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Effects of the short-term learned significance of task-irrelevant sounds on involuntary attention in children and adults

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ABSTRACT

The present study aimed to test effects of unexpected task-irrelevant environmental sounds, that were short-term learned to be significant, on deviance-related brain activity (event-related potentials; ERPs) and performance in children aged 9–10 years and young adults.

Participants performed three conditions. In the first ignore condition an oddball paradigm was presented including two neutral deviant sounds. In the second learning condition significance was attributed to one of the two deviant sounds by defining it as target. In the third condition participants then performed a version of an oddball paradigm, embedded in a narrative, that included the neutral and the now significant but task-irrelevant deviant sound. Results revealed decreased reaction times and hit rates elicited by significant compared to neutral deviant sounds in both age groups whereas P3a, an indicator of orienting of attention and novelty evaluation, was not affected by deviant's learned significance. In contrast, post-deviant processing, reflected by hit rates and ERPs in trials following a significant deviant compared to those following a neutral deviant, was differently modulated in children and adults. Moreover, a clear P3a was observed in the attend condition in both age groups but in the ignore condition in children only.

Results indicate that the short-term learned significance of task-irrelevant sounds modulates performance but not orienting and evaluation processes associated with the P3a. Importantly, results demonstrate children's increased susceptibility to task-irrelevant but significant sounds and the ongoing maturation of attention control in the late childhood.

1. Introduction

In a classroom children are exposed to many task-irrelevant sounds like whispers, pencils falling down, or steps on the corridor. Such events can involuntarily distract attention from task-relevant information. The processing and evaluation of unexpected distracting stimuli require resources that are no longer available to process task-relevant information. This can result in decreased performance of a task at hand (for an overview see, Escera, Alho, Schröger, and Winkler, 2000; Näätänen, 1992; Schröger, Giard, and Wolff, 2000, but see Parmentier, Elsley, and Ljungberg, 2010; SanMiguel, Morgan, Klein, Linden, and Escera, 2010; Wetzel et al., 2012). It can be assumed that the subjective relevance of task-irrelevant sounds affects involuntary attention and distraction processes. Referring to the classroom example, when pupils learn that steps on the corridor announce the end of the lesson then this sound might have a higher distracting or possibly a higher activating potential than a sound of a pencil accidentally falling down. The present study systematically examines the impact of task-irrelevant, unexpected sounds that were learned to be significant on deviance-related brain activity and performance.

As previous studies have shown school age children are, in contrast to adults, more susceptible to task-irrelevant auditory distractors like speech (e.g., Elliott and Briganti, 2012), noise (e.g., Klatte, Bergström, and Lachmann, 2013), or even small changes in sound features such as frequency (e.g., Wetzel, Widmann, Berti, and Schröger, 2006). The development of attention control is particularly associated with the maturation of the prefrontal cortex (Bunge, Dudukovic, Thomason, Vaidya, and Gabrieli, 2002; Fuster, 2002; Giedd et al., 1999; Huttenlocher, 1979). Imaging and morphometric studies reported that the prefrontal cortex matures at least until late adolescence (Casey, Giedd, and Thomas, 2000; Giedd et al., 1999; Gogtay et al., 2004; Konrad et al., 2005). Developmental changes in gray and white matter determine a more focused brain activity and increased speed of information processing during childhood (e.g., Casey et al., 2000; Fuster, 2002; Giedd et al., 1999; Sowell, Thompson, Tessner, and Toga, 2001).

The most famous example illustrating the impact which the learned significance of sounds has on behavior is the cocktail party effect (Moray, 1959). However, effects of the own name on the orienting of attention or on behavior are being challenged by current studies that do not report such effects (e.g., Eichenlaub, Ruby, and Morlet, 2012;

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Ljungberg, Parmentier, Jones, Marsja, and Neely, 2014). Subjective relevant sounds can capture attention from very early on as it was observed even in infants (Newman, 2005). However, less is known about the developmental trajectory of distraction by significant sounds. This is particularly true for environmental sounds occurring in daily life. Environmental sounds that could be identified (e.g., the sound of bell-ringings or clinking glasses) captured more attention than non-identifiable sounds in 7–8-year-old children but not in adults (Wetzel, Widmann, and Schröger, 2011). Wetzel et al. (2011) used an oddball paradigm including rarely presented identifiable (meaningful) and non-identifiable (meaningless) task-irrelevant novel sounds embedded in a sequence of frequently presented standard pure tones while subjects were instructed to focus their attention on a video clip. Similar studies have been performed with adults by Mecklinger, Opitz, and Friederici (1997) and by Escera, Yago, Corral, Corbera, and Nunez (2003). Deviant-related brain activity was measured by the event-related potential (ERP) component P3a. The fronto-centrally peaking P3a (also labeled Novelty P3) is associated with the involuntary orienting of attention towards an unexpected change in the environment (for review see, Escera et al., 2000; Friedman, Cycowicz, and Gaeta, 2001; Polich and Criado, 2006). In the context of a novelty evaluation model (Wetzel, Schröger, and Widmann, 2013) aspects of P3a are assumed to reflect evaluation processes (see also, Horvath, Winkler, and Bendixen, 2008). In the study with children, meaningful and meaningless distractor sounds elicited the P3a indicating orienting of attention or novelty evaluation in both age groups (Wetzel et al., 2011). Only in children meaningful sounds elicited larger P3a amplitudes than meaningless sounds indicating children's stronger capture of attention by meaningful sounds. The present study is based on the study by Wetzel et al. (2011). In the present study we asked whether the short-term learned significance of deviant sounds modulates deviant processing and which developmental differences can be observed. An oddball paradigm was presented twice, including two environmental deviant sounds. The first presentation included two neutral deviant sounds. In a subsequent learning task, significance was attributed to one of the deviant sounds by defining it as target sound. The second presentation of the oddball paradigm included exactly the same sounds as in the first presentation but with one of the deviant sounds now being significant (Fig. 1). The present study focused not only on effects significant deviants have on brain activity but also their impact on performance. Effects of distraction by unexpected and task-irrelevant sounds can be investigated by implementing a reaction time task not related to the distracting sounds or distracting features of sounds (Bendixen et al., 2010; Schröger and Wolff, 1998). In the present study the location of the sound source of standard and deviant sounds moved to the right or to the left. In an attend condition participants were asked to distinguish the moving direction. This task was successfully applied in a previous involuntary attention study with 7–8-year-old children (Wetzel, Widmann, and Schröger, 2009).

