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7 Psychology, 126, doi: 10.1016/j.biopsycho.2017.04.007

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9 **Task-optimal auditory attention set restored as fast in older as in younger**  
10 **adults after distraction**

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35 pages (including 7 figures and 1 table)

1 **Abstract**

2 The present study investigated how fast younger and older adults recovered from a distracted  
3 attentional state induced by rare, unpredictable sound events. The attentional state was  
4 characterized by the auditory N1 event-related potential (ERP), which is enhanced for sound  
5 events in the focus of attention. Younger (19-26 years) and older (62-74 years) adults listened to  
6 continuous tones containing rare pitch changes (glides) and short gaps. Glides and gaps could be  
7 separated in 150 ms, 250 ms, 650 ms or longer and the task was gaps detection while ignoring  
8 glides. With longer glide-gap separations similar N1 enhancements were observable in both  
9 groups suggesting that the duration of the distracted sensory state was not affected by aging.  
10 Older adults responded, however, slower at short glide-gap separations which indicated that  
11 distraction at subsequent levels of processing may have nonetheless more impact in older than in  
12 younger adults.

13

14 Keywords: attention, distraction, aging, N1

15

## 1 Introduction

2 Aging is associated with deteriorated frontal lobe functions which result in a decreased  
3 ability to inhibit the processing of irrelevant information (Guerreiro, Murphy & Van Gerven,  
4 2010; Hasher, Lustig & Zacks, 2007; Zanto & Gazzaley, 2014). This leads to greater  
5 susceptibility to distraction, that is, an inability to filter out task-irrelevant aspects of stimulation  
6 (Chao & Knight, 1997; Lustig, Hasher & Zacks, 2007; Mager et al., 2005). Numerous studies  
7 demonstrated that the impact of distracters on task-performance was stronger in older than in  
8 younger adults (e.g. Berti, Grunwald & Schröger, 2013; Carlson, Hasher, Connelly & Zacks,  
9 1995; Woods, 1992). Distraction, however, is not a unitary phenomenon, and ageing may affect  
10 some distraction-related processes while sparing others, which might be reliably delineated by  
11 method of event-related potentials (ERPs). Differences in distraction-related processes can be  
12 reflected by amplitude- or latency-differences in specific ERP components (Escera & Corral,  
13 2003; Horváth, Winkler & Bendixen, 2008). For example, Chao and Knight (1997) suggested  
14 that the age-related enhancement of the Pa mid-latency auditory ERP reflected decreased  
15 inhibition of incoming stimulation. Moreover, based on P3a latency differences, Horváth,  
16 Czigler, Birkás, Winkler and Gervai (2009) suggested that involuntary attention switching took  
17 longer in older than in the younger adults. The goal of the present study was to investigate how  
18 fast younger and older adults could restore the task-optimal attention set after distraction  
19 occurred. We utilized a recently developed, continuous stimulation distraction paradigm (Horváth  
20 & Winkler, 2010; Horváth, 2014a), which relies on the attentional modulation of the auditory N1  
21 ERP.

22 In most studies investigating the effect of aging on distraction and its electrophysiological  
23 correlates, involuntary attention switching was induced by rare (oddball) stimuli which broke the  
24 regularity of a sequence comprising frequent stimuli. Distraction was characterized by rare-  
25 minus-frequent (behavioral or ERP) response differences. Studies comparing distraction effects  
26 between younger and older adults showed either no significant differences or differences with the  
27 same sign. Specifically, behavioral distraction effects (e.g. rare-minus-frequent reaction time  
28 differences) were mostly comparable between younger and older adults (Amenedo & Diaz, 1998;  
29 Gaeta, Friedman, Ritter & Cheng, 1998; Getzman, Gajewski & Falkenstein, 2013; Horváth et al,  
30 2009; Iragui, Kutas, Mitchiner & Hillyard, 1993; Leiva, Parmentier & Andrés, 2014; Mager et

1 al., 2005), or, in some cases, older adults were more impacted by distracters (i. e. larger reaction  
2 time increase to rare stimuli, see Berti, Grunwald and Schröger, 2013; Woods, 1992).

3 The ERPs observable in the rare-minus-frequent difference waveform are generally  
4 interpreted as reflections of distraction-related processes: Sensory change- and deviance detection  
5 is thought to be reflected by the mismatch negativity (MMN, Näätänen, 1982), and the  
6 enhancement of the N1; the involuntary change in attentional orientation (distraction) is reflected  
7 by the P3a (Friedman, Cycowicz & Gaeta, 2001; Polich, 2007). Most studies found that in older  
8 adults the ERP amplitudes were smaller (MMN: Getzman, Gajewski & Falkenstein, 2013;  
9 Horváth et al., 2009; P3a: Gaeta et al., 1998; Iragui et al., 1993), or similar to those recorded in  
10 younger adults (MMN: Amenedo & Diaz, 1998; Berti, Grunwald & Schröger, 2013; Gaeta et al.,  
11 1998; Mager et al., 2005; P3a: Berti, Grunwald & Schröger, 2013; Getzman, Gajewski &  
12 Falkenstein, 2013; Mager et al., 2005). Similarly, the distraction-related ERPs were delayed (P3a:  
13 Gaeta et al., 1998; Getzman, Gajewski & Falkenstein, 2013; Horváth et al., 2009; Mager et al.,  
14 2005) or were elicited with similar latency as in younger adults (MMN: Amenedo & Diaz, 1998;  
15 Gaeta et al., 1998; Getzman, Gajewski & Falkenstein, 2013; Horváth et al., 2009; Mager et al.,  
16 2005).

17 In the present study, we utilized a different approach to measure the effects of distraction  
18 (Horváth & Winkler, 2010). Instead of interpreting the ERPs observable in the rare-minus-  
19 frequent difference waveforms, the present study exploited the well-known attentional  
20 modulation of the auditory N1 waveform to measure the time of recovery from distraction. In the  
21 following, we first briefly summarize the literature on the effects of attention on the N1. Then an  
22 overview of the studies suggesting that N1 might be a suitable tool to measure the recovery time  
23 from a distracted state is presented. Finally, we discuss these phenomena in the context of aging.

24 N1 is associated with the detection of change in auditory stimulation (Näätänen & Picton,  
25 1987). Numerous studies found that N1 was enhanced when the eliciting auditory event was in  
26 the focus of attention or the attention set was optimal to perform the task (Hansen & Hillyard,  
27 1980; Hillyard, Hink, Schwent & Picton, 1973; Lange, 2013; Okamoto, Stracke, Wolters,  
28 Schmael & Pantev, 2007). In contrast, attentional disruptions led to reduced N1 amplitudes  
29 (Horváth & Winkler, 2010; Horváth, 2014a, 2014b). The attentional enhancements might not  
30 only reflect a genuine N1 modulation, but also the emergence of other ERP components (Woods

1 & Clayworth, 1987), like the negative difference (Nd: Hansen & Hillyard, 1980) or processing  
2 negativity (PN: Alho, Paavilainen, Reinikainen, Sams & Näätänen, 1986; Alho, 1992; Näätänen,  
3 1982), which may overlap with the N1 (Näätänen, 1982; Woods & Clayworth, 1987). However,  
4 Nd and PN can be separated from the N1, because in contrast to the N1, they do not show a  
5 polarity inversion at the mastoids when the EEG is recorded with a nose reference (Alho et al.,  
6 1986). While the enhancement of N1 is considered to reflect enhanced auditory event and feature  
7 detection (Näätänen & Winkler, 1999), Nd and PN are regarded as correlates of voluntary, task-  
8 relevant processes, possibly indicating template-matching to the attentional trace (Alho, 1992;  
9 Näätänen, 1982), and related to sustained attention (Jemel, Oades, Oknina, Achenbach &  
10 Röpcke, 2003).

11 That the modulation of the N1 amplitude could be used to measure the recovery time from  
12 a distracted state is supported by several studies. First, Schröger (1996) found that when tone  
13 pairs were presented to participants, response accuracy to the second tone was reduced when it  
14 was preceded by a distracter in 200 ms (in comparison to those preceded by a distracter in 560  
15 ms). The performance decrease was accompanied by a positive shift in the ERP at around 100 ms  
16 following the tone onset. Because the positive shift also followed the distracter by about 300 ms,  
17 it could not be, however, decided whether it reflected an attenuation of the target-related N1, or  
18 the distracter-related P3a. Studies using the continuous stimulation paradigm introduced by  
19 Horváth and Winkler (2010) showed that task-relevant auditory events indeed elicited lower  
20 amplitude N1s when shortly preceded by distracter events. In this paradigm, continuous tones are  
21 presented, which alternate between two pitches by rare, short glissandos (glides). The  
22 participants' task is to detect and respond to frequently occurring short silent periods (gaps) while  
23 ignoring the glides. It was found that a 150 ms glide-gap separation resulted in reduced gap-  
24 related N1s and lower gap detection rates in comparison to gaps not preceded by other events in  
25 at least 1300 ms. In a later study using the continuous stimulation paradigm Horváth (2014a)  
26 found that the distraction effects (N1 amplitude and detection rate reductions) did not last longer  
27 than 650 ms. These results fit well into the literature of the auditory attentional blink (see for  
28 example, Shen & Mondor, 2006; Tremblay, Vachon & Jones, 2005). In most attentional blink  
29 paradigms, two target stimuli are embedded in a rapid tone-sequence, and detection of the second  
30 target is impacted when the separation of the targets is short (e.g. shorter than 270 ms: Horváth &  
31 Burgyán, 2011; 90-150 ms: Shen & Alain, 2010). Furthermore, Shen and Alain (2010) found that

1 the second target elicited lower-amplitude N1 when it was immediately preceded by the first  
2 target, in comparison to the case when the targets were separated by six intervening tones.

