Subject Instructions and Methods of Target Presentation in Accommodation Research

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Purpose. The authors investigated the potential of subject instructions to alter the static accommodative stimulus–response function. They also investigated whether the reduced cue environment of the Badal optical system leads to accommodative responses different from those that occur for targets presented in real space.

Methods. Static accommodative responses with three focusing instructions were compared to baselines obtained with minimal instruction to stabilize gaze. Static accommodative responses were recorded for targets presented in real space and in a Badal optical system.

Results. Individuals differ widely in their responses to Instruction 1 ("...make no special effort..."), although some adopt a relatively fixed position of focus. Responses with Instruction 2 ("...look at the words naturally...") and Instruction 3 ("...carefully focus...") are not significantly different from each other, but differ slightly from the responses with the baseline instruction ("pick a word in the middle of the block of text and look at it"). In a sample including most subjects, mean responses for Badal and real space targets are identical. However, it appears that some subjects have difficulty accommodating for Badal targets.

Conclusions. The authors recommend the use of Instructions 2 and 3 for investigation of the static accommodative response, with a number of provisos. Accommodative responses to Badal and real space targets are generally equivalent, but researchers should take care to identify those persons who have difficulties accommodating for Badal targets. Invest Ophthalmol Vis Sci. 1994;35:528–537.

Within the field of accommodation research, interest in subject instructions developed after various studies of the spatial frequency response function of accommodation yielded widely conflicting results.1–5 Owens suggested that subject instructions might account for some of these differences.6 Ciuffreda and Hokoda demonstrated that instructions could markedly affect the accommodative response to sinusoidal gratings.6 Although viewing grating targets at a stimulus level of 6 D, the responses of a single experienced subject varied by up to 3.5 D between instructions. Thus it would appear that instructions, acting through voluntary or higher order control, have the potential to alter significantly the accommodative response.

However, the effects of subject instructions on the static accommodative stimulus–response function have not yet been systematically investigated. If the aim of a particular study is to determine how people normally accommodate in a given situation, it would be important to know that the subject instructions are not significantly biasing the response in a particular direction.

Optical presentation of targets is popular in accommodation research, and systems based on the Badal principle7,8 are common. However, no research has yet demonstrated that response functions for Badal targets are identical to those for targets presented in real space. The Badal system removes a number of the monocular depth cues which, through proximal accommodation, are thought to play a role in directing the overall accommodative response.9 Furthermore, the awareness of the physical proximity of an object may affect the accommodative response, irrespective of its dioptric distance. For example, the "instrument
myopia suffered by microscope users has been partly attributed to the users accommodating for what they believe is a close object, although this hypothesis has been disputed. Apart from the possibility of small biases in the response with Badal targets, there have been incidental reports of definite subject difficulties in Badal systems—interestingly, for both experienced and inexperienced subjects.

This study aimed to determine which subject instructions are appropriate for investigation of the accommodative stimulus–response function and whether Badal system response functions are equivalent to those for real space targets.

METHODS

Subjects
Thirty-five adolescents and young adults (age range, 15 to 27 years) participated as subjects in the study. They were first-year optometry students, nonacademic staff members of the university, and members of the general public. None had previous experience as subjects in accommodation research, and all were unaware of the true purpose of the experiment. One subject participated in a pilot run of the experiment using the original protocol. Thirty-four subjects participated in the study proper with a final (but modified) protocol, although only data collected for 24 of these subjects could be used in the analysis. Five subjects were excluded because of errors implementing the protocol. Five more subjects were excluded because of high artificial cylinder values in the Canon Autoref readings attributed to corneal irregularity (one subject), moderate to high myopia (two subjects), or unknown origin (two subjects). Distance monocular visual acuities measured with a wall chart were 6/7.5 or better in both the left and the right eye. Amplitudes of accommodation by a subjective push-up method were found in a preliminary experiment to have negligible effects on Autoref readings.

Subjects gave informed consent to participation in the experiment on the understanding that a number of specified routine optometric procedures would be performed. However, subjects were not initially informed that refraction readings provided by the Autoref optometer would later be used to determine accommodative level. An awareness that accommodation was being measured might have biased the responses. The research followed the tenets of the Declaration of Helsinki and was also approved by the Queensland University of Technology Biomedical Ethics Committee.

