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Age differences in the Irrelevant Sound Effect: A Serial Recognition Paradigm

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In adults, the disrupting effect of irrelevant background sounds with distinct temporal-spectral variations (changing-state sounds) on short-term memory performance was found to be robust. In the present study, a verbal serial recognition task was used to investigate this so-called Irrelevant Sound Effect (ISE) in adults and 8– to 10-year-old children. An essential part of the short-term memory impairment during changing-state speech is due to interference processes (changing-state effect) which can be differentiated from the deviation effect of auditory distraction. In line with recent findings (Hughes et al., 2013), our study demonstrates that the changing-state effect is not modulated by task difficulty. Moreover, our results show that the changing-state effect remains stable for children and adults. This suggests that the differences in the magnitude of the ISE as reported by Elliott (2002) and Klatte et al. (2010) are most likely related to the increase in attentional control during childhood.

Keywords: the irrelevant sound effect, the changing-state effect, development, serial recognition task, task difficulty

When trying to focus on a mental activity, e.g., reading, writing or remembering, background speech seems to have a disturbing effect, even if it is irrelevant to the task at hand and should be ignored. In fact, a detrimental impact of irrelevant speech on several objective performance measures has been verified, in particular on short-term memory capacity. Colle and Welsh (1976) were the first to describe irrelevant speech to significantly impair performance in a verbal serial recall task, which is the standard measure for short-term memory capacity. Here, unrelated verbal items (e.g., digits, consonants, or words) are presented in a set order and have to be recalled in the exact presentation order. Performance in this task is not only significantly reduced by irrelevant speech but also by non-speech sounds (e.g., sine-wave tones), so that this empirically robust phenomenon is now referred to as irrelevant sound effect (ISE). Accordingly, not speech as such forms a necessary condition for the ISE, but a background sound's inherent changing state, characteristic with prominent temporal-spectral variations (for a summary, see Schlittmeier, Weißgerber, Kerber, Fastl, & Hellbrück, 2012). Narration is typically characterized by such temporal-spectral variations. To our knowledge, the disturbing impact of changing-state speech has never been surpassed in experiments on the ISE (Schlittmeier et al., 2012). On the contrary, steady-state background sounds, which to a great extent lack temporal-spectral variations, do not – or only to a small degree – affect performance (e.g., continuous noise; Schlittmeier et al., 2012).

The exact cognitive mechanisms underlying the ISE caused by irrelevant background speech are the source of a long-standing debate between several working memory models in the literature (for a review, see Jones, Hughes, & Macken, 2010). Nonetheless, all the models assume irrelevant changing-state speech to induce an interference-based loss of encoded information necessary to complete the serial recall task at hand. They differ – beyond other aspects – in particular with regard to whether attention processes are assumed to add to the behaviorally observed error rates in the serial recall paradigm during irrelevant speech or not. The recently proposed duplex-mechanism account of auditory distraction (Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013; Hughes, Vachon, & Jones, 2007) claims a distinction between two sources of the overall performance decrement during irrelevant changing-state sound: interference-based performance decrement (changing-state effect) and the deviation effect. The latter is a more general attention process independent of the memory task at hand (Bell, Röer, Dentale, & Buchner, 2012; Röer, Bell, & Buchner, 2013). The deviation effect is modulated by top-down control mechanisms (i.e., prior knowledge and task difficulty) and working memory capacity, whereby the changing-state effect (i.e., interference) is largely immune to top-down control and occurs in an obligatory manner (Hughes, 2014; Hughes et al., 2013; Sörqvist, 2010). Thus, the duplex-mechanism account assumes that interference of order information underlies the changing-state effect, since both serial recall task and automatic sound processing rely on the processing of order information (interference-by-process principle).

