# Differential Influences of Prism Adaptation on Reflexive and Voluntary Covert Attention

Christopher Striemer, Jeffery Sablatnig, James Danckert

NOTICE: This is the peer reviewed version of the following article: Striemer, C., Sablatnig, J., & Danckert, J. (2006). Differential influences of prism adaptation on reflexive and voluntary covert attention. *Journal of the International Neuropsychological Society*, *12*(3), 337-349, which has been published in final form at http://dx.doi.org/10.1017/s1355617706060553 in the Journal of the International Neuropsychological Society. Copyright Cambridge University Press.

**Permanent link to this version** http://roam.macewan.ca/islandora/object/gm:742

**License** All Rights Reserved

This document has been made available through RO@M (Research Online at Macewan), a service of MacEwan University Library. Please contact roam@macewan.ca for additional information.

# Differential influences of prism adaptation on reflexive and voluntary covert attention

Christopher Striemer, Jeffery Sablatnig & James Danckert*

Department of Psychology, University of Waterloo, Canada

*Correspondence and reprint requests should be addressed to:
James Danckert
Canada Research Chair (Tier II) in Cognitive Neuroscience
Department of Psychology
University of Waterloo
200 University Avenue West
Waterloo, Ontario, N2L 3G1
Ph: 1 519 888 4567 ext. 7014
Fax: 1 519 746 8631
Email: jdancker@watarts.waterloo.ca

**Acknowledgements**
This work was supported by a Heart and Stroke Foundation of Canada Masters Award to C.S. and a Natural Sciences and Engineering Research Council (NSERC) of Canada Discovery Grant (#261628-03) and NSERC Canada Research Chair (Tier II) award to J.D. The authors would also like to thank Mike Dixon, Yves Rossetti, and two other anonymous reviewers for their helpful comments on an earlier draft of this paper.

Word count: 4978

**Abstract**

Recent research has demonstrated some beneficial effects in patients with neglect using rightward shifting prismatic lenses. Despite a great deal of research exploring this effect, we know very little about the cognitive mechanisms underlying prism adaptation in neglect. We examined the possibility that prism adaptation influences visual attention by having healthy participants complete either a reflexive or a voluntary covert visual attention cuing paradigm before and after adaptation to leftward, rightward, or sham (no shift) prisms. The results for reflexive orienting demonstrated that a subset of participants with large cuing effects prior to prism adaptation were faster to reorient attention away from an invalid cue on the side of space opposite the prismatic shift post adaptation. For voluntary orienting, left prisms increased the efficiency of voluntary attention in both left and right visual space in participants with a small cuing effect prior to prism adaptation. In contrast, right prisms decreased the efficiency of voluntary attention in both left and right space for participants with a large cuing effect prior to prism adaptation. No significant effects were observed in the sham prisms groups. These results suggest that prism adaptation may exert a variety of influences attentional orienting mechanisms.

**Key Words:** neglect, parietal lobes, visuomotor adaptation, spatial representation, perceptual disorders, sensory motor performance

**Introduction**

Lesions of the right parietal cortex or the superior temporal gyrus often lead to the disorder of neglect in which patients fail to attend or respond to stimuli in contralesional space (Driver & Mattingley, 1998; Karnath, et al. 2001; Mort et al., 2003). Neglect is generally considered an attentional disorder (Danckert & Ferber, in press; Husain & Rorden, 2003) with many attempts at rehabilitation focusing on cuing the patient to attend to left space (Robertson, 1999).

Rossetti and colleagues (1998) recently developed a means of ameliorating some symptoms of neglect using prismatic lenses. Prior to wearing prisms the patient points to a subjective position straight-ahead of their body's midline while blindfolded. Typically, patients with neglect point to the right of true centre. Patients are then asked point to left and right targets while wearing prismatic lenses that shift vision 10º to the right. The visual displacement caused by the prisms necessitates a compensatory visuomotor transformation such that patients must adjust their pointing movements to the left to compensate for the rightward shift in vision (for review see Redding & Wallace, 2005). After prism adaptation (PA), straight-ahead pointing movements are typically shifted closer to the true midline (Rossetti et al.,1998). Perhaps more interesting are the after effects that PA has on patients such that after PA they bisect lines closer to the objective centre and demonstrated less neglect on figure copying. In addition, recent studies have shown that PA leads to beneficial after-effects in visual imagery (Rode, et al. 2001), postural imbalance (Tilikete et al., 2001), tactile extinction (Maravita et al., 2003) and temporal order judgments (Berberovic, et al., 2004).

A similar 'neglect-like' effect has been demonstrated in healthy individuals using leftward PA. Leftward PA necessitates a visuomotor transformation that results in a rightward shift in the subjective notion of straight-ahead, similar to the rightward bias in those same judgments exhibited by patients with neglect prior to adaptation. Such neglect-like patterns of behaviour have been observed for line bisection (Colent, et al., 2000; Michel, Pisella et al., 2003), postural control (Michel, Rossetti, et al., 2003) and haptic space exploration (Girardi, et al., 2004).

Although the observed effects on tasks such as line bisection, visual imagery, and tactile extinction suggest that PA influences higher level spatial representations, we still know very little about the cognitive and neural mechanisms underlying this effect. One hypothesis is that PA might influence mechanisms involved in visual attention. In order to examine this hypothesis we had healthy participants complete either a reflexive or a voluntary covert orienting of visual attention task (COVAT) after adaptation to 15° left, 15° right, or sham (no shift) prisms. The COVAT measures response time (RT) to cued (valid) and non-cued (invalid) targets while maintaining central fixation (Posner, 1980). Generally, RTs are faster for valid trials when compared with RTs on invalid trials. This is thought to reflect the fact that in valid trials attention has already been allocated to the cued location thereby decreasing RT, while invalid trials lead to slower RTs because a participant must first ‘disengage’ attention from the cued location and reorient attention to the non-cued (invalid) location (Posner, 1980; Posner et al., 1984).

## Methods

### *Participants*

For the reflexive orienting task, 20 participants (7 male) wore leftward shifting prisms, 20 (9 male, 2 left handed) wore rightward shifting prisms, and 20 (6 male, 3 left handed) completed the experiment using sham (no shift) prisms. For the voluntary orienting task, 26 participants (9 males, 1 left handed) wore leftward shifting prisms, 25 participants (7 males; 1 left handed) wore rightward shifting prisms, and 20 participants (10 males, 1 left handed) completed the experiment with sham prisms. None of the participants in this experiment participated in more than one condition. Participants were undergraduate students recruited from the University of Waterloo. All participants had normal or corrected to normal visual acuity. Informed consent was obtained prior to commencing the experiment and the experimental protocol was approved by the University of Waterloo ethics committee in accordance with the Helsinki Declaration.

*Apparatus and Procedure*

For the reflexive COVAT we used non-informative (i.e. 50% valid) abrupt onset peripheral cues. Target locations were indicated by green circles subtending 2.2° and presented 12.4° to the left and right of fixation. A cue consisted of the brightening of one peripheral landmark. Targets consisted of filled red circles presented entirely within the peripheral landmark.

Reaction times to detect targets were measured by external button press. All COVAT tasks were presented on an IBM compatible Pentium IV computer with a 19 inch CRT monitor (refresh rate 75Hz) and were created using Superlab software. Participants were seated 50cm from the monitor with their head in a chin rest. Participants were told to maintain central fixation[1]. A trial began with fixation and after a variable time period one peripheral landmark was brightened. This cue remained present until the participant responded. After a stimulus onset asynchrony (i.e., the time between cue onset and target onset; SOA) of 50ms, 150ms, or 300ms a

[1] While fixation was not strictly monitored, all participants reported having no difficulty maintaining fixation throughout. Furthermore, saccadic eye movements take around 200 ms to initiate such that eye movements to cued locations would not be possible at SOAs of 50 and 150.

target appeared at either the cued (valid) or non-cued (invalid) location. Participants performed 5 practice trials before completing the COVAT.