Apparatus
The accommodative response was measured using a Canon Autoref R-1 infrared optometer operating in its standard mode. The refraction readings provided by the Canon were calibrated against subjective refraction in a separate experiment. Cyclopentolate 0.5% was instilled in a number of eyes (n = 6), and their refractive errors were altered by hydrophilic contact lenses to simulate various degrees of accommodation (refractive ametropia). For each contact lens in place, both best sphere subjective refraction and Canon Autoref best sphere refraction were recorded. The mean calibration equation thus obtained was used to modify all later experimental Canon Autoref readings.

A calibrated scale was used to measure horizontal pupil diameters from a monitor displaying an image of the subject's right eye.

All targets had the same general form and angular dimensions regardless of presentation method or stimulus distance. The target was a block of high contrast text, 5° wide, set in Times Roman font. A letter height of 6/15 Snellen equivalent was used. The letter size was chosen to provide fine spatial detail at a few lines above acuity threshold. Gaze shifts within the 5° block of text were found in a preliminary experiment to have negligible effects on Autoref readings. A black surround field (22° X 24°) screened surrounding objects from view. All targets were set to a luminance of approximately 15 cd/m², which is sufficient to allow an accurate response function.

Targets were constructed for presentation in real space at nominal target distances of 2 m (0.5 D), 50 cm (2 D), 25 cm (4 D), and 16.7 cm (6 D), all based on the previously described dimensions. An optical stimulus presentation system based on the Badal principle was mounted on top of the Canon Autoref to present targets at stimulus levels similar to those presented in real space (Fig. 1). The system was a non-Maxwellian view and provided accommodative stimuli referenced to an arbitrary entrance pupil 3.05 mm behind the corneal vertex. Normal Autoref alignment procedures automatically placed the anterior focal point of the Badal lens very close to this arbitrary entrance pupil. An afocal telescope and ophthalmic trial lenses were used to determine the actual stimulus level at each nominal target setting for both the real space and Badal targets.

Procedures
A pilot run of the experiment was initially performed with one subject. This subject had difficulties relaxing focus to the 0.5 D Badal target after first focusing to the higher stimulus levels. As a precaution, the original protocol was modified to present targets always in ascending order of stimulus level.

Subjects were a measured subjective refraction throughout the experiment, but generally, for cylindrical components of less than 0.50 DC, a best sphere correction was worn. With full subjective refractions...
in place, targets could be placed at set stimulus levels for all subjects. Lens effectivity was negligible for all but one subject with myopia (subject 8, right eye refractive error −3.9 DS) and was not considered in later calculations. Comparisons between conditions would still have been valid for this subject. Natural pupil sizes were used throughout and ranged between 2.7 mm and 8.4 mm horizontal diameter in the right eye, depending on the particular subject and stimulus distance. Average minimum and maximum pupil sizes were 4.2 mm and 6.6 mm, respectively.

Measurements of the accommodative response to real space targets were first made under both binocular and right eye monocular viewing conditions with the instruction "pick a word in the middle of the block and look at it." This instruction was required for stabilization of gaze and subsequent measurement of accommodation with the Autoref. The responses recorded with this instruction were used as baselines against which the effects of three focusing instructions could be compared (see Discussion). The order of testing under monocular and binocular conditions was counterbalanced between subjects. Five to ten readings of accommodation were taken from the right eye at each stimulus level in the experiment.

Each subject was then introduced to a particular instruction, of which there were three, one instruction for each group of eight subjects. Each subject was assigned to a group based on order of presentation. Instructions were stated to the subject almost verbatim and without elaboration. To avoid the possibility of differential carry-over effects, each subject received only one of the three instructions.

