A comparison of accommodative and fusional convergence as cues to distance*

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The effectiveness of fusional as compared with accommodative convergence (with accommodation present in both cases) in determining perceived distance was investigated in this study. Luminous frames of two different visual angles at a nearly constant distance were viewed binocularly to provide fusional convergence and monocularly to provide accommodative convergence. Although some differences in reported size and distance of the frames occurred on the first presentations for binocular as compared to monocular observation, the most systematic differences between these two types of observation were present for the second (successive) presentations of the two frame sizes to the same Os. This is attributed to the relative size cue to distance occurring as a function of the different retinal sizes on the successive presentations. It was found that this relative size cue was more effective in modifying the perceived size and distance of the second presentations for monocular than for binocular observation. It is suggested that this reflects the greater effectiveness as a cue to distance of fusional as compared with accommodative convergence. This conclusion is of importance for studies concerned with the evaluation of convergence as a determiner of perceived distance.

A vergence of the eyes can occur as a consequence of several factors. One of these is the reflex to binocularly fuse the images in the two eyes of the attended object, i.e., a convergence results from the tendency to locate the image in each eye on corresponding parts of the fovea. Another factor for controlling the vergence of the eyes is the accommodation of the eyes to the distance of the object being viewed. The convergence of the eyes associated with accommodation is called accommodative convergence. Fusional vergence requires that the object be viewed binocularly, whereas accommodative convergence occurs even though the object is viewed with one eye only. Thus, from the viewpoint of the occurrence of appropriate values of accommodation and convergence to the object, monocular and binocular observation are equivalent. It is for this reason that a test of the combined operation of accommodation and vergence as cues to distance is sometimes made under monocular conditions of observation. But, although the same value of vergence can be attained by either fusional or accommodative-convergence, it should not necessarily be assumed that each of these provides equally effective cues of distance. It is possible that fusional convergence provides a more precise cue to distance than does accommodative convergence. This is possible because fusional convergence is considered to be more precise in its adjustment to object distance than is accommodation (Morgan, 1968), and it has been suggested that the weight which an O gives to a cue is directly related to its precision (Taylor, 1962). Another possible point of view is that the strength (effectiveness) of a cue system and its precision are simply different aspects of the same underlying process. From either of these points of view, the effectiveness of cues to the size and distance of an object under conditions in which all secondary sources of information are removed should be greater when the object is viewed binocularly rather than monocularly.

The possible increase in the effectiveness of distance cues from binocular as compared with monocular observation can be tested by placing another distance cue in opposition to the distance cues from accommodation and convergence. In the present study, the cue used to oppose the distance cues of accommodation and convergence is that of relative size. Suppose that two objects of the same shape but different retinal sizes located at the same distance from O are presented successively. The cues of accommodation and convergence would indicate that the two objects are at the same distance. The relative size cue resulting from the different retinal sizes of the successive presentations would indicate that the object of smaller retinal size was more distant. If monocular observation provides less effective distance information than binocular observation, it would be expected that the relative size cue between the successive presentations would result in more change in perceived distance in the former than in the latter case.

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EXPERIMENT

Apparatus

A light-tight observation booth was constructed such that O sat midway between two observation positions separated by 180 deg. Each position contained an adjustable head- and chinrest, nonrestrictive apertures through which O would view the stimuli, and a shutter which, when raised, permitted O to see the stimulus. The left aperture was covered when using monocular observation. The stimuli were two luminous rectangular frames (6 x 9 x 3/8 in. and 2 x 3 x 1/8 in.) produced by appropriately masking parts of electroluminescent panels. The frames were always presented with their long sides vertical. A frame of each size could be viewed one at a time through each of the observation positions. To accomplish this, a smaller electroluminescent panel (for the smaller frame) was situated immediately in front of the larger electroluminescent panel (see Fig. 1 in Gogel & Sturm, 1971), with the frames centered at the height of the observation position. This enabled a frame of each size to be presented independently for each observation position. The distance of the large frame was always 5 ft from O, with the small frame 1/8 in. closer. The brightness of the frames was always .048 fL. Great care was taken that no extraneous light would enter the observation booth and that nothing would be visible to O during the experiment except the frames. The remainder of the field of view was in total darkness.

Observers

The Os were 120 students from an introductory course in psychology. All Os had a near and far visual acuity of at least 20/20, corrected, if necessary, and all were naive as to the purpose of the experiment.

