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Age dependent changes of distractibility and reorienting of attention revisited: An event-related potential study

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A B S T R A C T

Adults of three age groups (18–27, 39–45, and 59–66 years) performed an auditory duration discrimination task with short (200 ms) or long (400 ms) sinusoidal tones. Performance was highly accurate and reaction times were on the same level in all groups, indicating no differences in auditory duration processing. Task irrelevant rare changes of the frequency of the stimuli were introduced to check whether the subjects, firstly, were distracted by changes in the environment while focusing on the task relevant information (indicated by prolonged responses), and, secondly, could re-focus on the relevant task after distraction. The results show that a distraction effect is present in all groups. Importantly, the 59–66 years group showed a behavioral distraction effect nearly twice as high as the other groups. The event-related brain potentials (ERPs) show mismatch negativity (MMN), P3a, and reorienting negativity (RON) elicited by deviants which are present in all groups. Aging effects on these ERP components were observable in all three components but a revealed a weak significant effect for the MMN only. Taken together, the behavioral and ERP results suggest that the function of balancing the processing of task irrelevant changes in the stimulation while focusing on task relevant information is effective during adulthood until the 7th decade of life.

1. Introduction

Age related changes in cognitive processing are well documented and may contribute to the subjective perception of increasing excessive demands in everyday life in elderly people. Some of these changes are attributed to a general slowing of cognitive processes (i.e. Salthouse, 1996), to deficits in inhibitory processes (i.e. Hasher and Zacks, 1988), or even to a long lasting sensory deprivation caused by impaired sensory functioning (i.e. Lindenberger and Baltes, 1994) with increasing age. We tested whether age effects are observable in an auditory distraction paradigm in which participants focus on task relevant information while task irrelevant information was irregularly changed. Usually, the processing of these irregular and unpredictable changes cannot completely be inhibited (see, for instance, Berti et al., 2004). Therefore, in this paradigm, effects of general impairment of information processing can be separately evaluated from

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age effects confined to the processing and inhibition of distracting events. By application of event-related brain potentials (ERPs) it is possible to analyze in detail the underlying sensory and cognitive functions which are susceptible to a potential age effect.

In order to deal with dynamic situations in everyday life, effective balancing between the processing of stored information in memory and new information provided by the sensory input is required. Coordination of processing old and new information is crucial for the reason that stored information is usually important for a current task but new information might indicate relevant changes in the environment to which an immediate response is expedient. The efficacy of this balance is mirrored in response time (RT) costs in processing of task relevant information in case of the concurrent presentation of task irrelevant information. For instance, in an auditory distraction paradigm (Schröger and Wolff, 1998), the rare and unpredictable change of the (task irrelevant) pitch of the auditory stimulus (so-called deviant) results in distraction of the processing of the (task relevant) duration of the stimulus, which is reflected in prolonged response times compared to the regular (with regard to pitch) standard stimulus (see Berti and Schröger, 2004, for a visual and Escera et al., 1998, for a cross-modal distraction paradigm). Usually, the magnitude of the RT cost is taken as a measure of the degree of distraction by irrelevant information (see Berti et al., 2004; but see Wetzel et al., 2012, for a detailed evaluation of the distraction effect) and it is assumed that the effectiveness of balancing between task demands and processing distracting information is reflected in a smaller distraction effect (see Berti and Schröger, 2003). A sequence of ERP components elicited by deviants in comparison to standard stimuli allows for a detailed analysis of the cognitive basis of these distraction effects (see, for instance, Berti et al., 2004; Berti, 2008a, 2012; Hölig and Berti, 2010; Horvath et al., 2008; for a review see Escera and Corral, 2007): Task irrelevant frequency changes elicit the mismatch negativity (MMN), P3a, and reorienting negativity (RON), suggesting that the deviation is detected by a pre-attentive process on the level of sensory memory (indexed by the MMN), followed by a switch of attention onto the new information (indexed by the P3a), and a subsequent reorienting back to the task relevant duration information (indexed by the RON). Importantly, the investigation of age effects on these components allows for a detailed evaluation of cognitive aging on different information processing steps.

Effects of aging are well documented for auditory sensory processes (Alain and Woods, 1999; Alain et al., 2004; Gaeta et al., 1998, 2002; Pekkonen et al., 1993; Rimmele et al., 2012) and involuntary allocation of attention (Fabiani and Friedman, 1995; Fabiani et al., 1998; Gaeta et al., 2001; Kok, 2000). For instance, Gaeta and colleagues investigated whether pre-attentive processing of deviations in a repetitive auditory stimulation is still effective in older adults when these deviants are defined in one feature (Gaeta et al., 1998) or a combination of features (Gaeta et al., 2003). In general, the MMN amplitude seems to decline with age, suggesting a decrease in the efficacy but no complete lack of pre-attentive, sensory processing (i.e., Cooper et al., 2000; Rimmele et al., 2012; for a review see Pekkonen, 2000). From this, Alain et al. (2004) argued that aging may result in a shift from automatic to controlled processing of deviations in sensory stimuli. Moreover, Fabiani and colleagues (Fabiani and Friedman, 1995; Fabiani et al., 1998) demonstrated that involuntary switching of attention is still effective in older adults, too, which is mirrored in the presence of the P3a component in both age groups. But again, there are age dependent changes in the P3a: while in younger adults the P3a has a frontal maximum, the P3a peak shifts from frontal to more central scalp areas in older adults. In addition, Gaeta et al. (2001) concluded that a greater sensitivity of subsequent cognitive processing steps (i.e., maintenance of attentional focus) for the output of automatic deviant processing on the level of sensory processing (i.e., the MMN system) may result in increased behavioral distraction effects.