Subjects in Group 1 received Instruction 1: "For the rest of this experiment, I want you to look at the words but make no special effort to focus on them. Let your eyes relax and let them choose a focus." This was a modification of an instruction used by Owens in the study of the Mandelbaum effect. Subjects in Group 2 received Instruction 2: "For the rest of this experiment, I want you to look at the words naturally, the same as you would when normally reading a book or sign at the same distance." This was a modification of instructions used by Owens and Giuffreda and Hokoda. Subjects in Group 3 received Instruction 3: "For the rest of this experiment, I want you to look at the words and carefully focus on them so that they are maximally sharp and clear at all times. Do not let the words become blurred by the slightest amount at any time." This was a modification of instructions used by Charman and Tucker and Giuffreda and Hokoda.

The results of this study should not be taken as indicative of the usefulness of the original sources in instructions. In the cases of Instructions 1 and 3, significant changes were made to the original sources in an attempt to increase anticipated differences in accommodative responses. Also, the source for Instruction 1 was only ever intended for use in a specific situation—the study of the Mandelbaum effect.

The right eye monocular accommodative response was then measured for targets presented in real space and in the Badal system at the various stimulus levels. Presentation method order (real space or Badal) was counterbalanced between subjects. The instructions were repeated intermittently throughout the experiment.

At the conclusion of the experiment, subjects were questioned about their believed ability to alter focus voluntarily and about whether they had been consciously altering focus during the latter part of the experiment.

**Analysis**

Sphero-cylindrical readings from the Canon Autoref were converted to best sphere values and a mean of usable readings calculated. The mean Autoref readings were converted to an accommodation response referred to an arbitrary principal plane 1.55 mm behind the corneal vertex, using the calibration equation previously obtained.

Accommodative error was used as the dependent variable in all analyses and was obtained by subtracting the accommodative stimulus from the accommodative response. Three analyses of variance were performed: the first for all three groups as a whole, the second for Group 1 separately, and the third for Groups 2 and 3 taken together. The decision to perform a number of separate analyses of variance was based on the results of post hoc comparisons from the analysis involving all three groups (see Results). Analyses of variance
variously used the between-subjects factor of Subject Group (three levels: group 1, group 2, group 3), the two within-subject factors of Viewing Condition (four levels: baseline real space binocular; baseline real space monocular; real space monocular with focusing Instruction 1, 2, or 3; Badal monocular with focusing Instruction 1, 2, or 3), and Stimulus Level (four levels: 0.5 D, 2 D, 4 D, 6 D). Note that the factor of Subject Group is not interchangeable in meaning with "Instruction." This is because the focusing instructions were only applied to the last two Viewing Conditions: in the first two Viewing Conditions, the baseline instruction was used. Although there were small differences between nominal and actual stimulus levels (for a nominal 6 D stimulus, the target in real space was at 6.125 D, and for Badal viewing it was at 5.875 D), these differences were ignored for simplicity of analysis and the nominal stimulus was used as a categorical variable.

To control the error rate throughout the experiment and to retain statistical power, only those post hoc comparisons answering specific hypotheses were tested. In determining the significance of a result, an approach recommended by Keppel was followed.19

RESULTS

All Subjects

Mean baseline stimulus–response functions demonstrate the classic form20 having a lead of accommodation at the lower stimulus levels and a lag at the higher stimulus levels (Fig. 2). Baseline binocular and monocular responses are not significantly different from each other (Table 1, comparison 1), in agreement with previous research.21

There are significant differences in the responses between Groups 1, 2, and 3 (ANOVA, $F_{2.21} = 10.8, P < 0.0006$); however, these trends are complicated by significant interactions between the factors of Subject Group, Viewing Condition, and Stimulus Level (ANOVA, Viewing Condition $\times$ Subject Group, $F_{6.63} = 13.2, P < 0.0001$; Stimulus $\times$ Subject Group, $F_{6.63} = 17.8, P < 0.0001$; Viewing Condition $\times$ Stimulus, $F_{9.189} = 10.4, P < 0.0001$; Viewing Condition $\times$ Stimulus $\times$ Subject Group, $F_{18.189} = 13, P < 0.0001$). Mean responses in Groups 2 and 3 are not significantly different from each other, but when taken together they are significantly different from the responses observed in Group 1 (Table 1, comparisons 2 and 3). Confidence intervals can be constructed for the true difference in mean response functions with Instructions 2 and 3. An average of the baseline binocular and monocular responses is subtracted from the real space or Badal response, and this parameter (the "difference from baseline") is used to compare Instructions 2 and 3. There appear to be no systematic differences between response functions for Instructions 2 and 3, although differences of up to 1 D are possible for any given stimulus level:

