Prism adaptation influences perception but not attention: evidence from antisaccades

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Prism adaptation has been shown to successfully alleviate symptoms of hemispatial neglect, yet the underlying mechanism is still poorly understood. In this study, the antisaccade task was used to measure the effects of prism adaptation on spatial attention in healthy participants. Results indicated that prism adaptation did not influence the saccade latencies or antisaccade errors, both strong measures of attentional deployment, despite a successful prism adaptation procedure. In contrast to visual attention, prism adaptation evoked a perceptual bias in visual space as measured by the landmark task. We conclude that prism adaptation has a differential influence on visual attention and visual perception in healthy participants as measured by the tasks used. *NeuroReport* 21:386–389 © 2010 Wolters Kluwer Health | Lippincott Williams & Wilkins.

NeuroReport 2010, **21**:386–389

Keywords: antisaccade task, attention, landmark task, perception, prism adaptation

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Received 20 January 2010 **accepted** 25 January 2010

Introduction

Prism adaptation has been shown to be a successful treatment for hemispatial neglect, for example Ref. [1]. It consists of visuomotor adaptation to an exposure to wedge prisms. Despite these results of successful treatment, the underlying mechanism of prism adaptation is still poorly understood. As hemispatial neglect is generally associated with an imbalance of visual attention across the visual field [2], one of the hypothesized effects of prism adaptation in hemispatial neglect is a redistribution of attentional resources in space [3,4]. One way to gain more insight into the mechanisms underlying prism adaptation is by assessing the effects of adaptation in healthy participants, for a review, see Ref. [5] on perceptual and attentional tasks. Some evidence suggests that prism adaptation influences the allocation of both voluntary and reflexive spatial attentional resources in healthy participants [6–8]. In contrast, results of both serial and parallel visual search tasks in healthy participants showed no effects of prism adaptation on the distribution of attention in space [9]. In this study, we used saccadic eye movements to measure the effect of prism adaptation on spatial attention in healthy participants. Saccadic eye movements are good indicators of spatial attention, as the preparation of an eye movement is always associated with a shift in spatial attention to the location of the next eye movement [10,11].

In this study, we have used the antisaccade task to measure the effect of prism adaptation on spatial attention in healthy participants. During the antisaccade task, participants either have to make a saccadic eye movement towards the appearing stimulus after stimulus onset (i.e. prosaccade trials) or a saccade in the opposite direction as quickly as possible (i.e. antisaccade trials) [12]. Results typically show that antisaccade trials have longer saccade latencies than prosaccade trials and that participants frequently make an erroneous saccade to the target in antisaccade trials [12,13]. Correct performance on antisaccade trials requires at least two intact attentional processes: (i) the ability to suppress a reflexive (exogenous) saccade towards the visual stimulus and (ii) the ability to generate a voluntary (endogenous) saccade in the opposite direction. In this study, performance on the antisaccade task before and after prism adaptation has been compared. If prism adaptation indeed influences the attentional deployment in visual space, differences will be observed in saccade latencies and the number of erroneous eye movements before and after prism adaptation.

Besides the effects on visual attention, the influence of prism adaptation on visual perception will be investigated using the landmark task. Participants perform multiple landmark tests in which they are requested to judge whether a line was pretransected to the left or to the right of its center [14,15]. Numerous studies have shown that prism exposure induces a bias in visual space perception in healthy participants, as shown by the perceptual landmark task [14,16,17].

Methods

Participants

Fifteen students [three males; 10 right handed; mean age: 22.0 years (SD: 2.4)] participated in the experiment. All had normal or corrected-to-normal visual acuity. They were naive to the purpose of the study. The study was approved by the appropriate ethics committee.

Apparatus

The stimuli were displayed on a laCie Electron 22-in Blue 3 CRT monitor (60 Hz, 1024 × 768 pixels).

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Eye movements were recorded using an Eyelink 1000 system (SR Research Ltd., Mississauga, Ontario, Canada) with a temporal resolution of 1 ms and a spatial resolution of 0.02°.

Participants were tested individually in a dimly lit room and were seated in front of the computer with their chin in a chin rest. Participants viewed the monitor from a distance of 57 cm in the antisaccade task. In the landmark test, the participant's head was kept aligned with the body midline by the chin rest with a viewing distance of 35 cm.

Stimuli and procedure

Each participant performed the landmark task three times. First, each participant performed the landmark task before prism adaptation to determine the subjective midline of the participant ('preadaptation'). Second, the landmark task was performed after prism adaptation to make sure that the participant was sufficiently adapted after removing the prism goggles ('postadaptation 1'). Third, the landmark task was performed again after the antisaccade experiment to make sure that the participants were still adapted during the antisaccade experiment ('postadaptation 2'). The sequence of the blocks was therefore as follows: first antisaccade task, first landmark task, prism adaptation, second landmark task, second antisaccade task, third landmark task. A chin rest was used for positioning the participants' head during the whole procedure.

