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Restricted adaptation to prism rearrangement*

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Changes in eye-foot and eye-hand coordination were measured following 20 min of squint prism viewing (alternate monocular viewing of the movements of each leg with the contralateral eye at 1-min intervals: prism base right for right eye and left for left eye). In different sessions, response changes were measured following the viewing of the left leg with the right eye (prism base right) for periods of 1 min interspersed with 1-min blank periods (periodic viewing). Sensorimotor changes following the alternate exposure condition were smaller and restricted to eye-foot responses.

Movements of limbs viewed through prisms produce changes in visually guided spatial responses; viewing arm movements through prisms produces changes in eye-hand coordination (Held & Freedman, 1963), and viewing leg movements produces corresponding changes in eye-foot coordination (Mikaelian, 1970). The results of the various conditions of prism viewing are not, however, necessarily equivalent. While compensatory in direction, they may be generalized or highly local. For instance, under certain conditions, sensorimotor changes produced by viewing arm movements are confined to the arm viewed through prisms (Harris, 1963; Mikaelian, 1963), while that produced by prism viewing of leg movements generalize to responses made with any limb, as well as whole body orientation (Mikaelian, 1970), although the magnitude of the generalized effect in each type of response following the latter exposure condition would vary.

The extent of adaptation, that is, the degree to which adaptation generalizes, reflects the locus of the prism-induced changes (Harris, 1965); the more central the locus, the more generalized the adaptation. This reasoning has lead to the stipulation (Mikaelian, 1970) that exposure to prismatic rearrangement results in at least two types of visuomotor alterations: a local effect and a generalized one. The more localized adaptation would be mediated by recalibration of target-directed limb responses, and thus confined solely to them, while the generalized effect would result from recalibration of target-directed orientations of the eye-head-body system, thereby affecting all responses requiring orientation. The magnitude of the evidenced adaptation measured following rearrangement would, of course, be the algebraic sum of these two components.

Is it possible to experimentally separate these two types of adaptation? A generalized effect was obtained in an earlier experiment where rearrangement consisted of viewing, through prisms, the trajectory of a dimly luminous spot moved by the leg (limb not visible) (Mikaelian, 1974). Adaptation following this visually diminished rearrangement condition was evident in eye-hand, eye-foot, and egocentric responses, much like generalized adaptation observed following rearrangement entailing view of the movements of the entire leg. Unlike the latter, however, the magnitude of the alterations in each type of sensorimotor response was equal following the diminished exposure condition, thus suggesting that the response shifts were due solely to a single central shift most likely resulting from recalibration of the head-body system.

The present experiment describes a procedure that, while entailing the eye-foot coordination system that normally produces generalized adaptation, is designed to produce only localized effects. The rationale is as follows: viewing through laterally displacing prisms alters the relationship between target-directed orientations of the head and of the limb (leg), viewing through opposite base prisms reverses the direction of the effects; however, if one views a different limb through the opposite base prisms, then the effect would be to recalibrate that limb in accordance with visual input from the new prism, while cancelling the effect on head orientations. Such an analysis leads to the following empirically verifiable predictions: (1) Viewing the movements of one leg through base-right prisms and those of the other through base-left prisms should produce opposite shifts in responses entailing each limb; (2) the sensorimotor shifts produced should be smaller in magnitude than those obtained by the more usual procedure (since the generalized component

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normally produced by the usual procedure will be lacking); and (3) the effects should not generalize to other types of sensorimotor responses (such as eye-hand coordination). The following experiment was designed to explore these possibilities.

METHOD

Subjects

Thirty-two college students with no apparent visual defects were used.

Apparatus

Details of the exposure and test apparatus have been given elsewhere (Mikaelian, 1970). The exposure apparatus consisted essentially of a slanted top table with prism goggles rigidly mounted on the slanted surface. During exposure, S rested his head on the goggles to view leg movements. Twenty-diopter wedge prisms were mounted on the goggles in opposite base orientation (base left for left eye and base right for right eye). An opaque shield held by S in front of the prism was used for monocular viewing.

The test apparatus consisted of the eye-foot coordination test box (Mikaelian, 1970) and the Held-Gottlieb type of eye-hand coordination test box (Held & Gottlieb, 1958). The former was designed to allow S to mark the location of visual targets with his foot, and the latter to mark the location of visual targets with his hand, without response feedback.

