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Interplay between supramodal attentional control and capacity limits in the low-level visual processors modulate the tendency to inattention

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A B S T R A C T

When engaged in a demanding task, individuals may neglect unexpected visual stimuli presented concomitantly. Here we use a change detection task to show that propensity to inattention is associated with a flexible allocation of attentional resources to filter and represent visual information. This was reflected by N2 posterior contralateral (N2pc) and contralateral delay activity (CDA) respectively, but also during high-order reorienting of attentional resources (known as anterior directing attention negativity, ADAN). Results show that differences in noticing and failing to notice unexpected stimuli/changes are associated with different patterns of brain activity. When processing (N2) and working memory (CDA) capacities are low, resources are mostly allocated to small set-sizes and associated with a tendency to filter information during early low-level processing (N2). When resources are high, saturation is obtained with larger set-sizes. This is also associated to a tendency to select (N2) and reorient resources (ADAN) to maintain extra information (CDA).

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1. Introduction

The ability to notice an unexpected visual stimulus has important implications for those working environments that involve safety procedures such as flying aeroplanes (Green, 2003; Harris, 2011; Paries & Amalberti, 1995), air traffic control or for eye witness accounts (Chabris, Weinberger, Fontaine, & Simons, 2011), nuclear industry (Budau, 2011), surgery (Musson, 2009), etc. Such activities require sustained attention on a demanding task together with an ability to detect potential unexpected changes in the visual scene. In the laboratory, brain activity underlying these processes (i.e., selection and maintenance of visual stimuli representation in visual working memory, VWM) can be studied using visual search and change detection tasks, and are thought to be crucial for the ability to consciously report the presence/absence of targets/changes.

Three important ERP components have been identified to reflect such mechanisms of attention and memory. First, is the N2pc that has been observed during visual search (Eimer, 1996) and pop-out visual search (Hickey, Di Lollo, & McDonald, 2009; Schubö, Wykowska, & Müller, 2007) tasks, and is thought to be involved in the selection-enhancement and inhibition of visual information. Next, is the contralateral delay activity (CDA; Drew & Vogel, 2008; Vogel & Machizawa, 2004; Vogel,

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McCollough, & Machizawa, 2005), which is a sustained contralateral waveform elicited during the retention interval in change detection tasks. Last, more prefrontally, an anterior directing attention negativity (ADAN) may be observed during the signalling control for the reorienting of attention towards the location of upcoming stimuli; this is reflected by a negative deflection occurring between 350 and 500 ms post-stimulus (Drew & Vogel, 2008; Harter, Miller, Price, Lalonde, & Keyes, 1989; Nobre, Sebestyen, & Miniussi, 2000; Simpson et al., 2006). It has been observed to be modulated by a centrally presented spatial cue in anticipation of an upcoming target, although it is not commonly associated with attentional processing *per se*, since it is not sensitive to task demands (Hopf & Mangun, 2000). It is considered a measure (amongst others such as P3 and SPCN; see Dell'Acqua et al., 2015; Eimer & Kiss, 2010) involved in the control of attentional resources, therefore playing an important role in the conscious representation during processing of stimuli.

Furthermore, other studies (Liesefeld, Liesefeld, & Zimmer, 2013; McNab & Klingberg, 2008), have also found an earlier prefrontal component (i.e., 200–300 ms) which has been interpreted as a prefrontal bias signal assumed to reflect active suppression of irrelevant information in a form of attentional weighting which is performed after the initial scanning process in the parietal areas (N2pc). (See also the discussion on the *Biased Competition Theory*, Desimone & Duncan, 1995; Duncan, Humphreys, & Ward, 1997.)

In sum, the N2pc is thought to reflect the selection of items (Eimer, 1996; Luck, Girelli, McDermott, & Ford, 1997; Luck & Hillyard, 1994a, 1994b; Woodman, Kang, Rossi, & Schall, 2007; Woodman & Luck, 2003; Hopf et al., 2000) whereas the CDA reflects the storage of the filtered items (McCollough, Machizawa, & Vogel, 2007) after active suppression/selection (prefrontal bias) and in concomitance with supramodal attentional control (ADAN; see Couperus, Alperin, Furlong, & Mott, 2014; Seiss, Gherri, Eardley, & Eimer, 2007).

