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A registered re-examination of the effects of leftward prism adaptation on landmark judgements in healthy people

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1. Introduction

If a person looks through laterally-displacing prisms, the alignment between the body and vision is altered, and initial attempts to act on visual targets will err in the direction of the prismatic displacement. By receiving visual feedback on these errors, the person can adapt to the altered alignment, and restore accurate performance. If the prisms are then removed, and the person reaches again for a visual target, they will now err in the *opposite* direction. This is the *sensorimotor aftereffect*, which reflects the compensatory adaptation for the prior prismatic displacement. Provided that normal visual feedback is available, this aftereffect will in turn be extinguished rapidly, returning the person to an un-adapted state. This classical cycle of prism adaptation is a compelling demonstration of the short-term plasticity of the human sensorimotor system.

In the past 20 years, the classical story has been extended through a new wave of research, sparked by the discovery that adaptation to a rightward optical shift of 10° (~ 17.5 prism dioptres) could temporarily reduce the symptoms of left neglect (Rossetti, Rode, Pisella, & Farne, 1998). Neglect is a pathological imbalance of spatial attention, cognition and behaviour, associated with damage to the right hemisphere, often following stroke. The amelioration of these symptoms far outlasted the expected sensorimotor aftereffects, persisting for hours and even days after prism exposure (McIntosh, Rossetti, & Milner, 2002; Rossetti et al., 1998). Moreover, the benefits were found to generalise to a range of visuospatial tasks (for a review, see Pisella, Rode, Farnè, Tilikete, & Rossetti, 2006), and to non-visual tasks based on haptic exploration (McIntosh et al., 2002) and mental representation (Rode, Rossetti, & Boisson, 2001; Rossetti et al., 2004). These findings suggest that, in addition to the sensorimotor aftereffects, prism adaptation may have previously unsuspected, longer-lasting aftereffects on spatial cognition. Prism adaptation may thus be a powerful tool for understanding the relation between low-level sensorimotor mappings and higher-level spatial cognition, and could potentially offer a simple, non-invasive therapy for neglect. However, although initial clinical trials did suggest some benefits over standard care (for summaries, see Fasotti & van Kessel, 2013; Kerkhoff & Schenk, 2012), larger-scale trials have yet to confirm reliable functional benefits of prism therapy for neglect (for an overview, see Ten Brink et al., 2017).

Nonetheless, the existence of the proposed *cognitive* aftereffects is supported by a parallel wave of research in healthy people, showing similar, albeit subtler, changes in spatial cognition following prism adaptation. Contrary to patients with left neglect, who are biased strongly to the right side of space, healthy people typically have a slight bias to the left, known by analogy as ‘pseudoneglect’ (after Bowers & Heilman, 1980; for a review see Jewell & McCourt, 2000). Where adaptation to rightward prisms had been found to reduce the rightward bias of neglect, adaptation to leftward prisms was found to reduce (or reverse) the leftward bias of pseudoneglect. This change in visuospatial bias was observed initially on a horizontal length estimation task, known as the landmark task (Colent, Pisella, Bernieri, Rode, & Rossetti, 2000). In the landmark task, a pre-transected line is presented, and the participant must judge which side is longer (or shorter). A gross measure of visuospatial bias is sometimes taken from the proportion of trials in which an accurately bisected line is judged to be shorter on the left (or right) (Harvey, Milner, & Roberts, 1995), but a more precise metric can be obtained by fitting a psychophysical function to responses across multiple transection positions, and extracting the point of subjective equality (PSE). Colent and colleagues (2000) reported that the PSE was shifted rightward after adaptation to leftward prisms; a similar result was then later for a manual bisection task, in which participants actively transect horizontal lines (Michel, Rossetti, Rode, & Tilikete, 2003).

This rightward shift in visuospatial perception after leftward prism adaptation has been interpreted as an experimental model for neglect (Michel, 2006; Michel, Pisella, et al., 2003). Subsequent studies reported similar shifts on other visual and non-visual spatial tasks that are commonly affected by neglect (e.g. Girardi, McIntosh, Michel, Vallar, & Rossetti, 2004; Loftus et al., 2009; Loftus, Nicholls, Mattingley, & Bradshaw, 2008; Nicholls & Loftus, 2007). Leftward prism adaptation may even induce other changes reminiscent of right hemisphere dysfunction, such as an increased tendency to focus on local details at the expense of global forms (Bultitude & Woods, 2010), and an impaired ability to remap spatial representations across saccadic eye-movements (Bultitude, Van der Stigchel, & Nijboer, 2013). However, the empirical evidence is not wholly consistent, and null findings have been reported for other measures and tasks that are often disturbed in neglect, such as temporal order judgements, space- and object-based attention, saccadic latencies and visual search (for a review, see Michel, 2006). Amongst the cognitive aftereffects that have now been investigated in healthy people, we will focus on the first, and most-often replicated finding of a rightward shift in the perceived midpoint of horizontal lines. To distinguish this from other cognitive changes, and from low-level sensorimotor aftereffects, we will refer to this shift as a *visuospatial* aftereffect of prism adaptation.