3 N1 elicitation also differs between age groups. For N1s elicited by tone onsets, N1  
4 amplitude was mostly found to be higher in older adults (Anderer, Semlitsch & Saletu, 1996;  
5 Amenedo & Diaz, 1998; Chao & Knight, 1997), or no age-related differences were observed  
6 (Getzman, Gajewski & Falkenstein, 2013; Horváth et al., 2009; Mager et al., 2005; Pfefferbaum,  
7 Ford, Roth & Koppel, 1980; Woods, 1992; but see also Berti, Grunwald & Schröger, 2013). In  
8 contrast, gaps in continuous tones seem to elicit lower amplitude N1s in older than in younger  
9 adults (Alain, McDonald, Ostroff & Schneider, 2004; Harris, Wilson, Eckert & Dubno, 2012).

10 Experimental data on the duration of the distracted state induced by rare auditory events,  
11 and its dependence on age is scarce. Slawinski and Goddard (2001) presented short sinusoidal  
12 tones in a rapid auditory stream, and participants had to identify the pitch (low, medium, high) of  
13 the tone with higher sound pressure than the others. When only the probe stimulus was presented  
14 with higher sound pressure, both groups completed the task adequately, although the younger  
15 adult group slightly outperformed older adults. When both probe and targets were salient, the  
16 performance of older adults was significantly reduced compared to the younger adult group in  
17 general, and older adults showed an impaired performance in time intervals from 90 to 450 ms.  
18 Both groups detected probes poorly from 90 to 360 ms, suggesting that recovery from distraction  
19 – reflected by behavioral indices – happens by about 360 ms in younger adults and slightly later  
20 in the older adults.

21 Based on the studies summarized above, the aim of the present study was to compare the  
22 duration of the distracted sensory state induced by task-irrelevant, rare stimuli between older and  
23 younger adults, as reflected by the modulation of the N1 ERP. We administered the continuous  
24 stimulation paradigm introduced by Horváth and Winkler (2010) with minor modifications. The  
25 participants' task was to listen to the continuous tone and press a button when a gap occurred,  
26 while ignoring glides. The presentation frequency of the glides (serving as task-irrelevant  
27 distracter events) was identical to the one used in the study by Horváth and Winkler (2010), that  
28 is, they could occur with 1/7 probability at every 1300 ms. Glides preceded potential gap-  
29 positions by 150, 250 or 650 ms. Gaps were presented with 50% probability every 1300 ms at  
30 one of these time-points. Gaps not preceded by any glides in at least 1450 ms (gap only trials)

1 allowed the measurement of the maximal gap-related N1 amplitude. We hypothesized that shorter  
2 glide-gap separations would lead to stronger N1 amplitude reductions because the optimal  
3 attention set for detecting a gap could not be fully restored after distraction occurred. We also  
4 hypothesized that in older adults, the effects of distraction – manifested in lower N1 amplitudes –  
5 would persist longer.

6

## 7 **Methods**

### 8 *Participants*

9           52 healthy adult women participated in the experiment: 25 younger (age: from 19 to 26;  
10 mean: 22.2 years) and 27 older (age: from 62 to 75; mean: 67.5 years) adults. Because of  
11 excessive amount of eye movement artifacts (3 younger adults) or poor task performance (false  
12 alarm rates above 40% - further 1 younger, and 9 older adults, or detection rates for 150 and 250  
13 ms gaps below 66% - resulting in low epoch numbers – another 5 younger and 2 older adults),  
14 only 32 participants remained in the final analyses. That is, our results are based on the  
15 behavioral and ERP data of 16 younger (age: from 19 to 26; mean: 22.6 years) and 16 older (age:  
16 from 62 to 74 years, mean: 67.3 years) persons. Participants were free of any neurological or  
17 psychiatric disease by their own admission. They were compensated by modest amounts of  
18 money for taking part in the experiment. The study was approved by the United Ethical Review  
19 Committee for Research in Psychology (Hungary), and all participants gave written informed  
20 consent.

21           All participants reported correct or corrected-to-normal vision. Only persons with hearing  
22 threshold differences not more than 20 dB between the two ears in the 250 - 2000 Hz range (as  
23 measured by a SA-6 audiometer, MEDIROLL, Debrecen, Hungary) participated in the  
24 experiment. Older adults had higher thresholds than younger adults at all frequencies (see Table  
25 1). To compensate for threshold differences, the amplitude of the experimental sounds were  
26 individually adjusted to 50 dB above the 75% hearing threshold for the continuous tone used in  
27 the experiment (as described below), using the single interval adjustment matrix (SIAM) method  
28 (Kaernbach, 1990; Shepherd, Hautus, Stocks & Quek, 2011). The older adult group was  
29 characterized with significantly higher IQ score than the younger adult group (Welch's unequal

1 variances t-test:  $t[29.521] = 4.963, p < .001$ ) as assessed by the Hungarian version of the  
2 Wechsler Intelligence Scale (WAIS-IV; Wechsler, 2008) administered in a separate session. The  
3 total mean score was 130.8 (SD = 14.18) in the older adults and 107.3 (SD = 12.4) in the younger  
4 adults group, suggesting that both groups were characterized with intelligence higher than the  
5 average as shown by one-sample Student's t-tests (older adults:  $t[15] = 8.673, p < .01$ ; younger  
6 adults:  $t[15] = 2.344, p = .03$ ).

7

### 8 *Stimuli and procedure*

9 Participants were sitting in a comfortable chair in a dimly lit, sound-attenuated room and  
10 listened to 4-minutes-long continuous tones through Sennheiser (HD-600, Sennheiser,  
11 Wedemark, Germany) headphones. The tones were generated with Csound version 5.17.11  
12 ([www.csounds.com](http://www.csounds.com)), with a sampling rate of 44.1 kHz. The tones consisted of three harmonics:  
13 the fundamental and the second and third harmonics (the first harmonic was missing), with equal  
14 amplitude. The base frequency was either 220 Hz (low) or 277 Hz (high), and the pitch of the  
15 tone changed occasionally from high to low, or low to high with a 10 ms transition time (glide).  
16 Glides could occur in the 4 minutes-long continuous tone at discrete time points separated by  
17 1300 ms steps, and they occurred randomly with 14.28% probability at each time point, with the  
18 constraint that successive glides were separated by at least 3900 ms. That is, in average, 27 glides  
19 were presented in a block. Beside glides, short gaps (10 ms long silent periods preceded by a 10  
20 ms linear fall and followed by a 10 ms linear rise) were also inserted in the tone. Gaps could  
21 occur at time points following the potential glide-time points within 650 ms with 50%  
22 probability. 35.7% of such gaps followed the potential glide time point by 150 ms, 28.6% by 250  
23 ms, and 35.7% by 650 ms. Gaps following actual glides within 650 ms, are referred to as *150 ms*,  
24 *250 ms and 650 ms gaps* in the following. The rest of the gaps (i.e. those which were not  
25 preceded by a glide within 1450 ms) are termed "*gap only*" trials. The schematic illustration of  
26 the tones including glides and gaps is presented in Fig. 1.

27 Participants performed a gap detection task: they were instructed to press a button held in  
28 their dominant hand when they detected a gap, while ignoring the glides. The first block was a  
29 training block which allowed participants to get familiar with the task. After the training block,



1 15 experimental blocks were presented. Each block started with a black “START” text displayed  
2 on grey background. After 10 s, the “START” text changed to a black fixation cross and the tones  
3 started to play. At the end of each block, feedback about the gap detection rate (the ratio of  
4 correctly detected gaps to all presented gaps) and the mean reaction time was displayed on the  
5 screen. Between the blocks, short (1-2 min) pauses were available as needed, with a longer (5-10  
6 min) break after the 7<sup>th</sup> experimental block.