Antisaccade task

Each trial began with the presentation of a colored central fixation cross ($1.0° \times 1.0°$) against a black background. A 'red' cross indicated a prosaccade trial, in which participants had to look at the target once it appeared. When the cross was 'green', participants had to look in the opposite direction of where the target appeared at an equal distance from the central fixation cross (antisaccade trial). After 1000 ms, the target (a gray circle of 2.0°) appeared at a distance of 13.5° on the right or on the left of the central cross. The target appeared on the same horizontal axis as the central cross. The antisaccade task consisted of 100 trials. Participants performed 25 practice trials during the first antisaccade task. When errors occurred on half or more of the practice trials, the training block was repeated. Antisaccade and prosaccade trials were mixed.

Landmark task

Fourteen black horizontal lines, 250 mm long and 1 mm thick, each centered on a separate A4 sheet of white paper were used. Each line had been transected at different distances. Of these 14 lines, two were transected in the center and 12 were asymmetrically transected: six at distances of either 2, 4, or 6 mm to the right of the true midpoint and six at distances of either 2, 4, or 6 mm to the left of the true midpoint. Participants were told that none of the transection marks was at the midpoint of the line, and they were asked to indicate verbally whether the transection mark was closer to the right end or to the left end. The different trials were presented on sheets of paper that were positioned directly in front of the computer screen on which the antisaccade task was presented. The order of the presentation of the lines was randomized.

Prism adaptation

As most research on prism adaptation in the normal population has found behavioral effects with left-shifting, but not right-shifting prisms [6,7], left-shifting prisms were used in this study. The prism goggles were fitted with wide-field, prismatic lenses, creating an optical shift of 15° to the left. The exposure period consisted of making pointing responses during 10 min to visual targets presented 10° to the right or left of the participant's body midline. During the prism exposure, participants were asked to point at a fast but comfortable speed; they could see the target, the 'second' half of their pointing trajectory and their terminal error. Their head was kept aligned with the body's sagittal axis by a chin rest [1]. View of the starting position and the 'first' half of the pointing trajectory was blocked by a board held under the participant's chin to ensure the optimal development of the adaptation.

For a successful prism adaptation procedure, a rightward shift of 3 cm of the landing position was required (as measured by a ruler) at the end of the adaptation period. This was measured by asking the participant to focus on one of the landing positions, then close one's eyes and make a pointing movement with closed eyes to this location and leave one's finger at the exact landing position. A board was held under the participant's chin to prevent perception of the start position or the arm. For two participants, the shift was less than 3 cm, hence, the prism adaptation procedure was repeated.

Analyses

Antisaccade task

Saccade latency was defined as the interval between target onset and the initiation of a saccadic eye movement. Trials were excluded when the saccade latency was lower than 80 ms or higher than 600 ms, or more than two and a half standard deviations away from the participant's mean latency. Trials in which no saccade or too small a saccade ($< 3°$) was made were eliminated as well. The endpoint of the first saccade had to have an angular deviation of less than 22.5° from the center of the target or the mirrored target location. In the first case, the saccade was classified as a prosaccade; in the second case the saccade was classified as an antisaccade. In other situations, the saccade was not analyzed.

Saccade latencies were analyzed using analysis of variance with stimulus location (left vs. right), task (antisaccade vs. prosaccade) and time (before vs. after adaptation) as within subject factors. Antisaccade errors (i.e. an eye movement to the target on an antisaccade trial) were analyzed using analysis of variance with stimulus location (left vs. right) and time (before vs. after adaptation) as factors.

Landmark task

The landmark task was analyzed by counting how many times a participant answered left or right when the transection mark was in the middle or in the other direction as indicated by the participant. A perceptual bias in a certain direction is indicated by the difference between these two numbers. This difference was computed such that a positive number refers to a rightward bias (indicating that the transection was on the left when it was in the middle or to the right).

Results were analyzed using *t*-tests (preadaptation vs. postadaptation 1, preadaptation vs. postadaptation 2, and postadaptation 1 vs. postadaptation 2). Only the transection marks at a distance of 2 or 4 mm left and/or right of the center were used, as there were no errors with a distance of 6 mm.

Results

Antisaccade task

Overall, 7.4% of the trials were excluded on the basis of the exclusion criteria (2.3% on the basis of the latency, the remaining trials because of directional errors other than erroneous prosaccades).

Saccade latency

No main effect was found on saccade latency for stimulus location ($F < 1$), indicating that there was no difference in latencies between stimuli that were presented to the left or right. A main effect of task was found [$F(1,14) = 93.31$, $P < 0.0001$], with shorter latencies in the prosaccade task ($M = 152$ ms, $SD = 30$ ms) than in the antisaccade task ($M = 219$ ms, $SD = 31$ ms). A main effect of time was found [$F(1,14) = 5.84$, $P < 0.05$]: overall saccade latencies in the preadaptation task were longer ($M = 191$ ms, $SD = 49$ ms) than saccades in the postadaptation task ($M = 180$ ms, $SD = 42$ ms). This is interpreted as a general training effect. None of the interactions reached significance (all $P > 0.10$).

