Illusory visual direction during and after backward head tilts

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When the head is returned to upright after prolonged backward tilt, people who are asked to look straight ahead look higher than they did before the backward tilting. One explanation attributes the illusory visual direction to a change in muscle responsiveness which develops after the head is returned to upright. According to this explanation, the illusory shift should be absent, or at least reduced, if the subjects are not returned to upright before testing. In the present study, the illusion was the same whether subjects remained tilted for testing or were returned to upright.

In many activities outside the laboratory, such as piloting aircraft or playing sports, accurate perception of direction is critical during and after head tilts which have been shown to cause illusory visual direction in laboratory tests. For example, an illusory direction effect occurs during backward head tilts (Ebenholtz & Shebilske, 1975) and persists as a negative aftereffect when the head is returned to upright (Shebilske & Fogelgren, 1977). In addition to its practical implications, the latter illusion has raised some important theoretical questions which are addressed in the present study.

The illusion under investigation was first observed by Shebilske and Fogelgren who measured perceived direction of gaze before observers' heads were tilted back and after the heads were returned to upright. Subjects attempted to look in the same direction on the pre- and posttests and did so quite accurately when their heads remained upright between the tests; however, when they read for as little as 3 min with their heads tilted back 20°, they looked about 3.5° higher on the posttest. Since the two conditions were equated in all respects except for the head tilt, the shift in the direction of gaze was attributed to an aftereffect of the head tilt.

Recently, Ebenholtz (1977) suggested an explanation of the illusory visual direction. He pointed out that eye muscles, like other muscles, are subject to posttetanic potentiation (PTP), which is a long-lasting increase in muscle responsiveness following repetitive stimulation. Furthermore, he suggested that when a state of PTP is caused by innervations from one source, it can be actively modified only by innervations from the same source. For example, if PTP is

caused by reflexive innervations, it can be actively neutralized by reflexive innervations in the opposite direction but not by voluntary innervations. This assumption, which was supported by experiments with fusional and voluntary eye movements (Ebenholtz, 1978), is the mainstay of Ebenholtz's account of illusory visual direction with head tilts. He pointed out that while eye position was the same for the upright and tilted subjects in the experiments by Shebilske and Fogelgren, the innervation pattern to the eye muscles was different. When subjects were tilted back, an extra component of innervation was added to the inferior eye muscles by the doll reflex, and an equal voluntary innervation was added to the superior muscles to hold the eyes in place, causing potentiation to build up in both sets of muscles. When subjects were returned to upright for the posttest, however, the innervation from the doll reflex was reset to a value that tended to neutralize the PTP in the inferior muscles. At the same time, according to Ebenholtz's hypothesis, the PTP caused by voluntary innervations to the superior muscles was neutralized at a slower rate because subjects simply rested their eyes instead of issuing new voluntary innervations that would have speeded the neutralization. As the result, after a rest period in the upright position, the greater PTP remaining in the superior muscles could explain all or part of the upward shift on the posttest. In Ebenholtz's own words, "the aftereffects of Shebilske and Fogelgren can be interpreted as due largely to the residual tonus of the upward-acting muscles reflecting the compensatory innervation issued to balance against the doll reflex when the head was tilted" (p. 600). This is a moderate version of the PTP neutralization hypothesis because it leaves room for other contributing factors. A stronger version that leaves no room for other factors is also possible, since, in principle, PTP neutralization could be sufficient.

The present experiment was designed to test both

This research was supported by NIE Grant R01-EY02291-01. We thank Sheldon M. Ebenholtz for helpful comments and Brian Bently, Inga Bunbary, Adam Harrell, Cathy LaVine, Rene Pierce, Carla Spurlock, and Van Renick for their help in data collection and tabulation.

the moderate and strong version of the PTP neutralization hypothesis by comparing the magnitude of illusory visual direction obtained by subjects who were given pre- and posttests in the upright position with that obtained by subjects who remained tilted back for the pre- and posttests. When subjects are returned to upright for the posttest, the PTP neutralization process has a chance to operate, but when subjects remain tilted, it does not. Thus, the moderate version of the PTP neutralization hypothesis predicts a greater illusory direction shift for subjects tested in the upright position, and the strong version predicts no shift when subjects remain tilted back for tests.