Although the ISE is well documented in adults, the performance-reducing effects of irrelevant changing-state sounds have only recently been examined in children. To date, only few developmental studies have examined the influence of irrelevant background sounds on serial recall task performance in children and adults (for a review see Klatte, Bergström, & Lachmann, 2013). Elliott (2002) presented the first study which investigated the impact of the ISE on the performance of participants at different ages (*M*= 8, 9, 11, 19 years). With age, working memory span increased, whereas the impact of irrelevant speech decreased – the ISE was highest for young children and lowest for adults (see also Elliot & Briganti, 2012). In contrast, a study by Klatte, Lachmann, Schlittmeier, and Hellbrück (2010) revealed rather small differences in the ISE between children and adults. In addition, theoretical explanations for developmental changes in the susceptibility to the ISE were different in both these studies.

While Elliott (2002) interpreted the findings in line with theories that stress the importance of attention for the ISE, Klatte et al. (2010) suggested two separate and independent mechanisms similarly to the duplex-mechanism approach adopted by Hughes et al. (2007). Here, the interference process was assumed to be obligatory, not open to top-down control and relatively stable across the life-span, but the component of attentional control is subject to developmental change (Hughes et al., 2013; Klatte et al., 2013; Sörqvist, 2010).

In the present study, we employed a serial recognition task in order to compare changing-state effects in 8 to 10-year-old children and adults. Typically, the changing-state effect is related to tasks which require serial recall (Beaman & Jones, 1997; Huges et al., 2007) or serial order processing (as assessed by serial recognition paradigm, see Gisselgård, Petersson, & Ingvar, 2004; Gisselgård, Udden, Ingvar, & Petresson, 2007). In a serial recognition task, a list of items is presented and then probed by a list that contains the same items, but their order may be altered. Due to this repeated presentation of memory items, the serial recognition tasks should demand memory for order much more strongly than memory for individual items (Gisselgård et al., 2007). The difference in the demand of memory capacity between serial recall and serial recognition is important when it comes to factors that may account for developmental change in the magnitude of the ISE. First, memory functions improve steeply across childhood (Elliott & Briganti, 2012; Henry & Millar, 1991; Swanson, 1999) and, second, recall is assumed to be more affected by irrelevant noise (e.g., traffic noise and meaningful irrelevant speech) than recognition (Hygge, 2003). This may account for the large differences found in the magnitude of the ISE in studies with children (Elliott, 2002; Klatte et al., 2010). When full recall of items and their serial order was required, the magnitude of the ISE was higher (see Elliott, 2002) than when recall of only serial order was tested (see Klatte et al., 2010). The latter can be assumed to capture changing-state effects in the ISE rather than the deviation effect (Gisselgård et al., 2007). According to the duplex-mechanisms account (Hughes et al., 2013) the changing-state effects are not modulated by task difficulty. Moreover, this should apply to children and adults because changing-state effects should remain relatively stable across the life-span (see also Klatte et al., 2010).

Method

Participants

Sixty-eight psychology students (aged 18 to 22 years; M = 20 years) participated in the experiment for course credit. The first group (n = 42, "same task adult group") completed the same task as the children group (n = 30) and consisted of 38 females. The second group of the adult subjects (n = 26, 22 females) completed a task which was adjusted for difficulty ("adjusted difficulty adult group"), so that their performance was comparable to that of the children. The group of children comprised 16 girls and 14 boys (aged 8 to 10 years, M = 9 years, 1 month). All participants reported normal hearing, as well as normal or corrected to normal vision. An informed consent was obtained from all participants, in case of the children also from their parents. Participation was voluntary.

Experimental Design

In this 2x2 mixed independent groups design, the performance on an immediate serial recognition task was investigated in children and adults. The within-subject factors were background sound (speech vs. pink-noise as baseline condition) and task difficulty (low vs. high working memory load). The latter was manipulated by the number of to-be-remembered words in the word list. Word lists comprised either 3 words (low WML) or 6 words (high WML) for children and same task adult group, and 5 (low WML) or 8 (high WML) words for adjusted difficulty adult group, with list length varying randomly. The list lengths were chosen based on pilot-data. The dependent variables were proportion correct (pc) of correctly identified as wrong/right-ordered word lists. An equal number of right and wrong ordered word lists was presented (i.e., 4+4 correct/ wrong word lists in the practice period and 32+32 correct/ wrong word lists in each experimental block).