For the voluntary COVAT we used the exact same procedure, the only critical difference is that we used a highly predictive (i.e. 80% valid) central arrow cue subtending 4.6˚ of visual angle. For voluntary orienting tasks using central arrow cues, previous research suggests that longer SOAs (i.e. SOAs >200ms) are required in order to observe significant cuing effects (Muller & Rabbitt, 1989). The need for longer SOAs is thought to reflect the amount of time required by the participant to interpret the meaning of the cue (i.e. left or right) as well as the time required to voluntarily allocate attention to that location. This is in contrast to reflexive orienting paradigms where the cues attract attention 'reflexively' and thus leads to the largest facilitatory effects at earlier SOAs (Klein, 2000). Thus for the voluntary COVAT we utilized longer SOAs of 300ms and 500ms to ensure that we would be able to observe a significant cuing effect[2].

The PA procedure used was adapted from Rossetti and colleagues (1998). Prior to adaptation, participants sat with their head in a chin rest and made five pointing movements to a subjective position straight-ahead of their body's midline with their eyes closed. The experimenter recorded the endpoints of these movements which were used to calculate each participant's pre PA notion of straight-ahead. Participants then wore wedge base prismatic lenses (Optique Peter, France) which shifted visual perception 15° to the left or right or induced no shift at all (sham prisms). Participants always used their right hand to point during adaptation. While wearing the prisms they were asked to point to targets to the left and right of an objective

[2] Different SOAs are used for the reflexive and voluntary COVAT based on prior research that demonstrates the largest RT advantage for validly cued targets in a reflexive orienting task occurs at early SOAs (~50ms; Maruff, et al., 1999), while RT advantages only arise at SOAs of around 200 to 300 ms in a voluntary COVAT (Muller & Rabbitt, 1989). It was important, therefore, to use these different SOAs in each task to ensure that a reliable cuing effect was observed in each task *prior to* adaptation taking place.

straight-ahead position once every 3-4 seconds for a period of 15 minutes. Immediately following PA and again at the conclusion of the experiment participants were asked to close their eyes and point to where they thought straight-ahead was five times. The endpoints of these pointing movements were recorded by the experimenter in order to determine the degree of adaptation to the prisms (post session) and how much participants had de-adapted from the prisms by the end of the experiment (late session; Figure 1).

*Data Analysis*

Average RTs were calculated for each trial type for each participant. Response times were discarded if they were 2 standard deviations above the participant's overall mean or if they were less than 150ms. To analyze the effects of PA on covert attention we calculated cue-effect sizes (CES) by subtracting the average RTs for valid trials from the average RTs for invalid trials at each SOA, with a positive score indicative of an RT advantage for valid trials, and a negative score indicative of an RT advantage for invalid trials. To examine whether or not PA had exerted a direction specific effect on covert orienting we calculated the CES for leftward and rightward shifts of attention at each SOA before and after PA. For leftward shifts the CES was calculated by subtracting RTs for validly cued right visual field targets from invalidly cued left visual field targets. Similarly, for rightward shifts the CES was calculated by subtracting RTs to validly cued left visual field targets from invalidly cued right visual field targets. For both left and right attention shift CES calculations the initial component of each trial type is identical – a shift of attention to a cue in the left or right visual field. The only difference is the need to reorient attention in the opposite direction to detect invalidly cued targets (see bottom panels of Figure 3).

After initial analyses of CES sizes pre and post PA suggested there was little or no influence of prisms on covert orienting we decided to repeat the analysis this time separating each group according to the magnitude of their CES prior to adaptation. We deemed this to be necessary based on the possible influence of ceiling or floor effects in pre-adaptation CES. That is, it is highly unlikely that an increase in CES will be observed post PA among individuals who demonstrate a large CES prior to adaptation (i.e., a ceiling effect may prevent the CES from getting any larger). Conversely, it is also highly unlikely that a reduction in CES will be observed in those individuals whose pre-adaptation CES is already low (i.e., a floor effect may prevent the CES from getting any smaller). If both effects were observed (i.e., a reduction in the large CES group post PA and an increase in the small CES group post-adaptation) these effects would cancel one another out in the whole group analysis. Therefore, each group (leftward shifting, rightward shifting and sham prisms) were further split into large and small CES groups according to their pre-adaptation CES at the 50ms SOA in the reflexive COVAT and the 300ms SOA in the voluntary COVAT using a median split procedure. That is, participants with a CES above the median were placed in the large CES group whereas participants with a CES below the median were placed in the small CES group. These CES data were then analyzed separately for each large and small CES group using a 3-way within subject ANOVA with session (pre vs. post PA), direction of attentional shift (left, right), and SOA (50, 150, 300 for reflexive; 300, 500 for voluntary) as within subject factors. Significant effects were evaluated using the Greenhouse-Geisser (1959) correction for conservative degrees of freedom. Post-hoc comparisons were carried out where appropriate using paired samples t-tests with Bonferroni corrections for the number of comparisons made.

*Planned Comparisons*

Previous research suggests that patients with parietal injury (with or without neglect) demonstrate a characteristic pattern of performance on the reflexive COVAT. Specifically, when the cue appears in the their right (ipsilesional) visual field and the target appears in their left (contralesional) visual field it takes them an abnormally long time to detect the target (Bartolomeo, et al., 2001; Morrow & Ratcliff, 1988; Posner et al., 1984; Posner, et al.,1987). Furthermore, this effect, referred to as the 'disengage deficit' is largest at short SOAs (~50ms; Losier & Klein, 2001). Given the fact that parietal lesions result in direction specific deficits in covert orienting which are largest at the shortest SOA's we used planned comparisons to examine the possibility that PA may affect covert orienting in a similar fashion. That is, we were interested in testing for direction specific effects of PA at the 50ms SOA in which spatially specific *deficits* following parietal injury are *most likely* to be found (Losier & Klein, 2001). In order to be conservative we used a Bonferonni correction to correct for the number of planned comparisons in each analysis (corrected p-value of .025). Effect sizes for the planned comparisons are reported using Cohen's *d* statistic (Rosnow & Rosenthal, 1996).

*Straight-ahead pointing*

Data from each pointing trial for each session (pre-PA, post-PA, and late) were converted to degrees of visual angle for each individual participant. Pointing to the left of midline was coded as negative whereas pointing to the right of midline was coded as positive. The mean deviation for each individual was then submitted to a one-way within subject ANOVA followed by post hoc comparisons using paired sampled t-tests with Bonferroni correction (p=.016). Separate analyses were conducted for each group.

**Results**

**Reflexive Orienting**

*Straight-ahead pointing*

For the leftward shifting prisms group ANOVA indicated a significant difference between the three pointing sessions ($F(1.83, 34.73)=38.11$, $p= .0001$). Post-hoc comparisons demonstrated a significant rightward shift in pointing post-adaptation (3.33º pre vs. 12.17º post; $t(19)=8.44$, $p=.0001$) demonstrating that participants adapted successfully to the prisms. In addition, there was no difference in pointing for post (12.17º) and late (11.73º) sessions ($t(19)=.42$, $p=.68$) indicating that participants remained adapted for the duration of the experiment (Figure 2).

For the rightward shifting prisms group there was also an effect of pointing session ($F(1.75,33.23)=101.35$, $p=.0001$) such that participants had a significant leftward shift in straight-ahead pointing post PA (2.03º pre vs. -11.55º post; $t(19)=13.49$, $p=.0001$) which was maintained at the late pointing session (-11.55º post vs. -9.60º; $t(19)=1.62$, $p=.12$) confirming that participants remained adapted to the prisms throughout the experiment (Figure 2).

In the sham group, ANOVA indicated no significant difference between the three pointing sessions ($F(1.76, 33.44)=1.65$, $p=.210$; 0.29° pre, 0.14° post, and -0.85° late).

Insert Figure 2 and Table 1 about here

*Cue-effect size analysis*

*Leftward shifting prisms*

Mean RTs for the large and small CES groups are presented in Table 1. The median CES at the 50ms SOA for the whole group pre-adaptation was 33ms. For the large CES group (N=10) analysis revealed a significant session x SOA interaction ($F(1.92, 17.30)=4.15$, $p=.035$) such that there was a large reduction in CES at the 50ms SOA post PA (31ms) relative to pre PA (50ms; $t(9)=3.36$, $p=.008$). Although the 3-way interaction between session, direction of attentional shift, and SOA was non-significant ($F(2,18)=1.50$, $p=.25$) we still carried out our planned comparisons to test for directional effects of PA at the 50ms SOA. These comparisons revealed that post PA there was a significant decrease in CES at the 50ms SOA for leftward shifts (45ms pre vs. 18ms post; $t(9)=2.72$, $p=.024$; $d=.86$) but not rightward shifts of attention (55ms pre vs. 45ms post; $t(9)=1.08$, $p=.307$; $d=.34$; Figure 3). In addition, there was no difference in RT for left and right for validly cued targets at the 50ms SOA post-adaptation (334ms vs. 346ms; $t(9)=1.83$, $p=.10$). There was also no difference in RT for left and right uncued trials post-adaptation (368ms vs. 376ms; $t(9)=1.04$, $p=.32$). This suggests that leftward PA has not led to faster RTs for detecting *any* target in the left visual field. Instead, PA led to faster reorienting of attention away from an invalid cue in the right visual field in order to detect a target in the left visual field.