METHODS

Subjects

The final sample of subjects consisted of 60 undergraduates at the University of Virginia, who participated for pay or to satisfy a course requirement. Four others started the experiment but were replaced because their straight-ahead judgments on the pretest were greater than $\pm 10^\circ$ from the objective straight-ahead.

Design

Participants were randomly assigned to one of four groups in a between-subjects design, with 15 subjects per group. Different conditions were arranged for each group by the factorial combination of two treatment factors, each of which had two levels. One factor was body tilt during the pre- and posttests, which was either 0 or 40° ; the other factor was a body tilt during exposure periods, which was also either 0 or 40° . The four conditions, showing body tilt during tests and exposures, were thus 0-0, 0- 40° , 40° -0, and 40° - 40° . The response measure was the shift in eye position judgments from pretest to posttest. A positive shift was one in which the judgment was higher on the posttest than the pretest, and a negative shift was one in which the judgment was lower on the posttest.

Instrumentation

The test display consisted of a vertical semicircular array of uniformly illuminated dots which were 0.67° in diameter, with their centers separated from each other by 1° . The dots covered an arc of about 170° , which extended beyond the visual field in both directions. The display was positioned 26.95 cm from the eyes, a distance equal to the radius of the perimeter. Each dot could be covered one at a time with a mask (cf. Shebilske & Fogelgren, 1977).

The exposure display was a single fixation dot which was equal in size and intensity to the other dots and could be placed anywhere on the perimeter.

The tilt table (La Berne No. 2101-H) was equipped with a shelf, a chair, and a styrofoam pillow, all of which tilted with the table. It was arranged like a child's feeding chair with the shelf in front of the subject and the table behind serving as a backrest. The styrofoam pillow, which was mounted on a ridged metal platform, held the back of the head, while a chinrest, which was mounted on the shelf, held the front. The shelf also held the test and exposure displays. The angle of the table could be read on an inclinometer and could be varied from 0° (perpendicular to the floor, subject seated in normal position) to 90° (horizontal to the floor, subject on back).

Procedure

In all conditions, the procedures were the same for controlling head position, measuring eye position, and controlling eye position during exposure periods. A different sequence of events was used for each of the four conditions.

Controlling head position. Head position was measured by means of an inclinometer (Pro. No. 30) attached to the head parallel to Reid's baseline, an imaginary reference line connecting the outer canthus to the center of the ear canal. Before the experiment, the inclinometer was read after a subject was told to put his or her head in its normal upright position. Since there was variability in the estimations, the upright position was defined as the average of six measures which were taken while the subjects stood in front of a blank wall and nodded freely between estimates. During the experiment, the inclinometer was checked before each test or exposure period to be sure the head was in the upright position when the table was at 0° and back 40° from upright when the table was tilted back 40° .

Measuring eye position. Eye position was measured by identical pretests and posttests, during which only the dots on the test perimeter were visible, and the subjects were instructed to choose that dot which was in their line of sight when their eyes were in their normal straight-ahead position. The instructions were clarified with a picture of a tilted head illustrating a line of sight perpendicular to the plane of a face, and it was emphasized that the same eye-in-head position was called for regardless of head or body orientation. When a dot was selected, it was identified by the experimenter who covered each dot one at a time until the fixated one was covered. The subjects were instructed to look at the chosen dot continuously until it was covered. During each test period, six measures were taken with the starting position of the mask counterbalanced 30° above or below center. The subjects closed their eyes between measures while the experimenter recorded the results.

Controlling eye position. The average of the pretest measures of eye position with the head upright defined the subjective straight-ahead eye position for each subject. During the exposure period in every condition, the subjects looked at a single fixation dot which was at the subjective straight-ahead eye position and was the only light visible in the room.

