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Authors
Cornsweet, TN
Crane, HD

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RESEARCH NOTE

TRAINING THE VISUAL ACCOMMODATION SYSTEM[1]

T. N. CORNSWEET and H. D. CRANE

Acuity Systems, McLean, Va. 22101 and Stanford Research Institute, Menlo Park, Calif. 94025, U.S.A.

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WHEN a visible target is suddenly displaced toward or away from a subject, it will cause the subject to respond by changing his accommodation in the appropriate direction, after a latent period of about 0·4 sec. The fact that the direction of the response is correct is puzzling, because, at least to a first order, the blur pattern on the retina has the same characteristics whether the target is too close to the eye or too far from it.

In principle, the change in the size of the retinal image that usually accompanies change in distance could provide the cue for correct accommodation. Further, in principle, second order effects resulting from chromatic and spherical aberration and curvature of field produce retinal light distributions that have a certain degree of asymmetry as the retina moves through the plane of optimal focus. Therefore, any of them might provide a cue necessary for a correct polarity of accommodative response to a change in target distance. In a series of unpublished experiments, we have shown that none of these possible cues is actually necessary for correct accommodation. Further, responses are correct when the target is visible only to one eye, and therefore ocular convergence is not necessary. Another possibility that has been proposed in the literature is that, during the latent period, the small fluctuations of accommodation that continually occur provide information to the system indicating which direction sharpens the image. We have also shown, however, that this "hunting" mechanism can be disabled without perturbing the correctness of the accommodative responses to step changes. In fact, our experiments have demonstrated that responses are correct even when all of these particular cues are simultaneously eliminated.

The experiment described below demonstrates in fact that *any* perceptible cue that reveals the direction of motion of the target is sufficient to permit the subject to make correct responses. No single cue or particular combination of cues is necessary.

We have previously described an automatic infrared optometer that continuously measures the instantaneous state of accommodation of an undrugged eye, without producing any visual stimulation of its own, CORNSWEET and CRANE (1970). For the experiment referred to here, we aligned our subjects in this device while they were viewing a dim point source through an artificial pupil 0·1 mm in dia. With such a target, the eye will remain pointed in a fixed direction so that the optometer will operate properly; however, because of the large depth of focus provided by the artificial pupil, the retinal image of the target is essentially unchanged even by large changes in accommodation. The subjects were also provided with binaural headphones. A tone was delivered to one ear whose pitch could be

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controlled either by turning a knob or by delivering any predetermined sequence of voltage levels to a voltage-controlled oscillator. The pitch of the tone in the other ear was controlled by the output of the optometer and therefore depended on the subject's state of accommodation. The subjects were asked to vary one of the pitches by turning the knob and to change their accommodation to maintain a match between the two pitches.

The two subjects were about 20 yr old and were emmetropic. Only one of the subjects had previous experience in our accommodation experiments. When they were first asked to perform this task, both subjects asserted that they simply could not do it; they did not have any idea of how to go about changing their accommodation appropriately. Nevertheless, they practiced, *ad lib.*, and were tested periodically. After a total of 3 hr of *ad lib.* practice, each of them was fully able to perform the task. As a test, we delivered a series of tones whose pitches were randomly selected, and their accommodative responses were indistinguishable in latency and accuracy from those responses that were normally elicited by random shifts in the distance of a real target seen through the natural pupil. These results are consistent with those of RANDLE (1970) of NASA Ames Research Laboratory.

We then changed the stimulus conditions. The subjects viewed two horizontal lines on the face of an oscilloscope, again through a 0·1-mm artificial pupil. We controlled the vertical position of one of the lines, and the vertical position of the other was controlled by the subjects' accommodative state (the output of the optometer drove the corresponding vertical amplifier of the oscilloscope). The subject's task was to keep the lines coincident; that is, when we changed the vertical position of one line, they were to change their accommodation so that the other line fell on top of it. Both subjects could perform this task after just a few seconds of practice. That is, the transfer from the first to the second task is great. It is as if, once the subjects learned to control their accommodation, they could do so regardless of the nature of the command signal.

After the subjects were trained, they were asked how they did it, and neither was able to verbalize what he was doing. They were then specifically asked whether they were imagining that an object was moving toward them or away, and they both said "no".

We conclude that any perceptible cue to the direction of a step displacement of a visual target is sufficient for a subject to make a correct accommodative response, once he has had training in which he is given immediate feedback about the state of his accommodation.

Because our subjects required 3 hr of practice for the first task and virtually none for the second, it is evident that even our experienced subject did not possess this skill when he first began as a subject, nor did he acquire it during our earlier experiments, in which we recorded his responses to visual stimuli at changing distances. However, that does not rule out the possibility that our subjects normally use a variety of cues related to the visual image when focusing on visual targets, even without the kind of training described above.

In the training procedures described here, changes in the subjects' accommodation level have virtually no effect on the blur of the retinal image, and the feedback about accommodation is in that sense entirely artificial. However, during normal visual experience, if some cue such as a change in retinal image size were to elicit an accommodative response, feedback would be provided through changes in the blur of the image itself, which may be a form of feedback that the visual system is well tailored to accept. In other words, it is possible that subjects may require only a short time to learn to use any given cue for accommodation when the feedback is natural (that is, a change in actual blur), but may require considerable practice to learn the different skill of controlling accommodation when the feedback that they must use is artificial, and when, as in our experiments, the feedback is erroneous in the sense that the visual blur does not actually change when accommodation does.

These results emphasize the extreme care that is necessary when conducting experiments on the accommodation system where the aim is to try to discover its basic control processes.

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