Insert Figure 3 about here

The CES analysis in the small CES group (N=10) revealed a significant main effect of SOA ($F(1.76,15.89)=9.70$, $p=.002$) with the CES being largest at the 50ms SOA (17ms). There were no main effects or interactions involving session suggesting that PA had no effect in the small CES group (Figure 3). Planned comparisons examining directional effects of PA at the 50ms SOA revealed no significant differences for leftward (5ms pre vs. 16ms post; $t(9)=1.29$, $p=.228$; $d=.40$) or rightward shifts of attention (22ms pre vs. 23ms post; $t(9)=.134$, $p=.896$; $d=.04$).

*Rightward shifting prisms*

Mean RTs for the large (N=10) and small (N=10) CES groups are presented in Table 2 (median CES at the 50ms SOA for the whole group prior to adaptation = 28ms).

Insert Table 2 about here

The outcome of the CES analysis was identical to that of the large CES group in the leftward shifting prisms group in that there was a significant session x SOA interaction ($F(1.87,16.81)=4.54$, $p=.029$). Post-hoc tests revealed a significant decrease in CES at the 50ms SOA after PA (41ms pre vs. 19ms post; $t(9)=4.87$, $p=.001$). Again, although the 3-way interaction between session, shift, and SOA was non-significant ($F(2,18)=.016$, $p=.984$) we carried out our planned comparisons to test for directional effects of PA on the CES at the 50ms SOA. There was a significant reduction in CES at the 50ms SOA post PA for rightward (48ms pre vs. 18ms post; $t(9)=3.66$, $p=.005$; $d=1.16$) but not leftward shifts of attention (34ms pre, vs. 21ms post; $t(9)=1.43$, $p=.186$; $d=.45$). This effect mirrors the effect found in the large CES group following leftward PA (Figure 3). In addition, there was no difference in RTs for left and right validly cued targets post-adaptation (365ms pre vs. 359ms post; t(9)=.76, p=.469) or for left and right uncued targets post-adaptation (387ms pre vs. 392ms post; t(9)=.617, p=.552).

For the small CES group (N=10) ANOVA indicated a significant main effect of SOA (F(1.67,15.06)=7.76, p=.007) with CES being largest at the 50ms SOA (16ms). There were no interactions involving session (pre vs. post). Planned comparisons also failed to reveal any significant directional effects of PA at the 50ms SOA for leftward (11ms pre vs. 23ms post; t(9)=1.19, p=.263; *d*=.37) or rightward shifts of attention (14ms pre, vs. 18ms post; t(9).32, p=.756; *d*=.10; Figure 3).

*Sham prisms*

Mean RT data for the large and small CES groups are presented in Table 3 (median CES at the 50ms SOA for the whole group prior to adaptation = 34ms).

Insert Table 3 about here

For the large CES group (N=10) ANOVA indicated a marginally significant main effect of session (F(1,9)=5.46, p=.044) with CES being smaller post PA (23ms pre vs. 18ms post). In addition, there was a main effect of SOA (F(2,18)=38.46, p=.001) with CES at the 50ms SOA (38ms) being larger than CES at the 150ms (22ms) and 300ms (2ms) SOAs. There were no other main effects or interactions.

For the small CES group (N=10) analysis revealed a significant main effect of SOA (F(1.9,17.12)=13.5, p=.0001) with CES at the 50ms SOA (18ms) being larger than CES at either then 150ms (3ms) or 300ms (-5ms) SOAs. No other main effects or interactions were significant.

**Voluntary Orienting**

*Straight-ahead pointing*

For the leftward shifting prisms group, analysis indicated a significant difference between pointing sessions (F(1.85,46.45)=121.12, p=<.0001). Post-hoc tests indicated that participants had a significant rightward shift in straight-ahead pointing (.44˚ pre vs. 13.35˚ post; t(25)=13.87, p=<.0001). This shift in pointing had begun to diminish by the late pointing session (13.35˚ post vs. 7.88˚ late; t(25)=7.47, p=<.0001), however participants were still significantly adapted compared to the pre adaptation session (.440˚ pre vs. 7.88˚ late; t(25)=9.03, p=<.0001; Figure 2).

In the rightward shifting prisms group ANOVA also indicated a significant difference between the three pointing sessions (F(1.94,46.62)=158.71, p=<.0001). Post-hoc analyses revealed that participants had a significant leftward shift in pointing post adaptation (.04˚ pre vs. -14.93˚ post; t(24)=19.27, p=<.0001). Similar to the leftward shifting prisms group, participants had begun to de-adapt by the end of the experiment (-14.93˚ post vs. -9.75˚ late; t(24)=5.83, p=<.0001), however they remained adapted when compared to baseline pointing (.04˚ pre vs. -9.75˚ late; t(24)=10.98, p=<.0001; Figure 2).

For the sham prisms group, analysis indicated that there were no significant differences between the three pointing sessions (1.04˚ pre, -0.62˚ post, -1.43˚ late).

*Cue-effect size analysis*

*Leftward shifting prisms*

Response time data for the leftward shifting prisms group are presented in Table 4. The median CES for the whole group at the 300ms SOA prior to PA was 28ms.

Insert Table 4 here

In the large CES group (N=13) ANOVA indicated a significant main effect of shift (F(1,12)=13.43, p=.003) with rightward shifts of attention (44ms) having a larger overall CES than leftward shifts of attention (24ms; Figure 4). There were no significant effects involving session, suggesting that PA did not influence voluntary covert attention in the large CES group.

For the small CES group (N=13) ANOVA revealed a significant session x SOA interaction (F(1,12)=9.14, p=.011) due to a significant *increase* in CES post PA at the 300ms SOA (11ms pre vs. 34ms post; t(12)=3.72, p=.003). There was not a significant session x shift x SOA interaction (F(1.92,23.12)=.159, p=.854) suggesting that PA increased the CES post adaptation equally for leftward and rightward shifts of attention (Figure 4). Given the fact that planned comparisons examining the direction of shift were conducted for reflexive shifts of attention despite a similar lack of a three-way interaction, we performed those same analyses here. This confirmed that the increase in CES was equivalent for leftward (18ms pre vs. 36ms post; t(12)=2.83, p=.015; *d*=.79) and rightward (4ms pre vs. 33ms post; t(12)=2.97, p=.012; *d*=.82) shifts of attention at the 300ms SOA.

Insert Figure 4 here

*Rightward shifting prisms*

Response time data for the rightward shifting prisms group are presented in Table 5. The median CES for the whole group at the 300ms SOA prior to PA was 29ms.

Insert Table 5 here

For the large CES group (N=13) ANOVA revealed a marginally significant session x SOA interaction ($F(1,12)=5.15$, $p=.042$). This appeared to result from a *decrease* in CES at the 300ms post PA (48ms pre vs. 24ms post; $t(12)=2.69$, $p=.019$). There was not a significant session x shift x SOA interaction (Figure 4), suggesting that the slight decrease in CES post PA was equal for leftward and rightward shifts of attention ($F(1,12)=.003$, $p=.96$). Planned comparisons for left and right shifts of attention revealed that the decrease in SOA at the 300ms SOA was not significant following the Bonferroni correction for either leftward (47ms pre vs. 23ms post; $t(12)=2.41$, $p=.032$; $d=.67$) or rightward (51ms pre vs. 25ms post; $t(12)=1.63$, $p=.128$; $d=.45$ ) shifts of attention. Thus, the reduction in CES following PA was not reliably different for left or right shifts of attention.