Sequence of events. In all conditions, the first four stages of the experiment were the same: the upright head position was measured with the subject standing, the apparatus was adjusted with the table at 0° , and the instructions were played on a tape recorder. For all groups, the subsequent basic procedure was a pretest, a 5-min exposure, and a posttest. The body tilts, in degrees, during the pretest, exposure, and posttest were as follows for the four groups: 0-0-0, 0- 40° -0, 40° -0- 40° , and 40° - 40° - 40° .

After the pretest, the subject rested for 1.5 min if the pretest and exposure tilt were the same; if they were different, the subject was tilted to the appropriate position for the exposure period at the rate of $1^\circ/\text{sec}$, then rested for the remainder of a 1.5-min interval. During a 5-min exposure period, the subject fixated a single fixation light that was positioned at his subjective straight-ahead. After the exposure, the subject rested for 1.5 min if exposure and posttest tilt were the same; if they were different, the subject was tilted to the appropriate position for the posttest at the rate of $1^\circ/\text{sec}$, then rested for the remainder of a 1.5-min interval. For subjects with pre- and posttests at 40° , this procedure was preceded by a pretest at 0° and a tilt to 40° .

RESULTS

Table 1 shows the shift in degrees of posttest minus pretest direction of gaze as a function of body tilt during exposure and tests. An analysis of variance with these two variables as between-subjects factors showed that the effect of tilt during exposure was significant ($F = 7.82$, $p < .01$), tilt during tests was not significant ($F = 1.95$, $p > .05$), and the two factors did not interact ($F < 1$).

The significant effect of tilt during exposure

Table 1
Shift in Degrees of Posttest Minus Pretest Direction of Gaze
as a Function of Body Tilt During Exposure and Test

Tilt During Exposure	Tilt During Test	
	0 deg	40 deg
0 deg	-.19	+1.27
40 deg	+2.79	+4.33

Note—Positive and negative numbers indicate upward and downward shifts, respectively.

suggests that head tilt caused an illusory shift in the direction of gaze. The amount of shift that can be attributed to head tilt is defined by the amount of shift obtained with the head tilted during exposure minus the amount of shift obtained without the head tilted during exposure. Thus, the illusory shift attributable to head tilt was $+2.98^\circ$ for subjects who were returned to 0° for tests and $+3.06^\circ$ for subjects who remained tilted back 40° for tests. The lack of an interaction in the analysis of variance suggests that the shift attributable to head tilt was comparable when tests were taken at 0 or 40° .

DISCUSSION

Contrary to predictions made by the PTP neutralization hypothesis, the present study suggests that illusory visual direction with head tilt develops before subjects are returned to upright, and it does not get larger after they are returned to upright. If PTP makes any contribution to the illusory shift, it must do so before subjects are returned to upright. During prolonged backward tilt, PTP may develop faster in the superior muscles which are voluntarily stimulated than in the inferior muscles which are reflexively stimulated, but possibilities other than PTP must be considered.

Whatever its cause, illusory visual direction with head tilt is real and substantial. To date, illusions ranging from 3 to 4° have been observed with 218 subjects in nine different conditions using the response measure employed in the present study. In addition, significant illusions have been observed with other response measures, including a pointing response, in an unpublished study in our lab. The implications of this illusion for theories of visuomotor

coordination have been discussed elsewhere (Shebilske, 1977, 1978). The practical implications of the illusion are currently being investigated in experiments outside the laboratory (Shebilske & Karmiohl, Note 1).

As an aside, notice that Shebilske and Fogelgren tilted only the head, whereas the present study tilted the whole body, which allowed larger tilts and longer uninterrupted exposure intervals. Yet, the illusion obtained in the present experiment was slightly less than that obtained by Shebilske and Fogelgren. Since the neck was not bent in the present study, it could be that any gain afforded by the larger tilt and longer uninterrupted exposure interval was offset by a smaller contribution from neck muscles and joints (cf. Takemori & Suzuki, 1969; Wade, 1969).

REFERENCE NOTE

1. Shebilske, W. L., & Karmiohl, C. M. *Athletes could help aviators by clarifying the nature of visuomotor coordination*. Paper presented at the meeting of the Psychonomic Society, San Antonio, 1978.

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(Received for publication July 5, 1978;
revision accepted October 18, 1978.)