] = 0.64; p = 0.53) or viewing condition (F [1, 48] = 0.20; p = 0.65). Interaction effects were not significant (F [2, 48] = 0.09; p = 0.91). Lastly, at the 0.5D level, similar results were found showing no effect among the target types (F [2, 48] = 1.02; p = 0.36) or viewing condition (F [1, 48] = 0.58; p = 0.45). There was no significant interaction (F [2, 48] = 0.40; p = 0.67).

Stability of the steady-state AR was assessed using a measure of variability of the 10 responses to each target type at the 4D stimulus level under the monocular viewing condition. This highest stimulus level was selected; since it is predicted to exhibit the greatest level of accommodative oscillation[12] and slow drift, especially under the monocular viewing condition without presence of vergence-driven accommodation.[1] A one-way ANOVA showed no significant difference (F [2, 24] = 1.754; p = 0.19) in the response variability (as ±SEM) between the Snellen (0.05±0.02D), LED (0.06±0.03D), and the transilluminator (0.08±0.04D) targets.

A number of subjects accommodated more accurately under the monocular viewing conditions with the Snellen versus the LED target, as well as for the Snellen versus the transilluminator beam. This was compared statistically using the non-parametric binomial test. Results revealed no significant difference for either the 0.5D (p = 0.5) or 2D (p = 0.09) levels between the Snellen and LED targets. There was a significant difference (p = 0.002) at the 4D stimulus level between the Snellen and LED targets.

Similarly, between the Snellen and the transilluminator beam, there was no significant difference for either the 0.5D (p = 0.54) or 2D (p = 0.5) levels. There was again a significant difference (p = 0.002) at the 4D stimulus level. Thus, at the 4D stimulus level, significantly more subjects accommodated more accurately for the Snellen target versus either the LED or transilluminator targets.

DISCUSSION

The results of the present study revealed no statistically significant differences in the mean steady-state ARs between the white LED and the high-contrast Snellen chart for any of the three test distances and two viewing conditions. These findings suggest that the white LED was an effective AS over the range of intermediate and near distances tested. Similarity of the monocular and binocular AR for all conditions could be due to limitations of AR level dictated and limited by the eye's depth of focus.[13] Thus, each target was found to be an effective AS, if not an optimal one.

Variability of the steady-state AR measured from the 10 AR obtained with each target type at the 4.00D stimulus level under monocular viewing condition revealed no significant difference among the three target types tested. As previously stated, this stimulus level was chosen due to higher accommodative fluctuations at 4.00 D when compared to the other stimulus levels, and hence more overall variability would be expected.[12] This would have the potential to exhibit differential variability.

Although the statistical analysis revealed no significant difference, the mean ARs to the LED were consistently less accurate than found for the Snellen chart by up to nearly 1.00 D, and exhibited slightly greater variability. While the LED target lacked specific detail centrally, when projected in the dark, its relatively discrete edge effects may have driven the blur aspect of the accommodation system. However, there may be a different or additional explanation. Considering the target distances used in the present study, it is predicted that a diffuse white LED lacking in specific detail would not stimulate blur-driven accommodation. Rather, it would stimulate proximal accommodation under the monocular viewing condition, and proximal combined with vergence accommodation under the binocular viewing condition.[14] This is based on Hung et al's[2] model findings. It suggests that the proximal influence and its drive to the accommodative system would be negligible only when the main direct feedback components of blur and disparity were present. This is supported by recent empirical findings.[15] However, with blur cues absent (i.e., open-loop), proximal accommodation would, by default, have a substantial (i.e., gain = 0.5) motor contribution (see also Rosenfield et al[14]). In the present study, the aggregate AR alone was measured. The individual component contributions from the blur and proximal accommodative motor outputs could not be distinguished.

The results for the transilluminator beam target were also statistically similar to the LED and the Snellen chart. AR was consistently lower for the Snellen chart with all subjects under monocular and binocular viewing conditions at the 2.00 D and 4.00 D stimulus levels. While the transilluminator target used in the present study lacked any central detail, luminance-based edge effects when projected in a dark room might have driven the accommodation system.