Procedure

After O was led blindfolded into the observation booth, the blindfold was removed and O was dark adapted for 5 min. Following this, O was presented with one of the frames and asked to report its apparent distance from his eyes in feet or inches or some combination of both. The shutter was closed and O turned and, after a 15-sec interval, placed his head in the other observation position, after which the shutter was raised at the second observation position and O reported the distance that the second frame appeared to be from his eyes.

Following this, O was asked to report the apparent size (height) of the frame he was viewing in feet or inches or some combination of both and, then, to report from memory the apparent height of the previously viewed frame. The successive presentations were always separated by 180 deg and were always of different size. Thus, if the small frame was presented first, the large frame was presented second, whereas if the large frame was presented first, the small frame was presented second. Sixty Os always viewed the frames monocularly and 60 other Os always viewed the frames binocularly. Half of each of these groups of 60 Os first viewed the small frame followed by the large frame, with the order of presentation reversed for the remaining Os of that group. The order in which the two observation positions were used was counterbalanced across Os.

Table 1
Means, Medians, and Standard Deviations in Inches of the Reports of Perceived Distance and Perceived Size (Height) of the Large and Small Frames for Monocular and Binocular Observation

	Perceived Distance				Perceived Size			
	First Presentations		Second Presentations		First Presentations		Second Presentations	
	Large	Small	Large	Small	Large	Small	Large	Small
	Monocular Observation							
Mean	60.1	47.2	23.6	159.1	21.0	3.4	8.4	15.2
Median	48.0	36.0	12.0	120.0	8.0	1.5	3.0	3.0
SD	53.2	58.8	25.7	140.5	26.2	5.4	13.7	19.4
	Binocular Observation							
Mean	52.0	77.3	45.0	90.4	20.0	5.3	11.1	14.5
Median	48.0	48.0	36.0	60.0	10.0	4.0	8.5	4.0
SD	42.8	74.6	25.3	97.5	24.5	4.7	10.7	25.0

Results

The results from the experiment are summarized in Table 1. Because of the skewedness of the data, medians rather than the means are considered to best represent the data. Throughout the analysis of the data, the Mann-Whitney U test (Siegel, 1956) was used to test the significance of the differences between the distributions.

First presentations. It will be noted that the median reported distance for the monocular conditions, first presentations, was less when the small frame rather than the large frame was used. Since this result was opposite to any theoretical expectation, a two-tailed test was used. It was found that in this case the bulk of the distance scores was not significantly different from the large as compared with the small frame ($z = 1.66$, $p > .05$). Nor, using a one-tailed test, was the bulk of the distance scores significantly greater with binocular observation for the small as compared with the large frame for the first presentations ($z = 1.41$, $p > .05$). The bulk of the distance scores on first presentations for monocular as compared with binocular observation, however, was significantly different for the small ($z = 3.34$, $p < .01$) but not for the large frame ($z = .30$, $p > .05$).

The reports of the size (height) of the frames on the first presentations are generally in agreement with the results expected from the distance reports. With binocular observation, the frames of different retinal size were perceived at about the same distance, and the ratio of the perceived sizes was similar to the ratio of the retinal sizes. The unusually small value of the median reported size of the small frame with monocular observation probably can be attributed to the tendency for the median report of the distance of the small frame to be small also. These interrelations of perceived size and perceived distance are consistent with the size-distance invariance hypothesis (Kilpatrick & Ittelson, 1953).

Successive presentations. By definition, the relative size cue, if it is effective, must be demonstrated to occur between the successive presentations of the different retinal sizes to the same Os. It will be noted that for monocular observation the median difference in perceived distance between first and second presentations to the same Os was 72 in. (120 — 48) and 24 in. (36 — 12), whereas for binocular observation the corresponding differences were 12 in. (60 — 48) and 12 in. (48 — 36). As is discussed in a previous paper (Gogel & Sturm, 1971), the most valid test of the effectiveness of the relative size cue is found by comparing the differences between the perceived distance scores from the first and second presentations. The test of this difference was significant in the case of monocular observation ($z = 3.91$, $p < .01$) but not in the case of binocular observation ($z = .89$, $p > .05$). It should not be concluded, however, that the size cue was ineffective between successive binocular presentations since the bulk of the difference in perceived distance between the second presentations of the small and large frame was significant beyond the .01 level ($z = 3.00$). But only in the case of monocular observation did a statistically significant change in perceived distance occur as a function of retinal size that could not be accounted for by the difference in perceived distance occurring on the first presentations. The finding that size cues between binocular observations can influence perceived depth is consistent with the study by Gogel and Sturm (1972) except that the tendency to perceive a greater difference in distance between second as compared with first presentations proved to be statistically significant in that study.