Material

Memory materials. Stimuli were taken randomly from a list comprising 30 common nouns (animals), and were presented visually as text on a computer screen.

Irrelevant sounds. Serial recognition performance was measured during two different background sounds: A pink-noise (1/f noise) was presented in the baseline condition (1), which does not impair performance but represents auditory stimulation, and in the irrelevant speech condition (2), a text about squirrels was read in the participants` mother language by a male voice which was void of prominent changes in intonation.

Apparatus

The experiment was carried out with Inquisit 3.0 runtime units. Patterns were displayed on Dell Latitude D505 displays in a 1280× 1024 resolution and at a refresh rate of 60 Hz. Participants gave responses on an external Response Pad (Cedrus, Modell RB–830) and wore headphones (Sennheiser, HD 201) for the presentation of the irrelevant speech.

Procedure

Participants were tested individually. They were told that the presented background speech was not relevant for their performance on the memory task and that it should be ignored. Additionally, they were told that only the order of the items had to be remembered and no item should be added or omitted. Further, participants should answer as fast and as accurately as they could. All participants completed two experimental blocks, each comprising 8 practice trails and 64 experimental trials. Practice trials were presented without background sound, but with feedback about correctness, followed by 64 experimental trials with either irrelevant speech or pink-noise as background sound conditions, presented through headphones. Thus, each subject completed 128 experimental trials [2 (sound) x 2 (task difficulty) x 2 (correct/wrong) x 16 (repetitions)]. The background sound condition to start with varied quasi-randomly over participants, and a short break was provided between the two sound conditions. The to-be-remembered words were presented one at a time at the center of the screen in Calibri style, font size 60. The viewing distance was approximately 60 cm. The words were shown at a frequency of 3 seconds per item. Prior to each new stimulus, a fixation cross appeared in the center of the screen for 750 msec. After the last item of each trial, and an interstimulus interval of 750 msec, a word list was presented and participants had to decide whether the words were ordered in their former presentation order (‚right') or not (‚wrong'). In the wrongly ordered word lists two randomly selected adjacent words (but not all words) were presented in a different order (see Figure 1). Furthermore, correct and wrong lists were presented intermixed in a random order. In each trial the words were randomly drawn from the list of 30 words.

The keys (left/ right) of the External Response Pad served for the input of answers (right/ wrong). The keys (left/right) were randomly assigned to represent right/wrong, but remained constant for each participant through two experimental blocks.

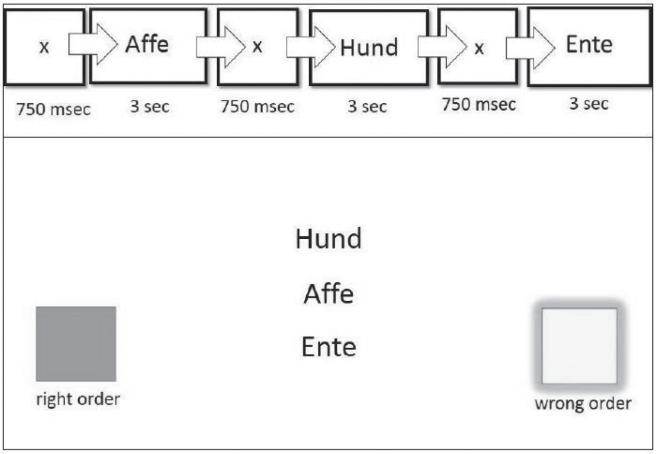

Figure 1. Exemplary trial used for children and adults. The participant correctly identified the wrong order of the items

Results

Proportion correct (pc)

A repeated measurements ANOVA with group (3; same task adult group; adjusted difficulty adult group; children) as a between-subject factor was performed to examine the effects of sound (2; pink-noise vs. speech) and task difficulty (2; low and high working memory load) on the proportion correct (pc) of answers in a serial recognition task. Figure 2 depicts pc data for all three groups.

