Biological Psychology 79 (2008) 139–147

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Do N1/MMN, P3a, and RON form a strongly coupled chain reflecting the three stages of auditory distraction?

János Horváth [a,b,*], István Winkler [a], Alexandra Bendixen [b]

[a] Institute for Psychology, Hungarian Academy of Sciences, POB 398, H-1394 Budapest, Hungary
[b] Institute of Psychology I, University of Leipzig, Seeburgstr. 14-20, D-04103 Leipzig, Germany

ARTICLE INFO

Article history:
Received 15 November 2007
Accepted 3 April 2008
Available online 10 April 2008

Keywords:
Attention
Distraction
Stimulus sequence effects
Event-related potential (ERP)
N1
Mismatch negativity (MMN)
P3a
Reorienting negativity (RON)

ABSTRACT

Distraction triggered by unexpected events is generally described in a serial model comprising (1) automatic detection of unexpected task-irrelevant events, (2) orienting towards the event, and (3) recovery from distraction. Processes taking place at the three stages are assumed to be reflected by the N1 and mismatch negativity (MMN); the P3a; and the reorienting negativity (RON) event-related potentials (ERPs), respectively. We investigated whether the processes indexed by these components form a strongly coupled chain, each co-varying with the preceding one. To this end, micro-sequence analysis of the ERPs elicited by unpredictable pitch-changes was conducted in an auditory duration discrimination task. Results indicated that the processes indexed by the above-mentioned ERPs are not strongly coupled. Pair-wise dissociations were found between the ERPs reflecting each processing stage: P3a can be elicited without concurrent N1-increase or MMN elicitation and without subsequent elicitation of the RON. Possible interpretations of P3a and RON are discussed.

1. Introduction

In everyday life, optimal performance can often be achieved by focusing on the task-relevant aspects of the incoming stimuli while disregarding other information. However, a "perfect" selective attention set, in which resources are used only for processing task-relevant events, cannot be achieved: task-irrelevant sensory events occasionally draw away our attention, that is, we get distracted (passive attention, see James, 1890). Though involuntary shifts of attention lead to temporary deterioration in task performance, they may also bring potentially important information into the focus of attention, thereby allowing re-evaluation of the whole situation. In the optimal case, distraction and the maintenance of goal-directed behavior are well balanced.

Distraction is usually triggered by unexpected events in the sensory environment. It is assumed that such events initiate a chain of processes starting with automatic detection of unexpected sensory information, followed by shifting of the focus of attention, and concluded by restoration of the task-optimal attention set (unless the distracting event requires immediate adaptive changes). In the present study, we investigated whether the above listed processes form a true causal chain, that is, whether or not each processing step is governed by the preceding one.

Distraction (i.e., an involuntary change of the selective attention set) is usually investigated in the *oddball paradigm*, in which some stimuli of a regular sequence are replaced by irregular ones. Regular stimuli are termed *standards*, irregular ones *deviants*. The sequence of distraction-related processes can be described by a three-stage sequential model (for a detailed summary of the model, see Escera and Corral (2003) and Escera and Corral (2007); also Horváth et al., in press; different parts of this model were described by Escera et al. (2000), Friedman et al. (2001), Näätänen (1990, 1992), Polich (2007), Polich and Criado (2006), Schröger (1997) and Schröger and Wolff (1998b). Processes of the three stages are thought to be reflected by specific event-related potentials (ERPs).

The *first stage* features sensory processes forming an adaptive filter, which minimizes the sensory-information load on capacity-limited processing resources. These processes do not require voluntary activation, although their outcome can be affected by some top-down processes (e.g., Hansen and Hillyard, 1988; Sussman et al., 2002). Two of these processes are thought to be directly reflected in ERPs: (1) an onset and simple (first-order) change detection process eliciting the N1 wave (for a review, see Näätänen and Picton, 1987); and (2) a separate sensory memory-based deviance-detection process indexed by the mismatch

* Corresponding author at: Institute of Psychology I, University of Leipzig, Seeburgstr. 14-20, D-04103 Leipzig, Germany. Tel.: +49 341 973 59 77; fax: +49 341 973 59 69.
E-mail address: horvath@cogpsyphy.hu (J. Horváth).

0301-0511/$ – see front matter
doi:10.1016/j.biopsycho.2008.04.001

negativity (MMN) (Näätänen et al., 1978; for a review, see Näätänen et al., 2007). The modality-specific component of the N1 wave reflects differential activation of neural elements sensitive to various stimulus features: stimulus-repetition leads to decreased responses, whereas change restores the full activation. The memory-based comparison process indexed by the MMN component compares incoming stimuli to representations generated on the basis of temporal regularities extracted from the auditory input. When a stimulus proves to be incompatible with the current regularity-representations, MMN is elicited. Thus, N1 and MMN can be regarded as first- and second-order change detectors. Both N1 and MMN are modality-specific (Czigler et al., 2002; Näätänen et al., 1978; Shinozaki et al., 1998); N1 usually peaks between 80 and 120 ms, whereas MMN peaks between 100 and 200 ms from the onset of change/deviance, respectively.