From these studies one may conclude that the efficacy of sensory pre-processing and involuntary allocation of attention changes in higher adulthood. On the one hand, automatic processing and detection of changes in the auditory stimulation may be impaired in general in elderly people, resulting in a reduced distraction by task irrelevant information. On the other hand, the ability to prevent distraction might also be impaired in elderly participants, resulting in an increased distraction by task irrelevant information potentially precluding any processing of the task relevant information.

Recently, a number of studies have applied the auditory distraction paradigm to a developmental perspective (see Wetzel et al., 2004, 2006, Wetzel and Schröger, 2007; Mager et al., 2005; Horvath et al., 2009). For instance, Mager et al. (2005) tested participants from two age groups (21–39 and 42–59 years) within the auditory distraction paradigm and reported no general slowing or accuracy effect in elderly adults as well as no differences in the MMN component between the two groups. On the other hand, accuracy in processing short stimuli were decreased in the older group and the P3a and the RON component were delayed or diminished in elderly adults in general. However, the error rate in the worst condition (short deviant tones) did not exceeded 10% in the elderly adults group, reflecting that task performance was highly accurate in all participants irrespective of the individual age. This pattern of results is generally supported by the findings of Horvath et al. (2009). Again, accuracy, response times, and distraction effects did not significantly differ between younger (19–24 years) and elderly (62–82 years) adults[1] . The pattern of ERP components were highly comparable with a remarkable difference concerning P3a and RON latency which were delayed in the elderly participants group. Neither the Mager et al. (2005) nor the Horvath et al. (2009) study yielded age related changes in the MMN. Therefore, these two studies do not support the notion of a general decline of cognitive functions. On the other hand, a study by Andres et al. (2006) applying the cross-modal distraction paradigm (in which changes in a task irrelevant auditory stimulation do distract the processing of task

[1] The study of Horvath et al. (2009) included also an additional group of 6 years-old children and originally tested for age effects over a broad age span. In the present study we focus on the results in the adults groups.

relevant visual stimuli) demonstrated an increase in distractibility in elderly (50–83 years) compared with young (16–29 years) adults as well as a general slowing in the elderly participants group. A study by Parmentier and Andres (2010) including a 18–29 years and 50–83 years group basically replicated these findings.

Taken together, it still remains unclear whether distractibility varies with increasing age in healthy aging: on the one hand, the studies by Andres et al. (2006) and Parmentier and Andres (2010) support the idea that susceptibility to distraction by irrelevant sounds is increased due to a decreased ability to inhibit irrelevant information (see Hasher and Zacks, 1988). On the other hand, the general results of the Horvath et al. (2009) and Mager et al. (2005) studies contradict this notion for the reason that they do not demonstrate strong age effects on behavioral data. (However, note that the accuracy in processing short deviant stimuli is reduced in elderly participants in Mager et al., 2005, which can be interpreted as increased distractibility with increasing age.) Importantly, it must be noted that the age groups in these four studies are very heterogenic making it hard to compare the results directly. One obvious difference is that different age spans are investigated in these four studies: while Mager et al. (2005) tested participants between 21 and 59 years (with the older adults group ranging from 42 to 59 years), Andres and colleagues (Andres et al., 2006; Parmentier and Andres, 2010) and Horvath et al. (2009) tap a much broader adult age span, ranging from 16 to 83 years in the Andres et al. study and from 19 to 82 years in the Horvath et al. study. A comparison of the young and middle aged participants in the Mager et al. study and the old adults group in the Andres et al. study, for example, suggests that an increase in distractibility could be observable at the earliest in the 7th decade of life. (But note that the elderly participants group in the study by Andres et al. includes participants around 50 years of age.) On the other hand, the results in the Horvath et al. study do not fit this interpretation, which can be due to the fact that the general task difficulty was adapted to fit to children (which were included into the study) and, therefore, might have been too easy for adults (see Section 3 in Horvath et al., 2009). In addition, the youngest participants in the Andres et al. (2006) study might also be too young to provide an adequate comparison with adults (see Wetzel and Schröger, 2007, for distraction effects in adolescents). Moreover, summarizing the behavioral distraction effects in the "old" adults group of these four studies (Mager et al., 2005; Andres et al., 2006; Horvath et al., 2009; Parmentier and Andres, 2010) depict highly comparable reaction time prolongations ranging between 40 and 50 ms[2]. In contrast, distraction effects in the "young" adults groups in these four studies range from around 15 ms (Parmentier and Andres, 2010) to 50 ms (Mager et al., 2005). From this it seems likely that the detection of a potential age effect on behavioral distraction depends also on the definition of the "young" adults. Finally, it is also noteworthy that the groups in these studies partly differ in group sizes. For instance, the two adult groups in the Horvath et al. (2009) study consisted of nine participants each while the group of young-adults and the group of old-adults in the Andres et al. (2006) study consisted of 22 subjects each, resulting in different statistical power of these studies.

