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Research report

Can an auditory multi-feature optimal paradigm be used for the study of processes associated with attention capture in passive listeners?

Paniz Tavakoli, Kenneth Campbell *

School of Psychology, University of Ottawa, Ottawa, Canada K1N 6N5

A R T I C L E I N F O

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A B S T R A C T

Objective: A rarely occurring and highly relevant auditory stimulus occurring outside of the current focus of attention can cause a switching of attention. Such attention capture is often studied in oddball paradigms consisting of a frequently occurring "standard" stimulus which is changed at odd times to form a "deviant". The deviant may result in the capturing of attention. An auditory ERP, the P3a, is often associated with this process. To collect a sufficient amount of data is however very time-consuming. A more multi-feature "optimal" paradigm has been proposed but it is not known if it is appropriate for the study of attention capture.
Methods: An optimal paradigm was run in which 6 different rare deviants ($p=.08$) were separated by a standard stimulus ($p=.50$) and compared to results when 4 oddball paradigms were also run.
Results: A large P3a was elicited by some of the deviants in the optimal paradigm but not by others. However, very similar results were observed when separate oddball paradigms were run.
Conclusions & significance: The present study indicates that the optimal paradigm provides a very time-saving method to study attention capture and the P3a.

1. Introduction

For purposes of survival, the observer must become conscious of highly relevant stimuli that occur outside of the focus of current, active attention. Such stimuli may trigger an interrupt in the central executive controlling the allocation of attention and cognitive resources, causing a switch of attention from the task-at-hand and refocused on the potentially more relevant stimulus. Such stimulus-driven control of attentional resources is called attention capture or passive (involuntary) attention (James, 1890).

A large amount of the processing of stimulus input takes place automatically, independent of attention and consciousness. The study of automaticity in information processing is facilitated by the recording of event-related potentials (ERPs), as they provide a means of determining the extent that to-be-ignored stimuli are processed. ERPs are the minute changes in the electrical activity of the brain that are elicited by a physical stimulus or an internal, psychological event. The involuntary capturing of attention and switching of attention to the processing of the potentially highly relevant input has traditionally been associated with a positive-going ERP component, labelled the P3a, peaking at about 250–300 ms following stimulus onset (Escera et al., 1998). More recently, researchers have questioned whether the P3a reflects the actual switching of attention or is better viewed as part of a process that leads to this switch (see Wetzel et al. (2013) and Parmentier (2014) for reviews).

Because of its association with the processes leading to attention capture, there is increasing interest in the P3a in clinical and applied settings. A major reason for this is because attention capture and the associated switching of attention have both positive and negative consequences. It does provide a means of becoming aware of a highly relevant stimulus input that occurs outside of the present focus of attention. On the other hand, the vast majority of the potentially relevant stimuli turn out, in fact, to be irrelevant. Processing of the irrelevant auditory input may thus "distract" attention away from other more relevant ongoing cognitive activities. An abnormally low threshold for the switching of attention may therefore lead to frequent, but needless, interruptions of these ongoing cognitive activities resulting in a number of clinical syndromes. On the other hand, an abnormally high threshold for the switching of attention is associated with other clinical syndromes. A wide variety of patient groups have been studied including, attention deficit hyperactivity disorder (Gumenyuk et al., 2005), schizophrenia (Atkinson et al., 2012; Hermens et al., 2010; Nagai et al., 2013), depression (Lepistö et al., 2004), Parkinson's (Solís-Vivanco et al., 2015; Yamaguchi et al., 2000), and alcoholism (Polo et al., 2003). Applied, developmental studies have reported a P3a-like positivity in infants (Háden et al., 2009;

* Corresponding author.
E-mail address: kenneth.campbell@uottawa.ca (K. Campbell).

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Kushnerenko et al., 2007), toddlers (Putkinen et al., 2012), children and adolescents (Shestakova et al., 2002; Wetzel and Schröger, 2007). P3a has also been studied during partial and complete unconscious states in patients with head trauma, concussions, or in coma (Kaipio et al., 2000; Morlet and Fischer, 2014), and during natural sleep in young adults (Macdonald et al., 2008; Ruby et al., 2008).

Recording ERPs in clinical and applied settings presents several problems. Many patient groups are unable to tolerate long testing sessions. The recording procedure thus needs to be as brief as possible. In many situations, the ERPs need to be recorded passively, without the requirement for sustained attention. If active attention to a task is required, whatever ERP differences emerge between the group of interest and controls might be attributed to an inability to remain vigilant and to sustain attention. In some cases, such as studies with the demented, infants and young children, and studies examining the effects of unconscious states, active tasks can obviously not be used.

The present study examines the results of a so-called multi-feature optimal paradigm that allows the recording of a P3a to six different types of auditory "deviants" in a single sequence. Data can therefore be collected relatively rapidly. We shall also demonstrate that this paradigm can be used to record a robust P3a to certain stimuli even though the subject is not actively attending to the auditory sequence.

