Behavioral rebound following isolation of attention

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Contributions

GE & LB designed the experiment. GE & AB performed the experiments. GE analyzed the data. GE & LB wrote the manuscript.

Competing financial interest

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Abstract

Stable sensory perception is achieved through balanced excitatory-inhibitory interactions of lateralized sensory processing. For example, left limb tactile stimulation inhibits somatosensory processing of the right limb tactile stimulation (Palmer et al., 2012 [1]) and inhibitory non-invasive brain stimulation to left attention regions increases right hemispheric attention processing (Hilgetag et al., 2001 [2]). In real world experience, sensory processing is rarely equal across lateralized processing regions, resulting in continuous rebalancing. We predicted rebalancing lateralized sensory processing following prolonged imbalance could cause a rebound in the opposite direction. Here, we isolated covert attention to one visual field with a 30-minute attention-demanding task and found an *increase* in attention in the opposite visual field after intervention. We suggest a rebound in lateralized attention in the previously unattended visual field due to an overshoot in attention rebalancing. Our finding of visual field specific attention increase could be critical for the development of clinical rehabilitation for patients with a unilateral lesion and lateralized attention deficits. Both homeostatic (Wu et al., 2020 [3]) and Hebbian plasticity (Pugh & Raman, 2006) [4] may have a role in the interplay between lateralized attention processing regions after visual attention imbalance, which is a crucial avenue of future research. Furthermore, applying our data as a case study for lateralized sensory processing, our results suggest a fundamental characteristic of lateralized processing interaction, which may be useful rehabilitation of unilateral stroke, outside of visual attention.

Main Text

Covert attention was measured using multiple object tracking (MOT), where objects were tracked either in both visual fields (bilateral; Figure 1a) or one visual field (unilateral), as they moved in amongst distractors. A set of targets and distractors were presented in the left and right visual fields and remained within their hemifield, never crossing the vertical midline. Forty-two participants performed bilateral MOT to obtain a baseline attention performance in the left and right visual fields. Next, participants were randomly assigned to one 30-minute experimental procedure: Group 1) isolate attention right: central fixation with right unilateral MOT, ignoring MOT stimuli on the left. Group 2) isolate attention left:

performed left unilateral MOT while ignoring the right MOT stimuli. Control Group 3) no isolation: tracking targets on both left and right using bilateral MOT. Immediately after the manipulation all participants performed bilateral MOT. We expected increased tracking performance in the unattended visual field in Group 1 and 2 following a rebound after prolonged attention imbalance (Figure 1b).

(*Insert Figure 1 Here*)

We found a main effect of session (pre- < post-manipulation; $\chi^2(1)=8.5860$, p=0.0033, General Linear Mixed Effects Model; *glmer*) and visual field ($\chi^2(1)=7.4387$, p=0.0064, *glmer*) in tracking performance, but no main effect of group ($\chi^2(2)=2.1633$, p=0.3390, *glmer*). Importantly, we found a significant 3-way interaction between group, session and visual field ($\chi^2(2)=7.0449$, p=0.0295, *glmer*) indicating the difference in tracking between groups was dependent on session and specific to visual field (see Supplemental for all model comparisons). In accordance with our hypothesis, the tracking performance in the visual field deprived of attention during manipulation was modulated for both group 1 and 2. In group 1, there was an increase in left visual field tracking after attention was isolated right (Figure 2d; Maroon empty bar, estimate=0.901, se=0.237, z=3.804, p=0.0004; *emmeans()* with *adjust "mvt"*), and in group 2, there was an increase in right visual field tracking after attention was isolated left (Figure 2d; Teal empty bar; estimate=0.418, se=0.193, z=2.170, p=0.030). Tracking accuracy was not significantly different from pre to post-manipulation in the visual field where attention was isolated during manipulation for either group (p>0.05). In our control group 3, we found no change in tracking in either the left or right visual field following 30 minutes of bilateral MOT (Figure 2c; p>0.05). Therefore, without attention isolation to one visual field, no tracking change occurred. Furthermore, we found a significant difference in the left visual field tracking between the isolate attention right group and the control group (estimate=-0.085, se=0.0385, t.ratio=2.218, p=0.029; *emmeans()*). However, no significant difference in tracking was found in the right visual field between the isolate left visual field group and control group (estimate=-0.007, se=0.0385, t.ratio=0.205, p=0.838; *emmeans()*). Importantly, no difference was found between groups prior to intervention (p>0.05; *emmeans()* with *adjust "mvt"*).

Forcing attention to one visual field for a prolonged duration resulted in an increase in attention to the opposite visual field immediately after manipulation. The boost of attention suggests a rebound in behavior following prolonged imbalance between lateralized attention processing regions. Rebalancing of neural activity is controlled via homeostatic plasticity [3]. The inactivated attention processing regions may benefit from homeostatic gain control to equalize visual field attention post-manipulation.

Post-inhibitory rebound spiking, where neuronal rebound has been demonstrated following prolonged inhibition, provides another plausible account of our findings [5]. Prolonged lateralized attention recruit lateralized attention processing regions [6], which in turn inhibit cortical homologues processing the opposite visual field [2]. It is plausible our behavioral rebound is a result of post-inhibitory spiking which initiated long term potentiation [4]. The post-inhibitory rebound account is also supported by the lack of difference in the right visual field between the control group and leftward attention isolation group. Right visual field processing is less lateralized in the cortex [7], potentially reducing lateralized inhibition and the subsequent post-inhibitory rebound.