In the present study, we aim at testing whether distractibility (measured in terms of RT costs in deviant trials) changes in the course of adulthood. In accordance with Mager et al. (2005) the upper age limit was restricted to 66 years in order to tap healthy aging in adults. However, to enable a more detailed view of possible functional changes we investigated three age groups with a narrow range, namely an 18–27 years group ($N=11$), a 39–45 years group ($N=10$), and a 59–66 years group ($N=11$). All participants had a normal IQ as measured by a German test for crystallized intelligence (German Vocabulary Test, WST, Schmidt and Metzler, 1992) and the average IQ did not differ between the three groups (for further details see Section 4.1 participants). The task was an auditory discrimination task (i.e., classifying sinusoidal tones of 200 ms or 400 ms duration as short or long tones) which is widely documented in adults (see, for instance, Schröger and Wolff, 1998; Berti et al., 2004). The short and long tones were either of a standard (700 Hz; 88% of the trials; Standards) or a deviant pitch (770 Hz; 12% of the trials; Deviants) but participants were instructed to focus on the tone duration only and to ignore any other stimulus feature. In addition, by applying a relatively long stimulus onset asynchrony (SOA) of three seconds (Roeber et al., 2003) we could avoid time pressure especially in the elderly participants, which might be a critical source of group differences without being a genuine source of age effects on cognitive functioning (see, for instance, the difference between short and long tone processing in Mager et al., 2005). Usually, the performance of the duration discrimination task is impaired in deviant trials; as demonstrated by Mager et al. (2005) and Horvath et al. (2009), distraction effects by irrelevant changes in the auditory stimulation should be observable in each age group in our study. However, taking into account the change of distraction effects in the studies by Andres et al. (2006) and Parmentier and Andres (2010) we expected age effects in the RT costs in deviant trials in the elderly age group; whether this effect is accompanied by a general impairment of the behavioral performance (i.e., the slowing of processing of the Standards) in elderly participants is an open question. Moreover, as Mager et al. (2005) and Horvath et al. (2009) demonstrated, the MMN should be unaffected by age in healthy elderly participants. In contrast, from the functional role of P3a and RON in this distraction paradigm (see Berti, 2008a,b; Hölig and Berti, 2010) we expected that a possible age effect in RTs will be mirrored in these two attention-related components.

2. Results

All participants performed the task highly accurately irrespective of the type of the stimulus; mean accuracy in all subjects was 96% in Standards and 92% in Deviants. A two-way ANOVA

[2] The distraction effects obtained in the Horvath et al. (2009) study were calculated from the RT data reported in Table 2. The remaining distraction effects were estimated from the graphical displays (i.e., Mager et al., 2005, Fig. 1A; Andres et al., 2006, Fig. 1B; Parmentier and Andres, 2010, Fig. 1b).

yielded no significant effect of Age group, $F(2, 29)=2.57$, $p=0.094$, $\eta^2=0.151$, nor a significant interaction of Age group and Stimulus type, $F(2, 29)=1.21$, $p>0.1$, $\eta^2=0.077$. Only Stimulus type revealed a significant effect in response accuracy, $F(1, 29)=14.84$, $p<0.001$, $\eta^2=0.331$. RT data—depicted in Fig. 1—show that the groups did not differ in processing and responding on Standards (note that the first two Standards after a Deviant were excluded from computation of mean behavioral and ERP data; see Section 4.4 Data analysis). Significant RT prolongation in Deviant trials were obtained within each group (for *t*-test statistics of the distraction effect see Table 1) suggesting that the task irrelevant frequency change was processed effectively irrespective of the individual age. Importantly, the distraction effect was markedly increased in the 59–66 years group (61 ms) compared with the two other groups (18–27 years: 27 ms; 39–45 years: 33 ms). These findings are mapped by the result of a two-way (Age group × Stimulus type) ANOVA of the RT data: there was no significant effect of Age group, $F(2, 29)=1.84$, $p>0.1$, $\eta^2=0.113$, but a significant effect of the Stimulus type, $F(1, 29)=50.04$, $p<0.001$, $\eta^2=0.633$, and a significant interaction, $F(2, 29)=3.47$, $p=0.046$, $\eta^2=0.191$, which might be due to the increased distraction effect. However, direct comparisons reveal no significant differences in distraction effects between the three age groups on a Bonferroni corrected 5% α level ($p=0.0167$): 18–27 years vs. 39–45 years: $t(19)=0.43$, $p>0.1$; 18–27 years vs. 59–66 years: $t(20)=2.22$, $p=0.038$; 39–45 years vs. 59–66 years: $t(19)=2.376$, $p=0.028$. In addition, a separate analysis confined to the RTs in Standard trials reveals no significant effect of Age group, $F(2, 29)=1.34$, $p>0.1$, $\eta^2=0.085$.

In all groups, Standard and Deviant stimuli (see Fig. 2) elicited a N100 which is maximal in the 39–45 years group. Deviance related differences in the ERPs are observable starting around 100 ms at Fz. Fig. 3 shows the deviance related effects for the three age groups separately depicted as difference waves (Deviant ERPs minus Standard ERPs). It is noteworthy that in each age group the MMN-P3a-RON complex is observable reflecting a comparable processing of deviants irrespective of the age of the subjects. The existence of the deviance related components in each group was confirmed by the outcome of the statistical analysis (see Table 1). Differences between the three age groups are also observable in all three components. The age effect is most pronounced in the early time window with a diminished MMN in the 59–66 years group compared with the other two groups. In addition, while younger participants exhibit one deviance related early negativity, in middle aged and elderly participants' two peaks contributing to the early deviance

