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Research report

Cueing spatial attention through timing and probability

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ABSTRACT

Even when focused on an effortful task we retain the ability to detect salient environmental information, and even irrelevant visual stimuli can be automatically detected. However, to which extent unattended information affects attentional control is not fully understood. Here we provide evidences of how the brain spontaneously organizes its cognitive resources by shifting attention between a selective-attending and a stimulus-driven modality within a single task. Using a spatial cueing paradigm we investigated the effect of cue-target asynchronies as a function of their probabilities of occurrence (i.e., relative frequency). Results show that this accessory information modulates attentional shifts. A valid spatial cue improved participants' performance as compared to an invalid one only in trials in which target onset was highly predictable because of its more robust occurrence. Conversely, cuing proved ineffective when spatial cue and target were associated according to a less frequent asynchrony. These patterns of response depended on asynchronies' probability and not on their duration.

Our findings clearly demonstrate that through a fine decision-making, performed trial-by-trial, the brain utilizes implicit information to decide whether or not voluntarily shifting spatial attention. As if according to a cost-planning strategy, the cognitive effort of shifting attention depending on the cue is performed only when the expected advantages are higher. In a trade-off competition for cognitive resources, voluntary/automatic attending may thus be a more complex process than expected.

1. Introduction

A powerful metaphor, the term 'concentration' immediately recalls the effortful act of close gathering of attention around a particular task. In so doing, reality tends to escape and a very small part of the world becomes the center of existence. This voluntary focusing of attention is highly demanding and the remaining flow of information from the environment is consequently ignored. Nevertheless, some pieces of information can break through selective focusing and be unexpectedly detected so that potentially important stimuli can still draw attention. A trade-off between selective attending and automatic capture is therefore advantageous. Indeed, both attentional modalities sub-serve crucial requirements: the former in planning and controlling, the latter in reacting to salient and unattended stimuli (Asplund et al., 2010; Corbetta and Shulman, 2002; Egeth and Yantis, 1997; Kastner and Ungerleider, 2000; Raz and Buhle, 2006).

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However, up to now the cognitive mechanisms involved in switching between top-down (i.e., voluntary) and bottom-up (i.e., automatic) processing of attention are still far from being fully understood.

Studies investigating the interplay between top-down and bottom-up processing demonstrated that a relevant feature for attentional capture is the attentional set. Attentional set can be defined as a behavioral predisposition to attend to stimuli sharing a specific property. Target onset is one of the characteristics allowing grouping of stimuli in an attentional set: participants instructed to react to abrupt-onset targets tend to respond to any suddenly appearing stimulus independently of its relevance for the task (e.g., Folk et al., 1992). The degree of similarity with the target is another powerful grouping feature (see for instance Santangelo and Spence, 2008, for a review): participants engaged in a typical spatial cueing paradigm (Posner, 1980) are influenced by presentation of a novel unattended stimulus sharing some features with the target but providing no spatial information. Albeit irrelevant for the task, this unattended information modulates response times to target stimuli preceded by both valid and invalid spatial cues (Hölig and Berti, 2010).

This pattern emerges also in the auditory modality: the so-called *oddball task* (see Parmentier, 2008 for a review) involves repeated presentation of a given sound (standard) and, on rare and random occasions, of sounds deviating from the standard according to pitch, intensity, location or spectrum (novels). Novel stimuli typically slowdown performance. In tasks of digit categorization in which a visual digit is preceded by a task-irrelevant sound, participants respond more slowly to digits following a novel/deviant sound compared to a standard one (Escera et al., 1998, 2002; Parmentier, 2008; Parmentier et al., 2010b). It has been shown that the increase of response times reflects the time required to shift attention to and from novels and not a slower processing of the targets (Parmentier et al., 2008).

Interestingly, novelty *per se* is not sufficient to generate distraction (Parmentier et al., 2010a): when task-irrelevant sounds act as implicit warning cues (i.e., by presenting them at fixed intervals from the target) participants' responses are not delayed if sounds are stripped of their informational value. That is, novelty-based distraction only occurs when the cognitive system makes use of the sound as a valid cue, namely when novelty falls within a stream of information used for goal-relevant purposes. In fact, novel sounds (but not standards) when valid as warning cues induce facilitation and not distraction (Parmentier et al., 2010a).

Similar findings are reported for living/non-living judgments on pictures (e.g., Van Mourik et al., 2007) and with words used as distracters (Parmentier et al., 2011). In this case the interference of the unattended information on participants attention is clearly acting through a semantic link. Taken together, these data demonstrate that unattended information can be analyzed along the physical and conceptual dimension even when attention is voluntarily maintained on a concurrent task, and the irrelevant stimuli need not be considered for its execution.

Another set of researches explored these peculiar attributes of distraction by manipulating predictability of the unexpected event (Lippert et al., 2007; Sussmann et al., 2003). For instance, when extra visual-cues allow subjects to predict the occurrence of an irrelevant sound change no sign of distraction is observed (Sussmann et al., 2003). Moreover, use of the extra visual-cue maximizes performance on the primary task so that in the predictable condition targets are better detected (Lippert et al., 2007). These results nicely show that determining the relevance of an event prior to its occurrence can suppress the involuntary orienting of attention, allowing to keep the focus of attentional resources on the task with higher priority for the individual (see also Couperus and Mangun, 2010). Quite paradoxically, since these studies focused on unattended information (namely, the extra visual-cue) they strengthened the demonstration that unattended stimuli are deeply processed. The crucial point remains that accessory information is not only the relative frequency of some stimuli, but also, and most critically, the relationship between them. The cognitive system seems, therefore, able to use incidental knowledge to predict upcoming events albeit engaged elsewhere.

The idea of top-down influences on behavioral responses in association with shifting of attention received support also from studies investigating *negative priming*. For instance, it has been shown that the inhibition of a stimulus and its associated response in one trial results in a slower response to the same stimulus if used as a target in the following trial (see Mayr and Buchner, 2007, for a review). Factors such as the previous cue direction, the previous trial type (valid, invalid, neutral or catch) and target position alternation were shown to exert influence inducing larger attentional costs and benefits following a valid than an invalid trial (Jongen and Smulders, 2007). All these effects clearly demonstrate that the brain maintains an independent degree of strategic control and regulates its confidence on the spatial cue according to whether correctly (or incorrectly) directed to the right location in the previous trial.

The degree to which accessory information can influence processing goes well beyond information related to a single event extending to stimulus contingencies delivered through multiple trials. Indeed, when participants are presented with targets differing in their probability of occurrence, cueing effects are only found for the more probable target (e.g., Kingstone, 1992; Klein and Hansen, 1990). For example, subjects benefit from predictive information about the location of the target provided by a cue-target relationship implicitly learned after repeated presentations (Lambert et al., 2000).

Probabilistic cuing is in keeping with other demonstrations about the effectiveness of statistical inference on human behavior. Participants can learn complex probabilistic contingencies that cannot be accounted for as short-term priming effects (see e.g., den Ouden et al., 2010; Druker and Anderson, 2010; Turk-Browne et al., 2010). A significant example is the phenomenon of contextual cueing (e.g., Chun, 2000; Chun and Jiang, 1998): the repetitive pairing of displays with given target locations leads to an improvement in target detection in a visual search task. Similarly, in a task of visual search and classification with stimuli appearing disproportionately on one side of a computer screen, classifications were faster for trials including a target located on the side of the screen with the higher probability of presentation (Geng