Direction constancy*

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A series of experiments investigating the constancy of perceived direction was conducted. Experiments 1, 2, and 3 indicated that the perception of direction, while close to constancy, exhibited a consistent departure from constancy of approximately 2.5 deg. Experiments 4 and 5 investigated the departure from constancy in terms of the information of the position of the eyes within the head and the information of the retinal area (local sign) being stimulated. The results of these experiments indicated that the departure from constancy was a function of the underestimation of the position of the eyes within the head.

A logical distinction can be made between the perception of direction to an object and the perception of the position of that object in the environment. Direction perception refers to the location of an object with respect to an O as origin. It is affected not only by changes of the position of the object, but also by changes of position of the O. The apparent direction of an object can change without a corresponding change in the apparent position of the object with respect to the environment by moving or turning the O. Similarly, the apparent direction may remain constant while the apparent position of the object in the environment changes by moving both the object and the O. Finally, both the apparent direction and the apparent position of an object may change by moving only the object. The perception of direction is further complicated by the fact that the O may use different reference points of his body as origin. An object could be directly in front of a person's body, to the left of his head, to the right of his line of sight, between his hands, etc. It is, therefore, important to define the reference point for the O.

When the head is used for the reference point, the direction on a horizontal plane to an object can be measured in degrees from a nodal point between the eyes (the cyclopean eye). Since, however, the eyes can move, the apparent radial direction from an O's stationary head to a fixed visible object in an otherwise dark room is a function both of the position of the eyes within the head and the space value of the region of

the retina stimulated by the image of the object (the local sign). Constancy would imply that a stationary object was perceived as possessing an invariant direction from a stationary O in spite of the variability of the position of its image upon the retina with different positions of the eyes. Thus, an object's direction is perceived as constant when the eyes and the retinal image move equal amounts in the same direction and when neither moves (disregarding tremor movements). If either the eyes or the retinal image moves without the corresponding movement of the other, a change in the perceived direction to the object should be observed.

When expressed in this way, direction constancy becomes analogous to size constancy. In size constancy, the phenomenal experience of size is a resultant of the size of the retinal image taking apparent distance into account. Perceived direction is a resultant of the space values of the retinal location taking eye position into account. If either the extent of the retinal image or distance information is misinterpreted, judged direction is affected.

If the information as to the position of the eyes is not correctly interpreted a stationary stimulus should appear to have changed direction when the O has changed his eye position, even if this is not noticed during the eye movement itself (Wallach & Lewis, 1966). If the degree to which the eyes are turned is underestimated, the apparent change in direction of the stimulus would be in the opposite direction of the eye position. If the degree to which the eyes are turned is overestimated, the perceived change in direction would be in the same direction as the movement of the eyes. These conclusions stem from the assumption that the local sign information is accurate (Weymouth, 1964). On the other hand, if the information as to the degree to which the eyes are turned is accurate, changes in the apparent direction to an objectively stationary target would be caused by inaccurate information of

the locus of the proximal stimulus. Thus, a perceived change in direction opposite to eye movements could be caused by either an underestimation of the degree to which the eyes are turned or by an overestimation of the local sign of the proximal stimulus, while a perceived change in direction in the same direction as the eye movements could be caused by either an overestimation of the degree to which the eyes are turned or an underestimation of the local sign of the proximal stimulus.

EXPERIMENT 1

Mach (1959) noted that when "in a very dark room we fix our eye upon a light A, and then suddenly look at a light lower down, B... the light A appears to make a rapid sweep... upwards [p. 129]." This observation questions the completeness of direction constancy. To test the constancy of perceived direction, 10 adult Os were brought into a dark room individually, asked to flick their eyes back and forth, and to report if they saw anything happening to a 1.27-cm luminous circle that was directly in front of their heads. All 10 Os spontaneously reported that the stimulus appeared to "jump" slightly in the opposite direction to their eye movements. The perceived movement could have been the result of the shift in the apparent direction to the stimulus rather than the streaking of the retinal image itself, since Wallach and Lewis reported that target displacements during eye movements were usually not noticed. The direction of eye movements and the distance from O to the stimulus seemed to have little, if any, effect. It was clear that the perceived change in direction to the stimulus was a small percentage of the actual eye movements, and that while constancy was almost complete, there was a small, consistent departure from it.

