Mental Imagery Cracked: Direct Monitoring of the Continuous Movements of Covert Visuospatial Attention During Motion Imagery

Regina Gregori Grgič[#1], **Enrico Calore**[#2], **Daniele Marini**[2], **Claudio de'Sperati***[1]
[1] Università Vita-Salute San Raffaele, Laboratory of Action, Perception and Cognition, Milano, Italy
[2] Università degli Studi di Milano, Dipartimento di Informatica, Milano, Italy
[#] These authors contributed equally to the work
*desperati.claudio@unisr.it

Abstract

We sought to provide direct evidence of the attention movements during dynamic mental imagery. Observers extrapolated in imagery the horizontal motion of a target with the gaze in central fixation. We recorded the steady-state-visual-evoked potentials (SSVEP) generated by flickering the left and right sides of the screen at two different frequencies. We found a consistent SSVEP modulation as a function of the imagined target position. Concurrent finger pointing, but not mental training, increased the SSVEP modulation. We conclude that the electrophysiological signature of covert visuospatial attention can be used to reveal non-invasively the continuous spatio-temporal dynamics of mental imagery.

Keywords: Mental imagery; Visuospatial attention; Motion; SSVEP.

Introduction

There is an endless debate on the nature of mental imagery, dating back at least to Aristotle and his reflections upon *phantasmata* and *phantasia*. Basically, two positions took the scene over the last decades, namely, the propositional theory and the pictorial theory, championed respectively by Zenon Phylyshyn (Pylyshyn, 2003) and Stephen Kosslyn (Kosslyn, 1994). An important distinction between these two views is the alleged discrete vs. continuous nature of mental imagery. More recently, far from being considered a purely mental faculty, mental imagery has been viewed as an enactive process involving sensori-motor functions, including eye movements (Hebb, 1968; Thomas, 2010).

Imagining a moving stimulus (motion imagery) is an interesting test-bed to verify theories on mental imagery, as it allows, at least in principle, to verify its spatio-temporal evolution (Shepard & Cooper, 1986). Indeed, a precise unfolding of eye movements in space and time has been observed during motion extrapolation (Crespi, Robino, Silva, & de'Sperati, 2012; de'Sperati, 1999, 2003b; Jonikaitis, Deubel, & de'Sperati, 2009). A similar, although necessarily much less precise, spatio-temporal evolution has been observed for covert visuospatial attention (the spotlight of attention); in that study, observers were asked to imagine a moving target without making eye movements (de'Sperati & Deubel, 2006), and a probe was flashed with various spatial and temporal offset relative to the imagined target position. Response times were used to reconstruct *a-posteriori* the trajectory of covert attention.

Here we sought to study directly the spatio-temporal evolution of covert attention during motion imagery without being constrained by the laborious and gross reconstruction work that measuring response times, but also accuracy-based indexes, necessarily imply.

To this end, we exploited the steady-state-visual-evoked potentials (SSVEPs), which provide a direct measure of cortical visual responsiveness, a hallmark of visuospatial attention (Carrasco, 2011; Clark & Hillyard, 1996). At variance with traditional visual evoked potentials, SSVEPs do not require averaging across several trials, and therefore are well suited, at least in principle, to quickly trace the continuous changes of cortical responsiveness (Vialatte, Maurice, Dauwels, & Cichocki, 2010). Indeed, SSVEPs have been used to investigate covert visual attention (Di Russo, Teder-Sälejärvi, & Hillyard, 2002). For example, covertly attending a flickering target increases the resulting SSVEP amplitude, as compared to allocating attention elsewhere (Muller, Teder-Salejarvi, & Hillyard, 1998). Here we move one step forward and ask whether SSVEP can be used to reveal the movements of visuospatial attention during a motion imagery task.

Methods

Participants

Five participants volunteered for the experiments (2 males, aged 20-52). Two of them were experienced subjects. Before starting the experiments the participants signed the informed consent, in accordance with the guidelines of the local Ethical Committee.

Stimuli and Tasks

Observers with the gaze in central fixation in head-restrained conditions were shown on a computer screen a visual target that moved horizontally with sinusoidal motion (0.2 Hz, ±9 deg). The target then disappeared, and the observer had to continue its motion in imagery. Throughout the trial, the left and right halves of the screen flickered at two different frequencies (15 and 20 Hz). Flickering was obtained by alternating a black and a white patch.

In a second task observers accompanied imagery with finger pointing to the invisible target, with the arm positioned on the table, far from the screen. Finger movements were unconstrained and were not recorded, but an experimenter checked that they were reasonably accurate.

A subgroup of 5 participants were instructed to follow a home training program consisting of 1 daily session for 7 consecutive days during which the tracking task – without finger pointing – had to be rehearsed, guided by a computer program.

Electrophysiological recordings

The EEG was recorded using the g.MOBIlab+ at 256Hz, with 4 electrodes positioned on PO7-PO8-Oz-Pz, referenced to the left ear lobe and grounded to FPz. The double-flickering stimulus generated continuously two SSVEPs in the posterior brain regions, at 15 and 20 Hz, whose size varied reciprocally as a function of the target position. The SSVEP amplitude was evaluated moment-by-moment using the Minimum Energy Combination algorithm with T estimation (Friman, Volosyak, & Graser, 2007).