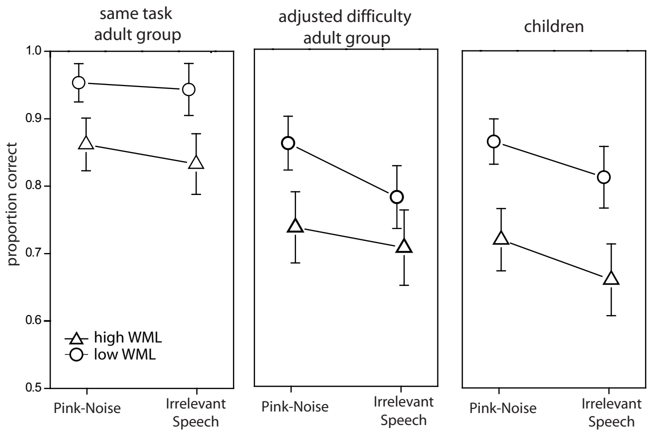

Figure 2. Pc data in the two sound conditions for the three

First, there was a significant main effect of group [$F(2, 95) = 31.82$, p <.001]. The Fisher LSD post-hoc test revealed no differences in performance of the children and the adjusted difficulty adult group ($p = .58$), but both were significantly less accurate than the same task adult group (both p <. 001). Furthermore, overall performance was significantly affected by the sound-condition, being generally higher in the baseline condition (pink-noise) than in the irrelevant speech condition [main effect of sound: $F(1, 95) = 14.53$, p <.001]. Additionally, a significant main effect of task difficulty was found [$F(1, 95) = 102.73$, p <.001], whereby proportion correct dropped strongly with increased memory list length.

Importantly, there was no significant interaction between sound and group [$F(2, 95) = 1.28$, $p = .28$], suggesting that the sound effect was not statistically different in the three groups. Moreover, the interactions between sound, group and task difficulty [$F(2, 95) = .74$, $p = .47$], as well as between sound and task difficulty [$F(1, 95) = .19$, $p = .73$] were not significant, suggesting no impact of task difficulty on the magnitude of the performance decrement during irrelevant speech in three groups (i.e., children, same task adult group and adjusted difficulty adult group).

In sum, the data show that: 1) the changing-state effect was similar in all three groups and 2) the changing-state effect was not affected by task difficulty (in terms of working memory load).

Discussion

The present study aimed to test whether the changing-state effect depends on age and task difficulty by comparing the performance of 8 to 10-year-old children, a same task adult group, and an adjusted difficulty adult group. This was investigated by a serial recognition task with two sound conditions (pink-noise and irrelevant speech), and two levels of working memory load (task difficulty). In this kind of task, subjects are not required to recall the items of the lists, but to decide whether the word order in the test-set is equivalent to the previously shown list of words or not (see also Gisselgård et al., 2007). Irrelevant speech, in the native language of the participants (German), served as a changing-state distractor and pink-noise as baseline condition. Since serial recognition tasks stress memory for order rather than memory for individual items (Gisselgård et al., 2007), the performance effects captured here reflect the changing-state effects resulting from obligatory interference in the processing of serial order information. Our results demonstrate that the interference-based changing-state effect is independent of task difficulty and age. This suggests that whereas the changing-state effect remains the same, the decrease of the ISE with age (as reported by Elliott, 2002 and Klatte et al., 2010) may be related to the improvement of attentional control in childhood (Klatte et al., 2013).