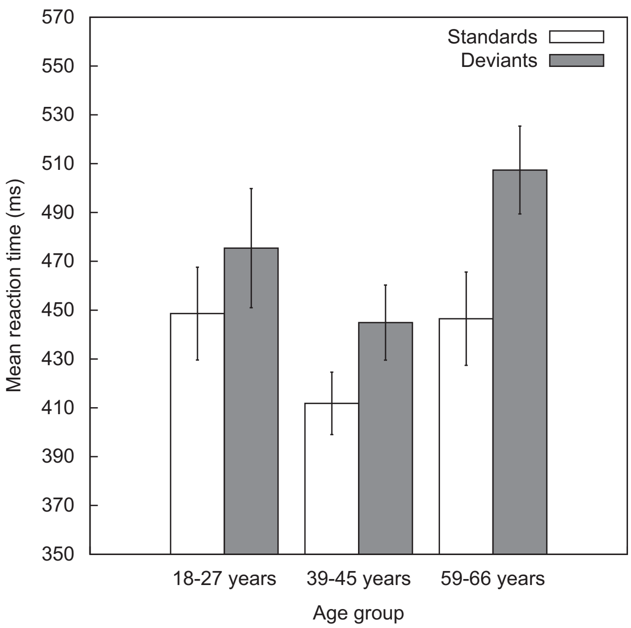

Fig. 1 – Mean RT (and standard error of mean) in standard and deviant trials separately for the age groups. A distraction effect as an index of automatic processing of task irrelevant information is visible in all three groups. Moreover, while responses in standard trials are highly comparable in all groups, the RT prolongation in the duration discrimination task caused by the frequency Deviants is approximately twice as big in subjects of the 59–66 years group compared with subjects from the two other groups.

Table 1 – Mean distraction effect and mean amplitude of the MMN, P3a, and RON component in the three age groups (and standard error of means) plus statistical evaluation against zero. Distraction effects (dRT) are depicted calculated as RT costs (RT in Deviant trials minus RT in Standard trials) for correct trials, and ERP effects (ERPs elicited by Deviants minus ERPs elicited by Standards) are measured in distinct time windows adjusted in each participant individually in order to tap MMN, P3a, and RON. For evaluation of a statistically significant difference from zero, Students *t*-values and (one-tailed) significance levels (*$p<0.05$, **$p<0.01$, ***$p<0.001$) are reported.

Age group	df	dRT		MMN		P3a		RON	
		ms	t	μV	t	μV	t	μV	t
18–27 years	10	27 (12)	2.17*	−1.43 (0.58)	2.45*	3.08 (0.74)	4.17**	−2.75 (0.60)	4.58***
39–45 years	9	33 (7)	4.72**	−1.70 (0.32)	5.25***	3.33 (1.29)	2.56*	−3.43 (0.62)	5.52***
59–66 years	10	61 (9)	6.66***	−0.44 (0.24)	1.83*	2.70 (0.55)	4.90***	−2.91 (1.06)	2.77*

Note: averaged ERP amplitudes were derived from group specific time windows; for each component, group specific peak latencies were obtained from the differences waves and the components time window were defined as peak latency ±20 ms (for details see Section 4.4 data analysis).
* Significance levels: $p<0.05$.
** Significance levels: $p<0.01$.
*** Significance levels: $p<0.001$.

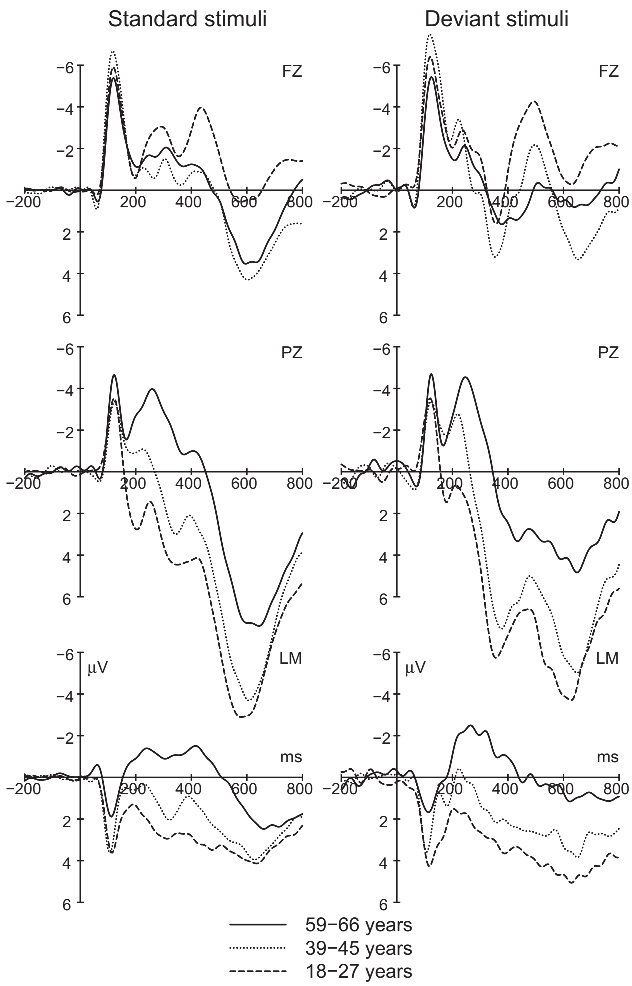

Fig. 2 – Grand-average ERPs at Fz, Pz, and LM elicited by Standard and Deviant stimuli separately for the three age groups. In each age group auditory stimuli elicited the N100 component reflecting efficient sensory processing irrespective of the subjects' age.