In the small CES group (N=12), ANOVA revealed a significant main effect of shift ($F(1,11)=8.12$, $p=.016$) with rightward shifts of attention (34ms) having a larger CES than leftward shifts of attention (15ms). There was also a main effect of SOA ($F(1,11)=5.72$, $p=.036$) with CES at the 500ms SOA (30ms) being larger than CES at the 300ms SOA (18ms; Figure 4). There were no significant effects involving session suggesting that rightward PA had no effect on voluntary covert orienting in the small CES group.

*Sham prisms group*

Response time data for the sham prisms group are presented in Table 6. The median CES for the whole group at the 300ms SOA prior to PA was 28ms.

Insert Table 6 here

For the large CES group (N=10) there was a significant shift x SOA interaction ($F(1,9)=6.91$, $p=.027$) with CES for rightward shifts of attention being larger than leftward shifts of attention at the 500ms SOA (27ms left shift vs. 54ms right shift; $t(9)=2.31$, $p=.046$). However, this difference was not significant after Bonferroni correction. There were no other significant main effects or interactions. In the small CES group (N=10), ANOVA did not reveal any significant main effects or interactions. This suggests that sham adaptation had no effect on voluntary covert orienting for either the large or small CES groups.

**Discussion**

Recent research suggests that PA may influence higher level spatial representations in patients with neglect. Despite a number of studies examining the effects of PA on these patients, we still know relatively little about the cognitive mechanisms underlying PA. One hypothesis is that PA may influence mechanisms involved in visual attention. What the current results show is that in healthy individuals, PA influences the way in which covert attention is oriented (or reoriented) across the visual field. For reflexive orienting, PA produced *direction specific* effects in covert orienting. More specifically, after adaptation to leftward shifting prisms, participants in the large CES group were *faster* at disengaging or reorienting attention away from an invalid cue in the right visual field. The results in the rightward shifting prisms group mirrored these effects with participants in the large CES group now being *faster* to disengage or reorient attention away from an invalid cue in the left visual field. Importantly, the effect of PA was only evident at the earliest (50ms) SOA. Participants in the sham prisms group showed no significant effects of PA adding strong support to the notion that the observed effects in the left and right prisms groups were specific to PA and are not simply reflective of a practice effect.

Together these results suggest that PA made reflexive attention “less sticky” on the side of space opposite the prismatic shift. That is, for a reflexive orienting task of the kind used here, faster disengagement from a non-informative cue can be seen as advantageous to the participant. Interestingly, the current results parallel those of Posner and colleagues (1984) in patients with parietal injury with the opposite effects on RT. Specifically, following right parietal injury patients were *slower* to reorient attention away from an invalid cue in the right visual field and vice versa for patients with left parietal injury. This may suggest that left prisms affect the right parietal cortex whereas right prisms affect the left parietal cortex. The current results also compliment the findings of a recent study by Berberovic and colleagues (2004) in which rightward PA reduced the rightward bias in temporal order judgments in patients with neglect, suggesting that prisms may influence the orienting of visual attention.

The results for voluntary orienting suggest that for individuals with a small CES prior to PA, leftward PA induced more efficient voluntary orienting. To pick up on the metaphor, leftward prisms made attention “more sticky” for both leftward and rightward attentional shifts in those individuals who’s CES was small prior to adaptation. This increase in the CES for left and right attentional shifts arose as a result of slower RTs for invalid trials coupled with faster RTs for valid trials post-adaptation (Table 4). These changes in RT can be seen as advantageous to the participant whose pre-adaptation RT advantage for valid trials was small to begin with. That is, it seems that prisms have altered the way in which these individuals attend to the cued location perhaps by speeding up their response to that location on the one hand (faster RTs to valid trials) and making them more reluctant to disengage attention from that location on the other (slower RTs to invalid trials). Alternatively, for participants with a large CES prior to PA, rightward shifting prisms led to a slight decrease in the efficiency of voluntary covert attention such that there was a *decrease* in CES post-adaptation at the 300ms SOA. This effect was not significant when left and right shifts of attention when analyzed separately, with the corresponding small effect size calculations. The smaller effect size and lack of significance when analyzed for each direction of shift may suggest that this effect of PA was less reliable than the effect observed for leftward shifting prisms. Finally, there were no significant changes in CES following sham adaptation which again lends strong support to the notion that the effects observed post PA for voluntary orienting were due specifically to the effects of the prisms.

Two questions that remain are why PA had non-directional effects in voluntary orienting, and, why left and right prisms produced contrasting effects on CES? As suggested earlier, left prisms may be affecting the right parietal cortex whereas right prisms may be affecting the left parietal cortex. This could also explain the apparent contrasting findings for voluntary orienting. Specifically, previous research suggests that in healthy individuals the right parietal cortex is dominant for voluntary shifts of spatial attention in both left and right space (Corbetta et al., 1993; Mesulam, 1999). Thus if left prisms influence the right parietal cortex one might expect an *increase* in the efficiency of voluntary attention for both left and right shifts. In contrast, if right prisms influence the left parietal cortex, this may serve to interfere with functioning within the right parietal cortex which may lead to a decreased CES for left and right shifts of attention. This theory is necessarily speculative and further research is needed to validate it.

A recent study by Morris and colleagues (2004) failed to observe any effects of PA on visual attention using a visual search task which undoubtedly involves voluntary attention. While this result is in direct contrast to the current findings it may be the case that prisms exert differential influence on processes involved in visual search versus cued target detection. Directing covert attention within a fairly uncomplicated environment such as the one used here in which there are only two possible target locations is a very different task when compared with a typical visual search task containing multiple targets and distracters that may reflect more closely the demands of ‘real world’ environments. Directing covert attention within a fairly uncomplicated environment such as the one used here in which there are only two possible target locations is a very different task when compared with a typical visual search task containing multiple targets and distracters that may reflect more closely the demands of ‘real world’ environments.

The current study demonstrates a possible cognitive mechanism by which PA may work, however it remains unclear as to the extent to which this mechanism could be exploited for real world rehabilitation purposes. At least one recent study (Jacquin-Courtois, et al., in press) has demonstrated that a single session of PA can have beneficial effects on wheelchair navigation in a patient with neglect in a hospital ward for up to 4 days post adaptation. Further research is obviously needed before any firm conclusions regarding PA and rehabilitation can be made. Towards this end, Rossetti and colleagues are currently carrying out a large scale long-term rehabilitation study using PA in patients with neglect which examines more directly the effects PA on activities of daily living (Y. Rossetti, personal communication, November 25, 2005). To reiterate, our current findings do not suggest that *covert attention* is rehabilitated in neglect, but that prism adaptation may operate – however effectively – by altering the way in which covert attention is deployed.

References

Bartolomeo, P., Sieroff, E., Decaix, C., & Chokron, S. (2001). Modulating the attentional bias in unilateral neglect: the effects of the strategic set. *Experimental Brain Research, 137*(3-4), 432-444.

Berberovic, N., Pisella, L., Morris, A. P., & Mattingley, J. B. (2004). Prismatic adaptation reduces biased temporal order judgements in spatial neglect. *Neuroreport, 15*(7), 1199-1204.

Colent, C., Pisella, L., Bernieri, C., Rode, G., & Rossetti, Y. (2000). Cognitive bias induced by visuo-motor adaptation to prisms: a simulation of unilateral neglect in normal individuals? *Neuroreport, 11*(9), 1899-1902.

Corbetta, M., Miezin, F. M., Shulman, G. L., & Petersen, S. E. (1993). A PET study of visuospatial attention. *Journal of Neuroscience, 13*(3), 1202-1226.

Danckert, J., & Ferber, S. (in press). Revisiting neglect. *Neuropsychologia*.

Driver, J., & Mattingley, J. B. (1998). Parietal neglect and visual awareness. *Nature Neuroscience, 1*(1), 17-22.

Girardi, M., McIntosh, R. D., Michel, C., Vallar, G., & Rossetti, Y. (2004). Sensorimotor effects on central space representation: prism adaptation influences haptic and visual representations in normal subjects. *Neuropsychologia, 42*(11), 1477-1487.

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika, 24*, 95-112.

Husain, M., & Rorden, C. (2003). Non-spatially lateralized mechanisms in hemispatial neglect. *Nature Reviews Neuroscience, 4*(1), 26-36.

