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Distraction and target selection in the brain: An fMRI study

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ABSTRACT

To attend successfully, a specification of what is currently relevant is necessary, but not sufficient. Irrelevant stimuli that are also present in the environment must be recognized as such and filtered out at the same time. Using functional magnetic resonance imaging, we showed that posterior brain regions in parietal, occipital and temporal cortex are recruited in order to ignore distracting visual stimuli, while the specification and selection of relevant stimuli is associated with differential activity in frontal cortex and hippocampal areas instead. The results thus suggest that the selection of relevant objects can be anatomically dissociated from the handling of competing irrelevant objects. The dissociation between the increased involvement of parietal and occipital cortex in handling distraction on one hand, and that of frontal cortex in target specification on the other provides neurophysiological support for models of attention that make this functional distinction.

In order to deal effectively with the sensory wealth of our environment, we rely on the process of attention to select only what is presently relevant to us so that we can ignore the rest (Bundesen, Habekost, & Kyllingsbæk, 2005; Pashler, Johnston, & Ruthruff, 2001; Raymond, Shapiro, & Arnell, 1992; Wolfe & Horowitz, 2004). Given its functional importance, it is of little surprise that attention has been studied extensively in both classical psychology and neuroscience. Recent neuroscientific studies have shown that neuronal activity associated with selective attention in the visual domain can be observed in relatively widespread brain regions, including parietal, temporal, and prefrontal cortex (Leonards, Sunaert, Van Hecke, & Orban, 2000; Nobre, Coull, Walsh, & Frith, 2003). The concurrent co-activity of these regions has led to the idea that a relatively large frontoparietal network is involved in the allocation of attention (Corbetta, 1998; Indovina & Macaluso, 2007).

Given the extent of the observed cortical activity, it seems likely that attention is a broad phenomenon in the brain, and may involve different sub-functions of the mind. One hypothesis that has been put forward is that the frontoparietal network can be functionally divided into a dorsal and a ventral part; the former is involved in goal-directed selection, while the latter acts as an interrupter driven by salient stimuli (Corbetta & Shulman, 2002; Fox, Corbetta, Snyder, Vincent, & Raichle, 2006). Others have proposed a somewhat similar distinction between the involvement of prefrontal cortex in instantiating top-down control and that of posterior parietal regions in bottom-up processing, based on studies conducted with monkeys (Buschman & Miller, 2007). One issue with both of these definitions of functional specificity is that stimulus salience is strongly influenced by current task settings, and thus it can be maintained that perception is realized through a continuous interplay between both endogenous (top-down) factors and exogenous (stimulus-driven) ones (Folk, Leber, & Egeth, 2002; Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). Indeed, supporting neurophysiological evidence has shown that both frontal and parietal brain regions respond to contextual and (target) location-specific modulation (Serences et al., 2005; Peers et al., 2005). Thus, it seems that the concepts of top-down and bottom-up control may prove hard to isolate by virtue of their tendency to intermix.

A view on attention championed by Duncan (1980), Desimone and Duncan (1995), Duncan and Humphreys (1989) offers a way out of the difficulties with finding 'pure' top-down or bottom-up processing. One can logically define two attentional sub-functions. Attending to something requires (1) the *selection* of the target stimulus, by matching it to a target template, and (2) the *filtering* or rejection of distracting stimuli that are also perceived. The concepts of top-down and bottom-up control are neutral to this classification. In particular the notion of a filtering function has inspired neurophysiological studies. As a result, the hypothesis has been put forward that parietal regions in the brain serve the function of filtering out (spatially) distracting stimuli (Friedman-Hill, Robertson, Desimone, & Ungerleider, 2003; Wojciulik & Kanwisher, 1999; also