related negativity. The early peak likely reflects genuine MMN and an overlaying N1-refractoriness effect (cf., e.g. Jacobsen and Schröger, 2001) and the later peak seems to consist of MMN and some N2b (cf. Schröger and Wolff, 1998). A series of two-way ANOVAs computed separately for the three components (see Table 2) reveal an effect of the factor Stimulus type in all three time windows. However, while Fig. 3 suggests decreased MMN, P3a, and RON amplitude in the 59–65 years group and increased P3a in the 39–45 years group, the statistical analyses by means of ANOVA reveal only a marginally significant interaction term in the MMN time window (see Table 2). Additional post-hoc comparisons of the MMN amplitude between the three groups obtain a significant difference in MMN amplitude between the oldest and the middle age group, only: 18–27 years vs. 39–45 years: $t(19)=0.39$, $p>0.1$; 18–27 years vs. 59–66 years: $t(20)=1.58$, $p<0.1$; 39–45 years vs. 59–66 years: $t(19)=3.18$, $p=0.005$ (Bonferroni adjusted 5% α level is $p=0.0167$).

To further analyze the effect of age on the different distraction related measures, linear regressions of age with the RT distraction effect and the MMN, P3a, and RON amplitudes were calculated. In order to meet the assumptions of linear regressions, the data were scanned for outliers prior to analysis resulting in the exclusion of the data sets of three participants (aged 24, 44, and 62 years; for details see Section 4.4 Data analysis); the analyzed data set comprised of 29 participants (14 female; age range 18–66 years; median 41 years). Fig. 4 depicts the scatterplots of age and the behavioral and ERP measures of distraction; the respective regression and determination coefficients are summarized in Table 3. A linear relationship between age and behavioral distraction is observable; the other three dependent variables show no correlations with age. Finally, a multiple linear regression model with age and P3a amplitude as independent variables explained the distraction effect best: $\beta_{Age}=-0.27$, $t(25)=0.61$, ns; $\beta_{P3a}=-12.09$, $t(25)=1.73$, $p=0.097$; $\beta_{Age\times P3a}=0.36$, $t(25)=2.11$, $p=0.045$; $R^2=0.19$, $F(3, 25)=3.24$, $p=0.039$.

3. Discussion

Unpredictable task irrelevant changes of an auditory stimulus disrupted the processing of task relevant information in each age group. Importantly, task performance was not completely impaired by distraction, allowing for high accuracy in the auditory discrimination task irrespective of the age. The behavioral results together with the deviance related ERP effects suggest that automatic processing of rare changes and subsequent attentional orientation is effective in persons up to 66 years. In addition, an increase in RT costs triggered by the processing and detection of an unexpected deviation in the environment is observable in participants around 60 years; a linear regression obtains that with increasing age behavioral distraction effects increase, too. The neurophysiological correlates of deviance detection (MMN) and attentional orientation (P3a and RON) are present in all three age groups, suggesting that distraction on the basis of sensory pre-processing triggering involuntary attention is effective in healthy adults between 18 and 66 years. These deviance related ERP components show also some differences between the age groups but only in the MMN time window these differences became significant on a 10% level.

The present results match the perspective of recent studies investigating aging effects in distractibility: as suggested by the studies of Mager et al. (2005), Andres et al. (2006), and Parmentier and Andres (2010), which together tap adulthood from 16 to 82 years, the behavioral distraction effect (i.e. increased RT in deviant trials) was increased in the 59–66 years group compared to the two other groups. The present distraction effect in the 59–66 years group is comparable to distraction effects reported for middle aged and elderly participants (in the range from 42 to 83 years) by Mager et al. (2005), Andres et al. (2006), Horvath et al. (2009), and Parmentier and Andres (2010). In addition, distraction effects in the 18–27 years and 39–45 years groups falls within the range of behavioral distraction effects in the young participants groups (age range 16–29 years) of the studies by Andres and colleagues (Andres et al., 2006; Parmentier and Andres, 2010) and Horvath et al. (2009). In contrast, the distraction effect in the young adults group in the Mager et al. (2005) study falls in the range of the oldest adults in our and the

