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Research report

Novel claustrum activation observed during a visuomotor adaptation task using a viewing window paradigm

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A B S T R A C T

Previous literature has reported a wide range of anatomical correlates when participants are required to perform a visuomotor adaptation task. However, traditional adaptation tasks suffer a number of inherent limitations that may, in part, give rise to this variability. For instance, the sparse visual environment does not map well onto conditions in which a visuomotor transformation would normally be required in everyday life. To further clarify these neural underpinnings, functional magnetic resonance imaging (fMRI) was performed on 17 (6M, age range 20–45 years old; mean age = 26) naive participants performing a viewing window task in which a visuomotor transformation was created by varying the relationship between the participant's movement and the resultant movement of the viewing window. The viewing window task more naturally replicates scenarios in which haptic and visual information would be combined to achieve a higher-level goal. Even though activity related to visuomotor adaptation was found within previously reported regions of the parietal lobes, frontal lobes, and occipital lobes, novel activation patterns were observed within the claustrum – a region well-established as multi-modal convergence zone. These results confirm the diversity in the number and location of neurological systems recruited to perform a required visuomotor adaptation, and provide the first evidence of participation of the claustrum to overcome a visuomotor transformation.

1. Introduction

Under normal circumstances, we have few problems using sensory information to respond to our environment. In fact, much of our ability to acquire and maintain the motor skills utilized on a daily basis capitalize on the ability to integrate and transform sensory information into a motor response. It has been established that our sensorimotor system is able to adapt to a wide variety of visual and mechanical perturbations, however, there is still little agreement in the literature as to the amount and location of neurological areas implicated in the performance of this task [1]. The bulk of our knowledge regarding the neurological correlates of visuomotor adaptation comes from prism adaptation (e.g. [2–7]). Until recently, prism adaptation was largely held to be a function of the cerebellum. The cerebellum not only receives proprioceptive information from the limbs, but also receives visual information from cortical and subcortical areas, and is therefore a logical site for a discrepancy between these two information streams to be detected and corrected. Visual information projects from medial extrastriate regions to the dorsolateral region of the pontine nuclei [8,9], and it is known that experimental lesions in monkey cerebellar mossy-fibre, where input from the pontine nuclei is received, abolish prismatic adaptation in macaque [10]. Further bolstering the role of the cerebellum, human patients with cerebellar lesions may display adaptation impairments [11–13]. For example, Martin et al. [11] reported patients with damage to the inferior olive (the source of climbing fibres to the cerebellar cortex) were severely impaired when adapting to lateral displacement prisms.

Other prism work, utilizing functional neuroimaging, has implicated the parietal region's role in visuomotor adaptation [2–6]. For instance, Clower et al. [2] used positron emission tomography to directly examine brain activation during a pointing task while the participant wore lateral displacement prisms. Consistent patterns of brain activation were observed in the posterior parietal cortex (PPC) contralateral to the pointing limb on trials where vision was displaced. Providing further support for PPC involvement during visuomotor adaptation, Fernandez-Ruiz et al. [3] had participants wear left/right reversing prisms during a pointing task during functional magnetic resonance imaging, and found areas of PPC that typically respond to contralateral movement goals were responding to ipsilateral pointing movements during exposure to reversing prisms. This result was interpreted as providing evidence that the PPC does not function in strictly vision or movement coordinates,

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but rather encodes the spatial goal of the movement in retinal coordinates. In other words, the PPC works as an intermediary between visual and motor codes [3].

Even though visuomotor adaptation studies utilizing prisms are the most prolific in the literature, there have been alternative methods employed in the examination of the neurological mechanisms involved in correctly performing visuomotor transformation and/or adaptation. Many of these studies have had participants execute a pointing or tracking movement under normal visual conditions and compared the obtained activation to activation observed when a perturbation was introduced. Distortions have included simple rotations [14–18], magnification [18], lateral shifts of location [2], and axis reversals [19,20]. Interestingly, the adaptation related activity observed differed substantially between studies, not only in the anatomical locations of regions of activity, but also in the number of regions recruited. In a descending order of frequency, activity was observed within the posterior parietal lobe, the cerebellum, prefrontal cortex, basal ganglia, premotor areas, sensorimotor areas, temporal and occipital cortices, and the thalamus.

The present study utilizes a novel computer-based task, the viewing window, which presents participants with degraded pictures of objects and asks them to identify the objects using a small user controlled area (the "window"). Within the window, the underlying image is displayed with normal clarity [21]. Although aperture viewing paradigms are not new, dating back nearly 200 years [22–24], in order to be used as a tool to assess visuomotor performance a number of significant changes were made. The method of controlling the window, the size of the viewing region, and the information available in the transitional region between the window and the periphery are examples of some of the changes that were employed. This procedure has successfully demonstrated group differences in transformation ability using behavioural measures [25] and has a number of potential advantages over previously used visuomotor adaptation tasks including removing the focus of the task from the visuomotor distortion itself, providing multiple opportunities to compare a target foveal location and resulting movement, and providing a variety of ways to manipulate both the visual and motor information participants are exposed to. Perhaps most importantly, it is a substantially more complex task than those used in previous studies examining the neurological underpinnings of visuomotor adaptation, better replicating naturalistic task circumstances. For example, participants are presented with rich visual stimuli (greyscale images of an object) in a task that allows for a free range of motion across a visual scene. We believe this more naturally replicates scenarios in which visuomotor transformations are required in our day to day lives and may provide further insight into the cortical regions responsible for successfully performing goal directed visuomotor adaptations than those revealed through the use of simplistic centre-out pointing movements.