Procedure

The experiment was designed to use each S as his own control (within-S design). Two conditions of exposure to prism rearrangement were used in four different sessions separated by at least 24 h. The "alternate" prism exposure condition entailed viewing the movements of one leg with the contralateral eye for 1 min and, upon an auditory time signal, alternating to view the movements of the other leg with the other eye for the next minute. The eye-leg alternation was executed at every 1-min interval for a total of 20 min. Upon the signal to alternate, S closed both eyes to prevent view of the leg during changeover; he then placed the opaque shield in front of the appropriate eye before resuming exposure.

The "periodic" exposure condition consisted of viewing the movements of the left foot with the right eye (base-right prisms) for 1 min (left eye covered with eyepatch) and, upon an auditory signal, closing that eye for 1 min. Alternation between viewing leg movements and closing the eye occurred at 1-min intervals for a period of 20 min. The "periodic" exposure condition was designed essentially as a control condition to determine whether the periodic nature of the "alternate" condition would interfere with adaptation, and also to produce appropriate base-line adaptation measures. It was felt that a single "periodic" exposure condition would be sufficient to generate needed data for comparison.

Each session entailed one set of sensorimotor tests (eye-foot or eye-hand), with contralateral eye-limb combinations tested successively, followed by exposure to rearrangement and then postexposure tests of the same coordinations. During the alternate exposure conditions, the eye-limb combinations used during the last minute of exposure was the same as that tested first during the postexposure test; thus, if, during the final exposure minute, the right-eye/left-foot combination was used, then the first postexposure eye-foot combination tested was the right-eye/left-foot followed by the left-eye/right-foot combination. If postexposure tests entailed eye-hand coordinations, then the right-eye/left-hand combination was tested first, followed by the left-eye/right-hand combination.

Sixteen Ss were used in Sessions A, B, and C. A new group of 16 Ss was recruited for Session D. Session A consisted of "alternate" exposure with eye-foot coordination tets, Session B also entailed "alternate" exposure with eye-hand coordination tests; Session C involved "periodic" exposure with eye-foot coordination tests; and Session D entailed "periodic" exposure with eye-hand coordination measures. The order of sessions and eye-limb combinations tested first was counterbalanced for Sessions A, B, and C. In Session D, eight of the new Ss were exposed with the left-eye/right-leg combination and the other eight with right-eye/left-leg combination.

RESULTS

The results are shown in Tables 1, 2, 3, and 4. The numbers represent, in degrees of visual angle, mean differences between the centroids of the pre- and postexposure markings. Positive numbers represent shifts in the expected (adaptive) direction; thus positive right-foot and left-foot data represent shifts in opposite directions as the prism bases were opposite.

Tables 1 and 2 represent data on changes in eye-foot and eye-hand coordination, respectively, generated by the "alternate" exposure condition. Tables 3 and 4 (a and b) are data from the "periodic" exposure condition; Table 3 shows changes in eye-foot responses following right-eye/left-foot exposure, while Tables 4a and 4b show changes in eye-hand coordination following right-eye/left-foot (base right) and left-eye/right-foot (base left) exposures, respectively.

The data show that 20 min of "alternate" eye-foot exposure generates significant adaptive shifts in eye-foot coordination, $t(15) = 5$, $p < .001$, without producing concurrent adaptive alterations in eye-hand coordination. A small change in right-hand/left-eye responses is evident; however, it is in the anti-adaptive direction. The data from the

Table 1
Changes (in Degrees of Visual Angle) in Eye-Foot Coordination Following 20 Min of Binocular Squint Prism Exposure*

S	Left Foot (Right Eye)	Right Foot (Left Eye)
1	4.1	2.0
2	1.8	5.6
3	3.2	5.2
4	5.6	3.3
5	2.1	3.5
6	0.0	4.4
7	0.8	4.8
8	1.9	−1.2
9	8.5	2.2
10	1.8	2.7
11	3.3	0.6
12	4.1	0.9
13	1.4	1.6
14	0.6	5.2
15	4.2	4.3
16	0.6	1.9
Mean	2.8	2.9
SD	2.1	1.9

*Alternate *viewing of right foot with left eye–prism base left, and left foot with right eye–prism base right. 20-diopter wedge prisms.*

Table 2
Changes (in Degrees of Visual Angle) in Eye-Hand Coordination Following 20 Min of Binocular Squint Prism Exposure*