Although a number of ERPs components reflecting allocation of resources have been identified, the way resources are allocated is still under debate. According to a flexible allocation of resources view, an undetermined (if not unlimited) number of items can be attended and stored in memory. This implies that the resources allocated to each item decrease as a function of the items *attended* (that can be expectedly or unexpectedly presented on the screen), with the result that the featural information of the attended *n*-th item will not be fully stored (Bays, Catalao, & Husain, 2009). If resources are allocated flexibly, all resources would be deployed irrespective of the number of items processed in a given array of stimuli, whereby a high number of item to attend would result in the loss of some information (i.e., not all the featural information of the stimuli will be processes since resources are diluted across a large number of stimuli). Therefore, one may expect that mean amplitudes in the ERP components underlying processes of visual search (as well as the associated behavioural performance) should be unchanged as a function of set-size until a point (i.e., capacity) where the dilution of the resources across stimuli cause poor processing of each item, therefore starting to affect performance (*appearance* of the capacity limit; see Bays et al., 2009). This implies that capacity may correspond to the precision, that is the number of neurons involved in the encoding of a certain number of items (Dayan & Abbott, 2001; Seung & Sompolinsky, 1993; Vogels, 1990). Therefore, ERPs in the latency of interest (e.g., N2pc, CDA) might show larger mean amplitudes (i.e., more negative) across different individuals when the population employed for storage of a given amount of items is larger. For instance, given the same set-size, an individual with a greater capacity may present more negative mean amplitudes when compared to one with a lower capacity (see for example the overall brain response measure during the N1 latency found in Papera & Richards, 2016, showing that individuals with low levels of inattention may recruit a larger population of neurons during encoding in the N1 latency, therefore potentially allowing the detection of unexpected stimuli).

Flexible resource models propose that the precision at which an item is stored will depend on the number of items to be stored and on the demands of the task (i.e., simpler tasks can be performed well even with high set-sizes requiring a high spread of resources, therefore achieving a low-resolution representation for the items; see: Bays & Husain, 2008; Bays et al., 2009; Wilken & Ma, 2004; Zhang & Luck, 2008). The flexible allocation of resources view also asserts an *uneven* spread of resources so that a stimulus may receive more resources at the cost of reducing the resolution of other stored items (Bays & Husain, 2008; Bays et al., 2009). This is particularly relevant in natural scenes, where an uneven distribution of resources may prioritize storage of more salient stimuli (see for instance, Itti & Koch, 2001; Papera, Cooper, & Richards, 2014).

In contrast, a fixed resource view would predict an equal and increasing allocation of resources, that is an *even* spread of resources so that each stimulus receives an equal deployment of resources until all resources have been allocated, leaving any further items not attended (i.e., "quantised" fashion; Barton, Ester, & Awh, 2009; Rouder et al., 2008; Zhang & Luck, 2008). This would reflect in an equally quantised amount of resources until no resources are left for the processing of further stimuli; ERP components would be modulated as a function of set-size, therefore leading mean amplitudes to increase but then saturate when capacity is reached (i.e., increasingly more negative mean amplitudes until saturation; Barton et al., 2009; Jost, Bryck, Vogel, & Mayr, 2010; Lee et al., 2010; Luck & Vogel, 1997; Rouder et al., 2008; Vogel & Machizawa, 2004; Zhang & Luck, 2008).

It is well known that resource limits in the low-level visual processors can be associated with a tendency to inattention (Dehaene & Changeux, 2005; Hannon & Richards, 2010; Mack & Rock, 1998; Most, Scholl, Clifford, & Simons, 2005; Most et al., 2001; Richards, Hannon, & Vitkovitch, 2012; Simons, 2003). Some researchers argue that failing to notice an unexpected stimulus occurs when early mechanism of exogenous attention and visual working memory are predominantly involved in another task, resulting in too few resources remaining for the processing of an unexpected stimulus or change (Papera & Richards, 2016). Other accounts propose that in most IB tasks the unexpected event is not relevant to the primary task, making it susceptible to inhibition and therefore prevented from reaching awareness (Richards, Hannon, Vohra, &

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