The effect of experienced limb identity upon adaptation to simulated displacement of the visual field*

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Ss were confronted with a situation which mimicked the visuomotor consequences of an 11-deg lateral displacement of the visual field (leftward in Experiment I and rightward in Experiment II). The displacement was effected by having E place his own finger to one side of S's nonvisible finger. Ss who were informed of this deception prior to the exposure period (informed group) manifested significantly less adaptation ("negative aftereffect" and "proprioceptive shift") than did Ss who were told that their vision would be displaced by the goggles which they were wearing (misinformed group). It was concluded that adaptation to visual rearrangement is strongly influenced by S's assumptions regarding the adequacy of his vision and the identity of the manual limb which he is viewing.

Much interest has centered in recent years on the capacity of human beings to adapt both motorically and visually to an optically rearranged visual field (e.g., Held & Freedman, 1963; Kohler, 1964; Harris, 1965). Most commonly, the distortion has entailed 11-15 deg of lateral displacement, effected by means of wedge prisms.

One line of investigation has been to specify the kinds of information concerning the visual rearrangement which the S requires in order for adaptation to occur. These studies have revealed the importance of such factors as the discrepancy between felt and seen position of the body (e.g., Hay, Pick, & Ikeda, 1965) and error-corrective feedback (e.g., Welch, 1969). Little or no research, however, has examined the role which the S's cognitive *interpretation* of the situation plays in the adaptive process. This was the primary aim of the present investigation.

An examination of the literature on prism adaptation indicates that in some experimental conditions (e.g., Held & Hein, 1958) the S is totally unaware that his vision has been displaced; in others, usually those in which the S is provided with such error-corrective feedback as target-pointing error (e.g., Coren, 1966), the S generally knows that his vision has been displaced and can verbalize the degree of distortion and its direction. Furthermore, it is undoubtedly the case that in both situations the S identifies the body limb he is viewing as his own. In the present investigation, an attempt was made to manipulate the S's interpretation of his visually rearranged environment by comparing (1) the situation in which he believes that his vision is displaced and that the visible body limb is his own with (2) a situation in which he believes (correctly) that his vision is unimpaired and that the visible limb belongs to the E. The question was whether or not the adaptive process is influenced by S's interpretation of the visuomotor discrepancy to which he is exposed. In the absence of any previous research on this question, it would be possible to argue (for example) that adaptation occurs "automatically" whenever a motor movement consistently leads to discrepant feedback regarding the visual locus of the body limb—even if it is known by the S that this feedback is untrustworthy.

As a part of the study, a means was devised for creating apparent visual displacement in the absence of actual optical distortion. In brief, the technique entailed having the E place his own luminous finger to one side of the S's nonvisible finger in such a manner as to suggest that the finger the S was viewing was his own and that it had been visually displaced by the goggles that he was wearing. This technique was suggested by a study carried out by Tastevin (1937; cited by Hay, Pick, & Ikeda, 1965).

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EXPERIMENT I

Method

Subjects. Thirty-six experimentally naive undergraduates from introductory psychology classes at the University of Kansas volunteered to participate in the experiment in order to fulfill one of the course requirements. The only restriction was that S be at least 5 ft 1 in. tall (due to the dimensions of the apparatus).

Apparatus and procedure. An illustration of the testing apparatus has been presented elsewhere (Welch & Rhoades, 1969). Briefly, it consisted of a horizontal occluding board, supported 30.5 cm above a table. The S sat on one side of the table, facing E and gripping a dental impression biteplate with his mouth. On the far side of the board, a vertical .5 x 19 cm luminous target was suspended from a rubber cord running above and parallel to the edge.

The experimental session consisted of three periods: preexposure, exposure, and postexposure. During the preexposure period, S was trained to point at the target. He reached forward with his right hand and curled his index finger around the far edge of the occluding board at the apparent position of the luminous target in the otherwise dark room. The S wore a luminous rubber finger with a thin wire attached to its palmar surface. On each pointing attempt, the wire left a vertical mark in a strip of clay on the far edge of the board, alongside a ruler. Visual feedback was precluded at E's discretion by means of a removable wooden barrier. Immediately after a response, a sliding door was lowered, the light turned on, and the response recorded. After S had demonstrated reasonably good target-pointing accuracy (errors of no more than 3 cm), eight measures were recorded with the target located directly in front of him and no visual feedback provided.