On behavioral level it is expected that neutral deviant sounds cause distraction effects that can either be similar in both age groups (Horvath, Czigler, Birkas, Winkler, and Gervai, 2009; Wetzel et al., 2009) or are increased in children (Gumenyuk, Korzyukov, Alho, Escera, and Näätänen, 2004; Gumenyuk et al., 2001; Wetzel and Schröger, 2007; Wetzel et al., 2006). There are also two hypotheses regarding the direction of effects of deviant's significance. On the one hand, significant deviant sounds might have a higher distracting potential than neutral deviant sounds. This hypothesis bases on a study by Escera et al. (2003) who reported delayed reaction times in trials including identifiable novel sounds relative to non-identifiable novel sounds. Because of children's immature attention control it is expected that significant deviant sounds will cause the strongest distraction effects in children. On the other hand, it can be hypothesized that deviant sounds' processing is facilitated. Events that are motivationally significant (because they are relevant for a task at hand or new) can induce facilitated processing (for review see, Aston-Jones and Cohen, 2005; Nieuwenhuis, Aston-Jones, and Cohen, 2005). The definition as target in the learning task strongly increases motivational significance as the sound type becomes relevant for the task. It is expected that motivational significance will be transferred to the following task even though the sound type is no longer defined as target. This benefit might be less pronounced in children because of immature attention control and information processing. Moreover, some distraction studies with adults reported negative effects of the deviant on reaction times in the following standard trial (Ahveninen et al., 2000; Berti, 2008; Roeber, Widmann, and Schröger, 2003). This post-deviant effect might be larger in children than in adults due to the increased susceptibility of children to deviant sounds.

In addition to behavioral measures, the ERP component P3a was also measured. P3a is discussed to be present from early childhood on (Kushnerenko, Van den Bergh, and Winkler, 2013; Putkinen, Niinikuru, Lipsanen, Tervaniemi, and Huotilainen, 2012; Shestakova, Huotilainen, Ceponiene, and Cheour, 2003). Brain responses to novelty have been described as rather similar in the age range of 5–16 years and in adults (Cycowicz and Friedman, 1997). Nevertheless, inconsistent results regarding the development of processes underlying P3a are reported in the literature (e.g., Courchesne, 1978; Cycowicz, Friedman, and Rothstein, 1996; Fuchigami et al., 1995; Gumenyuk et al., 2004; Horvath et al., 2009; Kihara et al., 2010; Ruhnau et al., 2013; Ruhnau, Wetzel, Widmann, and Schröger, 2010). More consistent is the finding of an anterior scalp distribution of P3a in children shifting to more central or parietal scalp areas with age (Cycowicz et al., 1996; Ruhnau et al., 2010, 2013; Wetzel et al., 2011). In the present study, on one hand, it is expected that significant and neutral deviant sounds elicit a similar P3a in adults because of the strong automatic nature of the mechanisms underlying P3a (Mecklinger et al., 1997; Muller-Gass, Macdonald, Schröger, Sculthorpe, and Campbell, 2007). On the other hand it has been reported that significant deviant sounds like the own mobile ring tone (Roye, Jacobsen, and Schröger, 2007) or the own name uttered by a familiar voice (Holeckova, Fischer, Giard, Delpuech, and Morlet, 2006) elicited enhanced P3a amplitudes in adults. Also Escera et al. (2003) reported stronger orienting of attention towards identifiable relative to non-identifiable sounds but the authors emphasized that this was only observed when sounds were covertly attended.

In children, significant deviant sounds might cause changed P3a amplitudes or latencies, indicating immature aspects of orienting attention and novelty evaluation mechanisms (Wetzel et al., 2011).

2. Material and methods

Participants. Eighteen healthy children (9.0–10.11[1)] years; mean age 10.3 years; 7 female; 15 right handed) and 18 healthy adults (21.5–30.6 years; mean 24.7 years; 9 female; 11 right handed) participated in the study. Handedness was measured with a shortened version of the Edinburgh Handedness Inventory (Oldfield, 1971). Children attended local schools. Most adults were students at the University of Leipzig. Participation was rewarded by a voucher for toys, CDs, DVDs, or books in a local shop (children) or by money or credit points (adults). Adults and parents (representing the child) gave written informed consent and children, additionally, gave verbal consent. All participants or parents (in case of children) reported normal hearing, normal or corrected-to-normal vision, no medication with effects on the nervous system, and no history of attention-related disorders. The project was approved by the local ethical committee of the Medical Faculty of the University of Leipzig.

Conditions. In all conditions sounds were presented from a central position in front of the participant and then moved to the right or to the left.

In the first condition (*ignore condition*) two neutral deviant sounds were presented embedded in a sequence of standard sounds, and participants were instructed to ignore the auditory stimulation while

[1] Year; month.