Signal acquisition was performed using the OpenVibe software framework, visual stimuli were presented by a custom C++/OpenGL application (Calore, 2014), while MatLab was used for off-line data analysis.

Results

The amplitude of each SSVEP (one at 15 Hz and the other at 20 Hz) was quantified every 250 ms and summed (with one signal inverted in sign due to the push-pull behavior of the two SSVEPs) to yield a single combined quantity (cSSVEP). The cSSVEP can thus be considered a valid proxy of the instantaneous cortical visual responsiveness.

When observers mentally tracked the invisible moving target spanning across the two visual hemifields flickering at different frequencies, the amplitude of the cSSVEP exhibited a clear target-contingent, sinusoidal-like modulation (Figure 1). Because the gaze was kept in central fixation, as verified by concurrent eye movements recording, the cSSVEP modulation was not determined by retinal stimulation, but rather to the oscillation of the attention focus, as a sort of virtual fovea.

To quantify the cSSVEP response during imagery, we computed, by means of a sinusoidal fitting procedure, the modulation gain as the ratio between the peak-to-peak amplitude of the cSSVEP modulation during imagined covert tracking relative to the amplitude during overt tracking of the visible target, recorded at the beginning of the experiment. In this way, a gain of 1 would indicate that during mental imagery the responsiveness of the cerebral cortex to visual stimuli is modulated as deeply as if the modulation were produced by a corresponding retinal stimulation, while a gain of 0 would indicate the lack of modulation.

Remarkably, without obviously ever approaching a value of 1, still the modulation gain was always rather high, ranging between about 0.2 and 0.3. Whereas accompanying covert tracking with finger pointing resulted in a significantly higher cSSVEP modulation gain (t_4=2.945, p=0.042), the improvement observed after the attention training was not statistically significant, as compared to the pre-training value (t_4=1.088, p=0.338).

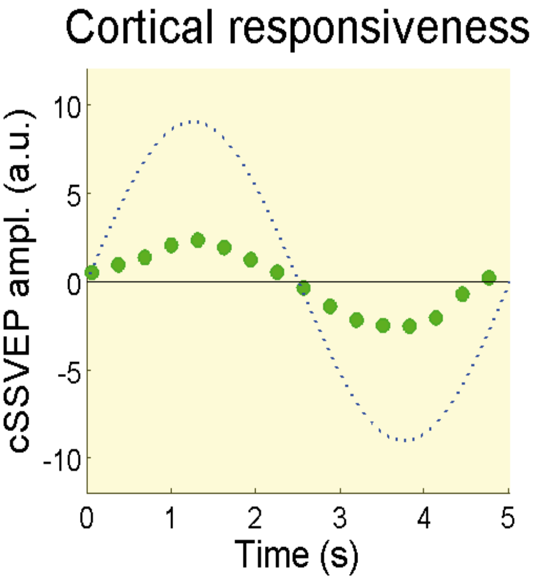

Figure 1: Sinusoidal-like, target-contingent cSSVEP modulation during mental motion imagery. Green trace, instantaneous cSSVEP amplitude (mean across trials and subjects). Blue trace, the virtual, to-be-imagined target trajectory. The cSSVEP trace was scaled so that a modulation with an amplitude identical to the target oscillation amplitude would have a gain of 1.

Discussion

This study has shown a remarkable target-contingent sinusoidal modulation of cSSVEP amplitude during mental motion imagery. Because visual cortical responsiveness is modulated by visuospatial attention, our findings suggest that the continuous monitoring of covert attention during mental imagery of dynamic scenes can be a precious tool to reveal how imagery unfolds in space and time. In the past, we have investigated dynamic mental imagery through eye movements (de'Sperati, 2003a). We found that both systematic sequences of saccades (Crespi, et al., 2012; de'Sperati, 2003b; Jonikaitis, et al., 2009) and, surprisingly, under certain conditions also sustained smooth pursuit eye movements (de'Sperati & Santandrea, 2005), could be generated when imagining a moving target. In keeping with those previous findings, we have now revealed the spatio-temporal dynamics of motion mental imagery in the absence of concurrent (oculo)motor behavior. In showing that attention followed closely the to-be-imagined target oscillation passing through the intermediate locations, our results fit hardly the propositional theory of imagery (Pylyshyn, 2003), and align with the perceptual-like and sensorimotor accounts (Kosslyn, 1994; Thomas, 2010).

The capability of imagining a moving target improved slightly but significantly when covert target tracking was accompanied by finger pointing. This observation suggests that finger pointing may help to focus visuospatial attention. Indeed, pointing is often used for fingerpoint-reading and for sharing attention in social contexts (Tomasello, Carpenter, & Liszkowski, 2007).

Finally, we did not find a significant increase of cSSVEP modulation during mental imagery after the attention training, as compared to the pre-training condition, although there was a tendency to increase the gain. Many reasons can be at the origin of this negative finding. Firstly, only 5 subjects participated to the training sessions. Secondly, the duration of the training was relatively short. Thirdly, the training was self-administered and not too exciting, as compared to attentional training programs based, e.g., on videogames (Franceschini et al., 2013), and it is possible that some participants were not motivated enough. Indeed, after the training there was a high gain variability. Thus, to definitely ascertain whether or not it is possible to improve mental imagery through attentional training, a more stringent and long-term program should be implemented in a larger subject sample.

Citations

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