Jacquin-Courtois, S., Rode, G., Boisson, D., & Rossetti, Y. (in press). Wheelchair driving improvement following visuo-manual prism adaptation. *Cortex*.

Karnath, H. O., Ferber, S., & Himmelbach, M. (2001). Spatial awareness is a function of the temporal not the posterior parietal lobe. *Nature, 411*(6840), 950-953.

Klein, R. M. (2000). Inhibition of return. *Trends in Cognitive Science, 4*(4), 138-147.

Losier, B. J., & Klein, R. M. (2001). A review of the evidence for a disengage deficit following parietal lobe damage. *Neuroscience and Biobehavioral Reviews, 25*(1), 1-13.

Maravita, A., McNeil, J., Malhotra, P., Greenwood, R., Husain, M., & Driver, J. (2003). Prism adaptation can improve contralesional tactile perception in neglect. *Neurology, 60*(11), 1829-1831.

Maruff, P., Yucel, M., Danckert, J., Stuart, G., & Currie, J. (1999). Facilitation and inhibition arising from the exogenous orienting of covert attention depends on the temporal properties of spatial cues and targets. *Neuropsychologia, 37*(6), 731-744.

Mesulam, M. M. (1999). Spatial attention and neglect: parietal, frontal and cingulate contributions to the mental representation and attentional targeting of salient extrapersonal events. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences, 354*(1387), 1325-1346.

Michel, C., Pisella, L., Halligan, P. W., Luaute, J., Rode, G., Boisson, D., et al. (2003). Simulating unilateral neglect in normals using prism adaptation: implications for theory. *Neuropsychologia, 41*(1), 25-39.

Michel, C., Rossetti, Y., Rode, G., & Tilikete, C. (2003). After-effects of visuo-manual adaptation to prisms on body posture in normal subjects. *Experimental Brain Research, 148*(2), 219-226.

Morris, A. P., Kritikos, A., Berberovic, N., Pisella, L., Chambers, C. D., & Mattingley, J. B. (2004). Prism adaptation and spatial attention: a study of visual search in normals and patients with unilateral neglect. *Cortex, 40*(4-5), 703-721.

Morrow, L. A., & Ratcliff, G. (1988). The disengagement of covert attention and the neglect syndrome. *Psychobiology, 16*(3), 261-269.

Mort, D. J., Malhotra, P., Mannan, S. K., Rorden, C., Pambakian, A., Kennard, C., et al. (2003). The anatomy of visual neglect. *Brain, 126*(Pt 9), 1986-1997.

Muller, H. J., & Rabbitt, P. M. (1989). Reflexive and voluntary orienting of visual attention: time course of activation and resistance to interruption. *Journal of Experimental Psychology, Human Perception and Performance, 15*(2), 315-330.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*(1), 3-25.

Posner, M. I., Walker, J. A., Friedrich, F. A., & Rafal, R. D. (1987). How do the parietal lobes direct covert attention? *Neuropsychologia, 25*(1A), 135-145.

Posner, M. I., Walker, J. A., Friedrich, F. J., & Rafal, R. D. (1984). Effects of parietal injury on covert orienting of attention. *Journal of Neuroscience, 4*(7), 1863-1874.

Redding, G. M., & Wallace, B. (2005). Prism adaptation and unilateral neglect: Review and analysis. *Neuropsychologia, article in press*.

Robertson, I. H. (1999). Cognitive rehabilitation: attention and neglect. *Trends in Cognitive Science, 3*(10), 385-393.

Rode, G., Rossetti, Y., & Boisson, D. (2001). Prism adaptation improves representational neglect. *Neuropsychologia, 39*(11), 1250-1254.

Rosnow, R. L., & Rosenthal, R. (1996). Computing contrasts, effect sizes, and counternulls on other people's published data: General procedures for research consumers. *Psychological Methods*, *1*(4), 331-340.

Rossetti, Y., Rode, G., Pisella, L., Farne, A., Li, L., Boisson, D., et al. (1998). Prism adaptation to a rightward optical deviation rehabilitates left hemispatial neglect. *Nature, 395*(6698), 166-169.

Tilikete, C., Rode, G., Rossetti, Y., Pichon, J., Li, L., & Boisson, D. (2001). Prism adaptation to rightward optical deviation improves postural imbalance in left-hemiparetic patients. *Current Biology*, *11*(7), 524-528.

Table 1: Mean response times and standard deviations (in brackets) for reflexive orienting in the leftward shifting prisms group as a function of target side, cue validity, stimulus onset asynchrony (SOA), and session (pre vs. post prisms). The standard deviations reported reflect the between subject variability.

| Pre Prisms | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left Target | | | | | | Right Target | | | | | |
| | Valid | | | Invalid | | | Valid | | | Invalid | | |
| SOA | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 |
| Large CES Group | 346(21) | 338(13) | 338(23) | 384(18) | 350(14) | 330(14) | 340(13) | 341(15) | 340(17) | 401(15) | 370(14) | 344(18) |
| Small CES Group | 357(23) | 346(27) | 345(20) | 376(17) | 340(18) | 334(21) | 370(30) | 345(25) | 338(20) | 380(27) | 358(24) | 332(26) |
| Whole Group | 352(24) | 342(23) | 341(23) | 380(17) | 345(16) | 332(19) | 355(30) | 343(21) | 339(19) | 391(22) | 364(20) | 338(22) |

| Post Prisms | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left Target | | | | | | Right Target | | | | | |
| | Valid | | | Invalid | | | Valid | | | Invalid | | |
| SOA | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 |
| Large CES Group | 333(20) | 321(13) | 318(6) | 364(29) | 330(26) | 322(16) | 346(15) | 325(12) | 318(18) | 378(19) | 340(24) | 322(25) |
| Small CES Group | 324(30) | 314(20) | 312(32) | 343(24) | 304(16) | 298(19) | 327(19) | 302(23) | 311(28) | 348(29) | 322(21) | 307(36) |
| Whole Group | 329(25) | 318(16) | 315(22) | 354(27) | 318(23) | 310(19) | 337(17) | 314(20) | 315(23) | 363(27) | 331(23) | 314(31) |

Table 2: Mean response times and standard deviations (in brackets) for reflexive orienting for the rightward shifting prisms group as a function of target side, cue validity, stimulus onset asynchrony (SOA), and session (pre vs. post prisms). The standard deviations reported reflect the between subject variability.

| Pre Prisms | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left Target | | | | | | Right Target | | | | | |
| | Valid | | | Invalid | | | Valid | | | Invalid | | |
| SOA | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 |
| Large CES Group | 345(20) | 341(18) | 350(30) | 391(29) | 352(33) | 341(41) | 357(30) | 340(27) | 346(26) | 393(29) | 363(29) | 352(50) |
| Small CES Group | 365(26) | 359(14) | 346(30) | 372(31) | 353(19) | 338(18) | 361(25) | 351(22) | 362(25) | 379(21) | 362(23) | 343(22) |
| Whole Group | 355(25) | 350(19) | 348(29) | 382(31) | 353(26) | 340(31) | 359(27) | 346(25) | 354(26) | 386(26) | 362(25) | 348(38) |

| Post Prisms | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left Target | | | | | | Right Target | | | | | |
| | Valid | | | Invalid | | | Valid | | | Invalid | | |
| SOA | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 |
| Large CES Group | 365(31) | 339(36) | 341(19) | 379(39) | 358(27) | 340(26) | 358(32) | 343(24) | 335(24) | 383(30) | 343(29) | 336(16) |
| Small CES Group | 350(23) | 331(22) | 346(41) | 368(19) | 346(28) | 333(44) | 346(23) | 339(25) | 352(63) | 368(34) | 339(17) | 339(24) |
| Whole Group | 357(28) | 335(29) | 344(31) | 374(30) | 352(28) | 337(35) | 352(28) | 341(24) | 344(47) | 375(32) | 341(24) | 338(20) |

Table 3: Mean response times and standard deviations (in brackets) for reflexive orienting for the sham prisms group as a function of target side, cue validity, stimulus onset asynchrony (SOA), and session (pre vs. post prisms). The standard deviations reported reflect the between subject variability.