EXPERIMENTS 2 AND 3

The purpose of these experiments was to quantify the departure from constancy found in Experiment 1 by having O indicate his apparent median plane by setting a light to appear straight in front of him while he was looking off to the side in a specific direction. It was expected from the results of Experiment 1, that an O's apparent median plane, with eyes turned, would shift slightly in the same direction as his eyes were turned because a stimulus in the objective median plane would appear to be displaced in the opposite direction.

Apparatus

A slide projector, covered by black cloth to eliminate stray light, was

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mounted on a frame so that it could rotate in a horizontal plane. The illumination was diminished by a rheostat so that the projected image was dim enough not to reflect light to other parts of the room. The projected figure was a circle 3.81 cm in diameter which was displayed on a homogeneous screen, 1.83 m from the O. The screen was curved so that all points along the horizontal path of the projected image were equally distant from the O. The projector was mounted on a platform directly above a bite plate so that any shift in the position of the projector would represent an equal shift in radial direction of the O. Dental wax was used on the bite plate to insure a constant head position. The O controlled the direction of the projected image by means of a cord connected to the projector and which ran across the desk in front of him. A protractor, mounted beneath the projector, showed the settings by means of a pointer attached to the projector mounting. Two red "night lights" were mounted on the screen, 1.27 cm below the path of the projected light. Each could emit a 1.27-cm-high x 0.64-cm-wide light, 30 deg to the left or right of O's objective median plane as he sat at the bite plate. The illumination from these lights was diminished by placing masking tape over the lighted areas. Switches for these lights were mounted near the projector. A blindfold was used to cover an O's eyes while being led into the experimental room.

Procedure

An O, tested individually, was led blindfolded into the experimental room, seated in a chair in front of the apparatus and a wax impression made of his teeth on the bite plate. O kept his head positioned on the bite plate for the entire testing period. The projector and its control were explained to him, and he practiced moving the projector until he could move it smoothly. A "base condition" was always run first in which O was told to look straight in front of him and to move the projected circle to be straight in front of his head. Four measures were taken in this condition, counterbalancing the starting positions.

At the completion of the base condition, the red fixation light was turned on. O fixated either the left (fixation-left condition) or right (fixation-right condition) light and set the projected light to appear straight in front of his head. He was reminded at the beginning of each trial to look at the fixation light, not to look directly at the projected light, but to

set the projected light directly in front of his head by judging its position "out of the corner of your eyes." Two trials were given immediately, followed by another two trials in the base condition. This procedure of fixation condition followed by base condition was continued until O had completed two fixation-left conditions of two trials each and two fixation-right conditions of two trials each. At this point, a final two trials on the base condition were given.

Between each setting, O closed his eyes and put his hands in his lap for 5 sec while E turned on a light, recorded the setting, and set the projector and fixation lights for the next trial.

The starting positions of the projected image were 25 deg to the right or left of the objective median plane for all conditions. The order of the starting positions was counterbalanced among conditions, and the starting positions and fixation conditions were counterbalanced among Os. In Experiment 2, both fixation lights were on during fixation conditions, whereas in Experiment 3, only one light was on at a time. [An experiment was also run without fixation lights on during settings to the apparent median plane. However, even after training, Os were unable to maintain eye position without a visible fixation point. Similar results have been reported by Cornsweet (1956), Ratliff and Riggs (1950), and Ditchburn and Ginsborg (1953).]

Observers

Sixteen Os were employed, eight in each of the experiments. They ranged in age from 16 to 23 years. Each O had normal vision and was naive to the purposes of the experiment. They were paid for participating.