7

### 8 *EEG recording*

9 The continuous EEG was recorded with a sampling rate of 500 Hz (with 100 Hz online  
10 lowpass filtering) with a Neuroscan Synamp 2 (Compumedics Inc., Victoria, Australia) amplifier  
11 with 61 Ag/AgCl electrodes mounted on an elastic cap (EASYCAP GmbH, Herrsching,  
12 Germany) arranged according to the 10% system (Nuwer, 1998). Two additional electrodes were  
13 placed at the mastoids. The reference electrode was placed on the tip of the nose and the ground  
14 electrode was attached on the forehead. Horizontal electro-oculogram was measured by  
15 electrodes attached near the outer canthi of the left and the right eye, and the vertical electro-  
16 oculogram was calculated offline as the difference of the signal between the Fp1 electrode and an  
17 additional electrode placed under the left eye. The continuous EEG data was filtered offline using  
18 a 30 Hz lowpass filter (Kaiser-windowed sinc finite impulse response filter, beta of 5.65, 907  
19 coefficients; 2 Hz transition bandwidth, stopband attenuation at least 60 dB).

20 For an overview of the ERP epochs selected for the analyses, see Figure 2. For all the  
21 ERP analyses, glides and gaps with no keypresses in the preceding 300 ms were selected, as well  
22 as gaps following such glides in 150 ms, 250 ms or 650 ms. “*Gap only*” trials were also selected:  
23 these gaps were not preceded by a glide in at least 1450 ms or by another gap in at least 3400 ms,  
24 that is, no distracting events were present before them. To estimate the gap-related ERP activity  
25 without potentially overlapping glide-related ERP waveforms, timepoints were selected in which  
26 gaps could but did not occur (i. e. 150 ms, 250 ms and 650 ms after potential glide timepoints and  
27 after the onset of glides which were not followed by any events in 650 ms), labeled as *control*  
28 *gaps*. 800 ms long epochs were extracted for each of these time-points including a 150 ms pre-  
29 timepoint baseline. Epochs with a signal range exceeding 150  $\mu$ V on any channel were discarded

1 from further processing. Average ERPs calculated from the control epochs were subtracted from  
2 the corresponding gap-related (150 ms, 250 ms, 650 ms and gap only) average ERPs. The  
3 resulting waveforms are referred to as *corrected* waveforms in the following. The averaged  
4 ERPs, control gaps and the corrected waveforms are presented in Fig 2.

5

## 6 *Statistical analyses*

7 Reaction times were analyzed only for detected gaps which were not preceded by any  
8 keypress in 300 ms, separately for each glide-gap separation (150 ms, 250 ms and 650 ms and  
9 gap only). Only responses which occurred between 120 ms and 1000 ms after the gap onset were  
10 included into analysis. Median reaction times were calculated for every participant, which were  
11 submitted to Group (younger adults / older adults)  $\times$  Gap Type (150 ms / 250 ms / 650 ms / gap  
12 only) ANOVA. Detection rates were submitted to an ANOVA of the same structure. The number  
13 of false alarms was also calculated by selecting glides with no preceding events in 300 ms which  
14 were followed by a keypress in 120 to 1000 ms. The ratio of these responses to all presented  
15 glides defined the false alarm rate which was compared between groups by Welch's t-tests.

16 Although our primary hypotheses were related to the modulation of N1 component, later  
17 waveforms (P2, N2, P3b) were elicited and modulated as well, therefore we included them into  
18 the analysis. Gap-related ERPs (N1, P2, N2, P3b) were identified in the group-average corrected  
19 waveforms for detected "gap only" trials. Individual N1, P2 and N2 amplitudes were measured as  
20 the average signal in a 20 ms long windows centered at the "gap only" peak latency in a fronto-  
21 central (FCz, Cz, Fz, FC1 and FC2) electrode cluster; P3b amplitudes were measured as the  
22 average signal in 100 ms long window centered at the "gap only" peak latency at a parietal  
23 cluster (Pz, POz, CPz, P1, P2) of electrodes to enhance signal-to-noise ratio. The "gap only"  
24 amplitudes were compared by Welch's t-tests between groups, then one-way ANOVAs were  
25 used to assess for different Gap Types (150 ms / 250 ms / 650 ms / gap only) separately for the  
26 two groups. Significant Gap Type effects were followed up by pairwise t-tests. To compare the  
27 glide-gap separation related modulation of the N1 amplitude between groups, the amplitudes  
28 were normalized by the gap-related N1 amplitudes measured in the corrected gap only  
29 waveforms for each group. These normalized amplitudes were submitted to Group (younger

1 adults / older adults)  $\times$  Gap Type (150 ms / 250 ms / 650 ms) ANOVAs. Glide-related N1 and  
2 P2 amplitudes measured at the fronto-central cluster for glides which were not followed by any  
3 gaps in 650 ms (*glide only*) were compared between younger and older adults groups using  
4 Welch's t-test. All statistical tests were conducted by using R (version 3.1.0, R Core Team,  
5 2014). Generalized eta squared ( $\eta^2_G$ ) effect sizes are also reported (Olejnik & Algina, 2003;  
6 Bakeman, 2005).

7

## 8 **Results**

### 9 *Behavioral performance*

10 Reaction times and gap detection rates are presented in Fig. 3. The Group  $\times$  Gap Type  
11 ANOVA of the reaction times showed a significant Gap Type main effect ( $F[3, 90] = 16.45, p <$   
12  $.001, \eta^2_G = .07$ ), and a significant Group  $\times$  Gap Type interaction ( $F[3, 90] = 4.83, p = .004, \eta^2_G =$   
13  $.022$ ). The Group main effect was not significant ( $F[1, 30] = .002, p = .961, \eta^2_G < .001$ ).  
14 Analyzing the two groups separately, in older adults a Gap Type main effect was found:  $F(3, 45)$   
15  $= 20.07, p < .001; \eta^2_G = .11$ , which was followed up by pairwise t-tests. Responses were  
16 significantly slower with decreasing glide-gap separations (i.e. all but the 650 ms vs. gap only  
17 comparison showed significant differences: t-scores  $> 3.238$ , p-values  $< .01$ ). In contrast, no  
18 significant Gap Type effect was found in the younger adults group:  $F(3, 45) = 2.67, p = .06, \eta^2_G =$   
19  $.04$ .

20 The ANOVA of the gap detection rates (Fig. 3., right) showed a significant Gap Type  
21 main effect only:  $F(3, 90) = 6.946, p < .001, \eta^2_G = .093$ , indicating that participants in both age  
22 groups detected more gaps with increasing glide-gap separation. Neither the Group main effect  
23 ( $F[1, 30] = .778, p = .385, \eta^2_G = .014$ ), nor the Group  $\times$  Gap Type interaction effects were  
24 significant ( $F[3, 90] = .58, p = .63, \eta^2_G = .001$ ).

25 Participants could also inadvertently respond to glides as well, not only to gaps. To assess  
26 this, we selected glide only trials (no following gaps in 650 ms) and the ratio of keypresses to  
27 them in 120 to 1000 ms interval was calculated. The occurrence rate of such false alarms did not  
28 differ between the older and younger adults ( $t[21.542] = .385, p = .703$ ): older adults responded

1 in average to 11.72% of glides and younger adults in 12.74% (note that participants with higher  
2 than 40% false alarm rate were omitted from the original sample).

3

#### 4 *Event-related potentials*

5 Individual ERPs were averaged separately for the two age groups and for the four gap  
6 types (gap only, 150 ms, 250 ms, 650 ms) on the corrected waveforms, as well as for glide only  
7 trials. The average number of epochs in the younger adults group was 50 ( $\pm 12$ ) for 150 ms gaps,  
8 41 ( $\pm 9$ ) for 250 ms gaps, 51 ( $\pm 11$ ) for 650 ms gaps, 604 ( $\pm 95$ ) for gap only trials and 138 ( $\pm 20$ )  
9 for glide only trials. In the older adults group, the number of epochs was 58 ( $\pm 12$ ) for 150 ms  
10 gaps, 44 ( $\pm 9$ ) for 250 ms gaps, 55 ( $\pm 8$ ) for 650 ms gaps, 666 ( $\pm 96$ ) for gap only trials and 150  
11 ( $\pm 20$ ) for glide only trials.

12 On the corrected gap only waveforms, a negativity (N1) was peaking at 152 ms at FCz in  
13 the younger and at 160 ms at Cz electrode in the older adult group. However, the mastoid polarity  
14 inversion peaked earlier in both groups (114 ms in the younger and 110 ms in the older adults),  
15 suggesting that the fronto-central waveform included multiple components: a supra-temporal N1  
16 and a PN (or Nd; Alho, 1986). Indeed, in the older adult group, two slightly overlapping peaks  
17 were elicited for short glide-gap separations. In the younger adults, these components might have  
18 completely overlapped, resulting in only a single observable peak. To investigate whether the  
19 supra-temporal N1 component was affected, an additional analysis was conducted in the time  
20 window of the earlier (mastoid) peak both at the fronto-central cluster and at the averaged  
21 mastoids. In the younger adults group, N1/PN was followed by a positivity (P2) peaking at 218  
22 ms at Cz lead but this component was absent in the older adults. Although a well identifiable P2  
23 was not present in the older adult group, a positive peak was nonetheless observable at 230 ms at  
24 AF8 electrode in the group-average corrected gap only ERP, therefore, in the older adult group  
25 the P2 amplitude was characterized as the average signal in the 220-240 ms interval. P2 was  
26 followed by a negativity (N2), peaking for gap only trials at 326 ms at Fz in the younger adults  
27 and at 328 ms at C1 in the old adult group. The P3b waveform for gap only trials reached its  
28 maximum amplitude at Pz in both groups, with 428 ms latency in the younger adult group, and at  
29 504 ms in the older adult group.

