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Research Report

Control of working memory: Effects of attention training on target recognition and distractor salience in an auditory selection task

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Behavioral and electrophysiological measures of target and distractor processing were examined in an auditory selective attention task before and after three weeks of distractor suppression training. Behaviorally, training improved target recognition and led to less conservative and more rapid responding. Training also effectively shortened the temporal distance between distractors and targets needed to achieve a fixed level of target sensitivity. The effects of training on event-related potentials were restricted to the distracting stimulus: earlier N1 latency, enhanced P2 amplitude, and weakened P3 amplitude. Nevertheless, as distractor P2 amplitude increased, so too did target P3 amplitude, connecting experience-dependent changes in distractor processing with greater distinctiveness of targets in working memory. We consider the effects of attention training on the processing priorities, representational noise, and inhibitory processes operating in working memory.

1. Introduction

1.1. Background

Attention is essential for implementing flexible, goal-directed behavior. Yet attentional processing is by no means isolated from other cognitive processes, and can be influenced by perceptual, language, memory, and response mechanisms. Here, we consider the role of working memory in directing attention. Information held in working memory can increase or decrease the efficiency of attentional processing (Awh et al., 2006; Cowan, 1995; Downing, 2000; Melara and Nairne, 1991; Postle et al., 2004). In fact, when performing attention and working memory tasks, distributed, overlapping brain networks are activated, including the mid-dorsolateral prefrontal cortex (PFC), the ventrolateral PFC, the parietal cortex, the anterior cingulate cortex, and the temporal cortex (Banich et al., 2000a, 2000b, 2001; Bledowski et al., 2004; Fan et al., 2003; Liu et al., 2004; MacDonald et al., 2000; Milham et al., 2001, 2003). Not surprisingly, then, recent theoretical models have considered explicitly

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how working memory modulates attentional processing (Awh et al., 2000; Cabeza et al., 2003; Lavie, 2005; Melara and Algom, 2003; Melara et al., 2005).

One suggested functional role of working memory is in maintaining an attentional bias (Banich et al., 2000a, 2000b; Desimone and Duncan, 1995) or processing priority (de Fockert et al., 2001) that guides attentional selection. In the Stroop (1935) task, for example, certain PFC activations reliably signal the task requirements (Brass and von Cramon, 2004; Derrfuss et al., 2005; for a review, see Brass et al., 2005) or task-relevant information (Banich et al., 2000a, 2000b, 2001) presumably held in working memory. As the load on working memory increases in an attention task, task-irrelevant information tends to be processed more extensively, manifested as increased activation in stimulus-specific areas of sensory cortex and resulting in larger behavioral interference from distractors (Banich et al., 2001; Lavie et al., 2004). One interpretation is that high memory load obscures processing priorities, allowing task-irrelevant information to undermine target recognition (de Fockert et al., 2001). This is perhaps why individuals with small working memory span are relatively more prone to distractions from irrelevant stimuli (Vogel and Fukuda, 2009). One aim of the current study is to ask whether improved inhibitory control over the task-irrelevant information held in working memory helps reestablish task-relevant priorities, thereby enhancing selective attention performance.

1.2. *Effects of training on inhibitory control of distractors*

To manipulate inhibitory control we trained participants to suppress task-irrelevant information in an auditory selective attention task. Studies of auditory discrimination and auditory selective attention indicate that tonal experience yields reliable, long-lasting electrophysiological changes associated with specific auditory functions. Training aimed at improving sensory discrimination, for example, has been shown to boost the amplitude of several distinct event-related potential (ERP) waves, including the mismatch negativity (Atienza and Cantero, 2005; Atienza et al., 2004; Kraus et al., 1995; Näätänen et al., 1993), the N1 wave (Reinke et al., 2003; Tremblay et al., 2001; Tremblay and Kraus, 2002; see also Menning et al., 2000), and the P2 wave (Alain et al., 2007; Atienza et al., 2002; Reinke et al., 2003; Shahin et al., 2005; Sheehan et al., 2005; Tremblay and Kraus, 2002; Tremblay et al., 2001; Tremblay et al., 2010). The current study seeks to identify effects of training aimed at improving selective attention on the auditory N1, P2, and P3 waves.

The auditory P2 wave has proven particularly amenable to experiential influence (Salo et al., 2003; Shahin et al., 2005). In discrimination paradigms, P2 is believed to reflect automatic access to perceptual representations (Tong et al., 2009). In selective attention paradigms, automatic access to distractors can be dampened through inhibitory control, and P2 indexes the course and extent of distractor inhibition (Garcia-Larrea et al., 1992; Melara et al., 2002). P2 also may serve as a pre-attentive alerting mechanism to improve perception (Tremblay and Kraus, 2002) or the fidelity of traces available in short-term memory (Atienza et al., 2002). The present study sought to link experience-dependent changes in the behavior of the P2 wave evoked by distractors – alongside the N1 and P3 waves – with improved inhibitory control of distractor information in working memory (Ceponiené et al., 2005).

1.3. *P3 as an index of salience in working memory*

As perceivers gain control over the distractors contained in working memory they are better able to recognize and classify task-defined targets. The P3 ERP wave provides an electrophysiological gauge of the salience and ease of classification of stimuli held in working memory (Donchin, 1981; Donchin and Coles, 1988; Karis et al., 1984). Distraction weakens P3 amplitude to targets (Melara et al., 2002), a result consistent with the established role of equivocation (Ruchkin and Sutton, 1978) or task complexity on P3 (e.g., Kramer et al., 1986; Okita et al., 1985). In the context of processing priorities, the presence of distracting stimuli may blur the perceived distinctiveness of targets from surrounding stimuli. To the extent that participants learn to inhibit distractors, as indexed by P2, one would expect both an increase in target salience in working memory (Alvarez and Cavanagh, 2004), measured by greater P3 amplitude to targets, and a decrease in distractor salience in working memory (Lu and Dosher, 1998; Wilken and Ma, 2004), measured by weakened P3 amplitude to distractors.

1.4. *Theoretical predictions of working memory on attention*

The present study considers how inhibition training affects auditory selection in the context of three current theories of attention: biased competition, signal detection, and tectonic theory. Each theory implicates working memory in modulating task-irrelevant information. From the perspective of biased competition (Desimone and Duncan, 1995), an attentional template held in working memory tilts processing in favor of task-relevant representations. The theory predicts that repeated stimulus exposure during training gradually highlights those features of distractor representations that are distinct from the template, leading to improved target detection in the face of distraction (Duncan and Humphreys, 1989). A signal-detection theoretic approach attributes decreased target sensitivity from distraction to overlap between target (signal) and distractor (noise) distributions (Wilken and Ma, 2004); as participants learn to ignore irrelevant signals, the representational activity of distractors in working memory would be expected to decrease (e.g., Lu and Dosher, 1998), thus reducing distributional overlap as a function of training. The tectonic theory of Melara and Algom (2003) holds that prefrontal control of working memory boosts activation to task-relevant information and suppresses activation of task-irrelevant information; training in distractor suppression would enhance the precision of control processes acting on distractor representations, thereby improving target recognition. Later we explore how accurately these theories capture the effects of inhibitory training on a set of behavioral and ERP indices of auditory selection.

1.5. *Changes in selection efficiency with temporal distance*

A final aim of the current study was to examine the effects of training as a function of the temporal separation between distractors and targets in the stimulus stream. Distractors and targets were separated by one, two, three, or four intervening