| Pre Prisms | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Left Target | | | | | | Right Target | | | | | |
| | Valid | | | Invalid | | | Valid | | | Invalid | | |
| SOA | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 |
| Large CES Group | 339(17) | 343(15) | 341(18) | 389(18) | 360(19) | 343(20) | 355(20) | 343(16) | 351(15) | 398(14) | 376(16) | 345(15) |
| Small CES Group | 345(35) | 336(17) | 336(19) | 358(14) | 333(12) | 317(17) | 349(16) | 335(14) | 335(25) | 367(19) | 343(17) | 334(19) |
| Whole Group | 342(29) | 340(16) | 339(19) | 374(17) | 347(17) | 330(19) | 352(18) | 339(16) | 343(20) | 383(18) | 360(18) | 339(16) |
| **Post Prisms** | | | | | | | | | | | | |
| | Left Target | | | | | | Right Target | | | | | |
| | Valid | | | Invalid | | | Valid | | | Invalid | | |
| SOA | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 | 50 | 150 | 300 |
| Large CES Group | 342(28) | 334(12) | 331(19) | 379(19) | 346(14) | 336(20) | 355(26) | 328(15) | 330(22) | 377(28) | 353(19) | 338(17) |
| Small CES Group | 341(25) | 314(24) | 319(19) | 357(15) | 316(18) | 305(21) | 336(26) | 320(17) | 305(24) | 360(16) | 326(11) | 317(28) |
| Whole Group | 341(27) | 324(18) | 325(19) | 368(17) | 331(17) | 321(21) | 346(26) | 324(16) | 318(23) | 369(22) | 339(16) | 327(22) |

Table 4: Mean response times and standard deviations (in brackets) for voluntary orienting for the leftward shifting prisms group as a function of target side, cue validity, stimulus onset asynchrony (SOA), and session (pre vs. post prisms).The reported standard deviations represent the between subject variability.

| Pre Prisms | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Left Target | | | | Right Target | | | |
| | Valid | | Invalid | | Valid | | Invalid | |
| SOA | 300 | 500 | 300 | 500 | 300 | 500 | 300 | 500 |
| Large CES Group | 306(21) | 295(23) | 344(18) | 334(29) | 314(21) | 305(17) | 366(23) | 335(29) |
| Small CES Group | 314(26) | 309(40) | 330(28) | 330(31) | 312(22) | 306(22) | 319(25) | 328(29) |
| Whole Group | 310(25) | 302(34) | 337(23) | 332(30) | 313(21) | 305(20) | 342(32) | 332(28) |
| **Post Prisms** | | | | | | | | |
| | Left Target | | | | Right Target | | | |
| | Valid | | Invalid | | Valid | | Invalid | |
| SOA | 300 | 500 | 300 | 500 | 300 | 500 | 300 | 500 |
| Large CES Group | 296(20) | 292(14) | 320(31) | 316(30) | 301(23) | 292(19) | 339(34) | 334(31) |
| Small CES Group | 299(27) | 293(26) | 338(22) | 316(21) | 302(22) | 303(21) | 332(30) | 319(19) |
| Whole Group | 297(24) | 292(21) | 329(29) | 316(26) | 301(22) | 297(21) | 335(32) | 327(25) |

Table 5: Mean response times and standard deviations (in brackets) for voluntary orienting for the rightward shifting prisms group as a function of target side, cue validity, stimulus onset asynchrony (SOA), and session (pre vs. post prisms). The reported standard deviations represent the between subject variability.

| | Pre Prisms | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Left Target | | | | Right Target | | | |
| | Valid | | Invalid | | Valid | | Invalid | |
| SOA | 300 | 500 | 300 | 500 | 300 | 500 | 300 | 500 |
| Large CES Group | 321(13) | 307(26) | 368(30) | 339(29) | 321(14) | 309(23) | 372(23) | 354(22) |
| Small CES Group | 298(23) | 293(30) | 313(22) | 324(22) | 309(19) | 299(26) | 325(16) | 335(30) |
| Whole Group | 310(18) | 300(28) | 341(31) | 332(25) | 315(17) | 304(25) | 350(24) | 345(25) |
| | Post Prisms | | | | | | | |
| | Left Target | | | | Right Target | | | |
| | Valid | | Invalid | | Valid | | Invalid | |
| SOA | 300 | 500 | 300 | 500 | 300 | 500 | 300 | 500 |
| Large CES Group | 323(24) | 305(26) | 347(31) | 348(45) | 324(15) | 315(27) | 348(38) | 353(29) |
| Small CES Group | 296(18) | 291(22) | 317(49) | 305(30) | 303(13) | 289(21) | 324(23) | 329(22) |
| Whole Group | 310(21) | 298(24) | 332(40) | 327(40) | 314(14) | 303(24) | 337(31) | 341(26) |

Table 6: Mean response times and standard deviations (in brackets) for voluntary orienting for the sham prisms group as a function of target side, cue validity, stimulus onset asynchrony (SOA), and session (pre vs. post prisms). The reported standard deviations represent the between subject variability.

| Pre Prisms | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Left Target | | | | Right Target | | | |
| | Valid | | Invalid | | Valid | | Invalid | |
| SOA | 300 | 500 | 300 | 500 | 300 | 500 | 300 | 500 |
| Large CES Group | 293(20) | 277(19) | 335(15) | 314(28) | 294(12) | 286(14) | 337(39) | 340(18) |
| Small CES Group | 279(15) | 272(19) | 293(16) | 304(24) | 282(18) | 278(21) | 302(28) | 297(25) |
| Whole Group | 284(17) | 272(19) | 310(20) | 305(25) | 285(15) | 278(17) | 315(35) | 314(26) |
| Post Prisms | | | | | | | | |
| | Left Target | | | | Right Target | | | |
| | Valid | | Invalid | | Valid | | Invalid | |
| SOA | 300 | 500 | 300 | 500 | 300 | 500 | 300 | 500 |
| Large CES Group | 275(17) | 267(12) | 311(23) | 300(39) | 279(10) | 275(27) | 314(30) | 313(29) |
| Small CES Group | 276(9) | 265(15) | 281(30) | 286(31) | 273(14) | 265(22) | 292(26) | 291(38) |
| Whole Group | 271(15) | 263(15) | 295(27) | 288(34) | 273(12) | 267(23) | 299(27) | 298(32) |

**Figure Captions**

**Figure 1.** To the left of the figure is a schematic depicting the sequence of events (from top to bottom) in a single trial of the reflexive COVAT. Solid lines indicate where the participant's eyes are fixated, dotted lines indicate where the participant's covert attention is directed. In a valid trial the target appears in the same location as the cue (bottom left) whereas for invalid trials, targets appear in the opposite location (bottom right). The schematic to the right of the figure shows the sequence of events for the entire experiment.

**Figure 2.** Pointing data in degrees of visual angle for reflexive (left panel) and voluntary (right panel) orienting for the leftward (top) and rightward (bottom) shifting prisms groups as a function of pointing session. Open bars represent the small CES group whereas grey bars represent the large CES group.

**Figure 3.** Data from the leftward (left panels) and rightward (right panels) shifting prisms groups for reflexive orienting. Data from the small cue effect size (CES) groups are presented in the top two panels while data from the large CES groups are presented in the bottom two panels. Within each group CES data are presented separately for leftward and rightward attentional shifts. All data are in milliseconds and error bars represent between subject variance. * Indicates a statistically significant difference. Grey bars represent pre adaptation CES data and open bars represent post-adaptation CES data. At the bottom of the figure is a schematic representing the calculation made for leftward and rightward attentional shifts.

**Figure 4.** Data from the leftward (left panels) and rightward (right panels) shifting prisms groups for voluntary orienting. Data from the small cue effect size (CES) groups are presented in the top two panels while data from the large CES groups are presented in the bottom two panels. Within each group CES data are presented separately for leftward and rightward attentional shifts. All

data are in milliseconds and error bars represent between subject variance. * Indicates a statistically significant difference. Grey bars represent pre adaptation CES data and open bars represent post-adaptation CES data. At the bottom of the figure is a schematic representing the calculation made for leftward and rightward attentional shifts.