Results

There was a tendency for the base condition settings to shift slightly over the experiment. The direction of these shifts was independent of the initial base condition and the previous fixation condition. Of the seven Os whose first base condition was to the left of the objective median plane, three Os made subsequent base condition judgments further to the left while four Os made judgments to the right. Of the nine Os whose first base condition settings were to the right of the objective median plane, four continued to go further to the right while five tended to go to the left in later base condition judgments. The direction of the shift was opposite to the previous fixation condition in 27 cases, while in the same direction in 28 cases.

Due to the instability of the settings

in the base conditions, mean scores for the two fixation-left conditions and the two fixation-right conditions were obtained in terms of the difference in degrees from an average of base condition settings immediately before and after the fixation condition for each individual. The results of this analysis are presented in Table 1.

For each experiment, an analysis of variance with repeated measures showed the conditions to be significantly different (Experiment 2, $F = 11.62$; Experiment 3, $F = 20.40$). Tukey's test for significant gap showed the base conditions to be significantly different from the fixation-right conditions in both experiments and from the fixation-left condition in Experiment 3 beyond the .01 level of significance. The difference between the base condition and the fixation-left condition in Experiment 2 approached significance ($p < .10 > .05$). No differences were found between Os (Experiment 2, $F = 1.18$; Experiment 3, $F = 0.87$).

In the fixation-left condition, 15 Os went in the predicted direction, while in the fixation right condition all 16 Os performed as hypothesized.

It is clear from these results that a slight departure from constancy occurs. Fixating a dim light 30 deg to one side affects judgments of the apparent median plane in the direction of the turned eyes.

The argument could be made that Os in Experiment 2 were not setting the projected light to appear straight in front of their heads but were trying to set it halfway between the two fixation lights. If this were the case, the settings should be much closer to the objective median plane than with one fixation light as in Experiment 3. By having both fixation lights on at the same time, any such relational effects should, if anything, minimize departures from constancy. While this might seem to be the case in the fixation-left conditions, the opposite result is obtained in the fixation-right condition. In a posttest interview with the Os, not one mentioned that he employed this strategy for setting the projected light. The fact that significant results were obtained in spite of this method being available to Os, and that the shifts in the fixation conditions of Experiment 3 was not substantially different from those in Experiment 2, lends further support to the conclusion that this method was not used and that the constancy of radial direction is not complete.

Since it seems plausible that the information about the direction of a visible stimulus in a dark room is obtained only from the retinal local sign and eye position, the evidence from the first three experiments seems

Table 1

Mean Shift in the Apparent Median Plane as Compared to Base Condition Judgments

	Fixation Left	Fixation Right	Combined
Experiment 2	1.67 Deg L (1.72 Deg)	2.93 Deg R (2.25 Deg)	2.30 Deg
Experiment 3	3.06 Deg L (1.46 Deg)	2.67 Deg R (1.41 Deg)	2.87 Deg
Combined	2.37 Deg L	2.80 Deg R	2.59 Deg

Note—Values within parentheses represent the median standard deviation within a condition.

to indicate that Os either underestimated the position of their eyes or overestimated the distance from the fovea to the retinal area stimulated.

EXPERIMENTS 4 AND 5

The first three experiments indicated that Os either underestimated the position of their eyes or overestimated the distance from the fovea to the retinal area stimulated. Experiments 4 and 5 were designed to test the accuracy of each of the two sources of information by minimizing the other source of information in judgments of direction. If eye position information is accurate, Os should be able to localize accurately the direction in which the eyes are turned (Experiment 4). If the retinal sign information is accurate, Os should be able to localize accurately the direction to an object seen peripherally (Experiment 5).

