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The time-course of auditory and visual distraction effects in a new crossmodal paradigm

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ABSTRACT

Vision often dominates audition when attentive processes are involved (e.g., the ventriloquist effect), yet little is known about the relative potential of the two modalities to initiate a “break through of the unattended”. The present study was designed to systematically compare the capacity of task-irrelevant auditory and visual events to withdraw attention from the other modality. Sequences of auditory and visual stimuli were presented with different amounts of temporal offset to determine the presence, strength, and time-course of attentional orienting and reorienting as well as their impact on task-related processing. One of the streams was task-relevant, while crossmodal distraction caused by unexpected events in the other stream was measured by impairments of behavioral task performance and by the N2, P3a, and reorienting negativity (RON) components of the event-related potential (ERP). Unexpected events in the visual modality proved to be somewhat more salient than those in the auditory modality, yet crossmodal interference caused by auditory stimuli was more pronounced. The visual modality was relatively constrained in terms of a critical time-range within which distraction effects could be elicited, while the impact of auditory stimuli on task-related processing extended over a longer time-range. These results are discussed in terms of functional differences between the auditory and visual modalities. Further applications of the new crossmodal protocol are deemed promising in view of the considerable size of the obtained distraction effects.

1. Introduction

The capacity of human information processing is limited (Welford, 1952). It is thus of utmost importance to prioritize incoming information, allocating more attentional resources to stimuli that are relevant for the current goals of the organism. This process of selective attention goes at the expense of currently irrelevant stimuli (James, 1890). Because of these processing costs, attention must not be entirely selective: The organism needs to remain susceptible to new environmental events which might signal danger and thus require immediate behavioral adaptation. Attention shifts can occur within one modality, such as noticing a car horn when engaged in a conversation (intramodal shift within audition), or between modalities, e.g. noticing the brake lights of the car in front while concentrating on a radio announcement (crossmodal shift from audition to vision). As the choice of warning signals for car driving illustrates, it is crucial to know about the capacities of different sensory modalities to interfere with each other (e.g., Scott & Gray, 2008). The present study was designed to compare crossmodal attention shifts between vision and audition.

The balance between focused attention and monitoring of the environment has been modeled in a class of distraction paradigms originally proposed by Escera, Alho, Winkler, and Näätänen (1998) in a crossmodal setting and in parallel by Schröger and Wolff (1998b) in an intramodal setting. In these paradigms, participants' attention is focused on a primary task while events outside the task set are presented such that they belong to a frequent (standard) or to an infrequent (deviant) category. Based on the idea that any change in a sequence of repetitive stimuli is distracting, deviant events are evaluated in terms of their interference with task performance (for review, see Escera, Alho, Schröger, & Winkler, 2000; Escera & Corral, 2007). Typical findings (e.g., Schröger, Giard, & Wolff, 2000) include a behavioral impairment of task performance (increase of response times [RT] or error rates) and a characteristic

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series of event-related brain potential (ERP) components elicited by deviant relative to standard stimuli. The registration of the deviant event is signaled by negativities with fronto-central distribution occurring at 150–250 ms after deviation onset, consisting mainly in the mismatch negativity (MMN; Näätänen, Gaillard, & Mäntysalo, 1978; Näätänen, Paavilainen, Rinne, & Alho, 2007; Schröger, 2005; Winkler, 2007) and N2b (Näätänen, Simpson, & Loveless, 1982; Novak, Ritter, Vaughan, & Wiznitzer, 1990; Patel & Azzam, 2005) components. A subsequent positive deflection at 300–400 ms after deviation onset (P3a component; Squires, Squires, & Hillyard, 1975; for reviews, see Friedman, Cycowicz, & Gaeta, 2001; Linden, 2005; Polich, 2007) is considered to be a reflection of involuntary attention switching towards the new event (Escera et al., 2000; Escera, Yago, & Alho, 2001). Finally, attentional reorienting to the primary task has been related to the reorienting negativity (RON) component between 400 and 600 ms post-deviation (Schröger & Wolff, 1998a; for replication and elaboration, see e.g. Berti, 2008a; Berti, 2008b; Escera et al., 2001; Munka & Berti, 2006; Yago, Corral, & Escera, 2001).

Along these lines, distraction has been investigated for auditory stimuli interfering with auditory primary tasks (Berti, Roeber, & Schröger, 2004; Rinne et al., 2007; Roeber, Widmann, & Schröger, 2003; Sabri, Liebenthal, Waldron, Medler, & Binder, 2006; Watkins, Dalton, Lavie, & Rees, 2007) or with visual primary tasks (Escera et al., 2001; Muller-Gass, Macdonald, Schröger, Sculthorpe, & Campbell, 2007; Munka & Berti, 2006; San Miguel, Corral, & Escera, 2008; Yago et al., 2001; Zhang, Chen, Yuan, Zhang, & He, 2006). Attempts to transfer the paradigm to the visual modality (Berti & Schröger, 2004, 2006; Grimm, Bendixen, Deouell, & Schröger, 2009; Kimura, Katayama, & Murohashi, 2008) have shown that distraction within vision is more elusive than within audition (for direct comparison, see Berti & Schröger, 2001). Very few studies looked at the influence of visual distracting events on auditory task performance (e.g., Alho, Woods, Algazi, & Näätänen, 1992; Astikainen, Lillstrang, & Ruusuvirta, 2008; Rees, Frith, & Lavie, 2001); they report electrophysiological signs of deviance processing, but no distraction effect on behavior (see also Boll & Berti, 2009, for an audiovisual task).

