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Assessing cross-modal target transition effects with a visual-auditory oddball

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ABSTRACT

Prior research has shown contextual manipulations involving temporal and sequence related factors significantly moderate attention-related responses, as indexed by the P3b event-related-potential, towards infrequent (i.e., deviant) target oddball stimuli. However, significantly less research has looked at the influence of cross-modal switching on P3b responding, with the impact of target-to-target cross-modal transitions being virtually unstudied. To address this gap, this study recorded high-density (256 electrodes) EEG data from twenty-five participants as they completed a cross-modal visual-auditory oddball task. This task was comprised of unimodal visual (70% Nontargets: 30% Deviant-targets) and auditory (70% Nontargets: 30% Deviant-targets) oddballs presented in fixed alternating order (i.e., visual-auditory-visual-auditory, etc.) with participants being tasked with detecting deviant-targets in both modalities. Differences in the P3b response towards deviant-targets as a function of preceding deviant-target's presentation modality was analyzed using temporal-spatial PCA decomposition. In line with predictions, the results indicate that the ERP response to auditory deviant-targets preceded by visual deviant-targets exhibits an elevated P3b, relative to the processing of auditory deviant-targets preceded by auditory deviant-targets. However, the processing of visual deviant-targets preceded by auditory deviant-targets exhibited a reduced P3b response, relative to the P3b response towards visual deviant-targets preceded by visual deviant-targets. These findings provide the first demonstration of temporally and perceptually decoupled target-to-target cross-modal transitions moderating P3b responses on the oddball paradigm, generally providing support for the context-updating interpretation of the P3b response.

1. Introduction

Every day, we encounter situations which involve switching attention across multiple sensory modalities in response to potentially relevant incoming information. These cases range from the mundane (e.g., hearing one's name while reading magazines in a dentist's office) to the potentially life-threatening (e.g., noticing a red light while listening to a car's radio). Almost seamlessly, an array of top-down control and bottom-up perceptual processes coordinate to extract information across multiple modalities, focusing our attention on the aspects of our environments most likely to be immediately relevant to our current goals. These processes can be conceptualized as the activity of an array of neural networks involved in alerting, orienting and controlling attentional responses towards incoming information (Fan et al., 2009; Posner and Petersen, 1990).

One of the most well-studied neural components associated with these attentional responses is the P300 event-related potential (ERP). The P300 response can be elicited by either rare task-irrelevant distractors or by infrequent task-relevant targets, with the former often being referred to as the P3a (Berti, 2013; Berti et al., 2004; Horváth et al., 2008; Schroger, 1996; Schroger and Wolff, 1998) and the latter as the P3b (Comerchero and Polich, 1999; Polich, 2007; Volpe et al., 2007; Wronka et al., 2012). The task-relevant focus of the P3b response, in particular, makes it uniquely suited towards assessing attention-related fluctuations involving the impact of the cross-modal context shifts which are the focus of the current study.

The P3b is a positive centroparietal ERP component peaking between 250 and 500 ms post-stimulus presentation (see Polich, 2007 for a review; Sutton et al., 1965). The P3b is often elicited using the classic two-stimulus oddball paradigm in which the presentation of sequences of repetitive stimuli (i.e., non-targets) are infrequently interrupted by the presentation of task-relevant deviant stimuli (i.e., targets) (Squires et al., 1975). Event-related potentials associated with these deviant-targets typically show an elevated P3b response relative to non-targets. Research has also shown that relative to the P3b response towards attended deviant-targets, deviant-targets that receive reduced levels of attention are associated with considerably weaker P3b responses (Alperin et al., 2013; Ciesielski et al., 1995).

One of the most influential interpretations of the P3b response comes from the context updating framework (Donchin, 1981; Donchin and Coles, 1988; Johnson, 1986; Polich, 2007; Polich and Criado, 2006) and various extensions of the framework's hypotheses (Donchin, 1981;

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Mecklinger and Ullsperger, 1993; Verleger et al., 2005). The context updating framework proposes that the overall P300 response reflects operations involved in allocating attentional resources towards detecting representational changes in incoming stimuli, assessing the degree to which they match internal representations in memory and updating of those representations in response to contextual change (Donchin, 1981; Kok, 2001; Polich, 2007; Polich and Criado, 2006). From this perspective, the P3b is proposed to reflect processes associated with target-categorization (Rac-Lubashevsky and Kessler, 2016; Walsh et al., 2017), context-updating and subsequent memory storage-related operations (Polich, 2007; Polich and Criado, 2006).

With regard to this proposed role for the P3b, researchers in this area have primarily focused on context manipulations involving temporal and sequence related effects. These investigations have shown that manipulations involving increased target interstimulus-intervals (ISI) (Fitzgerald and Picton, 1981; Polich et al., 1990) and target-to-target intervals (Gonsalvez et al., 1999; Gonsalvez and Polich, 2002; Holm et al., 2006; Struber and Polich, 2002) generally result in elevated P3b responses towards deviant-targets, with research indicating target-to-target intervals play a more important role relative to ISI related manipulations (Croft et al., 2003; Gonsalvez and Polich, 2002). Research has also shown that increased contextual difficulty in discriminating deviant-targets from non-targets also impacts the target related P3b response, typically resulting in reduced P3b amplitudes (Comerchero and Polich, 1999; Fedota et al., 2012).