Overall, the same task adult group achieved a higher percentage of correct scores than the children. This is in line with existing evidence which demonstrates progress in cognitive tasks (Henry & Millar, 1991) and improvement in working memory capacity (e.g., Fry & Hale, 1996). The detrimental effect of irrelevant speech on pc was by tendency smaller in the same task adult group than in the children groups. This is at least partially due to differences in overall cognitive functioning and, when task difficulty was low (3 words memory lists), adults showed ceiling performance. However, the patterns in the data were similar in children and the same task adult group as well as in the adjusted difficulty adult group (see also Figure 1). This is supported by the lack of interactions between sound and group. Hence, irrelevant speech affected the performance of all three groups in the same way. At first sight, the similar magnitude of the irrelevant speech effects in adults and children seem to contradict findings from previous studies (Elliott, 2002; Klatte et al., 2010).The data discrepancy is most likely due to the different methodological approaches used in all three studies.

First, the presentation time per item varied strongly between the studies. The item presentation time of 3 seconds was relatively long when compared to the presentation time of 1 second used by Elliott (2002) and Klatte et al. (2010). This may have led to a more efficient encoding and use of rehearsal strategies during the presentation in the trials. The stage of encoding seems to be most predictive for subsequent memory performance, but also particularly vulnerable to distraction (e.g., Craik, Govoni, Naveh-Benjamin, & Anderson, 1996). Since the speed of cognitive processes improves throughout childhood and adolescence (e.g., Fry & Hale, 1996), it could be that the short encoding time affected the performance of children more strongly than that of adults. Similar differences in encoding speed were reported by Meijer and colleagues (Meijer, de Groot, Van Boxtel, Van Gerven, & Jolles, 2006). They found that old-age subjects were affected more negatively by a short interstimulus interval than adults.

Second, the differences between the three studies might be related to distinctions in task demands. In Elliott's study (2002) subjects were required to type the serial answer on the number keypad in the order in which the items were presented. In Klatte et al. (2010), the same pictures were presented on the answer sheet and the recalled order of the items was captured through the numbering of the pictures. In our study, subjects did not have to recall items in their correct order (as in serial recall), but to indicate whether the order of the presented items was correct or not by pressing the corresponding button (serial recognition). Accordingly, it can be questioned whether the same serial recall performance is captured by all three studies, since subjects were faced with clearly different requirements. We argue that the differences in task demands are most relevant for the varying magnitudes of the ISE found in the three studies. It seems that a full serial recall of information from working memory is most sensitive to the disruptive effect of the irrelevant sound, whereas any kind of serial order recognition is less affected (see also Hygge, 2003). If so, the serial recognition task may only capture the changing-state effect as a part of the disrupting impact of irrelevant speech (Gisselgård et al., 2007). The fact that there was no interaction between the effects of irrelevant background speech and task difficulty (i.e., working memory load) supports this view and is in line with the findings by Hughes et al. (2013). They found that, as opposed to the deviation effect, the changing-state effect is not modulated by prior knowledge or task difficulty.

From developmental studies, it can be expected that working memory capacity increases across the childhood (Henry & Millar, 1991; Swanson, 1999). These age-related differences reflect demands on the access of new information and the maintenance of old information in working memory (Swanson, 1999). From the studies on the ISE it is well documented that individuals with higher working memory capacity are less susceptible to the deviation effect as a result of attention capture by irrelevant sounds (Hughes et al., 2013; Sörqvist, 2010). At the same time, there is no relationship between working memory capacity and the changing-state effect (Beaman, 2004; Hughes et al., 2013; Sörqvist, 2010). Indeed, the present study assessed lower working memory capacity in children than in adults. However, there were no interactions between task difficulty and sound or group, task difficulty and sound. Both findings suggest that the differences in working memory load were not related to the magnitude of the ISE. Since the ISE in the serial recall task used here is due to the interference in sequence processing (i.e., the interference-by-process mechanism), the results presented here support previous findings which suggest that differences in working memory capacity and task difficulty do not affect the changing-state effect (Beaman, 2004; Hughes et al., 2013; Sörqvist, 2010).

In sum, the present study provides new evidence of the development of the ISE and contributes to the understanding of the duplex-mechanism account of auditory distraction (Hughes et al., 2007, 2013).

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