S	Left Hand (Right Eye)	Right Hand (Left Eye)
1	3.2	−3.4
2	0.9	−2.4
3	7.8	3.4
4	1.9	−1.9
5	−3.2	1.5
6	0.0	−3.2
7	0.9	−6.9
8	0.0	−5.1
9	2.2	−3.6
10	4.6	−3.9
11	−0.7	−0.9
12	0.9	−4.1
13	−0.9	0.2
14	−3.2	−1.4
15	−1.4	1.9
16	−3.6	−2.2
Mean	0.6	−1.7
SD	2.9	2.8

*Alternate *viewing of right foot with left eye–prism base left, and left foot with right eye–prism base right.*

Table 3
Changes (in Degrees of Visual Angle) in Eye-Foot Coordination Following 20 Min of Monocular Prism Exposure*

S	Left Foot (Right Eye)	Right Foot (Left Eye)
1	5.6	6.1
2	3.5	6.2
3	2.0	1.3
4	2.5	5.6
5	9.6	1.3
6	1.2	5.9
7	8.4	3.8
8	5.0	1.8
9	3.7	3.3
10	1.7	6.9
11	7.4	7.1
12	1.8	3.1
13	7.6	2.6
14	4.0	6.2
15	6.3	7.6
16	6.0	7.2
Mean	4.8	4.8
SD	2.5	2.2

*Periodic *viewing of left foot with right eye–prism base right, 20 diopters.*

"periodic" conditions show shifts in both eye-foot and eye-hand responses. The former are significantly larger than that produced by the "alternate" conditions, $t(15) = 5$, $p < .05$. Except for one, all eye-hand shifts are significant beyond the .01 level (t tests); the one condition where these failed to reach significance was the right-eye/left-hand test following right-eye/left-foot exposure, a condition that has consistently generated variable results in other studies (Mikaelian, 1970).

DISCUSSION

The results show that the sensorimotor changes observed in both left and right eye-foot responses following "alternate" exposure are equivalent, considerably and significantly smaller than that produced by the "periodic" exposure condition, and do not generalize to eye-hand coordinations. These observations are in line with the expectations discussed earlier, and indicate that alternate viewing of the movements of one foot through base-left prism and those of the other through base-right prism generates selective and specific adaptation appropriate to each sensorimotor system.

The results from the "periodic" exposure condition show large shifts in eye-foot coordination in responses with the leg viewed through prisms, as well as with the unexposed leg, thus indicating the presence of interpedal transfer. Additionally, significant shifts in eye-hand coordination also occur in responses entailing either arm. Both sets of observations suggest that, unlike the "alternate" exposure condition, "periodic" exposure produces generalized adaptation which is comparable to that seen following the more usual exposure conditions.

These results indicate that it is possible to generate specific and localized sensorimotor adaptation by selective funnelling of appropriate reafferent information, and support further the additive model of adaptation to rearrangement as described earlier. It is apparent that without specific precautions exposure to rearrangement may produce both generalized and specific adaptation, thus invalidating any conclusions one may reach concerning its transferability. This possibility may account for the contradictory reports on intermanual transfer of prism adaptation where some investigators have

Table 4
Changes (in Degrees of Visual Angle) in Eye-Hand Coordination Following 20 Min of Monocular Prism Exposure

a. *Periodic* Viewing of Left Foot With Right Eye Prism Base Right, 20 Diopters			b. *Periodic* Viewing of Right Foot With Left Eye Prism Base Left, 20 Diopters		
S	LH (RE)	RH (LE)	S	LH (RE)	RH (LE)
1	0.0	+2.2	9	0.5	4.0
2	0.0	2.0	10	4.0	3.6
3	2.0	3.4	11	7.7	3.6
4	0.0	3.6	12	2.9	3.0
5	1.8	3.2	13	4.1	1.8
6	2.2	2.9	14	3.2	7.2
7	1.5	1.5	15	2.3	6.7
8	−2.9	1.4	16	0.0	4.3
Mean	0.6	2.5	Mean	3.1	4.3
SD	1.6	0.8	SD	2.2	1.7

Note–*LH = left hand, RH = right hand, RE = right eye, and LE = left eye.*

reported the presence, and some the absence, of such transfer. The present findings caution against indiscriminate comparisons between adaptation produced by different exposure conditions, and point to the need for more precise specification and control of the generating conditions.

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