One area of contextual influence which has however received significantly less attention is the case of cross-modality transitions or the shift from processing targets presented in one modality to assessing targets presented in another (e.g., processing a visual target after having previously heard an auditory one). The context-updating framework seems to suggest such cross-modal transitions would lead to an elevation in the P3b response given the elevated levels of contextual change present in cross-modal relative to within-modal shifts. Indeed, research by Brown et al. (2006) as well as Brown et al. (2007) utilized intermodal oddballs to show support for this proposal. In the intermodal variant of the classic oddball task, neural responses to deviant auditory targets embedded in a stream of frequent visual non-targets (Brown et al., 2006) or visual-auditory non-targets (Brown et al., 2007) are contrasted with responses to the same targets embedded in a stream of frequent auditory non-targets (i.e. unimodal oddball). Both these studies showed an enhanced P3b response towards auditory deviant-targets presented under intermodal relative to unimodal conditions (Brown et al., 2006, 2007).

Brown et al. (2006, 2007)'s findings indicate that, relative to unimodal conditions, the attentional response to auditory deviant-targets is stronger when preceding stimuli are presented in a different modality. However, it is unclear if these effects are driven by the increased deviancy of auditory stimuli in an otherwise primarily visual stream, or by facilitation of the auditory deviant-target response induced by context-updating from the prior visual (Brown et al., 2006) or visual-auditory stimulus (Brown et al., 2007). Furthermore, both Brown et al. (2006, 2007) found evidence to suggest that inter-modal and unimodal P3b oddball responses differ significantly in topography and time-course, which could either be driven by cross-modal transition-related effects or by the significant task-related differences between intermodal and unimodal paradigms. As indicated by Brown et al. (2006, 2007), further investigation of this topic was needed to shed light on the issue.

An investigation of the impact of cross-modal distractors by Berti (2013) also provides additional evidence on the impact of cross-modal transitions on oddball target processing. Berti (2013) utilized an auditory-visual cross-modal distraction paradigm in which participants classified visually presented numbers preceded by either frequent tones interrupted by rare deviant tones, or silence occasionally interrupted by the same infrequent deviants. In both cases, all tones were unrelated to the task and participants did not respond to them. Berti (2013)'s findings showed that the presentation of deviant auditory stimuli impaired visual information processing regardless of whether deviants were presented consistently or intermittently, suggesting a degree of transitional cost. While Berti (2013)'s findings are intriguing, it is important to note that these results focus primarily on the impact of auditory distractors. Thus the degree to which these effects correspond with effects involving cross-modal transitions across task-relevant targets remains unclear.

Behavioral evidence for the impact of such cross-modal transitions does, however, come from Leiva et al. (2015)'s work on the cross-modal impact of deviant distractors. Leiva et al. (2015) assessed the impact of auditory and visual distractors on odd-even digit categorization performance using an alternating oddball-digit classification task. In this design, participants classified presented digits as either being odd or even under one of four presentation conditions: (1) visually presented digits alternated with the presentation of a visual oddball stimuli stream, (2) visually presented digits alternated with an auditory oddball stream, (3) auditorily presented digits alternated with a visual oddball and (4) auditorily presented digits alternated with an auditory oddball. Leiva et al. (2015) found that auditory deviants had a stronger impact on subsequent digit classification performance while visual deviants had a weaker effect, which was nonetheless significant when both targets and deviants were made task-relevant. Like Brown et al. (2006, 2007) and Berti (2013), Leiva et al. (2015)'s results suggest that more cognitive resources are involved in the processing of target stimuli after a cross-modal transition. While Leiva et al. (2015)'s findings are intriguing, it remains uncertain if they will extend to target-to-target related influences within an oddball stimuli stream itself outside of a dual-task framework. In other words, whether the attentional response to deviant-targets will be directly impacted by the presentation modality of the preceding deviant-target stimulus.

Collectively, the context-updating framework (Donchin and Coles, 1988; Johnson, 1986; Polich, 2007; Polich and Criado, 2006), as well as Brown et al. (2006, 2007), Leiva et al. (2015) and Berti (2013)'s findings, suggest that the processing of a deviant-target presented in a different modality from the previously shown deviant-target will elicit an elevated P3b response relative to the processing of deviant-targets presented sequentially in the same modality. This prediction is driven by the increased level of context-updating in cross-modal relative to intra-modal transitions.

The present study aims to assess the evidence for this hypothesis on the impact of cross-modal transitions on attentional processing. To reduce task-related differences present between cross-modal and unimodal conditions (Brown et al., 2006; Brown et al., 2007), this study utilizes a single alternating cross-modal oddball task. In this design, auditory and visual stimuli are presented orthogonally in a fixed alternating order (i.e., auditory-visual-auditory-visual, etc.) with participants being tasked with detecting deviant targets in both modalities.

The target component in this investigation is the P3b as its theorized role in context-updating related operations makes it an ideal measure for assessing the cross-modal impact of processing targets presented under different cross-modal conditions. The goal of this study is to assess changes in the P3b response to auditory and visual targets as a function of the preceding target's modality. The primary hypothesis is that the P3b response towards current targets will be elevated when the preceding target was presented in a different modality from the current target relative when the preceding target was presented in the same modality.

2. Material and methods

2.1. Participants

Twenty-five undergraduate psychology students (19 Female, Mean Age = 22.00, SD = 6.73), were recruited from a subject pool at a large public university for this study. Twenty-three participants reported right-hand dominance as measured by Edinburgh Handedness