Next, S was instructed to use his left hand to manipulate a motor switch which caused the vertical target to travel laterally. The task was to move the target until it appeared to be straight ahead of S's nose. The S was to notify E of his "final decision" by tapping the table twice with his left index finger. After two practice trials (with visual feedback), S made eight of these "visual straight-ahead" responses, four with the target moving from right to left and four in the opposite direction (in a "RLLR" order). The starting position on a given side was varied nonsystematically.

For the third type of preexposure measure, E placed S's right index finger in a holder located straight ahead of S at the far edge of the board, the elbow being supported by a cushion. The remainder of the procedure was identical to that of the visual straight-ahead measurements, except that now S's task was to position the target directly above his unseen finger.

In summary, S demonstrated during

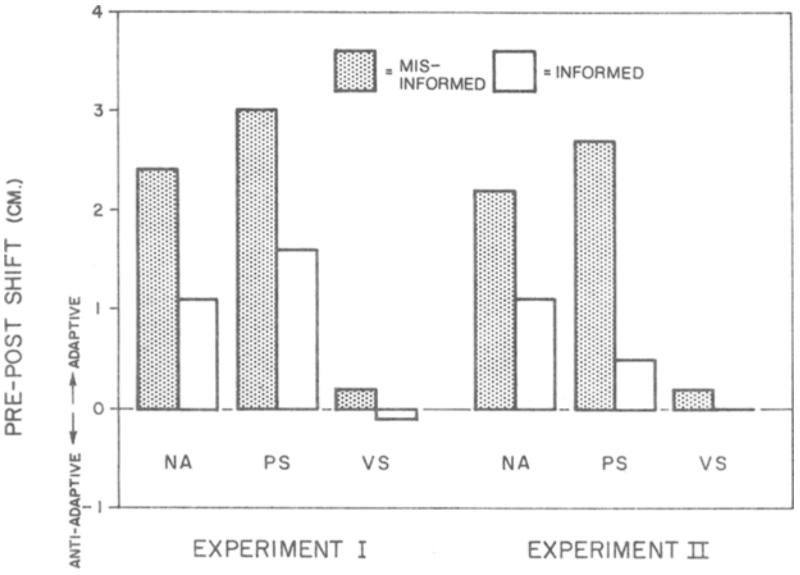

Fig. 1. Negative aftereffect (NA), proprioceptive shift (PS), and visual shift (VS) for misinformed and informed groups in Experiment I (leftward displacement) and Experiment II (rightward displacement).

the preexposure period his (1) ability to point at a target (with no feedback), (2) perception of visual straight-ahead, and (3) perception of the left position of his nonvisible right index finger. All settings were made in the dark, with S wearing clear-glass goggles (and informed that the goggles had no effect on his vision).

Next, S was trained on the target-pointing response he was to perform during the exposure period. This response differed in several respects from that used during the preexposure measurements. The sliding door was lowered immediately *before* S's finger emerged from behind the far edge of the board. After an average delay of about 1.5 sec, the door was raised and, because the barrier had been removed, S was able to see his motionless luminous finger. After approximately 2 sec of exposure, the sliding door was again lowered. The S practiced this response until it was judged to be acceptable.

An S in the misinformed group was told that, when pointing at the target, he would be wearing goggles which displaced his vision to the left (and was shown a pair of prism goggles). He was further instructed to correct for his initial errors in target pointing. His method for correcting was to note the error on one trial and attempt to bring the finger up accurately on the next. The statement that S's visual field would be displaced was, of course, false. Rather, a pair of weighted clear-glass goggles would be placed on his head and the luminous finger surreptitiously exchanged for a nonluminous one. When S brought up his finger (with the sliding door down), E would place his own finger, which was now luminous, 7.5 cm to the left of S's finger.[1] After the sliding door was raised, the only finger S could see would be E's, but he would assume that it was his own and that it had been visually displaced by the goggles he was wearing.

An S in the informed group was let in on the deception by being clearly advised of the events that would occur during the exposure period. Nevertheless, he was expected to do what was necessary to cause the position of E's finger to coincide with that of the target. If S (in either group) followed the instructions, he would soon learn to place his hand to the right of the target, because E always brought up his finger 7.5 cm to the left of S's finger.