To ascertain that there was no subtle effect of prism adaptation that could not be shown by the analyses described above, we tested whether saccade latencies of antisaccades preadaptation and postadaptation were different to the left and the right. If prism adaptation has an effect, it should be lateralized, thus showing a beneficial effect to the left and that is observed only in the postadaptation trials. At the start of the task (i.e. preadaptation), there was no difference between the latencies of antisaccades to the targets presented left ($M = 226$ ms, $SD = 35$ ms) and right [$M = 227$ ms, $SD = 36$ ms; $t(14) = 0.23$; $P = 0.81$]. Importantly, there was again no difference in postadaptation between targets presented left ($M = 212$ ms, $SD = 22$ ms) and right [$M = 212$ ms, $SD = 30$ ms; $t(14) = 0.10$; $P = 0.91$]. This indicates that prism adaptation did not evoke a difference in the saccade latency of antisaccades.

Antisaccade errors

The mean error rate was 13.7% ($SD = 10.9\%$). There were no main effects of antisaccade errors on stimulus location and time ($F < 1$). The interaction was not significant ($F < 1$).

Landmark task

In preadaptation, there was rightward bias in the landmark task ($M = 0.60$, $SD = 1.59$). This rightward bias was similar for left-handed and right-handed participants (the mean bias for both groups was 0.60). The rightward bias became even more stronger in the second landmark task [first postadaptation test; $M = 2.20$, $SD = 1.90$; $t(14) = 4.77$, $P < 0.001$]. The stronger rightward bias was still observed in the third landmark task [$M = 2.27$, $SD = 1.44$; $t(14) = 5.49$, $P < 0.0001$]. There was no significant difference between the second and third landmark task [$t(14) = 0.17$, $P = 0.87$], indicating that participants were still adapted during the third administration of the task.

Discussion

The aim of this study was to investigate whether prism adaptation influences attentional deployment in visual space in healthy participants. The results on the antisaccade task showed that prism adaptation did not influence the saccade latencies or antisaccade errors. As both saccade latencies and antisaccade errors are measures of attentional processes, this provides strong evidence that prism adaptation did not influence attentional deployment in the current task. Results on the perceptual landmark task did show a strong effect of prism adaptation, which is in line with earlier studies [14,16,17]. A rightward shift was obtained in the landmark task in both postadaptation tests, which indicated that participants were still adapted during the second antisaccade task.

In contrast to the null results on the antisaccade task, we showed in an earlier study [3] that prism adaptation to a rightward prismatic shift improved leftward orientation of attention following an endogenous, but not an exogenous, cue in two neglect participants. We suggested that prism adaptation ameliorates neglect by improving compensatory processes of leftward voluntary orienting rather than by a fundamental change in attentional bias. Although this suggestion explains why prism adaptation did not influence the more ‘reflexive’ attentional processes (i.e.

the prosaccade trials), it does not explain why prism adaptation did not influence the 'voluntary' attentional processes in the antisaccade trials.

The absence of an effect of prism adaptation in the antisaccade task is consistent with the results of a recent visual search experiment [9]. In this study, no effect of prism adaptation was observed on the attentional deployment in space in both healthy participants and neglect patients, although a recent study did find an effect on the visual search performance of neglect patients when unlimited search time was given to find a target [18]. The effect of prism adaptation on attentional deployment therefore appears to be restricted to neglect patients, see also Ref. [4].

The discrepancy between the results of studies with healthy participants and neglect patients is informative of the underlying mechanisms of prism adaptation. There is converging evidence that visual neglect is associated with an imbalance in the attentional distribution between the contralateral and ipsilesional visual field [19–22]. For instance, Walker and Findlay [19] proposed that visual neglect might be associated with an imbalance in the level of activity in the saccadic system. Activity in the contralesional visual field is permanently suppressed which makes it less likely that elements in that part of the visual field can compete for saccadic selection (i.e. to be a potential target for the next eye movement). It could therefore be that prism adaptation alleviates the imbalance between the contralesional and ipsilesional visual fields such that attentional deployment to the contralesional visual field is improved. Indeed, prism adaptation has shown to improve the ocular exploration of the neglected field [23,24]. The current finding that prism adaptation does not influence attentional deployment in healthy participants indicates that prism adaptation does not simply result in a stronger attentional focus in one visual field. Prism adaptation has an effect only when there is an a-priori imbalance between the two visual fields. Interestingly, tasks in which effects of prism adaptation in healthy controls are observed mostly reflect an a-priori imbalance in performance, such as number bisection [7], alphabet bisection [25], and grayscale tasks [6].

Conclusion

Prism adaptation has a differential influence on visual attention and visual perception as measured by the current tasks. Although visual 'attention' in the antisaccade task was not influenced by prism adaptation in healthy participants, adaptation to prism glasses did modulate visual 'perception' in the landmark task. It could be that an 'a-priori imbalance' between the two visual fields is necessary to observe the effects of prism adaptation.

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