1.1 Meta-analysis of visuospatial aftereffects of prism adaptation in healthy people

We have been unable to replicate the visuospatial aftereffects of prism adaptation on landmark judgements (or line bisection responses) in healthy people, despite several (unpublished) attempts. We recently completed a meta-analysis of these aftereffects, motivated in part by the desire to understand our own null results (McIntosh, Brown, & Young, 2019). Two previously unpublished null results were included, along with 16 published experiments for the landmark task, and 11 for the line bisection task, from a total of 12 sources (see Table 1, McIntosh et al., 2019). One salient conclusion was that the quality of evidence was higher for the landmark task than for line bisection. We further suggested that manual line bisection is a poor task choice for the study of visuospatial aftereffects, because the manual response to mark the perceived midpoint may be influenced by the low-level sensorimotor aftereffect. For these reasons, our focus in the present paper will be exclusively on visuospatial aftereffects in the landmark task.

Figure 1a shows a funnel plot of the standardized effect size (Cohen's d) for the shift in bias on the landmark task induced by a period of adaptation to leftward prisms. The y-axis represents the standard error of the estimate, which is a function of sample size [1/sqrt(n)], so that higher points on the plot are from experiments with larger sample sizes (n ranges from 7-40, median 12). The largest effect sizes, on the right of the plot, tended to be from studies with smaller sample sizes (n = 7-15), but were also associated with long exposures (≥ 10 minutes) to strong prisms (15°). Assuming that these differences in adaptation parameters, rather than sample size, might be responsible for effect size variations, we included duration of exposure (short, long) and prism strength as moderators in a random-effects meta-analysis. Figure 1b shows the moderated funnel plot of residual effect sizes; that is, the portion of the observed effects that could not be accounted for by these methodological factors. Moderate heterogeneity remained between studies, which might relate to other variations in the implementation of the landmark task (e.g. number of trials and transection positions) and/or chance factors; but the model was overall highly significant.

Figure 1c illustrates this model, showing the relation between the predicted effect size and prism strength, assuming a long period of prism exposure (≥ 10 minutes). There appears to be a dose-response relationship, with stronger prisms inducing larger visuospatial aftereffects. On this basis, we concluded that "*the visuospatial aftereffects of leftward prism adaptation are real and robust*" (p271, McIntosh et al., 2019), and we attributed previous failures to replicate these effects to the use of insufficiently powerful prisms (e.g. 10° rather than ≤15º), and/or brief adaptation protocols (< 10 minutes). We recommended that future studies should adapt participants to 15° (or higher) prisms, and for at least 10 minutes - with upward of 250 pointing movements - an amount of exposure that has been suggested to lead to consolidated, longer-lasting adaptation (Inoue et al., 2014). The predicted effect size for a long period of exposure to 15° prisms is very large (d = 0.94, 95% CIs 0.64-1.24) (Figure 1c).

1.2. A further failure to replicate

Following the meta-analysis, we have conducted a further study, as part of an undergraduate dissertation project at the University of Edinburgh (see Acknowledgements). The original purpose was to examine whether the visuospatial aftereffects of prism adaptation are modulated by the participant's initial perceptual bias on the landmark task, as some authors have suggested (e.g. Goedert, Leblanc, Tsai, & Barrett, 2010; Herlihey, Black, & Ferber, 2012; Schintu et al., 2017). To assess initial bias, we included a baseline block of the landmark task, followed by pre- and post-adaptation blocks separated by a period of prism adaptation. To ensure robust visuospatial aftereffects, we used the adaptation parameters recommended by our meta-analysis, exposing participants to 15° prisms, for a total of 350 pointing movements (~10 minutes). The methods were pre-registered at the open science framework, and the raw data are archived there (https://osf.io/f8b72/).

However, not only did we observe no modulation by initial perceptual bias, we were unable to confirm any effect of prism adaptation on landmark bias at all, even considering all 62 participants together. This total sample size is more than 50% higher than that of any prior published study, and it should have had near-perfect power (.9996 at alpha .05, one-tailed) to detect the lower-bound effect-size predicted from the meta-analysis (d = 0.64). But the shift in the PSE was indistinguishable from zero (Figure 2a). This unexpected result cannot be attributed to unsuitability of the landmark task, which was sufficiently sensitive to show clear pseudoneglect on average, and which had high test-retest reliability across the three blocks (Cronbach's alpha of .87). Nor can it be attributed to a failure to adapt participants sufficiently to the prismatic shift, because the sensorimotor aftereffect, measured by open-loop pointing, was very robust, with a mean shift of 9.63° (SD 1.96, d = 4.9), equivalent to 64% of the prism strength (Figure 2b).