At the outset of the exposure period, S gripped the biteboard with his mouth and closed his eyes while the goggles were placed on his head. Next, the misinformed S was told that there was something wrong with the luminous rubber finger that necessitated its exchange for another one. The luminous finger was replaced by the nonluminous one, all of this occurring with S's eyes closed. The informed S was told what E was doing. Next, E placed a luminous rubber finger on his own right index finger and extinguished the light. Then S opened his eyes and pointed at the apparent position of the target. After seeing the resulting "error," S made the appropriate change in reaching (on subsequent trials), in an attempt to match the position of the visible finger with that of the target.

There were 25 exposure trials, on the first 4 of which the target was located directly in front of S; on the remaining trials, its position was varied in a fixed irregular order among seven different locations, symmetrically arrayed with respect to S's body midline. After the last of the exposure trials, S closed his eyes and the "prism goggles" were replaced by clear-glass goggles (S being informed of this exchange). Then the measures of target pointing, visual straight-ahead, and felt finger position were taken, as in the preexposure period. The order of these postexposure measures was counterbalanced across Ss, in an attempt to equate for the three forms of adaptation any spontaneous decay which might occur after the last exposure trial (e.g., Hamilton & Bossom, 1964).

Finally, S was asked two questions: (1) Was the finger he had viewed during the exposure period ever experienced as his own, and (2) during the postexposure target-pointing measures had he made a conscious effort to point off to one side of the target.

It was assumed that both motor behavior and visual experience would be identical for the two groups. However, the misinformed S, thinking that his vision had been optically displaced, would interpret the luminous finger that he saw as his own; the informed S would be aware that his vision was unimpaired and should correctly experience the finger as belonging to E. On the basis of pilot data, it was predicted that adaptation would be greater if S believed that he was observing his own visually displaced finger than if he knew it to be E's.

Results

There were three measures of adaptation, each the difference between pre- and postexposure responses. A compensatory pre-post shift in target pointing is referred to as "negative aftereffect" (NA), an adaptive change in visual straight-ahead may be called "visual shift" (VS); and a change in felt finger position, "proprioceptive shift" (PS).

The results of Experiment I may be seen in the left half of Fig. 1. According to one-tailed t tests, NA was significantly greater than zero for the misinformed group [$t(17) = 4.90$, $p < .001$] and for the informed group [$t(17) = 2.08$, $p < .05$]. Likewise, both misinformed and informed groups revealed significant PS [$t(17) = 6.82$, $p < .001$ and $t(17) = 3.08$, $p < .005$, respectively]. On the other hand, neither group demonstrated significant VS [$t(17) = .44$, $p > .05$

and $t(17) = .50$, $p > .05$ for misinformed and informed groups, respectively]. Finally, one-tailed t tests revealed that the apparent difference in adaptation in favor of the misinformed group was statistically significant (.05) for both NA [$t(17) = 1.83$] and PS [$t(17) = 2.03$].

With regard to the question that asked if the finger S saw was ever felt to be his own, 12 misinformed Ss said "Yes" and 6 responded either "No" or ambiguously. On the other hand, 4 informed Ss replied affirmatively to the question, 12 said "No," and 2 responded ambiguously. When the responses to this question were categorized as either "yes" or "other" and a chi-square test run on the frequencies, the difference between the groups was significant ($\chi^2 = 7.29$, $p < .01$). In response to the second question, only 5 Ss (3 in the misinformed group and 2 in the informed group) reported deliberately pointing to one side of the target during the postexposure period. In every case, S gave as his reason for doing this that he was attempting to compensate for a constant error that he had noticed making during the practice target-pointing trials (prior to the preexposure measurements).

Discussion

The technique for inducing adaptation to visual displacement in the absence of an optical distortion proved successful. The method quickly led to significant visuomotor and proprioceptive adaptation for both experimental groups. One advantage of this technique over the use of prisms is the absence of prism-induced "side effects," such as chromatic fringes and the curvature of vertical contours. The fact that NA and PS were approximately equal in magnitude is contrary to the results of other studies from the present laboratory (e.g., Welch & Rhoades, 1969) but in line with Harris's notion that the basis of NA is a change in felt limb position (e.g., Harris, 1965). The failure to demonstrate a significant change in vision is somewhat puzzling, in light of a number of recent studies which have measured visual adaptation (e.g., Foley & Maynes, 1969). One plausible explanation is that the exposure period used in the present experiment was too short to induce this form of adaptation. Hay and Pick (1966), for example, found that during the initial hours of an extended prism-exposure period, adaptation was primarily motoric; changes in vision required a more extended period for their appearance.

