Effects of spatial cueing on overt orienting of gaze to attentive stimuli

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Abstract

The latency of visually guided saccades executed after a cueing condition was adopted as a more ecological index to explore how spatial attention, usually assessed by manual responses, operates in the visual field. Subjects executed saccades aimed towards one of 4 possible positions, equally distributed around a central fixation cross. Before the onset of the saccadic target, a visual cue was briefly presented at the same or at a different spatial location. The visual cue was non-predictive of the target position. Two experimental sessions were carried out, differing for the onset asynchrony between cue and target. A time-dependent coupling between the task-irrelevant location of the cue and the direction of a following overt shift of attention emerged. Clinical applications of the adopted experimental setting to neurological and psychiatric patients with motor impairments are discussed.

Keywords: Visuospatial attention; Spatial cueing; COVAT paradigm; Visually guided saccades; Eye tracking

1. Introduction

Selective attention is the process by which a sensory stimulus becomes the target to deal with in preference of others. The way by which it operates in the visual field represents a main topic of study, that traditionally gives a particular emphasis on attention based on location information (i.e., visuospatial attention).

In everyday life, people typically move their gaze before the onset of the manual response during an upper-limb movement towards a visual target (Dean, Martì, Tsui, Rinzel & Pesaran, 2011; Lünenburger, Kutz & Hoffmann, 2000; Prablanc, Echallier, Komilis & Jeannerod, 1979). Furthermore, recent neurophysiological studies reveal that motor control systems of eye and hand, even though anatomically segregated, are covertly coupled when visually guided ocular movements are made, namely during overt shifts of visuospatial attention, even in the absence of a hand movement (Falciati, Gianesini & Maioli, 2013; Maioli, Falciati & Gianesini, 2007). Thus, eye responses seem particularly appropriate to explore temporal facilitation or interference between attentive stimuli during visually guided behaviour tasks. However, over the last three decades spatial attention has been explored mostly by using visuo-manual reaction time paradigms. Among others, the Covert Orienting of Visual Attention Task (COVAT) is a computer-based spatial cueing paradigm which has been often employed to investigate the power of external stimuli to attract visuospatial attention (exogenous orienting) without accompanying ocular movements. In a typical example of this task, subjects keep gaze fixed on a central point and have to react, by making a speeded key pressing response, at the onset of a visual stimulus (target) in a peripheral location, within one of two empty boxes positioned to the left and to the right of the fixation point (Posner, 1980). The onset of the response target follows a spatial cue, e.g. a box flashing. For Cue-Target Onset Asynchrony (CTOA) up to 300-400 ms, key pressing responses are faster when both stimuli spatially correspond (valid condition) than when they fall in different locations (invalid condition) (Berger, Dori & Henik, 1999; Müller & Findlay, 1988; Posner & Cohen, 1984). Therefore, the cue is assumed to trigger a reflexive attention shift to its location which should facilitate visual processing at that spatial point. By contrast, for CTOAs larger than 300-400 ms the spatial cueing begins to reveal inhibitory effects, i.e. manual responses to valid targets are now slower. This interference effect on processing stimuli at a previously attended location is called Inhibition of Return (IOR) (Pratt & Abrams, 1995; Shepherd & Muller, 1989; Posner, Rafal, Choate & Vaughan, 1985).

The aim of the present work was to investigate the role of spatial cueing on the exogenous orienting of attention across the peripersonal visual space by measuring the speed of gaze shift to the target instead of the manual response reaction time. In fact, a thigh coupling between eye movements and reorienting of selective attention has been repeatedly demonstrated (Rizzolatti, Riggio, Dascola & Umiltà, 1987) and neuroimaging data reveal that oculomotor and attentional maps clearly overlap in central nervous system (Galletti et al., 2010; Corbetta et al., 1998; Nobre, Gitelman, Dias & Mesulam, 2000). To this end, gaze movements have been recorded during the execution of a modified COVAT paradigm, in which participants performed saccades towards one of multiple positions equally distributed in the visual field around a central fixation point. In order to explore facilitatory and inhibitory effects on the ocular behavior due to covert orienting of attention to a task-irrelevant visual stimulus, the time course of spatial cueing has been investigated by manipulating the temporal delay between cue and target.

2. Method

2.1. Participants

Eleven volunteers (6 female; mean age = 25.8, range = 21-39 years) normally sighted, with no history of head trauma, neurological disease and cognitive deficit were enrolled in the study. Subjects were naïve to the purpose of the experiment and gave their written consent to participate to it. The study was conducted in accordance with the ethical guidelines set forth by the *Declaration of Helsinki*.