1.3 The need for unbiased evidence

This latest null result is hard to ascribe to a lack of statistical or prismatic power, but an alternative explanation could be that the targeted effect size (d = .64), estimated from prior literature, was over-optimistic. A meta-analysis enables a weighted overview of the available evidence on a question, but if the evidence is biased, or highly heterogeneous, then the overview may be distorted. At the same time, meta-analytic methods such as funnel plot visualization, can aid in the identification of such problems. In an unbiased literature, larger samples, at the top of the funnel plot, should give convergent estimates of the true effect size, and the spread of estimates should increase symmetrically around this value for progressively smaller sample sizes, lower in the plot. If the studies are relatively homogeneous, then around 95% of data points should fall within the triangular region. In Figure 1a, the heterogeneity between prism adaptation studies is high, but this could be related to differences in the adaptation procedure between studies. Once prism strength and exposure duration are included as moderators, the residual effect sizes show much less heterogeneity (Figure 1b).

The funnel plot can also be useful for identifying potential publication bias, which would be indicated by a lateral asymmetry of the distribution of estimates with respect to the triangular region. The prototypical bias would be the non-publication of small sample studies that fail to show a significant (positive) effect, leading to a sparsity of data for the lower left portion of the triangle. This would encourage a negative relationship between sample size and effect size. Common tests of publication bias, such as Eggers test of asymmetry, are based on the evaluation of (appropriate transformations of) this general relationship.[1] As Figure 1b indicates, our random-effects meta-analysis of visuospatial aftereffects of prisms in the landmark task did not suggest any obvious publication bias.[2] Figures 1d-1f, on the right side of Figure 1, show how the meta-analysis would be altered by updating it to include our new study (Section 1.2). Compared with Figure 1b, Figure 1e shows more residual heterogeneity, and an increased degree of asymmetry, albeit not exceeding the threshold for significance.

Another possible form of publication bias can be evaluated by visualising the timeline of reported effect sizes by date of publication. A *decline effect* may sometimes be seen, if an effect enters the literature with inflated estimates of effect size, followed by later studies finding more modest effects (e.g. de Bruin & Della Sala, 2015). Figure 3a shows that the visuospatial aftereffects of leftward prism adaptation on the landmark task are subject to an apparent decline effect, perhaps related also to a tendency for increasing sample sizes in later studies. Rather than basing our view of the visuospatial aftereffects of prism adaptation too firmly on a literature that may be biased, a productive way forward would be to use this literature to frame a novel attempt to obtain an unbiased estimate of the magnitude of these effects.

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[1] Egger's test actually tests whether the y intercept departs from zero, for a linear regression of standardised effect size on precision (reciprocal of the standard error of the effect size estimate) (Egger, Davey Smith, Schneider, & Minder, 1997).

[2] This was not true for the meta-analysis of manual line bisection studies, where a significant asymmetry was found, even after moderation (see McIntosh et al., 2019). This is another reason for preferring to focus on the landmark task in the present study.

1.4. The present study

In this study, we aim to obtain an unbiased estimate of the effects of leftward prism adaptation on PSE in the landmark task. The methods are an elaborated version of those of our recent study (Section 1.2), using strong wide-field wedge prisms (15°) and an extended adaptation procedure (350 movements). In addition to a leftward prism group, the study will include a control group exposed to a sham adaptation procedure, to control for possible non-prism-specific effects. For instance, the adaptation protocol involves repetitive movements of the right arm, but limb movements may differentially activate the contralateral hemisphere and thereby affect the lateral allocation of attention (Jewell & McCourt, 2000); unilateral limb activation has even been applied as a rehabilitation strategy in neglect (Robertson & Hawkins, 1999). Moreover, the evaluation of visuospatial aftereffects is based on a comparison of pre- and post-adaptation blocks of landmark trials, separated by a lengthy adaptation block, but there is evidence that landmark PSE can be shifted rightward by reductions in generalised arousal and alertness, due for instance to time on task, or tiredness (Benwell, Thut, Learmonth, & Harvey, 2013; Dufour, Touzalin, & Candas, 2007; Manly, Dobler, Dodds, & George, 2005). It thus seems essential to control for any such generalised effects, in order to isolate the effect of prism adaptation itself.

Surprisingly, only one study of the visuospatial aftereffects of prism adaptation on landmark PSE has included a sham control group, and this study did not observe a PSE shift in either group (Experiment 1, McIntosh et al., 2019). Slightly more common has been the inclusion, in five studies, of a rightward prism adaptation comparison group (Berberovic & Mattingley, 2003; Colent et al., 2000; Schintu et al., 2014, 2017; Striemer, Russell, & Nath, 2016). It is sometimes claimed that such studies have shown that the visuospatial aftereffects of prism adaptation are specific to leftward prisms (see e.g. Michel, 2016); but this conclusion has only been inferred from significant effects of leftward prisms in the context of null effects of rightward prisms, and never from a direct statistical comparison between groups. Moreover, Berberovic and Mattingley (2003) unexpectedly found that, for one version of the landmark task (in extrapersonal space), rightward prism adaptation induced a significant shift in PSE *in the same direction* as that induced by leftward prisms, a result that defies easy interpretation. If the data are gathered from all of these studies, and plotted together, it is not at all clear that the visuospatial aftereffects of leftward prisms differ from those of rightward prisms (Figure 3b). The specificity of visuospatial aftereffects to the leftward *direction* of prisms, would thus be interesting to test further. However, it is secondary to the more fundamental issue of whether the visuospatial aftereffects of leftward prisms are themselves robust. We prioritise the inclusion of a sham adaptation condition, over a rightward adaptation condition, in order to focus resources on the more fundamental question.