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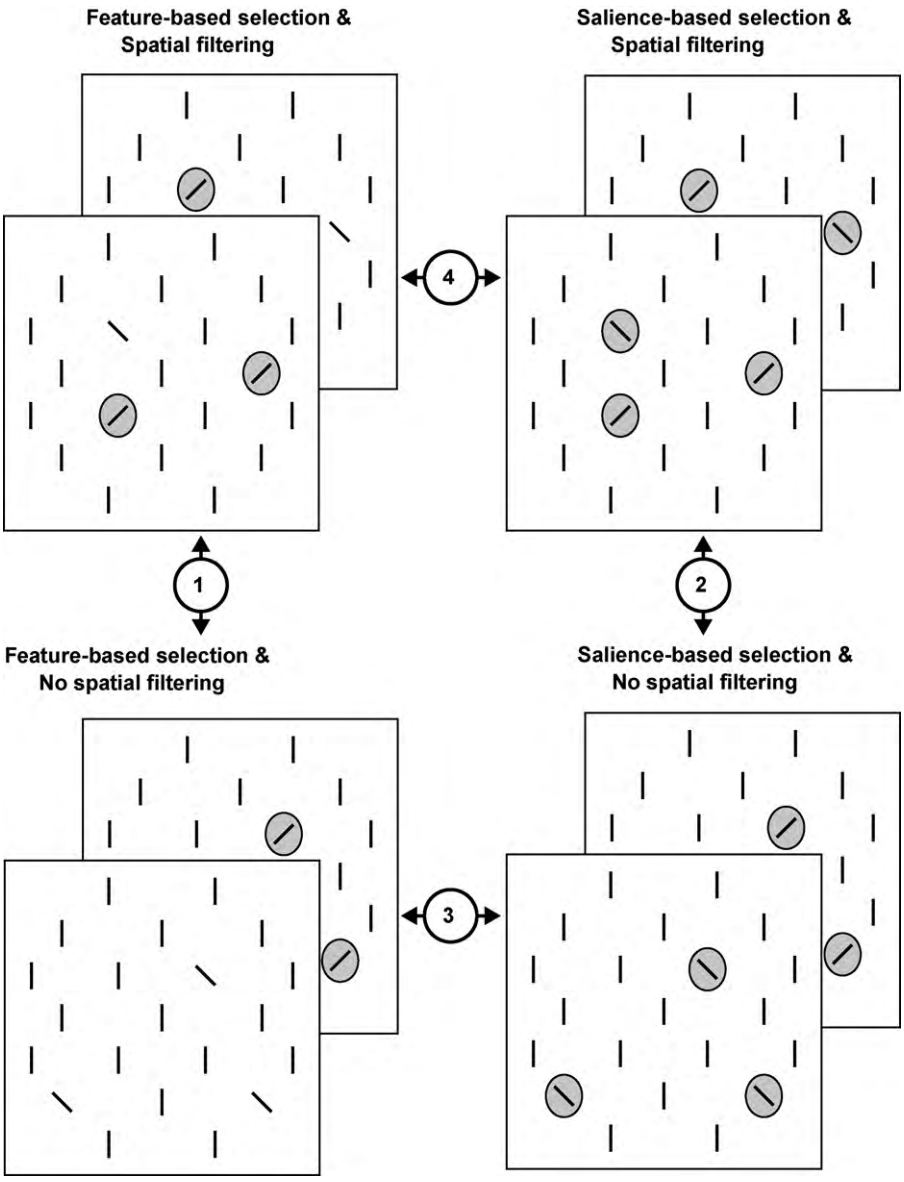

Fig. 1. Schematic representation of the experimental design. Top left panel represents the feature-based selection & simultaneous (target-related) spatial filtering condition. Target lines (circled in gray) are drawn simultaneously with distractor lines (with the opposite orientation offset). Top right panel shows the salience-based selection & (stimulus-level) filtering condition. Both orientations are shown simultaneously, and both are targets. Bottom left panel shows the feature-based selection & no filtering condition. Targets and distractors are shown sequentially. Bottom right panel shows the salience-based selection & no filtering condition. All sequentially presented orientation offsets are targets.

cf. LaBerge, Carlson, Williams, & Bunney, 1997, who proposed a similar division between control and preparatory processes). Some evidence for at least a rudimentary form of spatial filtering was obtained by reports of an interaction between lateral inhibition and attentional goals in closely coupled areas such as V4 and inferior temporal cortex (IT) in monkeys (Desimone & Duncan, 1995; Reynolds & Desimone, 2003). Although these results to date indeed support (one half of) the hypothesis of Duncan and colleagues, to our knowledge there has not been an attempt to find the neurophysiological correlate of both the filtering as well as the selection function. In order to successfully distinguish target selection from distractor filtering, both of those aspects should be studied and dissociated within one design. To do so was the purpose of the present study.

To study how the brain deals with distraction and target selection we used functional magnetic resonance imaging (fMRI) to scan the brains of our participants while they performed a simple attentional search task. A multi-target visual search paradigm was used. Participants were asked to look for and count and report a number (0–4) of ±45° tilted lines in an array of vertical lines (21 in total). The task was designed to decompose the classic contrast between feature search and singleton detection (Bacon & Egeth, 1994), by breaking it down to functions of filtering and target selection. In feature search mode, observers have to select specific target stimuli, defined by specific feature values, and have to process or filter out all non-targets. In singleton detection mode, observers can select any salient stimulus, and thus do not need to filter salient non-targets at the same time (as these do not exist).

In the present design, these two conditions were instantiated so that participants were either performing feature-based selection or salience-based selection (Fig. 1; left vs. right panels). That is, they were either looking for target stimuli, defined by a particular feature (i.e., a specific orientation), or they were simply looking for salient stimuli in the visual field. Furthermore, the need to perform