In order to test the accuracy of these two sources of information, a third sensory system was necessary by which comparisons could be made based on the different sources of information. Several techniques for localizing the direction from a O to an object were tested, such as pointing with the extended arm, positioning a sound source, etc. A head-turning technique was finally employed because it produced the lowest intertrial variability. However, preliminary investigations indicated that the head turning technique contained a constant error of its own which would also have to be taken into account. Thus, any effect of the misinterpretation of eye position information or retinal sign information would be exhibited in terms of a difference between trials in which this error should be evident and trials in which only the errors inherent in the head turning technique, itself, would be evident. If a source of information was accurate, no differences between trials should be evident and any errors obtained would be attributed to the constant error of the head turning technique itself.

In Experiment 4, O was required to turn his head in the direction in which his eyes had previously been turned to fixate a target. This experiment minimized retinal sign information by having O use foveal vision only. If eye

position information is underestimated, O should underestimate the direction to the peripheral target. In Experiment 5, O was required to turn his head in the direction of the retinal sign of the peripheral target. This experiment minimized eye position information by having O maintain his eyes in the primary position. If retinal sign information is overestimated, O should overestimate the direction to the peripheral target. Underestimations and overestimations would be in relation to the control trials rather than to the actual direction to the target, because of the constant error within the head turning technique itself.

Apparatus

A chair, which could be raised or lowered, was affixed beneath a 1.68-m-high platform. O, sitting in the chair, fitted his head into a football helmet attached, through the platform, to a marker on a protractor. The helmet was free to rotate in a horizontal plane. A tight chin strap assured the translation of all head rotations into helmet rotations which were indicated on the protractor. The projector and rheostat described in Experiments 2 and 3 were mounted on the platform and projected a 1-in. circle onto a white plastic curved screen, 1.22 m in front of O and extending 45 deg to the right and left of the objective median plane of the O. The projected image was 5.08 cm above the eye level for O. In Experiment 5, an additional fixation circle, 1.91 cm in diam, was projected on the screen directly in front of O.

Procedure

The Os were individually tested. Each O was brought into the experimental room and seated in the chair with his head strapped tightly in the helmet. He was given some practice turning his head while wearing the helmet before the trials began. The room lights were turned off and the trials began. For each trial, O sat with his head pointing straight ahead of his body, fixating one of the stimuli for 5 sec. Following this, the lights were turned off and O quickly turned his head to point where he thought the peripheral stimulus had been. To counteract psychophysical starting position effects, he moved his head in one of two ways: directly to where the image had appeared or well past the locus of the image and then back to the direction he felt the image had appeared. E informed O which approach direction was to be used for each trial. When the O was satisfied that his head was pointing directly at the spot where the image had been, he informed E and closed his eyes. E then turned on a light, recorded the head position, turned off the light, and told O to turn his head forward for the next trial. If necessary, E positioned O's head to be pointing directly in front of his body by turning the helmet. The approach directions were counterbalanced in the eight trials with the image to the right of O (image-right conditions) and in the eight trials with the image to the left of O (image-left condition) in ABBABAAB order of "directly to" and "past and back" trials. The approach directions and image-left and image-right conditions were counterbalanced among Os within each experiment.

After completing the experimental conditions, Os were given control conditions to both the image-right and image-left conditions. The control conditions consisted of the identical procedure as O had received except that the image remained visible during the positioning of O's head. In order

Table 2
Mean Underestimations of the Head to a Peripheral Stimulus Viewed Foveally (Experiment 4) and Peripherally (Experiment 5)

	Image Left (Deg)	Control Left (Deg)	Difference (Deg)	Image Right (Deg)	Control Right (Deg)	Difference (Deg)
Experiment 4						
Mean	11.0	7.1	4.0	8.2	4.4	3.9
SD	3.4	2.9	0.8	3.0	3.0	2.4
Mean		7.8			4.7	
SD		2.7			2.8	
Experiment 5						
Mean	6.5	5.1	1.5	7.0	4.7	2.3
SD	3.3	2.6	2.1	3.0	2.9	2.8

Note—SDs are expressed as the median SD within a condition except for the difference scores between conditions in which the SD is between Ss.

to further quantify any constant errors within the head-turning technique, half the Os within Experiment 4 received only the control conditions. The approach directions and image-right and image-left conditions were counterbalanced, as in the first part of the experiment.