Confidence intervals for the differences in means mean Instruction 3 "difference from baseline" less mean Instruction 2 "difference from baseline" and associated 95% confidence intervals (diopters)

**FIGURE 2.** Mean accommodative error as a function of stimulus for (a) Group 1 ($n = 8$), (b) Group 2 ($n = 8$), and (c) Group 3 ($n = 8$). Responses with the baseline instruction are plotted for real space binocular viewing (crossed squares) and real space monocular viewing (hollow squares). Responses under the respective instructions are denoted by half-filled symbols: real space monocular viewing with Instruction 1, 2, or 3 (half-filled squares), Badal system monocular viewing with instruction 1, 2, or 3 (half-filled diamonds). Groups 1, 2, and 3 received Instructions 1, 2, and 3, respectively in the non-baseline conditions. Note the differences in scale between the various ordinates. Note that all plots have been staggered along the abscissae for clarity. Error bars represent between-subject variability and denote $\pm$1 SD.
TABLE 1. Single Degree of Freedom Comparisons and Their Outcomes

<table>
<thead>
<tr>
<th>Comparison Number</th>
<th>Group(s)</th>
<th>Comparison</th>
<th>Qualifications</th>
<th>F</th>
<th>P</th>
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<tr>
<td>1</td>
<td>All</td>
<td>BaseBin vs BaseMon</td>
<td>All stimulus levels</td>
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<td>0.63</td>
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<td>2</td>
<td>2, 3</td>
<td>Group 2 vs Group 3</td>
<td>All viewing conditions and stimulus levels</td>
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<tr>
<td>3</td>
<td>All</td>
<td>Group 1 vs (Group 2 and Group 3)</td>
<td>All viewing conditions and stimulus levels</td>
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<tr>
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<td>2, 3</td>
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<td>All stimulus levels</td>
<td>13.1</td>
<td>0.004*</td>
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<tr>
<td>5</td>
<td>2, 3</td>
<td>InstBDL vs Base</td>
<td>All stimulus levels</td>
<td>6.1</td>
<td>0.015†</td>
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<td>6</td>
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<td>(InstRS and InstBDL) vs Base</td>
<td>At 6 D</td>
<td>35.8</td>
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<td>7</td>
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<td>At 0.5, 2, and 4 D</td>
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<td>0.40</td>
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<td>All stimulus levels</td>
<td>7.0</td>
<td>0.01†</td>
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* Differences significant at the Bonferroni corrected level (P < 0.0033).
† Differences falling between the uncorrected and the corrected significance levels (0.05 < P < 0.0033) and for which judgment was reserved.

BaseBin: Baseline real space binocular response. BaseMon: Baseline real space monocular response. Base: Average of the real space binocular and real space monocular responses under the baseline instruction. InstRS: Real space monocular viewing response with Instruction 1, 2, or 3. InstBDL: Badal system monocular viewing response with Instruction 1, 2, or 3.

real space viewing
at 0.5 D, 0.0 ± 0.22
at 2 D, 0.12 ± 0.26
at 4 D, 0.03 ± 0.2
at 6 D, 0.19 ± 0.76

Badal viewing
at 0.5 D, 0.0 ± 0.16
at 2 D, −0.05 ± 0.22
at 4 D, 0.03 ± 0.21
at 6 D, −0.15 ± 0.31.

Groups 2 and 3

Instruction 2 and Instruction 3 have almost negligible effects on the accommodative response function (Figs. 2b, 2c). However, for real space viewing, these small differences from the baseline are statistically significant (Table 1, comparison 4). For Badal system viewing, differences from the baseline are equivocal (Table 1, comparison 5). Real space and Badal responses, taken together, do not differ significantly from the baseline responses at 0.5 D, 2 D, and 4 D, but at 6 D responses with Instructions 2 and 3 are significantly more accurate than the baseline responses by about 0.20 D (Table 1, comparisons 6 and 7). Real space and Badal responses are not significantly different from each other (Table 1, comparison 8). Confidence intervals demonstrate that for normal experimental purposes, response functions to real space and Badal targets are identical: confidence intervals for paired observations; mean values of real space response less Badal response and associated 95% confidence interval (diopters): at 0.5 D, −0.03 ± 0.06; at 2 D, 0.07 ± 0.10; at 4 D, 0.13 ± 0.14; at 6 D, −0.08 ± 0.10).