Figure 1

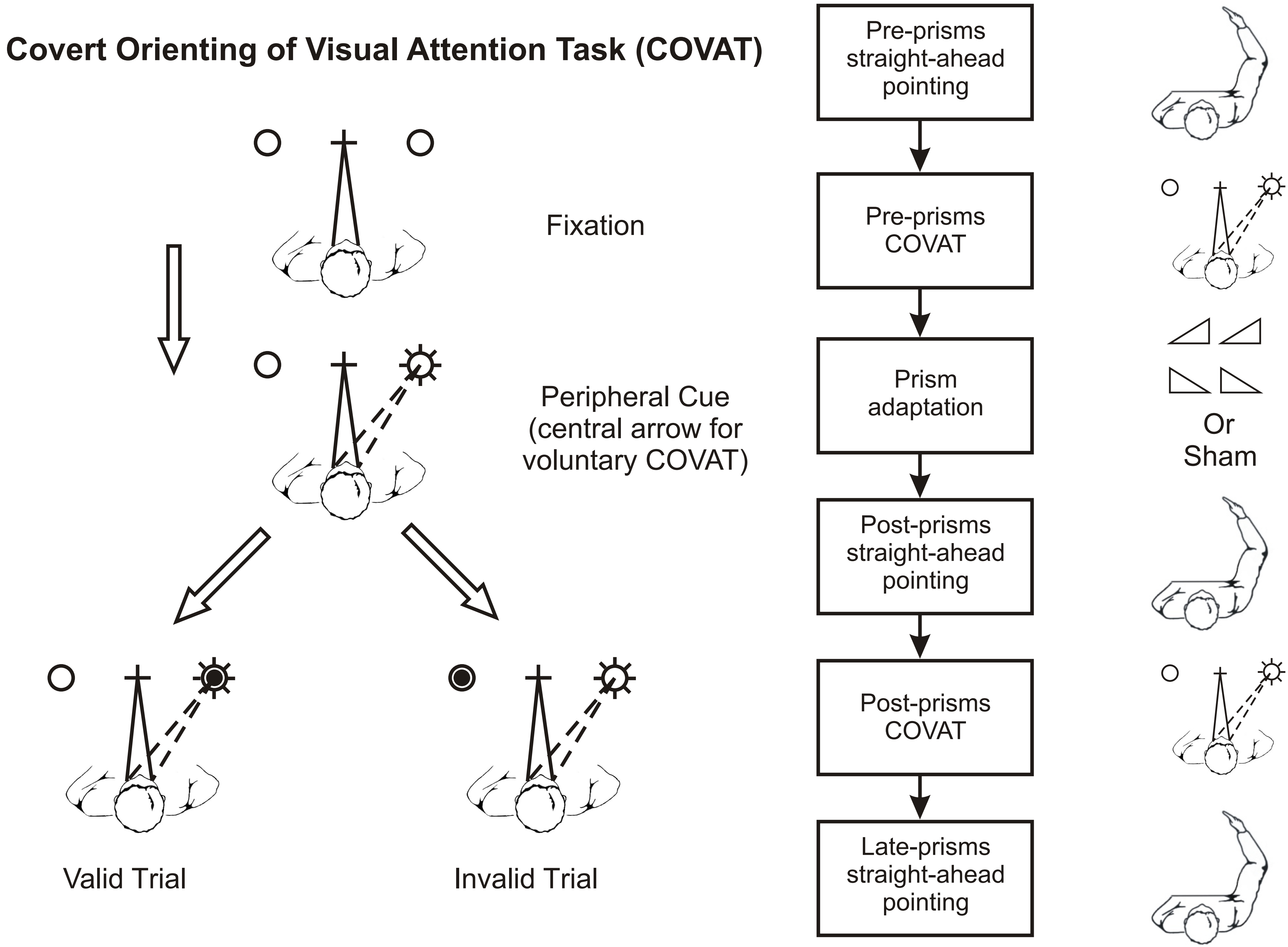

Covert Orienting of Visual Attention Task (COVAT)
Fixation
Peripheral Cue
(central arrow for
voluntary COVAT)
Valid Trial
Invalid Trial
Pre-prisms
straight-ahead
pointing
Pre-prisms
COVAT
Prism
adaptation
Post-prisms
straight-ahead
pointing
Post-prisms
COVAT
Late-prisms
straight-ahead
pointing
Or
Sham

Figure 2

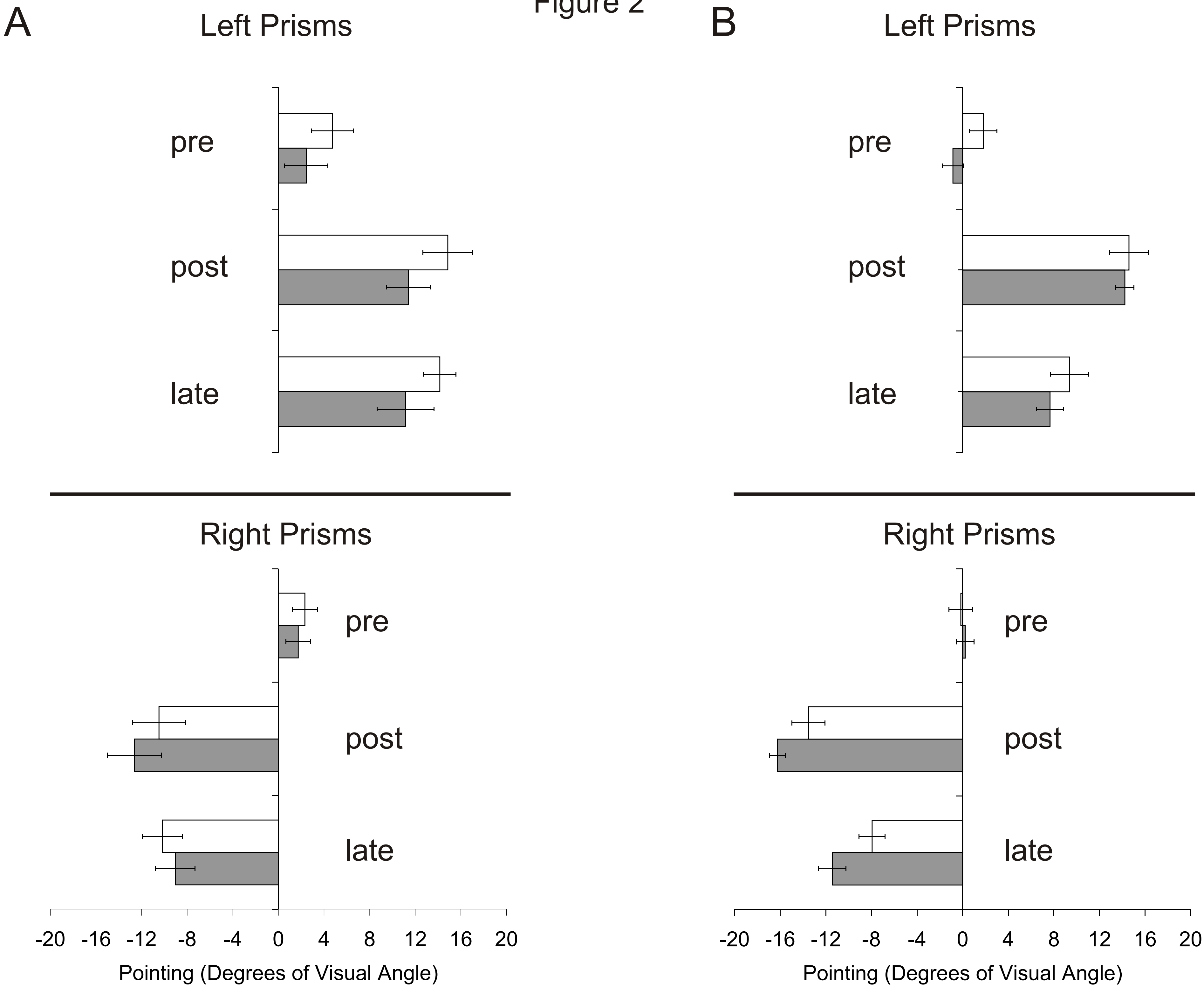

A
Left Prisms
pre
post
late
Right Prisms
pre
post
late
-20 -16 -12 -8 -4 0 4 8 12 16 20
Pointing (Degrees of Visual Angle)
B
Left Prisms
pre
post
late
Right Prisms
pre
post
late
-20 -16 -12 -8 -4 0 4 8 12 16 20
Pointing (Degrees of Visual Angle)