2.2. Setting and procedure

Participants sat 80 cm ahead a tangent computer screen (21'', 1980p, ASUS, Taiwan) with the head stabilized by a chin-rest. Four empty boxes (placeholders) and a white central fixation cross were always displayed against a black background. Each placeholder was placed at the corner of an ideal square surrounding the central cross, with an eccentricity of 7 degrees. One hundred milliseconds after the beginning of the trial, a placeholder flashed for 50 ms (cue) and, shortly after, a green square (target) appeared for 2000 ms inside one of the placeholders. Subjects maintained the gaze on the fixation cross until the onset of the target, which in turn required a fast eye movement to it. When the target disappeared, subjects had to fixate the central cross and a new trial begun.

The experimental paradigm was designed by paying a particular attention to avoid that top-down, cognitive factors, as expectancies, might affect the investigated cueing effects. Thus, the possible combinations between cue and target have been managed in order to make the cue non-predictive of the target position. To this end, one third of trials were valid ("v"), i.e. the target appeared at the cued location, whereas the remaining trials were invalid. Invalid targets laid in the opposite side of the cue, with equal random probability along either its horizontal or vertical meridian. Therefore, a horizontal invalidity ("hi") or a vertical invalidity ("vi") could occur between visual stimuli.

All subjects performed two experimental sessions, which differed for CTOA: in one session it was fixed at 200 ms ("CTOA-200" session), in the other it was 400 ms ("CTOA-400" session). Each session comprised 5 blocks of 36 trials (with 3 min intervals between blocks), yielding an overall number of 180 trials (60 trials for each of the 4 target-eccentricities × 3 cue-target combinations).

During the experiment, horizontal and vertical gaze coordinates on the computer screen were measured by a remote tracking system based on infrared videooculography (Tobii X120, Tobii, Sweden; sampling rate: 120 Hz; accuracy: 0.5 degrees, approximately). Ocular responses were logged and analyzed off-line using a custom-written Visual Basic application.

3. Results

The dependent measure was the Saccadic Latency (SL), which was defined as the time delay between the presentation of the target and the onset of the saccadic eye movement. A velocity criterion defined the detection of a saccade, whose beginning coincided with the first sample at which the gaze velocity exceeded 50 cm/s. A trial was accepted for statistical analysis when the following criteria were fulfilled: (1) gaze was kept on the central cross until the target onset; (2) the gaze displacement was directed towards the target; (3) SL was shorter than 600 ms; and (4) SL was longer than 90 ms, in order to reject anticipatory responses. These acceptance criteria were fulfilled in all subjects in 97.9% and 95.4% of trials for CTOA-200 and CTOA-400 sessions, respectively.

A two-way repeated measure ANOVA on mean SLs for each subject was performed with CTOA (CTOA-200, CTOA-400) and "trial validity" (v, hi, vi) as factors. A significant "CTOA × trial validity" interaction was present ($F[2, 50] = 3.599$, $p = .035$). Post-hoc analyses (paired samples t-tests) revealed that, as depicted in Figure 1, visually guided saccades did not differ in a statistically significant manner for hi and vi conditions, both in CTOA-200 session (295 ms ± 55 ms SD and 291 ms ± 48 ms SD, respectively) and in CTOA-400 session (289 ms ± 48 ms SD and 287 ms ± 46 ms SD, respectively). A different picture emerged from the comparisons of data between valid and invalid trials. In the CTOA-200 session, t-tests showed that the speed of saccades towards a valid target (267 ms ± 54 ms SD) differed in a highly significant manner ($p \leq 0.0002$) from latencies of ocular movements executed towards an hi target as well as towards a vi target (t = -8.831 and t = -5.538, respectively). On the contrary, when CTOA was fixed at 400 ms the latency of visually guided saccades did not vary significantly whether cue and target laid in the same spatial location (290 ms ± 40 ms SD) or not.

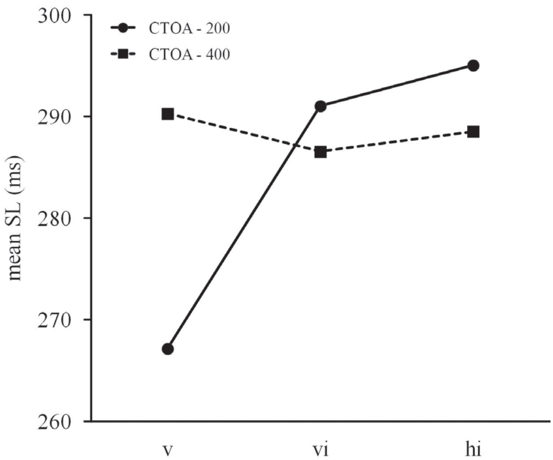

Figure 1. Mean SLs for valid and invalid conditions obtained for CTOA-200 and CTOA-400 sessions