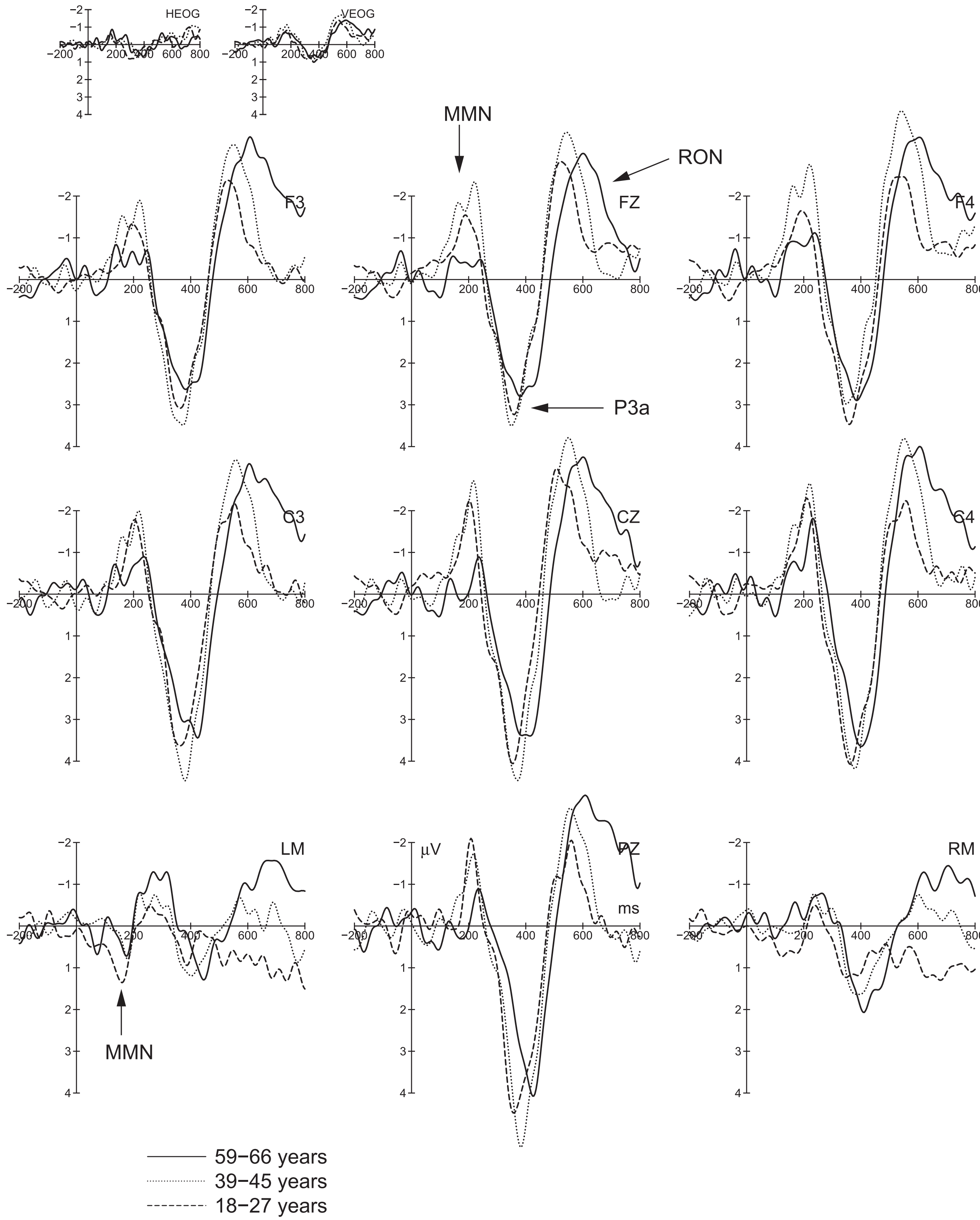

Fig. 3 – Difference waves obtained by subtracting Standard ERPs from Deviant ERPs are presented separately for the three age groups. Age effects are visible in the MMN, P3a, and RON component.

other three studies; the age range in this group was 21–39 years. Interestingly, neither the Mager et al. (2005) nor the Horvath et al. (2009) study obtained a significant aging effect in the behavioral distraction effects (even though there is a numerical difference in the Horvath et al. study which might have become statistically significant with a higher number of

Table 2 – Statistical evaluation of effects of Stimulus type (Standard vs. Deviant) and Age group (18–27 years vs. 39–45 years vs. 59–66 years) by means of two-way ANOVAs separately for MMN, P3a, and RON. F-values and partial η^2 are summarized.

Component	df's	MMN		P3a		RON	
Factor		F	η^2	F	η^2	F	η^2
Stimulus type	1, 29	23.97***	0.453	35.10***	0.548	43.01***	0.597
Age group	2, 29	2.25	0.134	0.49	0.033	3.59*	0.198
Interaction	2, 29	2.58°	0.151	0.13	0.009	0.19	0.013

° Significance levels: $p<0.1$.
* Significance levels: $p<0.05$.
*** Significance levels: $p<0.001$.