Previous research has provided a wide-range in the regions of reported activity, suggesting differences in methodology, or tasks may be leading to increased variability. Specifically, the superior and inferior parietal lobules (BA 40) [1,14,19], the precuneus (BA 7) [26], and the posterior cingulate gyrus (BA 23, 29, 31) [19] have all been implicated in the performance on visuomotor transformation and adaptation. Though less commonly reported in previous studies, additional regions of activity have been identified in areas of the occipital lobe, the cuneus (BA 17, 18) [26,27], and the lingual gyrus (BA 18, 19) [19]. Finally, regions of interest within the temporal lobes, include the temporo-parietal junction (BA 39, 40) [28], and the frontal lobes consisting of the anterior insula, and anterior cingulate (BA 24, 32) [19]. It was hypothesized that the viewing window would recruit similar neural networks to those reported above, however, due to the use of the viewing window task, it was expected that the cortical regions involved in performing a goal directed visuomotor adaptation would display higher levels of activity than those previously reported.

2. Materials and methods

2.1. Participants

All experimental procedures received approval from the Psychology and Sociology Research Ethics Board of the University of Manitoba and the National Research Council's Research Ethics Board. All participants provided written informed consent before participating in any of the experiments and completed a pre-screening form to ensure it was safe for them to participate. Seventeen (6M, age range 20–45 years old; mean age = 26, SD = 6.8) participants were recruited from the University of Manitoba's introduction to psychology participant pool or through "word of mouth". Participants were right-handed, fluent in English, and had normal or corrected-to-normal vision as reported in pre-test screening, and reported their computer ability as "very proficient" on a Likert-type scale. Participants had no history of neurological disease and were naive to the objective of the study. All participants received $25.00 to cover travel expenses, with those recruited from the participant pool also receiving course credit.

2.2. The viewing window

The "window" was a circular region roughly corresponding with the size of useful foveal vision (2.98°), with a 51 pixel length radius, covering a total area of 8171 pixels. The outermost region of the window displayed the underlying image at full blur. The innermost regions displayed the image at normal clarity (see Fig. 1), with a smooth transition between these two regions. This gradient border was used to provide a more natural viewing experience. Participants were given both written and verbal instructions prior to beginning, and the correct use of the trackball and viewing-window was demonstrated by the experimenter. Participants were told that they could move a window around the screen, using the trackball, which would display the underlying object in perfect clarity. Participants were instructed to identify the presented object as quickly but as accurately as possible, and to signify their identification by pressing either of the buttons located on the trackball. Additionally, participants were told some of the trials would be difficult and that if they were unable to identify a given object, to take a "best-guess". Three visuomotor-flip conditions were created by varying how the participant's body movements affected the onscreen movement of the viewing window. During the No Flip condition, the movement of the window was matched to the participant's movements of the trackball. In each of the solitary x-axis and y-axis Flip conditions, only one dimension (horizontal or vertical) of movement was reversed. For example, in the x-axis Flip condition, leftward movements of the trackball resulted in the viewing window moving towards the right of the presented image.

2.3. Training

Participants were verbally instructed outside of the magnet as to how to perform the task, and were verbally reminded once inside the bore of the magnet. The first functional scan for all participants was used as a practice and was not included in the reported analyses. This ensured all participants were not only accustomed to the task, but also used to the auditory noise associated with the functional scan.

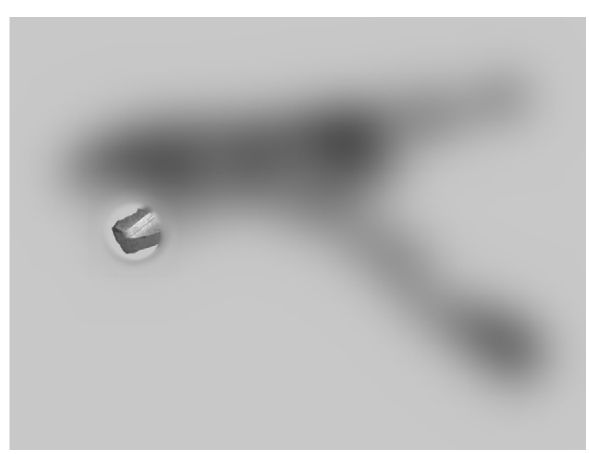

Fig. 1. Viewing window illustration. The circular viewing window displays the underlying image in normal clarity, while the remainder of the image is heavily blurred. The target item is a pair of vice-grips.