The responses to the first question suggest that the attempt to simulate prism-displaced vision was reasonably successful for the misinformed group and that even some Ss in the informed group experienced the illusion. However, spontaneous comments from several Ss suggested that this question was ambiguous in that it failed to discriminate clearly between what S *perceived* and what he *knew* to be true. With regard to the second question, the responses provided some confidence that Ss in both groups were, for the most part, pointing in a "natural" manner during the postexposure period.

Returning to the behavioral data, it is apparent that the differences in adaptation between the two groups for both NA and PS were in the predicted direction, suggesting that the *interpretation* which S gives to the discrepancy between felt and seen position of the limb is influential for the adaptive process. However, since neither the size nor the reliability of these differences was very impressive and because only leftward displacement had been examined, it was deemed essential to replicate the experiment, using simulated rightward displacement.

EXPERIMENT II

Method

Subjects. Thirty-six Ss from the same population used in Experiment I comprised two groups.

Apparatus and procedure. The apparatus was identical to that of Experiment I. However, the procedure differed in several respects. The major differences were that the simulated prism displacement was to the right and that a new research assistant gathered the data. Another discrepancy was in terms of the criteria for using S's responses. Data were made void for any of the following reasons: (1) S was unable to master the preexposure target-pointing response after 5 trials with lights on and 10 trials in the dark, (2) the range of responses made on any one of the three preexposure series of measurements was equal to or greater than 10 cm, or (3) S moved or removed his finger during the exposure period at least once before his view of it had been blocked by the sliding door. Enforcement of these criteria led to the replacement of seven Ss. The question regarding S's perception of the visible finger during the exposure period was replaced by one which made clear the distinction between perception and knowledge about the situation. The S was also asked to indicate at what point in the exposure period he began to experience the finger as his own and for what proportion of the total period this experience occurred. In addition, he was asked to describe the strategy he had used during the adaptation period in order to make the visible finger and target coincide. The final question, as in Experiment I, asked if S had pointed in a "natural" manner during the postexposure trials.

Results

All 18 Ss in the misinformed group and 13 in the informed group responded "Yes" to the question asking if the finger they saw was ever experienced as their own. The remaining Ss in the latter group either said "No" or, in a few cases, answered ambiguously. According to a chi-square test, the difference between the groups in ratio of "yes" and "other" responses, although not large, was statistically significant ($\chi^2 = 5.76$, $p < .02$). A more striking difference between the groups was seen when compared on S's estimate of the proportion of time the finger was felt to be his own. For purposes of analysis, the responses were categorized as signifying 0, 1/4, 2/4, 3/4, or 4/4 of the total exposure period. The average response for the misinformed group was 86% and for the informed group 38%, a difference that is statistically significant [$t(34) = 2.47$, $p < .01$]. Most Ss (in both groups) who reported experiencing the illusion only part of the time said that it occurred in the middle or latter portion of the exposure period. In order to discover if extent of reported illusion was related to level of subsequent adaptation, Pearson product-moment correlations were run between the two variables for the informed group only. The results were rs of −.25 between extent of illusion and NA and −.21 between the first variable and PS. Neither correlation was significant at the .05 level [$t(16) = -1.03$ and $t(16) = -.86$ for NA and PS, respectively]. With regard to the strategy used during the exposure period, 7 misinformed and 8 informed Ss reported pointing at an "imaginary target" to one side of the apparent target. The remaining Ss divided themselves among a number of miscellaneous strategies. Obviously, there was no real difference between the two groups on this variable. All but 3 Ss (1 in the misinformed group and 2 in the informed group) indicated that they had pointed in a "natural" manner at the target during the postexposure period.