The 0.50 D AS represents a somewhat unique case. There was no statistically significant difference between the AR for the transilluminator and Snellen conditions at the 0.50 D level. The mean transilluminator AR was closer dioptrically to the AS than with the Snellen target. A possible explanation is that: under reduced or degraded stimulus conditions, the AR would shift towards the tonic accommodation level of about 0.5D.[16] Thus, one would actually predict that in the presence of a poor accommodative stimulus, the AR would be about 0.5D. This happens coincidentally to be the AS level. With a more optimal AS, such as the Snellen target at 0.5D or so, the AR might actually be a bit less dioptrically, due to the latitude provided by the depth of focus. Especially under the monocular condition (open-looped vergence), in the presence of a poor blur-driven stimulus, the AR tends to shift towards the tonic level. This effectively increases the response level with the transilluminator when compared to the AR with the Snellen target.

The present results are not consistent with the findings of Owens et al,[9] and Rosenfield.[10] They reported that the accommodative state with a bright, diffuse retinoscopic beam target was close to the default tonic accommodative level under monocular viewing conditions, even at the closer distances. The lack of agreement between findings may be due to differences in the stimulus conditions and proximal contribution influence, as well as the apparent absence of edge effects with their specific diffuse target. However, there may be another reason for these differences**.**The empty-field laser refraction values reported by Owens et al[9] were considerably higher than the contemporary tonic accommodation values (about 0.50-1.00D). This was presumably due to the proximal influence of the laser speckle pattern used in their optometer. These values were also correlated with the near retinoscopy values, that might have had a significant proximal contribution in their study when tested at a near distance. Similarly, the individual near retinoscopy values (at 40cm) and AR measured in the dark reported by Rosenfield[10] were poorly correlated (r = 0.03) and demonstrated many higher values (e.g., 3.14D, 3.40D, etc) of tonic accommodation than expected with more modern instrumentation.[16] Again, this could be attributed to the proximal influence at the tested near distance.

The parametric analysis revealed no significant difference among the three targets. However, additional non-parametric directionally-based response analysis using the binomial test indicated that most of the subjects responded significantly more accurately to the Snellen target, as compared to either the LED or the transilluminator beam. This was true at least at the highest stimulus demand (4.00 D) where the accommodative error would be expected to be maximal via proportional control.[17] This indicates that at the highest AS magnitude tested, the Snellen target was in reality more effective than either the white LED light or the transilluminator beam in evoking the most accurate AR in most subjects.

Summary

Our findings indicate that both LED and a diffuse transilluminator beam were sufficiently effective under the present stimulus conditions in driving the overall steady-state AR. It was most accurate for the Snellen chart target. Hence, if required for specific test condition demands, either an LED or even a transilluminator containing our specific AS attributes would be sufficient to stimulate blur-driven and proximally-driven accommodation under monocular viewing conditions. An example would be for use in accommodative tracking in an functional magnetic resonance imaging (fMRI). However, under binocular viewing conditions, for example vergence tracking in an fMRI system, it would be less critical. The robust vergence-accommodation stimulus would then supply a substantial additional drive to the accommodative system.[14,15] Thus, to ensure adequate stimulus effectiveness under one's specific test environment, AR should be assessed objectively prior to commencement of the study.

Lastly, our findings have an important clinical implication with respect to vision therapy strategy. The clinician may elect to use a non-optimal AS, such as an LED or transilluminator, during the initial stages of the therapy to reduce the accuracy demand on the accommodative system. A large LED or transilluminator target would be initially used, and then reduced in size to make the task more difficult. This would allow the patient to succeed with the task, as greater system error would be tolerated without penalty. Then, as the treatment progressed, an optimal AS such as the Snellen target requiring more accurate focusing could be used to fine-tune the focusing ability.

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Note

The authors have no proprietary interest in any of the equipment used in this study.

Sources

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b. The LED Light Inc, 1617 Fairview Dr., Carson City, NV 89701-6868, theledlight.com
c. Welch Allyn Inc, 4341 State Street Road Skaneateles Falls, NY 13153-0220

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