The present study is proposed as a Registered Report, which seems well-suited to furnish unbiased data on this question. There is sufficient prior literature to enable informed predictions about the expected effect size, yet sufficient doubt about the true effect size that the question is worth asking. The literature has a convergent set of methods, so it is relatively straightforward to specify an appropriate design. At the same, the Registered Reports process, by putting peer review before data collection, maximises the chance that any undesirable idiosyncrasies of our design, which might reduce its ability to elicit the aftereffects of interest, can be identified and amended in advance. Finally, to reduce the possibility of inscrutable lab-specific effects, the study is a collaboration across two sites. Both teams have published positive findings of visuospatial aftereffects of prism adaptation, in healthy people (e.g. Bultitude, Van der Stigchel, et al., 2013; Bultitude & Woods, 2010; Girardi et al., 2004)[3] and in patients with right hemisphere lesions (e.g. Bultitude & Rafal, 2010; Bultitude, Rafal, & List, 2009; Nijboer, McIntosh, Nys, Dijkerman, & Milner, 2008; Schindler et al., 2009). However, we both also have null results in our respective file drawers. This alone gives us cause to believe that this literature is subject to at least some degree of publication bias, making a fully-preregistered investigation all the more relevant.

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[3] Though not only positive results (Bultitude, Downing, & Rafal, 2013; Bultitude, List, & Aimola Davies, 2013; Dijkerman et al., 2003; Ten Brink et al., 2017).

2. Methods

2.1. Participants

Two hundred and four participants will be included, assigned equally to two adaptation condition groups: prism adaptation and sham adaptation. Our initial plan is that 51 participants will be tested for each condition at each site, assigned sequentially to alternating groups, though the eventual numbers at each site will depend on recruitment and testing capacity. Initial criteria for recruitment will be: age between 18 and 40; self-reported right handedness with normal mobility in the right hand and arm; self-reported fluency in English, to ensure understanding of instructions; ability to read normal text at 50 cm viewing distance without glasses (contact lenses are allowed); and no reported history of neurological injury (e.g. stroke) or illness (e.g. multiple sclerosis). Recruited participants will be excluded and replaced if the laterality quotient from the Edinburgh Handedness Inventory (EHI: Oldfield, 1971) is negative, if they fail our near-vision screening test (see Section 2.2), if they do not complete the entire session, or if a significant binomial logistic regression cannot be fit to their responses in one or more blocks of the landmark task.

2.2. Procedure

The participant will first complete the EHI, and the Porta test, to provide measures of hand and eye dominance. They will then sit at a table with their head in a chin-rest, centrally facing a touchscreen (active display 525*297 mm; resolution 1680*1050 pixels), tilted slightly back from vertical, with a viewing distance of 500 mm to the screen centre. The participant will be shown a white screen with five letters in black Sloan font, 2.3 mm high. Provided that the participant reads all five letters correctly at the first attempt, they will be allowed to progress to the main experiment.[4]

The room lighting will be dimmed to a low ambient level. On the table in front of the chin-rest, there will be a start button for the right hand, with a direct reach path to the screen centre of 450 mm. A black shelf (160 mm deep), just below the chin-rest, will block the direct view of the hand on the desk, and occlude the first half of the reach path to the screen. In the open-loop pointing and prism adaptation blocks, the participant will use the right hand, keeping the left hand on their lap. In the landmark task, the participant will respond using

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[4] This is not a formal test of visual acuity, but a simple screening step to confirm that there is adequate acuity at 500 mm viewing to resolve the landmark stimuli clearly. The letters presented subtend 0.26°, and the gap size that must be resolved in order to identify the letters in Sloan font is 1/5th of this value (0.05°). This approximates a visual acuity of 0.32 (LogMAR 0.5), which is at the lower boundary of near-normal vision.

foot pedals, keeping both hands in their lap. The participant will be unable to see either hand at any time, except during the prism adaptation procedure.

The testing session will include pre- and post-adaptation blocks of landmark judgements, and open-loop pointing, in order to measure visuospatial aftereffects and sensorimotor aftereffects respectively. The immediate pre- and post-tests, around the adaptation procedure, will form the hypothesis-testing core of the experiment. A baseline block of landmark trials will also be included at the beginning, to allow for exploratory investigations of the possible moderating influence of baseline perceptual bias (Goedert, Leblanc, Tsai, & Barrett, 2010; Herlihey, Black, & Ferber, 2012; Schintu et al., 2017). A late block of landmark trials will also be performed after the core experiment, to allow for exploration of visuospatial aftereffects over a longer post-prism period (cf. Schintu et al., 2014). Finally, a late open-loop pointing block will be added at the end to allow us to probe the state of adaptation at the end of the experiment. The session will thus have 11 phases: baseline landmark task (~6 minutes); pre-prism landmark task (~6 minutes); pre-prism open-loop pointing (~1 minute); prism adaptation (≥ 12 minutes); post-prism open loop pointing (~1 minute); post-prism landmark task (~6 minutes); late landmark task (~6 minutes); late open-loop pointing (~1 minute). The procedure for each task is described below.