From the pattern of distance reports shown in Table 1, it seems that the relative size cue was more effective in counteracting the accommodative and convergence cues of perceived equidistance for monocular as compared with binocular observation. This conclusion is supported also by the pattern of results from the reports of perceived size. The more effective the relative size cue, the more the perceived size in the second presentation would tend to be equal to that of the first presentation, despite the difference in the retinal sizes of the two presentations. The differences in median perceived size between the first and second presentation is 6 in. (10.0 — 4.0 in.) and 4.5 in. (8.5 — 4.0 in.) with binocular observation. The corresponding differences are 5 in. (8.0 — 3.0 in.) and 1.5 in. (3.0 — 1.5 in.) with monocular viewing. Since the change in apparent distance between successive presentations was less with binocular than with monocular observation, perceived size varied more with retinal size in the former than in the latter case.

DISCUSSION

It can be concluded that the relative size cue which would make the successive presentations of the different retinal sizes appear at different distances and have the same apparent size was more effective when monocular rather than binocular observation was used. In both viewing conditions, the effect of the convergence and accommodative cue was to make the two frames appear at the same distance. The ability of these cues to make the physically equidistant frames *appear* equidistant despite the relative size cue is a measure of their effectiveness.

According to this criterion the combination of accommodation and convergence was more effective for binocular than for monocular observation. But, it should be noted that the precision of convergence and accommodation in determining perceived distance with either binocular or monocular observation was not impressive, as is indicated by the standard deviations of the distance reports in Table 1. Also, the variability between Os as indicated by the standard deviations does not suggest that binocular observation was more precise in determining perceived size and distance than was monocular observation. Although some differences in standard deviations occur between these two types of observation, these differences probably reflect the tendency in experiments of this kind for standard deviations to increase with increasing values of the means. The greater effectiveness of fusional as compared with accommodative convergence found in this study is not reflected necessarily in a greater precision of size and distance judgments from fusional convergence. Three additional conclusions from the data of this study are also worth noting. The reduction in the effectiveness of the relative size cue to distance for binocular as compared with monocular observation implies that at least accommodation together with fusional convergence can be a cue to distance. In addition, in agreement with the study by Gogel and Sturm (1971), the present study demonstrates that the relative size cue can occur between successive stimuli separated by 180 deg. Also in agreement with this previous study, it seems that the effect of the angular size of the first presentation upon the perceived size of the second presentation occurred even though the Os did not indicate the perceived size of the first presentation until after the second presentation (of different retinal size than the first) had occurred. In other words, it was not necessary for the Os to respond verbally to the size of the first frame in order for the perceived size of this frame to influence the perceived size of the subsequent presentation.

The study of vergence or accommodation as cues to distance has a long and continuing history in which different researchers have arrived at different conclusions concerning the effectiveness of these cues (see Biersdorf, 1966; Biersdorf, Ohwaki, & Kozel, 1963; Crannell & Peters, 1970; Gogel, 1961, 1962; Heinemann, Tulving, & Nachmias, 1959; Richards & Miller, 1969). One problem in this research is that it is extremely difficult, if not impossible, to isolate either accommodation, convergence, or the combination of the two cues from other (extraneous) distance information. For example, if the E adjusts the stimulus objects at the different distances to have the same apparent brightness or the same visual angle in order to avoid the brightness or size cue from contributing to the discrimination, these extraneous cues will interfere with the effectiveness of accommodation or convergence as a cue to distance since they will indicate that the different stimuli are all at the same distance. Furthermore, even if all such conflicting cues could be eliminated, a factor termed the specific distance tendency would remain to modify the perceived distances. This is the tendency for objects, in the absence or severe reduction of distance cues, to appear at a near distance from O (Gogel, 1969). It is likely, therefore, that the effectiveness of convergence or accommodation as a distance cue cannot be tested in a situation in which all extraneous information (such as size, brightness, or the specific distance tendency) has been eliminated. The results from the present experiment suggest that in the presence of extraneous cues (in this experiment the relative size cue to distance) a relation between convergence and perceived distance will be more readily demonstrated when fusional convergence rather than accommodative convergence is used.

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