1           Glide only trials elicited a clear N1 in both groups, peaking at 130 ms at FCz in the  
2 younger, and at 106 ms at Fz in the older adults. The ERP amplitudes were compared between  
3 the two groups using Welch's t-test. In the younger adult group, N1 was followed by a P2  
4 peaking at 206 ms at Cz. This component was less obvious in the older adult group (the  
5 maximum amplitude peak was at AF8 at 216 ms). The ERP results are plotted in Fig. 4 and the  
6 corresponding scalp topographies of the analyzed components are presented in Fig. 6 and Fig. 7.

7           In the later N1 time window, younger adults exhibited significantly higher (more  
8 negative) amplitudes in the corrected gap only waveforms than older adults ( $t[29.382] = -3.14$ ,  $p$   
9  $= .004$ ). Therefore, we compared the amplitudes elicited by the four Gap Types, separately for the  
10 two age groups. Significant Gap Type main effects were present both in the younger ( $F[3, 45] =$   
11  $23.133$ ,  $p < .001$ ,  $\eta^2_G = .28$ ) and the older adult group ( $F[3, 45] = 6.462$ ,  $p < .001$ ,  $\eta^2_G = .138$ ).  
12 The follow-up paired t-tests revealed that in the younger adults all four amplitudes differed from  
13 each other (all t values  $> 3.218$ ; all p values  $< .006$ ), except for the 650 ms gaps and gap only  
14 trials which were similar ( $t[15] = .068$ ,  $p = .947$ ). In the older adults, the 150 ms gaps amplitudes  
15 differed only from 650 ms ( $t[15] = 2.739$ ,  $p = .015$ ) and from gap only trials ( $t[15] = 3.999$ ,  $p =$   
16  $.001$ ); and the 250 ms gap amplitudes were also lower than amplitudes elicited by gap only trials  
17 ( $t[15] = 2.459$ ,  $p = .027$ ). For the normalized amplitudes, the Group  $\times$  Gap Type ANOVA  
18 showed only a significant Gap Type main effect ( $F[2, 60] = 16.661$ ,  $p < .001$ ,  $\eta^2_G = .163$ ),  
19 indicating that N1 amplitudes increased with increasing glide-gap separation (Fig. 5, left).  
20 Neither the main effect of Group ( $F[1, 30] = .012$ ,  $p = .914$ ,  $\eta^2_G < .001$ ), nor the Group  $\times$  Gap  
21 Type interaction ( $F[2, 60] = .335$ ,  $p = .717$ ,  $\eta^2_G = .004$ ) were significant, however. For  
22 normalized amplitudes, see Fig.3.

23           In the earlier N1 time window (i.e. at the latency of the mastoid polarity inversion),  
24 amplitudes in the corrected gap only waveforms did not differ in the two groups at the fronto-  
25 central electrodes ( $t[29.376] = .267$ ,  $p = .792$ ). The Group  $\times$  Gap Type ANOVA for normalized  
26 amplitudes showed no significant effects (Group main effect:  $F[1, 30] = 1.392$ ,  $p = .247$ ,  $\eta^2_G =$   
27  $.03$ ; Gap Type main effect:  $F[2, 60] = 3.131$ ,  $p = .051$ ,  $\eta^2_G = .034$ ; Group  $\times$  Gap Type interaction:  
28  $F[2, 60] = 1.83$ ,  $p = .169$ ,  $\eta^2_G = .02$ ). No significant amplitude differences were found at the  
29 mastoids either (between-group amplitude differences in the corrected gap only waveforms:  
30  $t[29.976] = .748$ ,  $p = .46$ ; for the Group  $\times$  Gap Type ANOVA for normalized amplitudes: Group

1 main effect:  $F[1, 30] = 1.863, p = .182, \eta^2_G = .026$ ; Gap Type main effect:  $F[2, 60] = 1.136, p =$   
2  $.328, \eta^2_G = .021$ ; Group  $\times$  Gap Type interaction:  $F[2, 60] = 1.806, p = .173, \eta^2_G = .033$ ).

3 Because the gap-related P2 waveform was not readily observable in older adults (see  
4 Fig.6), we analyzed the amplitudes without normalizing the data in Group (younger adults / older  
5 adults)  $\times$  Gap Type (150 ms / 250 ms / 650 ms / gap only) ANOVA. Not only the main effects of  
6 Group ( $F[1, 30] = 15.922, p < .001, \eta^2_G = .259$ ) and Gap Type ( $F[3, 90] = 4.464, p = .006, \eta^2_G =$   
7  $.048$ ) were significant, but the Group  $\times$  Gap Type interaction as well:  $F(3, 90) = 4.253, p = .007,$   
8  $\eta^2_G = .046$ . Analyzing the two groups separately, while Gap Type did not affect the amplitudes  
9 in the P2 time window in the older adults ( $F[3, 45] = .079, p = .97, \eta^2_G = .002$ ), younger adults  
10 exhibited significantly lower amplitudes as glide-gap separation interval decreased ( $F[3, 45] =$   
11  $8.66, p < .001, \eta^2_G = .161$ ). Following-up the main effect in the younger adult group, paired t-  
12 tests revealed that the amplitudes of 150 ms gaps were significantly lower than 650 ms gaps  
13 ( $t[15] = -3.041, p = .008$ ) and gap only trials ( $t[15] = -3.096, p = .007$ ). The amplitudes of 250 ms  
14 gaps also differed from 650 ms gaps ( $t[15] = -3.346, p = .004$ ) and from gap only amplitudes  
15 ( $t[15] = -3.539, p = .003$ ).

16 Because of the obvious overlap between the N2 and P3b waveforms (Fig. 4 and Fig. 7),  
17 corrected amplitudes in the N2 time-range were submitted without normalization to a Group  
18 (younger / older adults)  $\times$  Gap Type (150 ms / 250 ms / 650 ms / gap only) ANOVA. The  
19 ANOVA revealed neither a significant Group main effect ( $F[1, 30] = 2.326, p = .138, \eta^2_G = .051$ ),  
20 nor a Group  $\times$  Gap Type interaction ( $F[3, 90] = .838, p = .477, \eta^2_G = .009$ ). Only a significant  
21 Gap Position main effect was found:  $F(3, 90) = 9.69, p < .001, \eta^2_G = .09$ , showing that glide-gap  
22 separation intervals had similar effect on N2 amplitudes in both groups.

23 The P3b in gap only trials was elicited with significantly higher amplitudes in the younger  
24 adult group than in the older adult one ( $t[29.211] = 2.615, p = .013$ ). Analyzing the groups  
25 separately, the corrected amplitudes did not differ from each other in the younger adult group  
26 ( $F[3, 45] = .626, p = .602, \eta^2_G = .014$ ), whereas in the older adults, the Gap Type main effect was  
27 significant:  $F(3, 45) = 6.251, p = .001, \eta^2_G = .084$ . The amplitude of gap only trials was higher  
28 than any other gap types (150 ms gaps:  $t[15] = -3.045, p = .008$ ; 250 ms gaps:  $t[15] = -2.344, p =$   
29  $.033$ ; 650 ms gaps:  $t[15] = -4.402, p < .001$ ) and the difference between 150 ms gaps and 650 ms  
30 gaps was also significant ( $t[15] = 2.132, p = .05$ ). Glide-related N1 and P2 amplitudes were

1 compared between older and younger adult groups by Welch's t-test on the same fronto-central  
2 cluster as in case of gap-related ERPs. For the N1 no significant difference was found ( $t[28.536]$   
3  $= 1.302$ ,  $p = .203$ ), however, P2 amplitude was significantly higher in the younger than in the  
4 older adult group ( $t[29.882] = -4.224$ ,  $p < .001$ ).