Group 1

With Instruction 1, many subjects adopt lags of accommodation that increase with stimulus level (Fig. 2a). Responses for both real space viewing and Badal system viewing under Instruction 1 differ significantly from the baseline responses, and this effect is most noticeable at the higher stimulus levels, equivocal at 2 D, but not significant at 0.5 D (Table 1, comparisons 9 to 14). There are equivocal differences between real space and Badal viewing responses (Table 1, comparison 15), but the presence of large within-subject variability observed in a few subjects must temper these findings.

Between-subject differences under Instruction 1 are large (Fig. 3). Three natural clusters of subjects, however, are evident based on the slopes of the stimulus–response functions. Subjects in the first cluster (subjects 3, 9, 15, and 18) consistently relax their accommodation toward some intermediate value. Subjects in the second cluster (subjects 6 and 21) are inconsistent in their responses, whereas subjects in the third cluster (subjects 12 and 24) consistently maintain accurate accommodation. Some subjects in Group 1 demonstrate responses that fluctuate widely (Fig. 4).
**DISCUSSION**

**Subject Instructions**

Response functions with Instruction 2, "...view the target naturally..." and Instruction 3, "...focus carefully..." are not significantly different from each other, although they both differ slightly from the baseline responses. In this study, Instruction 3 did not lead to an increased accommodative response compared with Instruction 2. In contrast, Ciuffreda and Hokoda\(^6\) thought that for sinusoidal gratings an instruction to "obtain the best possible focus" (similar to this study's Instruction 3) would lead to voluntary positive accommodation and an increased accommodative response, whereas the instruction to "focus all targets naturally, without straining" (similar to this study's Instruction 2) would lead to a reduced response. Previous studies of the accommodative response with sinusoidal gratings generally demonstrate considerable lags or leads in the response, thus providing some latitude for voluntary accommodation to obtain a more accurate response. On the other hand, baseline responses in this study are accurate, and if extra voluntary accommodation is brought into play consciously to maximize target contrast, its effect would be too small to be reliably detected.

The mean responses with Instructions 2 and 3 for targets at 6 D demonstrate about 0.20 D less accommodative lag than for the baseline responses. This small effect could be the result of a time order effect because the responses with focusing instructions were always recorded after the baseline responses, and the 6 D responses were always recorded after those for the other stimulus levels.

Subjects' perceptions of their own responses provide an insight into the use of voluntary accommodation under the various instructions. When provided with Instructions 2 and 3, subjects in Groups 2 and 3 described their responses variously as focusing on the words, keeping the letters clear, looking at the words, or concentrating on the words. However, two subjects in Group 3 also reported making conscious adjustments in their focus whenever they noticed any blur. Of the 16 subjects in Groups 2 and 3, five reported transient blurring of the target and four made general statements on target clarity.

Four subjects in Group 1 maintained flat response profiles with Instruction 1 (Fig. 3, Cluster 1). Of these four subjects, three perceived they were making some change in their accommodation, describing it as either relaxing the eyes (subject 15), allowing the words to go blurred (subject 18), or not focusing on the letters (subject 3). One subject (subject 9), though stating no conscious control over accommodation, maintained a
reasonably flat response profile nevertheless. She stated that most of the targets were blurred in any case and to see them clearly would have required concentration. She was obviously suspending normal attention to the target but was unable to verbalize her actions adequately, an inability similar to that reported in another study.\textsuperscript{22} The subjects in Group 1 with variable responses under Instruction 1 (Fig. 3, Cluster 2) described attempts to relax focus as either relaxing the eyes (subject 21) or not focusing on the letters (subject 6). Finally, the two subjects in Group 1 who maintained accurate responses under Instruction 1 (Fig. 3, Cluster 3) made some interesting observations. Subject 12 stated that she maintained steady gaze on a word while attempting not to take notice of the word. This clearly indicates an attempt to suspend normal attention to the accommodative target. Subject 24 said she was able to accommodate voluntarily but was not doing so in the experiment. She may have interpreted the instruction as requiring accommodation to the target but without "special effort." Because several other subjects under Instruction 1 relaxed their focus, some of the variability between subjects might be the result of differing interpretations of the instruction. Six subjects in Group 1 described target clarity (or blur) during the experiment, and these reports matched the objective accommodative responses in every case.