Landmark Task: The participant will sit with their hands in their lap, and their two feet resting on identical foot pedals, 300 mm either side of the midline. The participant will be shown a series of horizontal lines, against a black background, in mid-level grey (colour code # 969696). Each line will be 250 mm long and 1mm thick, transected by a 15mm vertical line, 1mm thick. Participants will be instructed to indicate which side of the line is longer (or shorter), by pressing the pedal under the left or right foot. At each testing site, the judgement required (longer/shorter) will be alternated between consecutive participants within each adaptation group, in order to counterbalance the effects of any consistent response bias to favour the left or right pedal. The line will remain on the screen until a response is made, upon which the screen will be filled by a greyscale white noise pattern for 500 ms, to reduce retinal persistence from the previous trial, and then a black field for 500 ms, before the next trial. Any responses made in under 200 ms will be excluded as anticipations, with the trial recycled to the end of the block. Lines will be transected at 0.5, 1, 2, 4 or 8 mm to the left or right of the centre with 16 lines for each of these conditions. Four of these 16 lines will be centred on the screen, and two each will be shifted by 3, 6, and 9 mm to the left and to the right. The task will comprise 160 lines in total, with the order of trials shuffled randomly.

Open-loop pointing: The participant will make five pointing movements from the start button towards a (10 mm) grey dot at the centre of the screen. They will be instructed to make smooth, fast movements, and to try to arrive at the screen in synchrony with an auditory tone (100 ms, 500 Hz), which will onset 400 ms after button release. For this task, the participant will wear LCD glasses and will press the start button to clear the glasses and show each dot. The glasses will become opaque on button release, occluding visual feedback from the entire movement. The next trial will begin when the button is pressed and at least 1600 ms have elapsed since the end of the previous trial. Before the first assessment, participants will be given a short practice session, without LCD glasses, to familiarise with the procedure, and timing requirements.

Prism Adaptation (closed-loop pointing): The participants in the prism adaptation group will wear goggles with 15° leftward, wide-field wedge prisms; those in the sham adaptation group will wear glasses with plain lenses. The participant will make pointing movements towards a (10 mm) grey dot, appearing at the vertical midline of the screen, and at a random horizontal coordinate within 100 mm (~11°) to either side of the horizontal midline. The hand will be occluded by the shelf during the first half of the reach path, with visual feedback available for the second half. Participants will be instructed to make smooth, fast movements, and to try to arrive at the screen in synchrony with an auditory tone (100 ms, 500 Hz), which will onset 400 ms after button release. They will be asked not to deliberately correct for any errors observed; this is to discourage conscious compensation for the prismatic shift, and thus to encourage true sensorimotor adaptation (i.e. spatial realignment, rather than strategic calibration; Redding & Wallace, 2002). The dot will disappear once the screen is touched, and the next trial will begin when the button is pressed and at least 1600 ms have elapsed since the end of the previous trial. The maximum pointing rate will thus be once every two seconds; and 350 pointing movements will be made in total (minimum exposure duration ~12 minutes).

2.3. Dependent variables

Landmark task. For each block of the landmark task, a binomial logistic regression will be fitted to model the probability of a left-is-shorter (≡ right-is-longer) response according to the transection location. If the fit is significant (Wald test, $p < .05$) then the model will be used to calculate the point of subjective equality (PSE; the transection point in mm at which the probability of a left-is-shorter response is .5) and the Just Noticeable Difference (JND; half of the transection distance in mm between .75 and .25 probability of a left-is-longer response).

PSE and JND represent the bias and sensitivity of landmark judgements respectively. The critical dependent variable will be the shift in PSE following prism adaptation, calculated as the PSE in the pre-adaptation block subtracted from that in the post-adaptation block. A negative value indicates a leftward shift in PSE, and a positive value a rightward shift.

Open-loop pointing. For each pointing trial, the horizontal displacement of the touch response from the target centre will be calculated, with leftward error signed negative and rightward error positive. For each block separately, the mean error will be calculated, and expressed in degrees of visual angle. The critical dependent variable will be the immediate sensorimotor aftereffect, which is the shift in error following prism adaptation, calculated as the open-loop pointing error in the pre-adaptation block subtracted from that in the post-adaptation block. The late sensorimotor aftereffect will also be calculated, as the error in the late block subtracted from that in the pre-prism block, in order to assess the state of adaptation at the end of the experiment.

Prism Adaptation (closed-loop pointing): Pointing error (horizontal displacement from target centre) will also be recorded for closed-loop pointing, in order to track error reduction during the prism-adaptation procedure.