5

## 6 **Discussion**

7         The goal of the present study was to measure how fast younger and older adults restored  
8 task-optimal attention set after distraction occurred. To characterize the duration of the distracted  
9 state, N1 amplitudes elicited by gaps were measured in a gap detection task in which the temporal  
10 separation between distracters (glides) and targets (gaps) was manipulated. In younger adults,  
11 gaps elicited a series of N1, P2, N2 and P3b waveforms; in older adults, however, P2 was absent.  
12 N2 and P3b overlapped partially. Gaps elicited smaller N1s in older than in younger adults; the  
13 magnitude of N1 reduction with decreasing glide-gap separation was, however, similar in the two  
14 groups. The lack of polarity inversion at the mastoids in the time window of the negative fronto-  
15 central N1 peak suggests that the amplitude reduction was not caused by the modulation of the  
16 auditory N1 subcomponent, rather, that it was caused by the absence of an additional negativity,  
17 presumably a PN reflecting the matching of the auditory event to a task-relevant sensory  
18 template. With shorter glide-gap separations accuracy decreased. Whereas older adults responded  
19 systematically slower as glide-gap separations got shorter, glide-gap separation did not  
20 significantly influence reaction times in younger adults. The distracter glides elicited similar N1s  
21 in both groups, but P2 was more pronounced in younger adults.

22         The lower gap-related N1 amplitudes in the older than in younger adults, are in line with  
23 previous studies (Alain et al., 2004; Harris et al., 2012); and the modulation of N1 amplitudes  
24 also fits, and extends the literature. The decreased N1 amplitudes at 150 and 250 ms glide-gap  
25 separation suggest that the distracted state persisted for at least 250 ms, while the lack of  
26 difference between the N1s elicited in the gap only and the 650 ms glide-gap separation trials  
27 suggest that attention was restored by 650 ms after distraction occurred. These results are on a par  
28 with the results by Schröger (1996), Horváth (2014a) and Horváth and Winkler (2010). The  
29 topographical distribution of the N1-effect (no polarity inversion at the mastoids) and its latency

1 (i.e. peaking later than the positive N1 aspect at the mastoids) also support the notion (Horváth,  
2 2014a) that the modulation of the N1 waveform might be not a “genuine” modulation of the  
3 auditory N1 subcomponent, but the modulation of the overlapping processing negativity which is  
4 characteristically elicited by task-relevant auditory events (Näätänen, 1982).

5 In contrast to the N1 which was present in both groups, a readily observable P2 was  
6 elicited only in the younger adults. In the young adults, however, it was characterized with  
7 similar pattern as the N1 modulatory effect: as glide-gap separation decreased, P2 amplitude also  
8 became lower. The functional role of P2 waveform is poorly understood. Recent studies show  
9 that N1 and P2 are rather independent components (Crowley & Colrain, 2004) and P2 might  
10 index processes related to detection threshold mechanisms and stimulus evaluation (Ceponiene,  
11 Alku, Westernfield, Torki & Townsend, 2005). The P2 attenuation pattern in younger adults  
12 indicates that the distracting effect of glides also affected stimulus evaluation processes since  
13 attention was still captured by glides as demonstrated by Horváth and Winkler (2010) as well: in  
14 their study, P2 was attenuated to 150 ms glide-gap separation compared to the gaps presented  
15 alone. In the present study, the absence of P2 in the older adults might be explained with the  
16 superimposition of earlier negative ERPs, especially the PN: PN might overlap the P2 time  
17 interval and cancel that component as suggested by Crowley and Colrain (2004). Also, because  
18 Harris and colleagues (2012) found reduced P2 amplitudes to gaps in older adults, the age-related  
19 changes in gap detection processes also could lead to this effect.

20 The pattern of later ERP waveforms supports the interpretation of the N1/PN modulation  
21 presented above. When glides and gaps were presented with a longer separation (650 ms and gap  
22 only trials), an N2 was elicited. For 150 ms and 250 ms gaps this component was entirely absent  
23 in both groups. Since N2 is thought to reflect categorization and decision mechanisms (Folstein  
24 & Van Petten, 2008; Patel & Azzam, 2005; Ritter, Simson, Vaughan & Macht, 1982), these  
25 results suggest that the disruption of the attentional template also affected these later, endogenous  
26 processes, irrespectively of age. The subsequent P3b waveform indexing target detection (Polich,  
27 1997) was also modulated by the presence of distracters: both groups demonstrated amplitude  
28 decrease with decreasing glide-gap intervals. One could interpret this effect as disturbance in  
29 target identification, however, it is important to note that the N2 at least partly overlaps P3b in the  
30 frontal areas. This overlap might modulate P3b amplitudes which might be not identical in



1 **different conditions**. Moreover, some studies revealed that in tasks requiring sustained attention, a  
2 further processing of attended stimuli might be present (Näätänen & Michie, 1979), especially in  
3 the older adults, also leading to P3 modulation (Karayanidis, Andrews, Ward & Michie, 1995).  
4 The present study does not allow the separation of these contributions, therefore the results on N2  
5 and P3b should be interpreted cautiously.

6 In order to discuss the effects of attention on gap-related ERPs, it is important to take into  
7 consideration glide-related ERPs well. Glides elicited an N1 and a P2 in both groups but N2 and  
8 P3b were not present. The N1 and P2 pattern was similar to those observable on gap-related  
9 ERPs: while N1 was pronounced in both groups, older adults demonstrated only moderate P2.  
10 The latter could be explained with age-related P2 differences in gap processing (Harris et al.,  
11 2012) or the partial superimposition with the previous negativity (Crowley & Colrain, 2004).

12 The behavioral results are in line both with the electrophysiological results and with the  
13 literature. The accuracy scores in younger and older participants were affected by different glide-  
14 gap separations similarly: both groups detected gaps less accurately when glides preceded them  
15 in short time intervals, reflecting the presence of a distraction effect in general (Berti, Grunwald  
16 & Schröger, 2013). **Lower target detection rates for brief distracter-target separations were also**  
17 **demonstrated in discrete (Horváth & Burgyán, 2011; Schröger, 1996) and in continuous**  
18 **stimulation protocols (Horváth, 2014a; Horváth & Winkler, 2010).** Our results regarding the lack  
19 of group differences in target detection rate with the change of distraction-target separation  
20 interval is at odds with the results of Slawinski and Goddard (2001), who found that while both  
21 age groups detected targets following attention capture by 360 ms poorly, the performance of  
22 older adults was still impaired at 450 ms. An explanation to the difference between the two  
23 studies might be that while Slawinski and Goddard (2001) utilized discrete sinusoidal tone pips in  
24 rapid presentation, we presented continuous complex tones which led to lower task difficulty and  
25 better performance even at cognitively demanding conditions. **It is also important to note that the**  
26 **exclusion of participants with insufficient numbers of responses to gaps could bias gap detection**  
27 **rate results.**

28 Reaction time data differentiated groups more strongly than gap detection rates. Older  
29 participants slowed gradually as glides and gaps got closer to each other. In contrast, younger  
30 adults could keep their response speed steady between the different glide-gap separations. That is,

1 as task difficulty increased, older adults needed to invest more effort into the task while younger  
2 adults could maintain their performance, in other words, older adults had to compensate with  
3 enhanced attention (Reuter-Lorenz & Cappell, 2008; Zanto & Gazzaley, 2014). Albeit for the  
4 first sight it seems that older adults are more susceptible for distraction, taken accuracy data into  
5 consideration, this response pattern might suggest differences not only in cognitive abilities but in  
6 task performance strategies as well. On one hand, a trade-off mechanism might be present in  
7 older adults favoring high accuracy over speed (Leiva, Andrés & Parmentier, 2015). It was  
8 demonstrated that older adults tended to be more cautious than younger adults even when they  
9 were instructed to respond as fast as possible, which is also related to age-related structural  
10 changes in brain connectivity (Forstmann et al., 2011). On the other hand, motivational and  
11 detection threshold factors could also lead to reaction time differences: while older adults seemed  
12 to be motivated to achieve high performance and demonstrated enhanced attention during the  
13 whole experiment, younger adults might have not put much effort in responding quickly while  
14 they could keep accuracy high (Horváth et al., 2009; Iragui et al., 1993; Leiva, Andrés &  
15 Parmentier, 2015). In summary, the present study demonstrated that older adults did not need  
16 more time to recover from the sensory effects of distraction than younger adults. This was  
17 reflected in the similar modulation of the N1 (presumably mainly the processing negativity) as  
18 the glide-gap separation interval shortened which was not influenced by age: from gaps without  
19 preceding glides to 150 ms glide-gap separation both groups showed gradual amplitude  
20 attenuation. The modulation of N2 and P3b indicated that the disruption of attentional trace  
21 caused by glides affected later processes as well, like stimulus categorization and target detection.  
22 The behavioral results showed that while both groups kept gap detection accuracy high, older  
23 adults slowed down as glide-gap separation decreased in contrast to younger adults whose  
24 reaction times were not affected. Taken together, our results suggest that although the distracted  
25 state does not last longer in the older than in the younger adults, older subjects were nonetheless  
26 more affected by distracters in consecutive processing levels as reflected by reaction times.