In adults, imbalance of visual input through covering of one eye (monocular deprivation) causes an increase processing for the *deprived* eye [8]. The strengthening of the deprived eye has parallels to our study, where we find the strengthening of attention to the unattended (or attention-deprived) visual field. Using magnetic resonance spectroscopy (MRS), Lunghi et al. [8] demonstrated the strengthening of the deprived eye correlated with decreased GABAergic inhibition in the early visual cortex. Rebound activity with decreased inhibition has also been found when examining center-surround receptive fields in cat primary cortex [9]. Rebound activity was mediated by lack of excitation of the center rather than increased inhibition from the surround. Six sessions of monocular deprivation to the unhealthy eye can restore visual acuity in amblyopic adults lasting at least one year [10]. Using right attention isolation, we may exacerbate the visual field attention imbalance in right lateralized stroke patients, which could cause rebound in the impaired left visual field.

Our results demonstrated that thirty minutes of tracking to one visual field did not induce training within the attended visual field, and therefore could not account for a training transfer to the unattended visual field. Previous research has demonstrated multiple sessions of MOT are necessary for successful training [11].

Using MRS, follow-up studies examining GABA and glutamate complex concentration following attention isolation would characterize the mechanism underlying the rebound effect [12]. Finally, forcing activity imbalance between other lateralized sensory processing networks and recording subsequent behavioral impact could illuminate a rebound characteristic shared across sensory modalities. Unilateral stroke patients exhibiting lateralized deficits in domains other than attention could greatly benefit from rehabilitation protocols using simple imbalance of sensory input.

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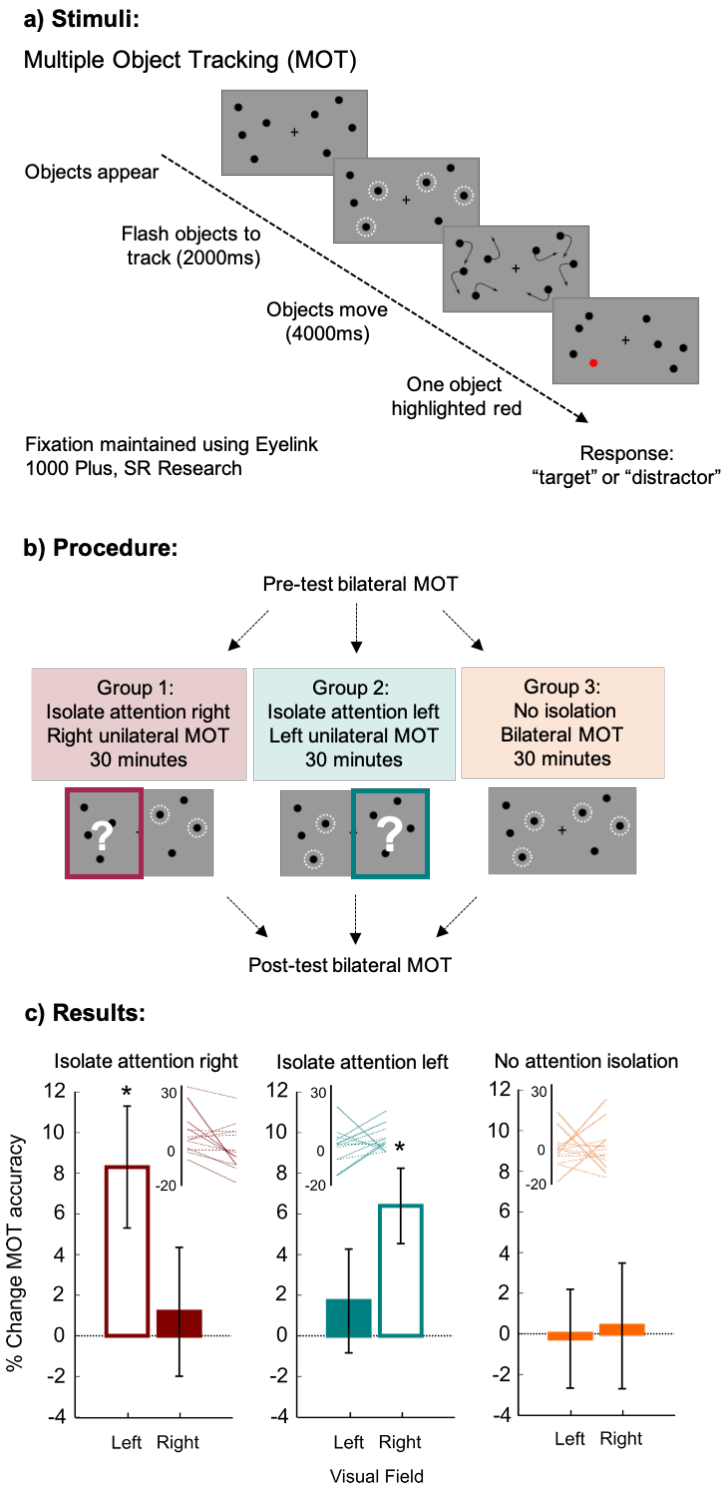

Figure 1: a) Stimuli. Visual field specific attention measured using bilateral multiple object tracking (MOT). Fixation maintained using Eyelink 1000, SR Research. **b) Procedure.** Unilateral MOT employed to isolate attention to one visual field for 30 minutes in Groups 1 and 2. The difference from pre- to post-test bilateral MOT in the unattended visual field determines visual field specific change in attention. **c) Results.** Isolate attention right Group 1 in maroon, Isolate attention left Group 2 in teal, No isolation, bilateral tracking Group 3 in orange. Empty bars in Groups 1 and 2 indicate visual field unattended during attention isolation period. * above empty maroon bar indicates $p<0.004$, * above empty teal bar $p<0.03$. Individual subject data provided in the inlet. Note y-axis difference from averaged data.