4. Discussion

Traditionally, covert shifts of attention have been detected by using manual reaction times as measure of processing efficiency of visual targets. Converging evidence from behavioural literature indicates that the speed of key pressing responses considerably improves when the onset of a target quickly follows a cue which is informative of the target position. However, we reasoned that fast eye movements are the most common motor behaviour elicited by the onset of salient attentive stimuli in the visual space. Consistent with this viewpoint, it has been shown that typically a saccade is made shortly before a hand movement to a common target is initiated (Dean et al., 2011; Lünenburger et al., 2000; Prablanc et al., 1979). In turn, the initiation of a visually guided saccade is preceded by a mandatory shift of attention towards the target (Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher & Blaser, 1995). The deployment of attention results to be tightly linked to the processes for target selection and motor programming of a saccadic eye movement, even for covert shifts of visuospatial attention (Hamker, 2005; Thompson, Biscoe & Sato, 2005; Ignashchenkova, Dicke, Haarmeier & Their, 2004; Moore, Armstrong & Fallah, 2003). Consistently with this viewpoint, neuroimaging evidence reveals that covert attention and eye movements share a common neural network (Galletti et al., 2010; Corbetta et al., 2000; Nobre et al., 2000). In the present study we explored cueing effects by combining a COVAT paradigm with the recording of overt shifts of spatial attention, which were assessed by the speed of the onset of visually guided saccades. Results need to be considered across different perspectives.

Briefly, from a methodological viewpoint, measuring eye movements helps to explore cognitive mechanisms underlying visuospatial attention by preventing the risk of incurring well-known spatial stimulus-response compatibility effects described for manual responses. Indeed, it has been shown that the position of a visual stimulus determines the speed of the subsequent key pressing. This effect is so strong that it is maintained even if the spatial location of the stimulus is irrelevant for responding (for a review, see Proctor & Vu, 2006).

From a behavioural perspective, the main goal of the present study was to investigate whether a covert orienting of spatial attention affects visually guided ocular movements. We found that the speed of the saccadic onset crucially depends on the spatial relationship between the gaze target and a location previously marked by an exogenous cue, although it is uninformative about the effective direction of the forthcoming ocular movement. Mainly, our results reveal that a high facilitation on SLs occurs when the spatial position to reach by gaze is compatible with a location previously cued.

Moreover, our data show a strong dependence of this facilitatory effect of valid target on CTOA. Indeed, saccadic eye movements are faster when cue and target occurred in a close temporal proximity (200 ms). Noteworthy, the facilitation of ocular performance is present even if the cue is totally non-predictive of future target location. In fact, the gaze target is more likely to appear in an uncued position. Therefore, we are facing an absolutely automatic, bottom-up effect, to which expectations or other cognitive factors can hardly play a role. This result finds support from previous studies which document a facilitation of manual responses to valid trials also when the target is more likely to appear in an uncued spatial location (Remington, Johnston & Yantis, 1992; Jonides, 1981).

Moreover, we found that SLs are considerably slower when a valid target is presented after a longer time delay (400 ms) from the onset of the cue. In this case, the ocular performance tends to approach the latency of ocular movements directed towards uncued locations. Thus, the found facilitation turns to an inhibition when CTOA increases.

To summarise, the present study shows that the facilitatory effect of cue-target compatibility is far from being unspecific. On the contrary, it depends on the length of the time interval between the onset of the stimulus which covertly attracts the visuospatial attention and the presentation of the target to reach through an overt orienting of it. Interestingly, a CTOA of 400 ms falls in the boundary range in which facilitation turns to IOR when cue effects are assessed by manual responses (Lupiáñez, Milán, Tornay, Madrid & Tudela, 1997).

5. Conclusion

The paradigm employed in the present study was efficacious in disclosing cueing phenomena by using ocular responses in healthy people. From a clinical perspective this work should be considered a pilot study for addressing efforts to design reliable procedures aimed at improving the cognitive assessment, in the field of neuropsychological, neurological and psychiatric practice, of people suffering from motor impairments. This is the case, among others, of children affected by cerebral palsy, who first inspired us this viewpoint. The typical movement disorders (e.g., spasticity, ataxia) of these patients makes difficult to apply the procedures normally employed by clinicians and cognitive neuropsychologists, like paper-and-pencil tests or COVAT reaction time paradigms. This represents a crucial limitation considering that cerebral palsy is usually accompanied by perceptual, cognitive and behavioural deficits. To conclude, a broader view would suggest that the combination of state-of-the-art techniques for non-invasive recording of ocular movements together with COVAT-like paradigms could encourage a rightful way for disentangling and quantifying the complex relationship between attentional deficits and visuo-motor impairments, which often accompany neurological and neuropsychiatric disorders.

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