27

## 28 **Acknowledgements**

1 The present study was supported by the Hungarian Scientific Research Fund – OTKA (104635),  
2 the 2015<sup>th</sup> year fund of Doctoral School of Psychology, Eötvös Loránd University, and the János  
3 Bolyai Research Scholarship of the Hungarian Academy of Sciences (János Horváth).

4

## 1 **Figure captions**

2 Fig. 1: The schematic design of the experimental tones reflecting glide-gap separation intervals  
3 and epoch types. The different colors represent the different glide-gap separations in the  
4 continuous tone.

5 Fig. 2: The gap-related raw ERPs, the corresponding control ERPs and their difference (corrected  
6 waveforms) for each glide-gap separations.

7 Fig. 3: Group mean reaction times (left) and gap-detection rates (right; both with standard errors  
8 of the means indicated by whiskers) in the younger and older adult group for the four types of  
9 gaps (150, 250, 650 ms glide-gap separation, and gap only trials).

10 Fig. 5: ERP Group-mean normalized gap-related N1 amplitudes (with standard errors of the  
11 means indicated by whiskers) for of 150, 250 and 650 ms glide-gap separations measured at a  
12 fronto-central cluster (FCz, FC1, FC2, Fz, and Cz). The amplitudes were normalized by the  
13 corresponding group-mean ERP amplitudes for the corrected gap only trials.

14 Fig. 6: Topographies of the group-mean gap- and the glide-related ERPs in the N1 (top and  
15 middle rows, measured at mastoid and at fronto-central peaks) and P2 (bottom) intervals in the  
16 younger and older adult groups. The amplitude scales differ between groups in order to  
17 adequately represent the shapes of topographies while showing the amplitude differences for each  
18 gap type within each group.

19 Fig. 7: Topographies of the group-mean later gap-related components. N2 is presented in top and  
20 P3b is presented in bottom row. The amplitude scales are set to reflect the amplitude differences  
21 within each group.

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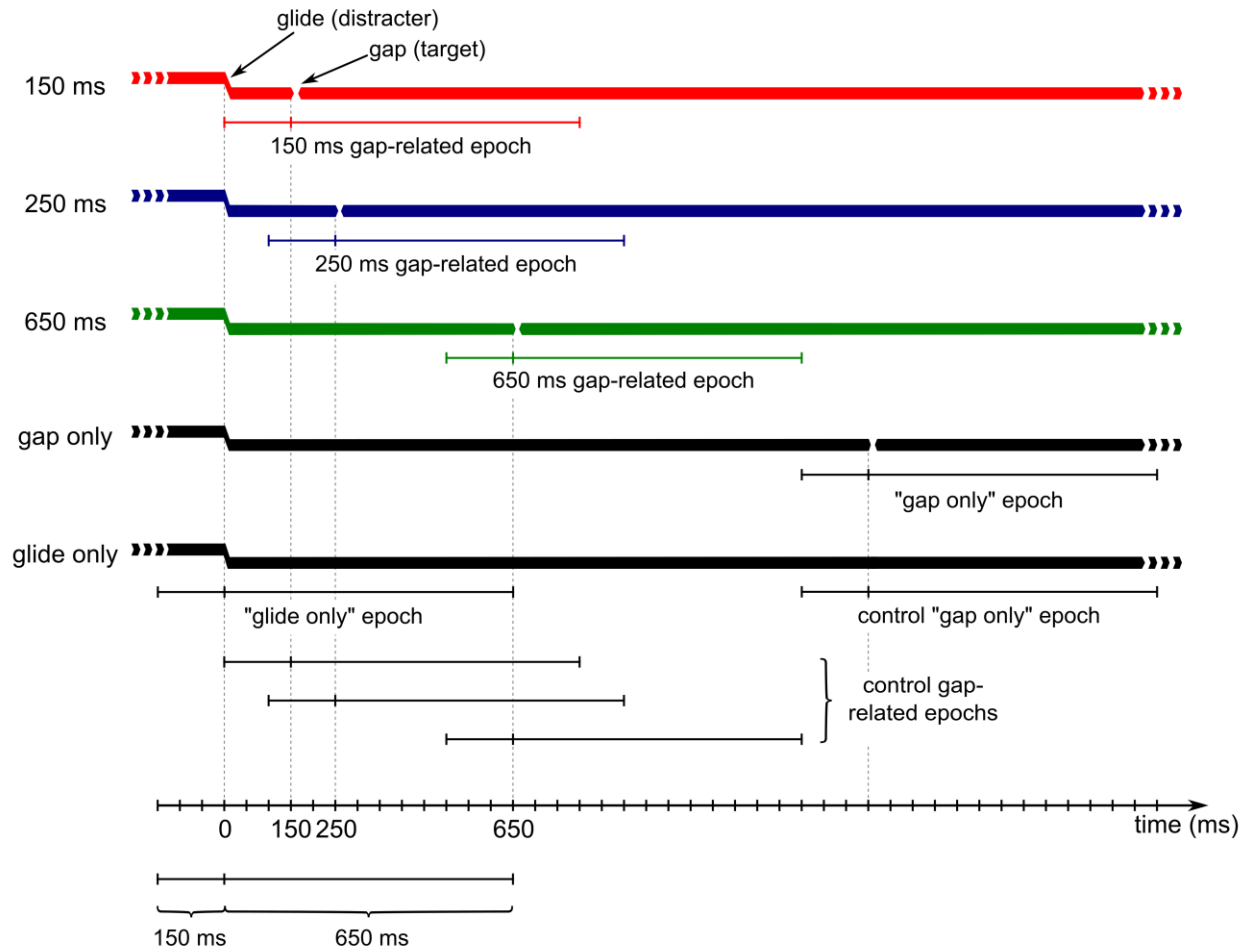
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20  
21

1

<b>Group</b>	<b>250 Hz</b>	<b>500 Hz</b>	<b>1000 Hz</b>	<b>2000 Hz</b>
<b>Younger</b>	14.38 (±4.16)	8.91 (±5.34)	2.81 (±4.91)	3.59 (±4.62)
<b>Older</b>	25.78 (±7.94)	23.125 (±10.75)	14.69 (±10.54)	23.125 (±12.94)
	t = 7.195, p < .001	t = 6.695, p < .001	t = 5.776, p < .001	t = 8.043, p < .001

2 **Table 1. Group-mean hearing thresholds (dB) and standard deviations in the**  
3 **younger and older adult groups.**