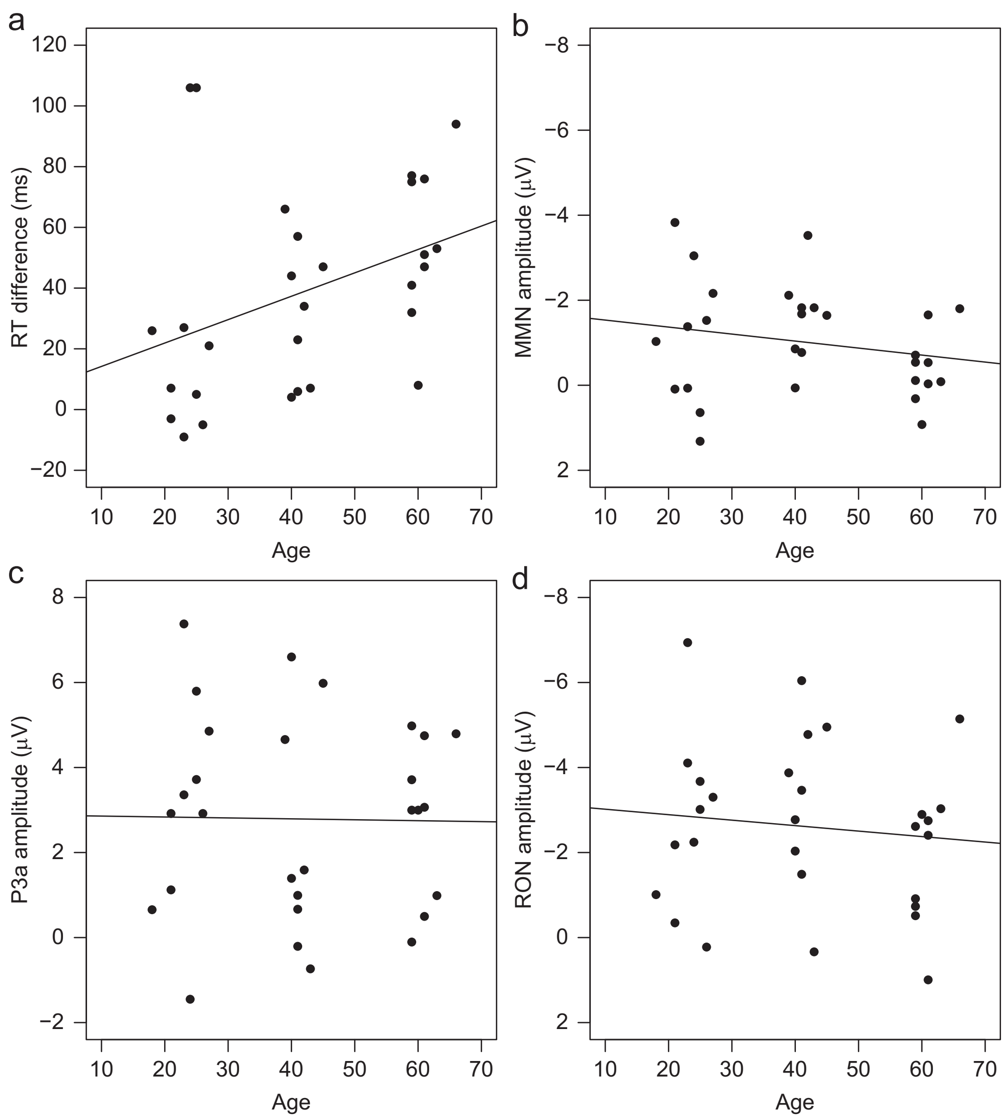

Fig. 4 – Scatterplots of age and behavioral and ERP distraction effects (N=28). The regression lines are based on linear regressions of age with the respective measure (RT distraction effect or ERP amplitude); the coefficients of the linear regressions are summarized in Table 3.

participants). This might be due to fact that the task itself could have been too easy (Horvath et al., 2009) or the age groups were not distinct enough (Mager et al., 2005) to tap a potential age effect. On the other hand, one may assume that in the present study an increase in the distraction effect in the 59–66 years group might be due to the long SOA (3000 ms) compared with these studies because this allows for slower responses in case of distraction. This is unlikely because

Table 3 – Summary of linear regressions of behavioral and ERP distraction effects by age. Estimated β coefficients and adjusted R^2s are reported.

Dependent variable	β	SE	t(27)	R^2	F(1, 27)
RT effect (ms)	0.77	0.37	2.07*	0.10	4.28*
MMN amplitude (μV)	0.02	0.01	1.12	0.01	1.22
P3a amplitude (μV)	−0.01	0.03	0.08	−0.04	0.01
RON amplitude (μV)	0.01	0.02	0.56	−0.03	0.31

* Significance levels: $p<0.05$.

in the Andres et al. (2006) study the time window to respond was 1200 ms but the distraction effect was also increased in the older group (see also Parmentier and Andres, 2010). Taken together these studies suggest that behavioral distractibility increases with age. Moreover, from the present study it might be assumed that a remarkable increase in distractibility begins in the 7th decade of life in healthy aging: while the 59–66 years group differs numerically from the two other groups, the 18–27 years and 39–45 years groups obtained virtually the same distraction effects. Also the Mager et al. (2005) and the Horvath et al. (2009) studies do fit into this perspective because the former obtained no effect of age group in the range from 21 to 59 years and the latter reported a (numerical) increase in the 62–82 years group. Moreover, it is possible that the observed increase of the distraction effect in the 50–83 years group in the studies by Andres et al. (2006) and Parmentier and Andres (2010) is mostly due to higher distraction effects in older participants (e.g., 60–83 years). Finally, the age effect on distractibility was not accompanied by an age effect on processing of Standard stimuli supporting the interpretation of a highly specific age effect confined to deviance processing.

The present results support the finding by Mager et al. (2005) and Horvath et al. (2009) that the neuro-physiological correlates of the processing of deviancy do not generally differ in early and middle adulthood: in all three age groups, the MMN, P3a, and RON components were elicited by Deviants suggesting an effective processing of the unexpected change. However, a reduction of the MMN amplitude in the 59–66 years group is visible in the difference waves which is in line with research on sensory auditory processing reporting an increase of MMN amplitude with age (Alain and Woods, 1999; Alain et al., 2004; Gaeta et al., 1998, 2002; Pekkonen et al., 1993; Rimmele et al., 2012). For instance, Rimmele et al. (2012) demonstrated a decline of MMN amplitudes with several types of stimuli in a group of participants with an average age of 66 years (range 60–72 years). This may explain why the Mager et al. (2005) study did not report age dependent changes in the MMN amplitude: with an upper age limit of 59 years pronounced aging effect on the level of sensory processing seem unlikely on basis of the findings by Rimmele et al. (2012).