In Experiment 4, O fixated the 30-deg peripherally projected image for 5 sec before turning his head to its perceived direction. In Experiment 5, an O fixated the circle directly in front of him but saw the peripherally projected image "out of the corner" of his eyes for 5 sec before turning his head in the direction of the peripherally seen image.

Observers

Sixteen Os were employed in each of the experiments. All were college students, had normal eyesight, were naive to the purposes of the experiments, and were paid for their participation. These students ranged in age from 17 to 22 years.

Results

As seen in Table 2, the head-turning technique produced an underestimation of the extent necessary to turn the head to a point at a 30-deg peripheral target. In Experiment 4, only four Os overestimated this extent in a control condition. Every O, in Experiment 4, made greater underestimations in the image conditions than he did in the appropriate control conditions. Within Experiment 5, five Os overestimated on a control condition and two Os overestimated on an image condition. Seven Os in this experiment made larger underestimations in a control condition than they did in that image condition.

Overall, the control conditions were not significantly different from each other ($F = 0.31$), but each was significantly different from an objective score of 0.0 deg underestimation. In Experiment 4, an analysis of variance with repeated measures proved significant between conditions ($F = 9.91$, $p < .01$). Tukey's procedure for the comparison of means showed each image condition to be significantly different ($p < .01$) from its control condition. No significant differences between conditions were found in Experiment 5 ($F = 2.43$, $p > .05$). The amount of the differences between the image and control conditions to the left and right within each experiment was not significant.

DISCUSSION

The results of Experiment 4

demonstrate that there is a clear tendency to underestimate the degree to which the eyes were turned even after subtracting out the constant error displayed in the control conditions. When the eyes were turned 30 deg to either side of the objective median plane of the head, Os interpreted them as being turned somewhat less than 30 deg. Since, in this experiment, the only information about the direction to the image came from the eyes' positions, it seems reasonable to conclude that a misinterpretation of eye position information does occur.

Os in Experiment 5 did not overestimate the degree to which it was necessary to turn their heads in order to line up with the location of a peripherally perceived stimulus. In fact, there was an insignificant tendency in the opposite direction (i.e., greater underestimation in the image conditions than in the control conditions).

Experiments 4 and 5 support the hypothesis that the departure in direction constancy found in the first three experiments is due to a misinterpretation of the eye position information and not due to a misinterpretation of local sign information.

Thus, direction constancy from a fixed head position might be expressed by the formula $D = f(E, V)$, where D represents the perceived direction from the head to an object in space, E represents the registered eye position within the head, and V represents the space value of the retinal area stimulated by the image of the object. The registered eye position, rather than the actual eye position, is used for E because there appears to be a discrepancy between these two measures of eye position. Further evidence for this discrepancy stems from studies in which it was shown that the actual position of the eyes could move as much as two degrees without a corresponding change in the phenomenal position of the eyes (Cornsweet, 1956).

An unexpected result both in Experiments 4 and 5 was the extent of Os' inability to point their heads accurately at a stimulus located 30 deg on the side of the objective median plane. Os consistently underestimated this amount. One explanation for these results could be that the psychophysical starting position effects were not completely balanced. Thus, turning the head past the locus of the stimulus and then back to point at the stimulus may not produce as much of a starting position effect as simply turning the head directly to

point at the stimulus. However, Os underestimated consistently even in trials using the "past and back" method.

Another explanation of these results might be that there is a general tendency to underestimate the amount necessary to turn any part of the body to point at a peripheral stimulus. In either case, since this effect was taken into account in both Experiments 4 and 5, it would not seem that this phenomenon can explain the departure from direction constancy observed in Experiments 1, 2, and 3.

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