2.4. Statistical analysis

Main hypothesis. The critical inferential analysis relates exclusively to the immediate pre- and post-prism blocks of the landmark task, at the core of this experiment. We will compare the shift in PSE between groups (prism, sham), using an independent t-test, with a one-tailed alpha criterion of .02. This will test the hypothesis that the prism adaptation group show a significant rightward shift of landmark PSE, by comparison to the sham adaptation group.

This analysis will be supplemented by a Bayesian independent t-test, performed in JASP (JASP Team, 2019). The Bayes Factor will estimate the relative strength of evidence for the predicted rightward shift of PSE in the prism group, over the null hypothesis of no difference from the sham group. The shift hypothesis will be represented by an informed prior, based on the meta-analysis of McIntosh, Brown, & Young (2019), updated to include our recent study (Section 1.2). For a prism strength of 15°, the meta-analysis predicts an average effect size of 0.79 (SE 0.17 CI 0.47 to 1.11) (Figure 1f). The informed prior will be a normal distribution, centred on this predicted effect size (0.79), with a standard deviation equal to the standard error of the meta-analytic estimate (0.17).

Outcome-neutral criterion. We will require evidence that the prism adaptation group adapted sufficiently to the prisms. Facchin, Folegatti, Rossetti, & Farnè (2019) have estimated the average sensorimotor aftereffect at around 38% of prism strength. Our recent study, using an adaptation protocol similar to that of the present experiment, found a sensorimotor aftereffect of 64% (Figure 2b). Our operational criterion will be that an average differential immediate sensorimotor aftereffect of at least 5° (one-third of the prism strength) must be observed in the prism group, compared to the sham group, in order to allow for a meaningful interpretation of the main analysis.

Exploratory analyses: PSE in the baseline block of the landmark task will enter into an exploratory analysis of the possible modulatory influence of baseline bias on visuospatial aftereffects (e.g. Goedert, Leblanc, Tsai, & Barrett, 2010; Herlihey, Black, & Ferber, 2012; Schintu et al., 2017). PSE in the late block will be included in this analysis, to assess the possibility that visuospatial aftereffects vary with time post-adaptation (Schintu et al., 2014). JND will also be subjected to an exploratory analysis of prism aftereffects, and the late sensorimotor aftereffect will be used to assess the state of adaptation at the end of the experiment. We may also explore the inter-correlations between error reduction during adaptation, sensorimotor aftereffects, and visuospatial aftereffects, and between landmark performance and other participant characteristics (sex, and hand and eye dominance).

2.5. Power

The sample size is calculated to provide .9 power to detect the effect targeted by the main hypothesis, with an alpha criterion of .02 (one-tailed). The expected effect size is drawn from the meta-analysis of McIntosh, Brown, & Young (2019), updated to include our recent study (Section 1.2). We will target the lower bound value of the expected effect size for a prism strength of 15° (0.79, SE 0.17, CI 0.47 to 1.11). For this lower-bound effect size ($d = 0.47$), the required power will be achieved at a group size of 102, with balanced allocation to the two groups. We will thus include 204 participants in total, with 102 per group.

This sample size would, of course, be more than adequate for the outcome-neutral criterion of a 5° differential sensorimotor aftereffect, were this criterion to be put to a statistical test. In our recent study, using a similar adaptation procedure, the standard deviation of the sensorimotor aftereffect was 1.96°. Assuming a similar standard deviation, a 5° sensorimotor aftereffect would have a standardised effect size of around 2.55, so that 5 participants per group would achieve .90 power, with an alpha criterion of .02 (one-tailed).