It is hypothesized that both processes can call for higher level, capacity-limited attentional processes, when their activation exceeds a variable threshold, the level of which is set by top-down control (e.g., stronger or weaker focus on the ongoing behavior; Schröger, 1997). Therefore, small changes or deviations may not reach the second processing stage (attention switching), whereas large changes or deviations usually trigger involuntary attention switching to the stimulus, which elicited the large N1/MMN (Escera et al., 1998; Näätänen, 1990; Rinne et al., 2006; Schröger, 1997). Typically, slow gradual changes in the environment are automatically incorporated into an implicit representation of the sensory environment and thus may go unnoticed unless they are attended. In contrast, the same change occurring suddenly may capture one's attention. Some processes related to attention switching are thought to be reflected by the fronto-central P3a component, which usually peaks at about 300 ms from the onset of the change/deviance and is at least partly modality-independent (Escera et al., 2000; Friedman et al., 2001; Knight and Scabini, 1998; Schröger, 1996). Note, that although P3a is often taken to reflect the process of involuntary attention switching itself, there is no general consensus on the precise role of P3a within the second processing stage (Dien et al., 2004).

Finally, in the *third processing stage*, if the event that triggered an attention switch does not require immediate adaptive changes (i.e., the task priorities do not change), the task-optimal selective attention set is restored. This function is hypothesized to be reflected by the modality-independent, fronto-central reorienting negativity (RON) component, which peaks 400–600 ms after the onset of change/deviation (Berti and Schröger, 2001; Schröger et al., 2000; Schröger and Wolff, 1998a,b).

Schröger and Wolff (1998a,b) introduced a paradigm optimized for investigating all three stages of distraction by behavioral and ERP measures. In this auditory distraction paradigm, a sequence of stimuli varying in two features is presented. One auditory feature (e.g., sound duration) is task-relevant; the other (e.g., pitch) is task-irrelevant. The task-relevant feature varies equiprobably (e.g., 50% of the stimuli are short, the other 50% long), whereas levels of the task-irrelevant feature are unevenly distributed across the stimuli (e.g., 90% of the sounds have high, whereas 10% have low pitch). On each trial, participants perform a discrimination task based exclusively on the task-relevant feature. It has been shown that infrequent unexpected changes in the task-irrelevant feature (deviants) cause distraction: responses to deviants are usually slower than to standards; the N1 amplitude increases and MMN, P3a, and RON are elicited by deviants. Several studies using this paradigm provided evidence compatible with the three-stage model of distraction. It has been shown that larger deviations elicit larger N1/MMN, P3a and RON components, suggesting that activation of the corresponding processes is correlated with each other and with the magnitude of stimulus deviance (Berti et al., 2004; Escera et al., 2001; Yago et al., 2001). Bendixen et al. (2007) found that all three components showed increasing amplitudes when the deviant was preceded by longer standard-stimulus sequences.

On the other hand, it seems also likely that the processes indexed by P3a and RON are not fully governed by N1/MNN. A number of studies obtained evidence suggesting that P3a and RON can be modulated by factors not affecting N1/MMN. Winkler et al. (1998) found that whereas the MMN amplitude saturated at intermediate magnitudes of stimulus deviance, the P3a amplitude increased with further increases of the magnitude of deviance. Berti and Schröger (2003) found that some manipulations of working memory load did not affect the N1/MMN amplitude, but resulted in decreased P3a and RON amplitudes. Distraction-related processing can also be limited to the first stage of the model: Ritter et al. (1999) and Sussman et al. (2003) showed that it is possible to prevent the elicitation of P3a and RON by making the occurrence of deviants fully predictable through the use of visual cues. However these manipulations had no effect on the elicitation and amplitude of the N1/MMN. One model-conforming explanation of these findings is that it is possible to dynamically raise or lower the threshold through which bottom-up activation can reach the attention-switching mechanism (Schröger, 1997). On the other hand, it is also possible that knowledge about the occurrence of the deviant could only be utilized by the processes of the second and third stages of the distraction model, but not by those of the first stage.

The auditory system rapidly adapts to changes in environment. A number of studies suggest that after one or two repetitions of a stimulus (i.e., two or three stimulus presentations), a subsequent change can elicit MMN (Bendixen et al., 2007; Horváth et al., 2001; Winkler et al., 1996). Furthermore, increasing N1/MMN amplitudes are elicited by changes following homogeneous micro-sequences of increasing length (Giese-Davis et al., 1993; Sams et al., 1983). If processes of the three-stage distraction model form a tightly coupled chain then the presumed ERP correlates of these processes should exhibit similar patterns of behavior as a function of the length of the homogeneous micro-sequence of sounds preceding a deviant stimulus.

In the present study, we investigated distraction-related ERP responses elicited by sound change following repetitive micro-sequences. We term such stimulus changes as "local deviants". We employed a variant of the auditory distraction paradigm introduced by Schröger and Wolff, 1998a,b; described above), in which, instead of presenting different levels of the task-irrelevant stimulus feature with uneven probabilities, the two levels of this feature were delivered equiprobably (that is, there were no global deviant or standard stimuli within the sequences). Because the order of the sounds was randomized, repetitive micro-sequences of various lengths emerged incidentally within the sound sequences. Local deviants of the task-irrelevant stimulus feature (change in the task-irrelevant feature following a micro-sequence within which the task-irrelevant feature was constant) can be expected to cause distraction and thus elicit the distraction-related ERP components. In contrast, repetitions of the task-irrelevant stimulus feature ("local standards") should not cause distraction. If the processes indexed by the sequence of N1/MMN, P3a, and RON form a causal chain, then the amplitudes of these components should exhibit similar behavior as a function of the length of the homogeneous micro-sequence preceding local deviants. Different patterns of behavior of these ERP components would suggest that the processes reflected by these components do not form a tightly coupled sequence, or that the functional interpretation of some of these components should be reconsidered.