Some subjects in Group 1 adopt stimulus–response functions with greatly reduced slopes when given Instruction 1 (Fig. 3). Using a simple blur-based (retinotopic) control model of accommodation, this would correspond to a reduction of accommodative controller gain. However, a model such as this ignores the significant role proximal factors are likely to play in directing the accommodative response.\textsuperscript{9} When viewing a target in real space, a flat response function would require suppression of both the retinotopic (blur-based) system and the spatiotopic (proximal-based) system. An attentional mechanism might direct this process. Attention voluntarily directed away from an object might, according to this explanation, render its depth cues unavailable to the spatiotopic system and actively suppress controller gain in the retinotopic system. Attention can be actively redirected from centrally viewed targets during a cognitive task.\textsuperscript{23} Furthermore, at least two subjects in this study (subjects 9 and 12) suspended attention to the target to relax accommodation. Alternatively, a rigid accommodative posture might be maintained either through true voluntary accommodation or secondarily through voluntary convergence. True voluntary accommodation cannot be ruled out in the subjects of this study. However, accommodation driven by voluntary convergence is unlikely because it is accommodation that appears to drive the voluntary near response.\textsuperscript{22}

Francis et al\textsuperscript{24} made a distinction between voluntary accommodation and "effort to see." Our study supports their concept that there are at least two voluntary processes involved in oculomotor control, namely, attention to a target (which can be initiated, maintained, or suspended) and the more active "true" voluntary accommodation.

The effects of the various instructions were compared with the arbitrary baseline responses recorded with an instruction to "pick a word in the middle of the block of text and look at it." This is the minimum required to control gaze and allow measurements to be made with the Autorefr. Whether the responses recorded with this baseline instruction are identical to those that occur in the real world is unknown, although to obtain measures of the accommodative response in a truly surreptitious manner would be extremely difficult. The response functions so recorded would be dependent on the task being performed at the time and on other cognitive factors,\textsuperscript{25} so it is unlikely that any one response function could be established as the truly "normal" response. Considering these arguments, the baseline responses of this experiment approximate the normal responses expected from naive subjects when participating in accommodation research and when provided with a minimal instruction to stabilize gaze.

Instructions 2 and 3 lead to responses close to those that occur normally, except perhaps at high stimulus levels where they may lead to a more accurate response. Instructions 2 and 3 (or variants of these)
can be recommended for accommodation research but with a number of provisos based on considerations from other studies. This study used well-illuminated, high-contrast, broad spatial frequency band targets, and pupil sizes were relatively large (4.2 mm to 6.6 mm, on average). For these conditions, accommodation is accurate over a large range of stimulus distances. However, where there is normally any significant inaccuracy in the response function, Instructions 2 and 3 may have different effects. For sine wave gratings there is normally a lag of accommodation, and the instruction to "carefully focus" can lead to positive voluntary accommodation. By extension, Instruction 3 is probably better avoided in cases in which there are normally inaccuracies of accommodation, for example, low luminance, targets of very poor contrast, small pupil size, and amblyopia.

Letter size and target form may interact with the subject instructions. For example, if large letters are used as targets, some subjects might normally (as in Instruction 2) accommodate only enough to resolve the letters. However, if instructed to focus the letters carefully (as in Instruction 3), these subjects might accommodate more accurately. Although this possibility limits the general applicability of our findings, a letter size several lines above acuity threshold (6/15 Snellen equivalent in this study) is representative of many everyday tasks.