Figure 3

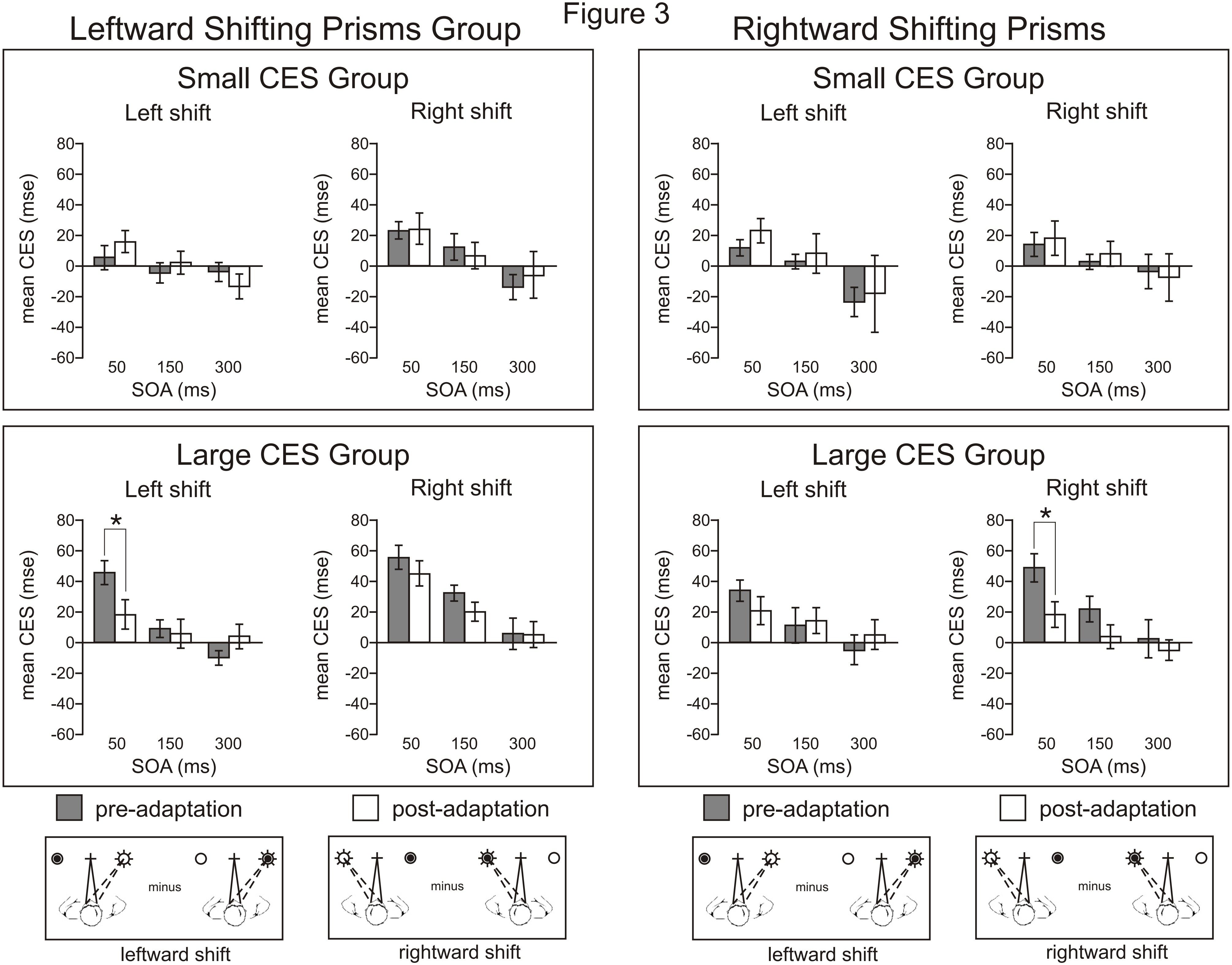
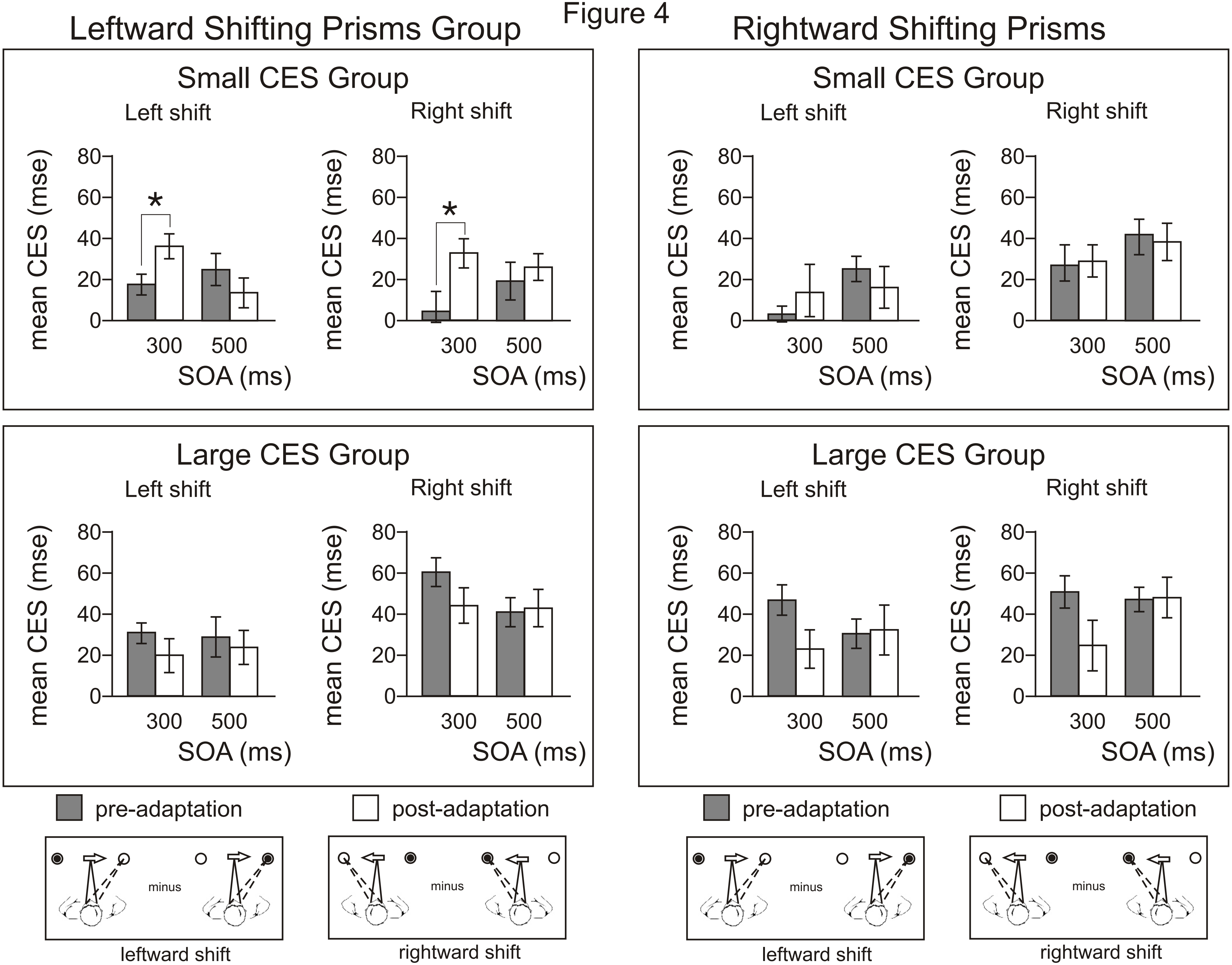

Leftward Shifting Prisms Group
Rightward Shifting Prisms
Small CES Group
Large CES Group
Left shift
Right shift
mean CES (mse)
SOA (ms)
80
60
40
20
0
-20
-40
-60
50
150
300
*
pre-adaptation
post-adaptation
minus
leftward shift
rightward shift

Figure 4



Leftward Shifting Prisms Group
Rightward Shifting Prisms
Small CES Group
Large CES Group
Left shift
Right shift
mean CES (mse)
80
60
40
20
0
300
500
SOA (ms)
*
pre-adaptation
post-adaptation
minus
leftward shift
rightward shift