1.1. *The oddball paradigm*

The P3a is typically elicited using the so-called auditory oddball paradigm. The oddball sequence consists of a frequently occurring homogeneous "standard" stimulus. At rare and unpredictable (or "odd") times, a feature of the standard is changed to form a "deviant". The subject is often asked to focus attention on a visual task (for example, reading a book or watching a silent video) and to ignore the auditory sequence. Because attention is not directed toward the auditory stimuli, the ERPs are thus elicited passively by these stimuli. In the classic Näätänen model (1990, 1992), attention capture is triggered by two distinct mechanisms by which a task-irrelevant auditory stimulus may eventually be consciously perceived. In this model, stimulus onsets (a change from the absence of a stimulus) and offsets (a change from the presence of a stimulus) activate a transient-detector system, reflected in the auditory modality by the "N1" ERP component, peaking at about 100 ms. Both the standard and deviant therefore elicit an N1. The output of this system varies directly with acoustic energy and the rarity of stimulus presentation. Thus, a rarely occurring deviant that signals an increase in intensity will elicit a larger N1 than a less intense, more frequent standard. A stimulus does not however need to be intense to capture attention. A second mechanism, the change detector system, as the name implies, detects change in *any* feature of the stimulus, including its pitch, location, duration, and/or intensity. The output of the change detector system is reflected by a different negativity, the mismatch negativity (MMN), peaking at about 100–200 ms after stimulus onset. A more recent model maintains that the MMN is elicited by a mismatch between the current auditory input and the predictions formed on the basis of the trends or rules that are automatically detected in recent auditory stimulation (Näätänen et al., 2011; Paavilainen, 2013; Winkler, 2007; Winkler et al., 2009), the repeating, homogenous standard stimulus in the oddball paradigm thus being a special case of acoustic regularity. Highly novel deviants might elicit both a larger N1 than the standard, and also an MMN. This increase in negativity after the occurrence of the deviant is often called a deviant-related negativity (DRN) because it represents a composite negativity, the spatial and temporal summation of the N1 and MMN.

If the output of the transient or change detector system is sufficiently high, a trigger is sent to the central executive resulting in a switch of attention away from ongoing, attended cognitive tasks and toward the interrupting stimulus event. P3a is thought to reflect at least part of the processes that lead to and cumulate in the capturing and switching of attention. Thus, while any perceptible stimulus change will elicit an MMN/DRN, only a small number of these stimuli will also elicit a P3a. In general, the probability of eliciting a P3a increases with the extent of stimulus change.

Stimuli whose features vary widely from pure tone standards, such as novel environmental sounds (e.g., musical instruments, animal sounds, novel sounds) and white noise, have been demonstrated to elicit a large amplitude P3a in passive paradigms (Cahn and Polich, 2009; Kushnerenko et al., 2007). A change in a single feature of the standard stimulus can also elicit a large P3a particularly if this change represents about a 10 dB increase in intensity, but even a very large 20 dB decrement in intensity can elicit a small amplitude P3a (Macdonald et al., 2008; Muller-Gass et al., 2006) although a small decrement will not (Rinne et al., 2006). Many studies have employed small frequency and duration deviants but these elicit only a small amplitude or absent P3a.

1.2. *Active attention*

The P3a has also often been elicited in very attention-demanding (or "active") intra- and inter- modality studies. In a now classic study, Schröger and Wolff (1998) presented subjects with equally probable short- and long-duration auditory stimuli. The subject's task was to actively listen to and signal the duration of the stimuli by pressing an appropriate key. At rare and unpredictable times, the frequency of the stimulus was slightly changed. This frequency deviant was however irrelevant to the duration detection task. The small frequency change did nevertheless elicit a P3a. Importantly, its presentation resulted in a deterioration in performance on the duration detection task. The behavioural deterioration in performance thus provides an independent measure of the switching of attention; presumably the presentation of the deviant resulted in a switch of attention from the processing of the relevant feature of the stimulus (its duration) and toward the processing of an irrelevant feature (its frequency). Another advantage of the use of the active paradigm is that the P3a can be elicited by deviants that represent a small extent of change from the standard. In passive paradigms, a large extent of change appears to be required. Unfortunately, as mentioned above, in many applied and clinical settings, studies requiring active, sustained attention cannot be employed. Moreover, Grimm et al. (2008) have noted that the amplitude of the DRN increases dramatically when attention is directed to the auditory sequence compared to when it is ignored. The authors note that this might be because of a very large increase in the amplitude of another overlapping negativity, the N2b, which summates with the DRN. Distinguishing between the DRN and the N2b can however be extremely difficult. Many applied researchers are interested in differences associated with the DRN/MMN. Again, as mentioned previously, when a task requires active attention, whatever ERP differences emerge might reflect an inability to focus attention rather than an ability to detect change.

1.3. *The optimal paradigm*

The MMN/DRN has often been used in a very large number of applied and clinical studies of the detection of change and sensory memory (see reviews by Bartha-Doering et al. (2015) and Näätänen et al. (2012)). The amplitudes of the MMN/DRN and possible subsequent P3a are typically much smaller than the ongoing,