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Figures and legends

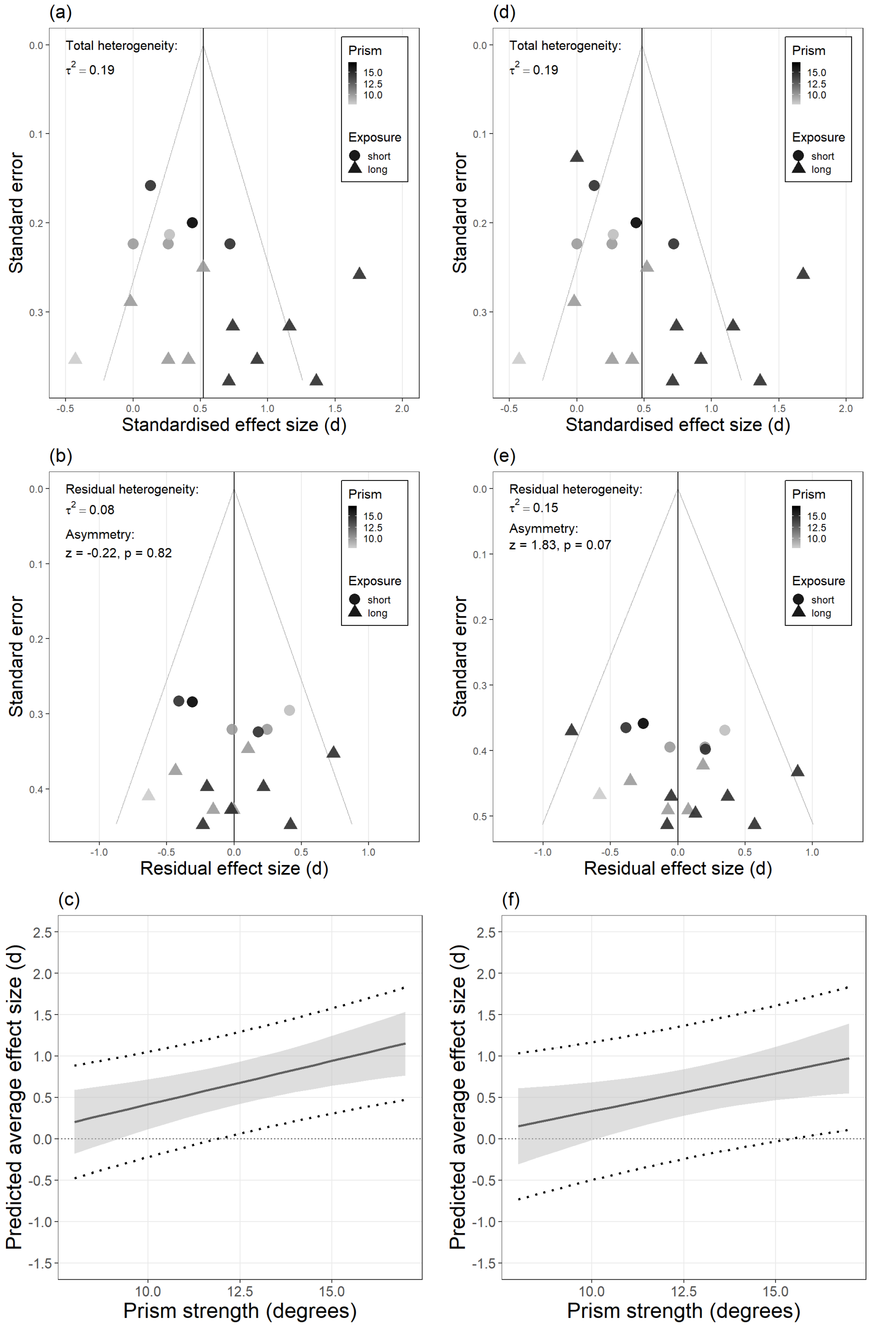

Figure 1. The panels in the left column (a-c) summarise the random effects meta-analysis of the cognitive effect of prism adaptation on landmark bias, and those in the right column (d-f) show the corresponding plots, updated to include the data from the study reported in Section 1.2. **(a, d)** The unmoderated random-effects funnel plot of standardised effect size by standard error (larger studies are higher in plot). The triangular region follows the 95% confidence region at each level of standard error, and is centred on the meta-estimate of average effect size. **(b, e)** The moderated funnel plot of residual effect size, after prism strength and exposure duration (short, long) have been accounted for, where a long period of prism exposure is defined as ≥ 10 minutes. **(c, f)** Predicted average effect size by prism strength, assuming a long exposure. The grey shaded region shows the 95% confidence intervals, and the dotted lines show the 95% prediction intervals.