The present study was designed to systematically compare crossmodal distraction between the visual and auditory modalities in the framework of attentional orienting and reorienting. The comparison aimed at the presence, amplitude, and time-course of behavioral and electrophysiological distraction effects. Stimulus sequences were composed of parallel auditory and visual streams presented simultaneously or with a constant amount of temporal offset. One of the streams was task-relevant, while the capacity of unexpected events in the other stream to withdraw attention from the primary task was investigated. Both streams followed a continuous roving-standard protocol (Cowan, Winkler, Teder, & Näätänen, 1993) with stimulus changes after every two to six repetitions. The task was defined as a discrimination of repetition versus change in the relevant stream; distracting events consisted in stimulus changes in the irrelevant stream.

As crossmodal attentional links between vision and audition have been revealed in many studies for voluntary and involuntary spatial attention (e.g., Driver & Spence, 1998; Eimer & Driver, 2001; Eimer & Schröger, 1998), crossmodal distraction is also expected in the present non-spatial distraction paradigm. Following previous studies (Berti & Schröger, 2001; Boll & Berti, 2009), it was hypothesized that the auditory distracters would interfere with the primary visual task more than the visual distracters would interfere with the primary auditory task. Since visual and auditory information are processed at different speeds (e.g., Lewald & Guski, 2003; Nicolas, 1997; Wallace, Wilkinson, & Stein, 1996), and since the two modalities may have specific time-courses of attention capture, distraction effects were compared for different amounts of temporal offset between streams. In order to exclude that asymmetries in crossmodal distraction effects might be due to the saliency of the changes per se, the processing of task-relevant changes was also compared between modalities.

2. Materials and methods

2.1. Participants

Thirteen healthy volunteers with self-reported normal hearing and normal or corrected-to-normal vision participated in the experiment. None were taking any medication that might affect the central nervous system. According to the Declaration of Helsinki, written informed consent was obtained from each participant prior to the beginning of the experiment. Data collection was cancelled for one participant because of failure to complete the behavioral task at the required speed even after extensive training. Mean age of the remaining twelve participants (four male, one left-handed) was 26.7 years.

2.2. Apparatus and stimuli

Participants were seated in a sound-attenuated and electrically shielded chamber. A computer screen, visible through a glass pane, was placed outside the chamber at a distance of 100 cm relative to the participant. Auditory and visual stimuli were presented in a continuous series. Within each modality, stimulus-onset asynchrony (SOA) was held constant at 1000 ms. Between modalities, SOAs of 400, 200, or 0 ms were tested in different blocks. Participants were provided with a response keypad.

Auditory stimuli were presented binaurally via headphones with an intensity of ca. 70 dB SPL (measured by HMS III artificial head, HEAD acoustics, Germany). They were chosen from a selection of 90 natural and artificial sounds such as musical instruments, human and animal sounds, door-knocking and other everyday noises, synthesized computer sounds, etc. Sounds were RMS-normalized and had a length of 500 ms each (including 10 ms rise and 10 ms fall times). Visual stimuli were presented with a duration of 500 ms each in the center of the screen, subtending a visual angle of 7.5°. They were chosen from a selection of 90 naturalistic images such as animals, flowers, food, clothes, vehicles, and the like.

Auditory and visual stimulus sequences were concatenated from chains of 3, 4, 5, 6 or 7 identical stimuli in a row (with random order of the chains; see Fig. 1 for a stimulus sequence example). Within a block, a different stimulus from the set was chosen for each chain. Sequences in the two modalities were randomized independently of each other, giving rise to four possible events (average probability is indicated in brackets): repetition in both modalities (65%), auditory repetition and visual change (15.5%), auditory change and visual repetition (15.5%), change in both modalities (4%). Stimulation was randomized individually for each participant. In total, 3600 auditory and 3600 visual stimuli were presented.

2.3. Procedure

In different blocks, participants were instructed to attend either to the auditory or to the visual sequence and to press one response key if the stimulus remained the same as the previous stimulus in the relevant modality, and another response key if the stimulus changed. Key assignment was counterbalanced across participants.

Participants completed six blocks of the auditory and six blocks of the visual task, with stimuli in the other (task-irrelevant) modality preceding the task-relevant stimuli by 400, 200, or 0 ms in two blocks each. Blocks with auditory and visual task instructions were presented in alternation; the starting task was counterbalanced across participants. Order of the SOA levels was randomized for the first half of the blocks of each participant, and then repeated in the second half.

At the beginning of the experimental session, participants completed half-minute practice blocks until the criteria of 90% correct trials overall and 80% correct 'change' responses were met. After training, experimental blocks consisting of 61 chains (12 of each length, one additional to compensate for the beginning chain) with a duration of 5 minutes per block were administered. Total duration of an experimental session was approximately 60 minutes. No feedback on single trials was given, but subjects were informed on their overall performance per block in terms of the percentage of correct responses and the mean RT, and were encouraged to stay within the established response criteria.

2.4. Data recording and analysis

Events with stimulus changes in both modalities were excluded from the analysis because not enough trials were accumulated to consider them separately. The remaining three event categories (repetition in both modalities, task-relevant change, task-irrelevant change) served to conduct two main types of analyses. First, the processing of task-relevant changes was compared with that of task-relevant repetitions within each modality (*relevant change effect*) in order to obtain an index of saliency of change for each modality and to compare these indices between the