4

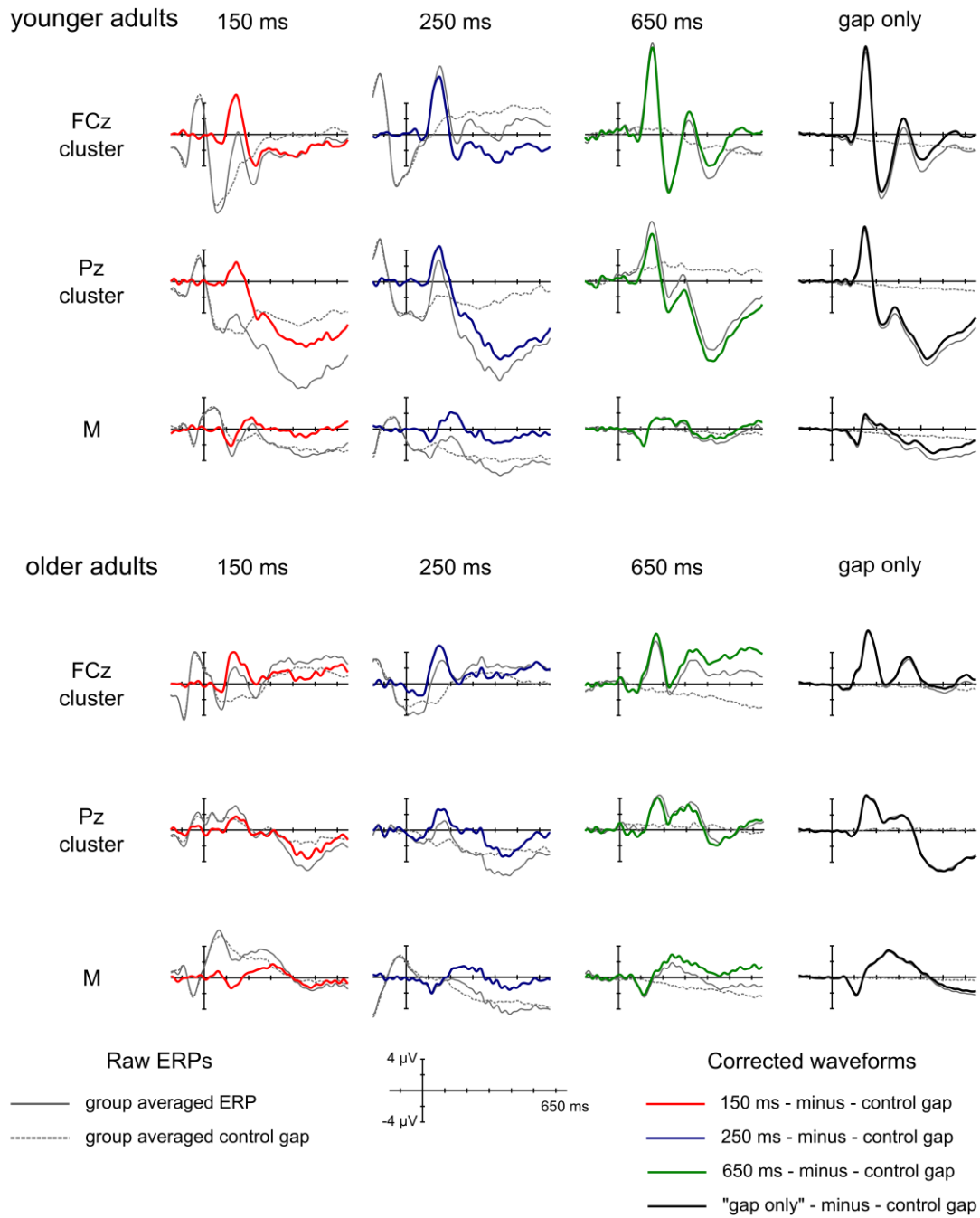


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2 **Fig. 1:** The schematic design of the experimental tones reflecting glide-gap separation intervals  
 3 and epoch types. The different colors represent the different glide-gap separations in the  
 4 continuous tone.

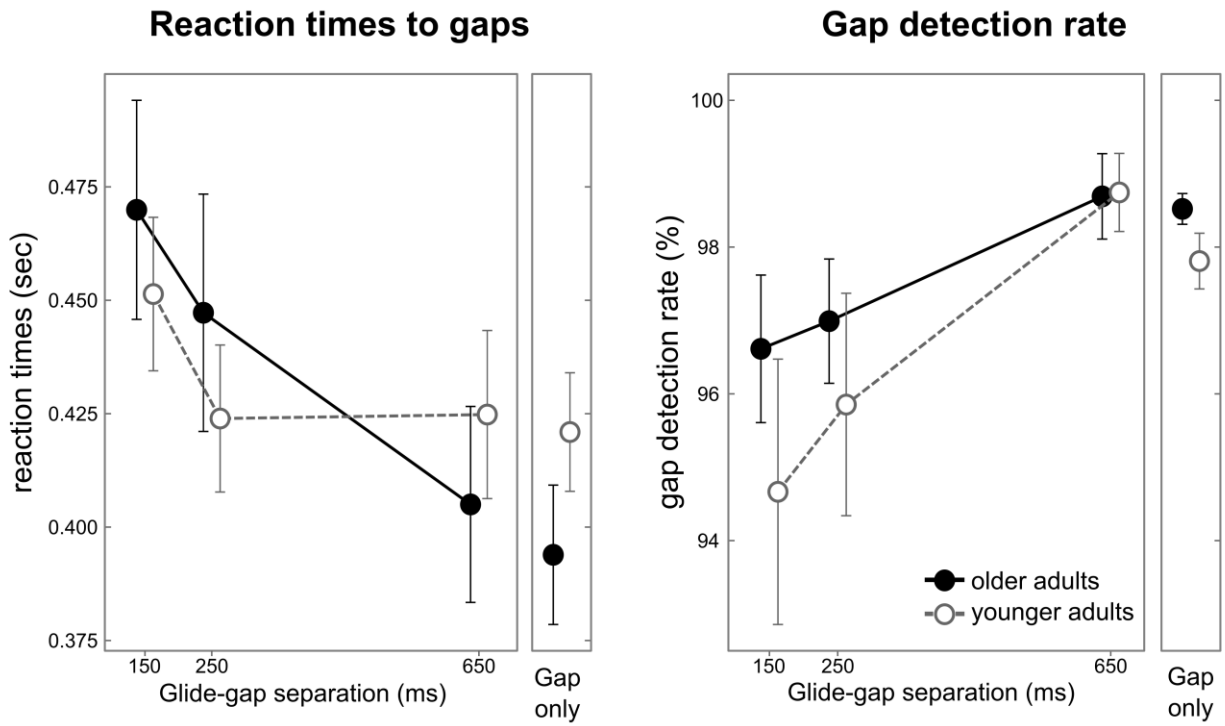
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## Glide-gap separation



1  
 2 **Fig. 2:** The gap-related raw ERPs, the corresponding control ERPs and their difference (corrected  
 3 waveforms) for each glide-gap separations.

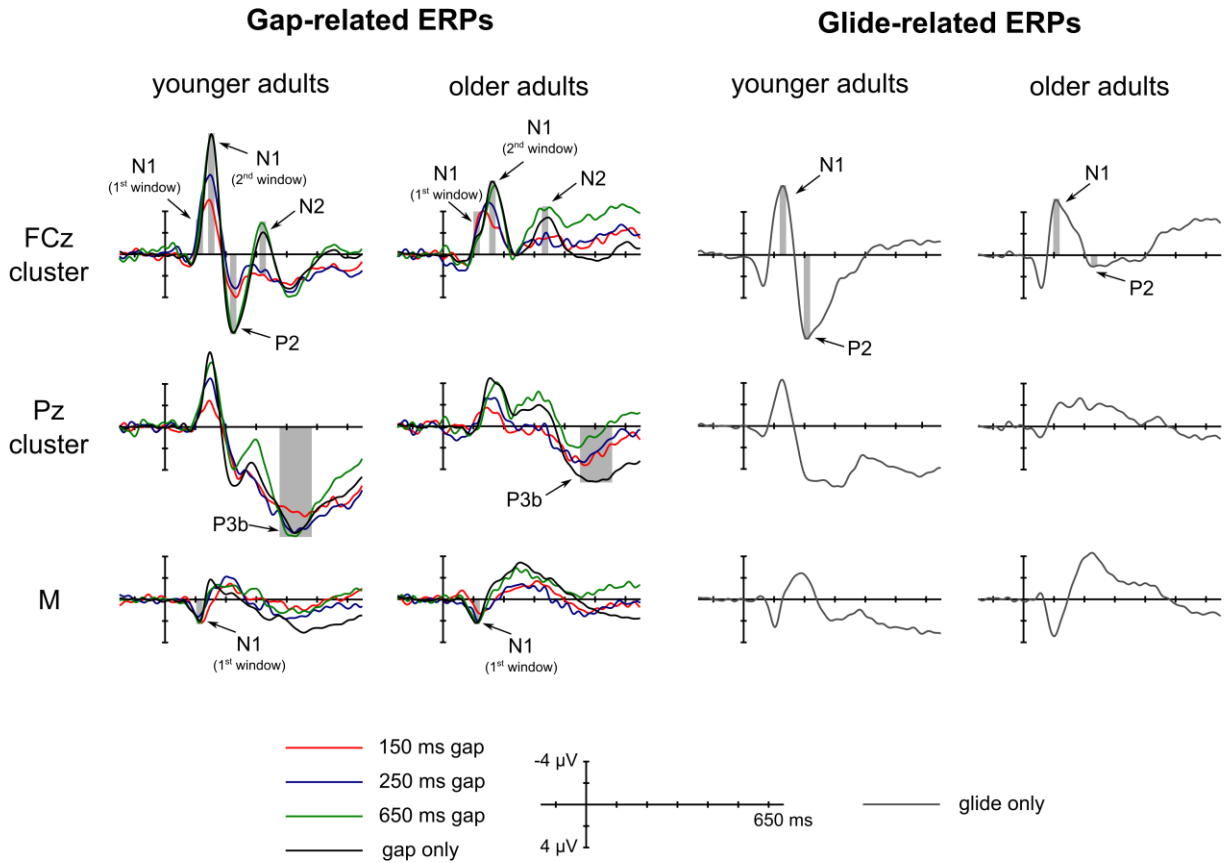
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1  
2

3 **Fig. 3:** Group mean reaction times (left) and gap-detection rates (right; both with standard errors  
 4 of the means indicated by whiskers) in the younger and older adult group for the four types of  
 5 gaps (150, 250, 650 ms glide-gap separation, and gap only trials).

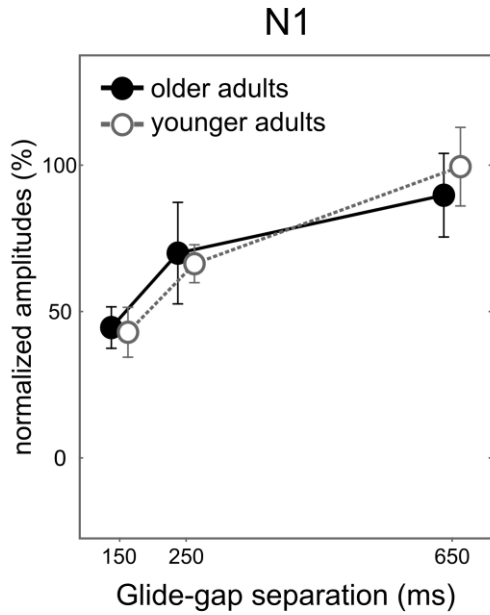
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1  
 2 **Fig. 4:** The ERP results of the study. In the left side of the figure gap-related ERPs are presented  
 3 plotted at the investigated clusters for younger and older adults separately. In the right side the  
 4 control glide-related ERPs are shown. The grey bands index the time windows (20 ms for N1, P2  
 5 and N2 and 100 ms for P3b) where statistical analyses were assessed.