The results in terms of the adaptive measures may be seen in the right half of Fig. 1. As in Experiment I, both the misinformed and informed groups demonstrated statistically significant adaptation in terms of NA [$t(17) = 4.07$, $p < .001$, and $t(17) = 3.06$, $p < .005$, respectively]. However, while PS was significant for the misinformed group [$t(17) = 6.00$, $p < .001$], this was not true for the informed group [$t(17) = .65$, $p > .05$]. No change in vision (VS) was measured [$t(17) = .29$, $p > .05$, and $t(17) = .05$, $p > .05$, for misinformed and informed groups, respectively].

The difference between the two groups on the PS measure proved statistically significant [$t(34) = 2.47$, $p < .02$] for a two-tailed test. However, even a one-tailed test failed to demonstrate a significant difference with regard to NA [$t(34) = 1.67$, $p > .05$].

Although confounding existed (e.g., the fact that different Es were used), the data of the two studies were combined and a three-factor mixed analysis of variance (Winer, 1962) was performed. The factors were "prism displacement" (left/right), "group" (informed/misinformed), and "type of adaptation" (NA/PS/VS). As expected, "prism displacement" was a nonsignificant variable [$F(1,68) = .64$, $p > .05$], while "group" was statistically significant [$F(1,68) = 12.55$, $p < .001$], as was "type of adaptation" [$F(2,136) = 16.92$, $p < .001$]. A Scheffé test indicated that the significant variance for this third factor was due to the difference between VS and both PS and NA, the latter two being essentially equal in magnitude. None of the interactions proved statistically significant.

Discussion

The results of the questions asked at the end of the experiment suggest, in general, that the illusion was present for both informed and misinformed groups, but was much more compelling for the latter. It appeared also that the groups cannot be distinguished from each other in terms of the target-pointing strategy used during the exposure period.

With regard to the measures of adaptation, it is clear that Experiment II led to results similar to those of the first experiment. Two discrepancies, however, were the failure to find significant PS for the informed group and the lack of a statistically significant difference between the two groups on NA. However, when the data from both experiments were combined, the misinformed Ss revealed greater adaptation on both dependent measures.

GENERAL DISCUSSION

The most important conclusion to be drawn from the present investigation is that the process of adaptation to rearranged vision may depend, at least in part, on the S's belief that his visual field has been altered and/or his acceptance of the visible body limb as his own. A mere sensory discrepancy between motor movements and their visual consequences is apparently not sufficient for maximal adaptation. An assumption crucial for this argument is that Ss in the misinformed and informed groups were, in fact, engaging in identical activities during the exposure period. This assumption appears to have been met in that no differences between the two groups in visuomotor behavior were observed and, as indicated previously, the groups did not reveal a systematic difference in reported strategy for aligning visible finger and target.

It is important to note, however, that even when the S knew that the goggles he was wearing did *not* distort vision, some adaptation occurred. There are at least two ways to interpret this result. On the one hand, it may be that a certain amount of adaptation can occur in the presence of a consistent discrepancy between motor behavior and visual feedback, even when the S believes that the two are not intrinsically related. Another alternative, however, is that the instructions to the informed group were only partially effective in their aim. That is, it appears from their comments that many of the Ss in this group at least occasionally experienced the visible finger as their own, even though they knew better. This "visual capture," in turn, could be the basis of the partial adaptation that occurred for these Ss. Some doubt is cast upon this hypothesis, however, by the absence of a correlation between the extent of reported illusion and the adaptation achieved by the informed group. On the other hand, it is not clear how much trust can safely be placed in S's estimate of the proportion of time that he experienced the illusion. Clearly, more stringent experimental control over S's interpretation of his experience during the exposure period will be necessary before a final decision can be made regarding the importance of this variable for adaptation.

The results of the present investigation indicate that, in studies of adaptation to prismatic distortion, an important element of the adaptive process is the S's awareness that his vision is rearranged and/or that he is observing his own body limb. It is possible that the operation of the first of these cognitive factors (i.e., awareness of the distortion) is involved in the finding that prism adaptation is significantly enhanced when Ss are provided with error-corrective feedback.

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NOTE

1. The choice of the 7.5-cm separation between S's and E's fingers was based on a pilot study demonstrating this to be the amount by which objects at the far edge of the occluding board are visually displaced by a 20-diopter wedge prism. By using this displacement, the results of the present study may be compared to those of most experiments on prism adaptation, which have usually used 20-diopter prisms.

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