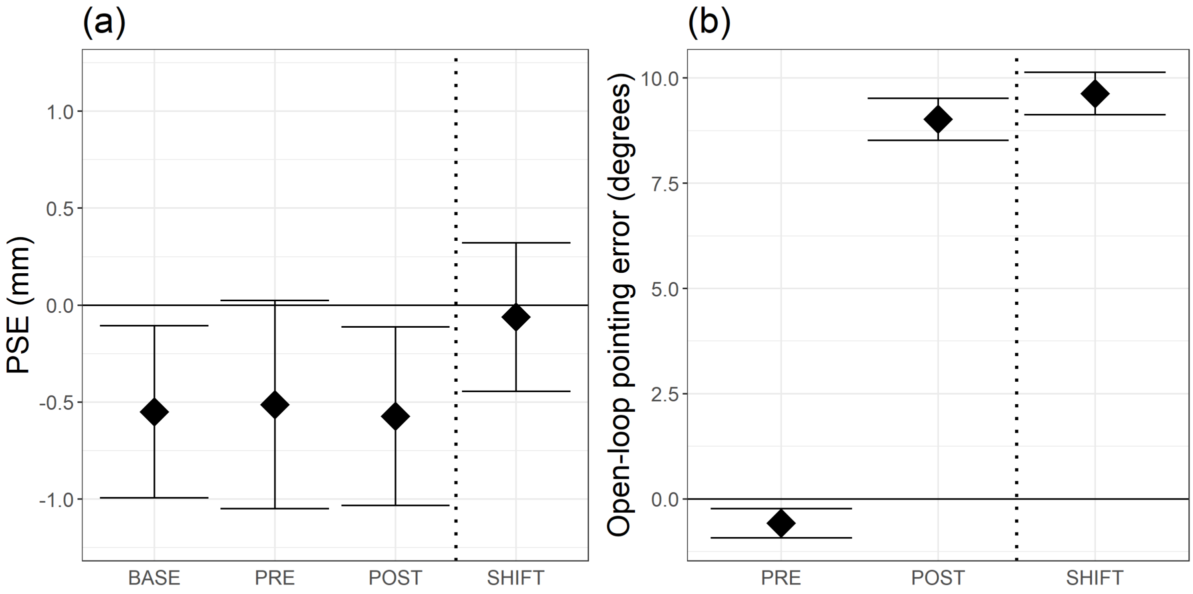

Figure 2. Summary of results for the study reported in Section 1.2. **(a)** Landmark PSE of 62 participants in the baseline, pre-adaptation and post-adaptation blocks. SHIFT is the subtraction of pre- from post-adaptation bias, and represents the visuospatial aftereffect. **(b)** Open loop pointing error in the pre- and post-adaptation blocks. SHIFT is the subtraction of pre- from post-adaptation pointing error, and represents the sensorimotor aftereffect. Error bars represent 95% confidence intervals.

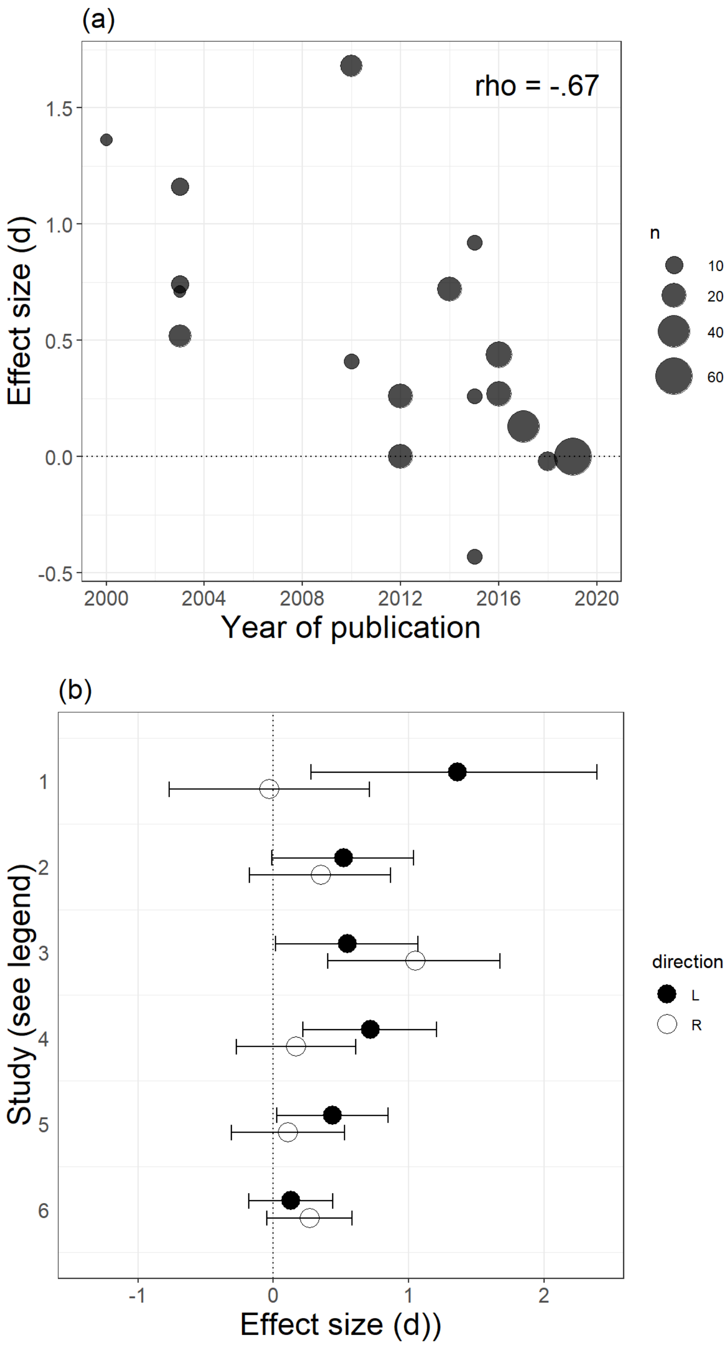

Figure 3. **(a)** Effect size by year of publication, showing a decline effect with time. The point size is scaled by sample size. The plot includes the study reported in Section 1.2 (rightmost point). **(b)** Effect size, for left and right prism adaptation groups, for five experiments that have included groups adapted to opposite directions of shift: (1) Colent et al. (2000, 15° prisms); (2) Berberovic & Mattingley (2003, peripersonal space, 10° prisms); (3) Berberovic & Mattingley (2003, extrapersonal space, 10° prisms); (4) Schintu et al. (2014, 15° prisms); (5) Strimer et al (2016, 17° prisms); (6) Schintu et al. (2017, 17° prisms). Positive effect sizes represent a rightward shift in landmark bias. Error bars represent 95% confidence intervals.

CRediT author statement

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