6

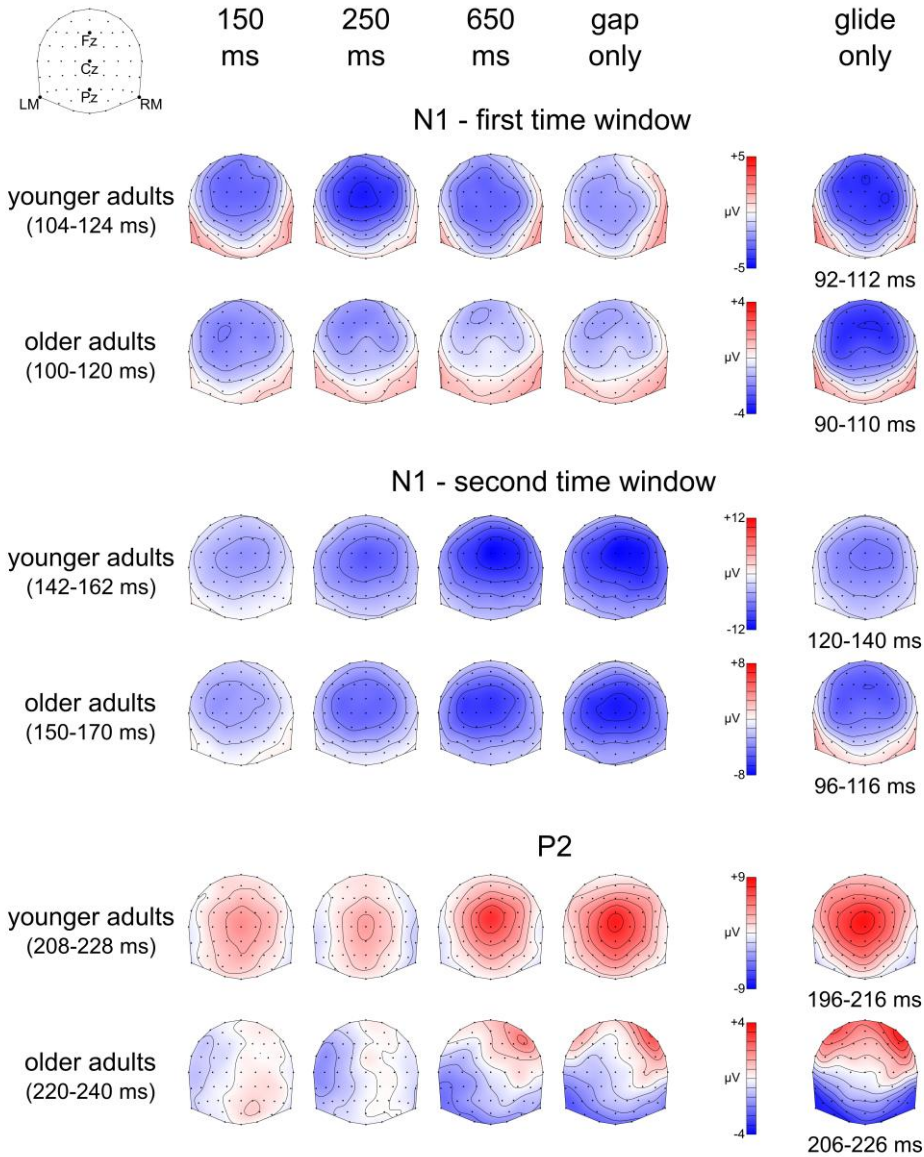




1  
2 **Fig. 5:** ERP Group-mean normalized gap-related N1 amplitudes (with standard errors of the  
3 means indicated by whiskers) for of 150, 250 and 650 ms glide-gap separations measured at a  
4 fronto-central cluster (FCz, FC1, FC2, Fz, and Cz). The amplitudes were normalized by the  
5 corresponding group-mean ERP amplitudes for the corrected gap only trials.

6

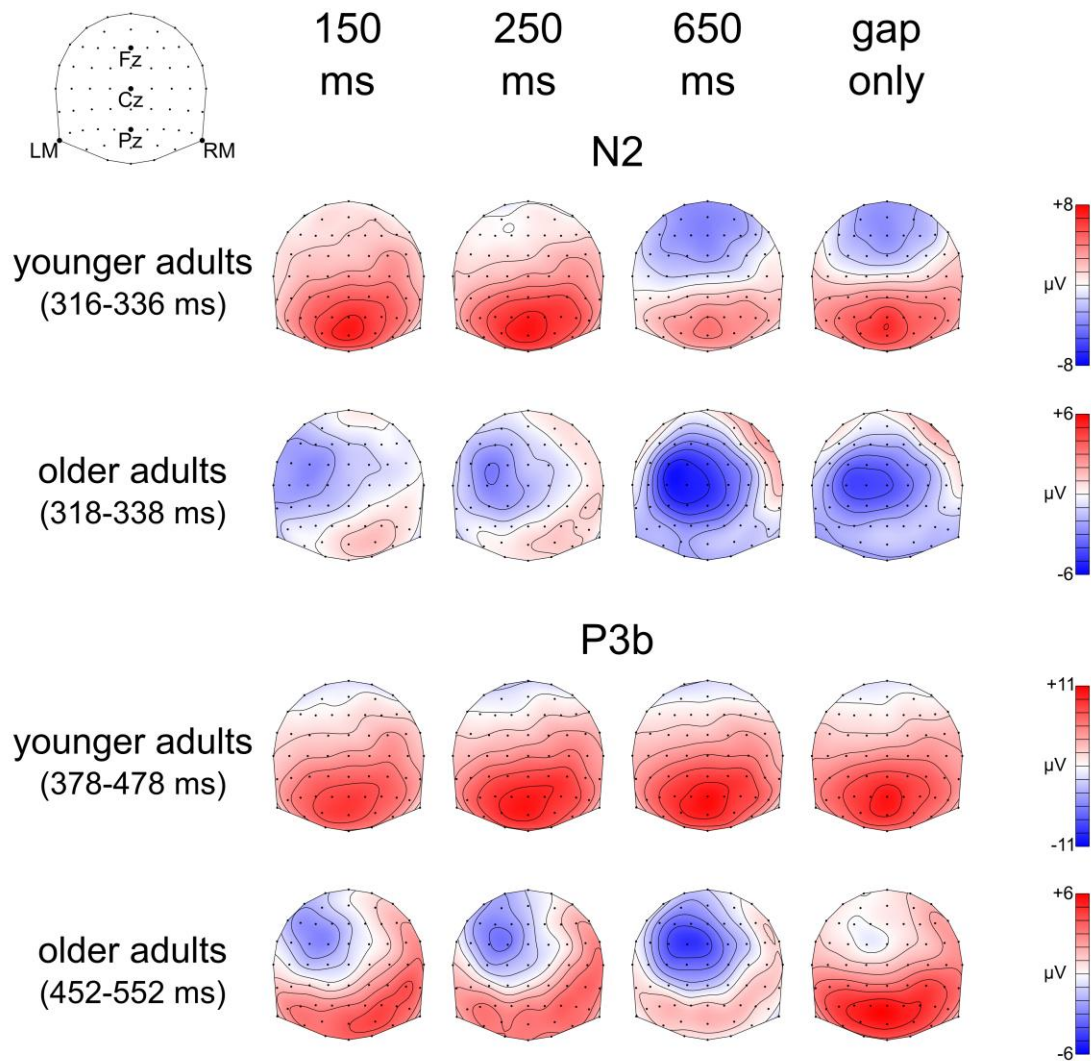
## Topographical distributions of gap- and glide-related N1 and P2



1  
 2 **Fig. 6:** Topographies of the group-mean gap- and the glide-related ERPs in the N1 (top and  
 3 middle rows, measured at mastoid and at fronto-central peaks) and P2 (bottom) intervals in the  
 4 younger and older adult groups. The amplitude scales differ between groups in order to  
 5 adequately represent the shapes of topographies while showing the amplitude differences for each  
 6 gap type within each group.

7

## Topographical distributions of gap-related N2 and P3b



1  
 2 **Fig. 7:** Topographies of the group-mean later gap-related components. N2 is presented in top and  
 3 P3b is presented in bottom row. The amplitude scales are set to reflect the amplitude differences  
 4 within each group.