Another possibility with inexperienced subjects is to dispense with focusing instructions altogether and simply give instructions related to the task to be performed in the study. Experienced subjects would be better supplied with a focusing instruction because of the likelihood of biased focused strategies from participation in previous research.

Subject instructions should be considered carefully at the design stage of an experiment and checked for possible ambiguities or nuances of meaning. Instructions should be delivered consistently to all subjects, preferably verbatim, and repeated at regular intervals to provide constant reinforcement. Even small differences in the wording of an instruction can lead to major differences in the outcome. Owens and Adams and Johnson both investigated the Mandelbaum effect and found accommodation to be accurate for all their subjects when using the instruction "relax and let your eye choose a target." In contrast, the instruction used in the present study, "...look at the words but make no special effort to focus on them. Let your eyes relax and let them choose a focus," leads in general to response functions markedly different from those observed in the previous two studies. There are differences between the instructions. In the two studies of the Mandelbaum effect, the instruction to "relax" was countered by the definite instruction to "choose a target." In this study, choosing a "focus" was an ambiguous instruction, and those subjects who were able used voluntary or other higher order control to "relax" their focus. It is also possible that subjects in this study interpreted "...make no special effort..." simply as "...make no effort..."

**Badal Versus Real Space Presentation**

Response functions for real space and Badal system targets are equivalent for practical purposes, and this suggests that it is valid to investigate static accommodation with a Badal system.

In the Badal system many of the monocular depth cues are absent. Target size and luminance do not change with stimulus level. There are no familiarly sized objects, nor is there interposition of targets in depth. Despite the paucity of available depth cues, almost every subject was able to accommodate accurately in the Badal system (disregarding subjects who received Instruction 1). A number of suggestions can be made as to the strategies used by subjects to accommodate in the Badal system. Although some subjects might have used voluntary accommodation to "hunt" for the target, not all subjects could voluntarily accommodate. Alternatively, as the subject approached the apparatus from a distance of about 50 cm, the 0.5 D Badal target was physically situated at a distance of approximately 2 D. Assuming the subject accommodated to the 2 D level, only a small amount of reflex accommodation was required to clear the target. From that point, targets were always moved in steps of 2 D or less, making it possible for reflex accommodation to clear the targets. Reflex responses to the targets would have depended on the low spatial frequency components of the target initially to drive the response.

Another possibility is to use as a cue the small lateral shifts of the target or small changes in angular subtense with stimulus level due to alignment errors of the Badal system.

Although the static accommodative response appears to be similar for both real space and Badal viewing, it is unlikely the same would be true for the dynamic accommodative response. For example, the addition of a changing size (looming) cue to the changing blur cue provided by the Badal system generally leads to more accurate responses with reduced phase lags. Although real space viewing provides other depth cues besides looming, it is likely that dynamic responses would be more accurate in real space than for Badal system viewing.

Although objects normally increase in size as they move toward the eye, the real space targets in this study maintained constant angular size. This may have reduced the input to the spatiotopic system by removing the cue of familiar size. However, other depth cues...
were still available, so it is difficult to estimate the potential magnitude of this effect. Also, dynamic size cues (looming) were available for a short time as the experimenter adjusted each target to its correct position. This cue was not consistent in duration or magnitude across conditions and may have led to variability in the initial responses to the target.

Under Instruction 1, two subjects (subjects 6 and 21) demonstrate greater lags of accommodation for real space viewing than for Badal viewing. Because of counterbalancing, both subjects viewed the real space target after the Badal targets, and the observed differences may simply represent a practice effect.

In general, most subjects can adequately accommodate to Badal targets, but some subjects are unable to perform this task adequately. The single pilot subject in this study was unable to relax accommodation, and it is likely that instructions also operated voluntary or reflex accommodation and may have led to variability in the initial responses to the target.

Further Investigations

This study investigated the steady state response of accommodation, and it is likely that instructions also lead to differences in the various dynamic characteristics of accommodation. The interrelationships between subject instructions and target form are potentially of importance to oculomotor research where a wide variety of targets is used.

Key Words

instructions, Badal system, voluntary accommodation, attention, proximal accommodation

References

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