In the present study, P3a and RON amplitudes reveal no significant aging effect on the level of group analysis. This is in contrast with the findings by Horvath et al. (2009) and Mager et al. (2005). As noted above, the behavioral distraction effect is usually interpreted as an index of individual distractibility (see, for instance, Schröger and Wolff, 1998; Berti et al., 2004) and is functionally connected especially with P3a and RON (see, for instance, Berti et al., 2004; Berti, 2008a; Horvath et al., 2008; Hölig and Berti, 2010). Therefore, an age effect in this behavioral measure should be mirrored in the ERP results. However, the multiple linear regression analysis suggests that the P3a amplitude mirrors the behaviorally relevant factor of stimulus-triggered attentional distraction but that the effect of involuntary attention is mediated by additional factors: in the present study, the individual distraction effect is explained best by an interaction of age and the P3a. A likely explanation is that the P3a amplitude reflects individual distractibility and that age affects participants with high and low distractibility differently. In contrast, the RON amplitude is assumed to reflect different aspects of attentional control (see Berti, 2008a) which might be the reason that this is not a stable predictor for the distraction effect. Moreover, some participants of the 18–27 years group show "negative" RT costs (see Fig. 4a) which can mirror behavioral facilitation by the deviant trials (i.e., faster responses in deviant compared with standard trials, see Wetzel et al., 2012). This effect as well as the general high variability in the 18–27 years group may conceal potential aging effects in the present study.

The present results suggest diverging aging effects on different levels of processing with an earlier decline in the sensory processing steps compared to later levels of cognitive control. This is in line with the idea of a more controlled processing in elderly and old participants because of a decrease in efficacy in automatic deviance processing on the sensory level as reflected by the MMN decline, (see Alain et al., 2004). It is also possible that the decrease in sensory sensitivity may be compensated by an increase of sensitivity to the output of sensory pre-processing on the level of attentional control systems (see Gaeta et al., 2001). Again, this would support the idea of different aging affects in different sensory and cognitive systems. The assumption of diverging aging-related changes in different ERP components is also supported by the finding of a variety of maturational and aging effects over the cortex during the human lifespan (see Sowell et al., 2003).

In general, the present study does not support a simple interpretation of developmental changes in adulthood claiming steady decline of neuro-cognitive functions and behavior: the finding of an increased distraction effect seems to match to the perspective focusing on inhibition deficits in elderly and old people (Hasher and Zacks, 1998). In addition it is likely that older participants (70+ years) show stronger aging effects in general and we would expect that the P3a and RON components will obtain age effects when a group of "old-olds" would be included (see Horvath et al., 2009). On the other hand, the present paradigm taps the highly important function of being open for the detection of changes in the environment while processing task relevant information in memory. In this case, the inhibition perspective is not adequate because inhibiting the stimulus that contains the task irrelevant information precludes the processing of the task relevant information, too. In other words, it is not possible for the participants to completely shield themselves from detecting and attending to a change in the stimulation (see, for instance, Berti and Schröger, 2003; Berti et al., 2004). In addition, the function tapped by the present paradigm is to balance processing of task relevant and task irrelevant stimulus features and to overcome distraction as fast as possible (after the new information is identified as irrelevant). This balancing is successfully managed by all participants in the present study and only the elderly participants seem to require more time in overcoming distraction. Finally, it is worth noting that these aging effects are accompanied by a high accuracy rate in performance demonstrating that sensory and cognitive processing remain efficient in healthy aging up to 66 years.

4. Experimental procedure

4.1. *Participants*

Thirty-five adults participated voluntarily in this study and were recruited by advertisement in local newspapers. The participants were included when a screening of their medical, neurological, and cognitive status assessed by a short questionnaire[3] showed no problematic finding and when they met one of the following age criteria: around 20, 40, or 60 years. Prior to data analysis, the data sets of two subjects were excluded from data analysis because of technical problems during data acquisition which resulted in a termination of the experiment. Another subject from the 39 to 45 years group was excluded from final data analysis because of a too high error rate in task performance (34% wrong responses in Standard and 45% wrong responses in Deviant trials). Finally, the following three groups were constituted with regard to the age range: a 18–27 years group ($N=11$; median: 24 years; five male), a 39–45 years group ($N=10$; median: 42 years; five male), and a 59–66 years group ($N=11$; median: 61 years; six male).

All participants reported to be healthy and free of hearing problems at the time the study took place and had no history of neurological or psychiatric illness. None of the participants was taking medications that affect the central nervous system. Furthermore, a brief intelligence test screening (German vocabulary test WST; Schmidt and Metzler, 1992) revealed no group differences: 18–27 years participants: IQ=101.3, 39–45 years participants: IQ=108.4, 59–66 years participants: IQ=106.9; one-way ANOVA with factor Age group: $F(2, 29)=1.436$, $p>0.1$, $\eta^2=0.09$.

The study was approved by the local Research Ethic Committee of the University Leipzig, Medical Faculty. Moreover, in accordance with the Declaration of Helsinki all, participants gave informed written consent after the nature of the study was explained to them. All participants received payment (6 Euro/hour) for their participation.

[3] We applied a questionnaire of the Clinical EEG Research Laboratory of the University Hospital Leipzig which was regularly used for initial screening of the medical and mental status of potential participants prior to final inclusion in a study. It is important to note that this questionnaire was not formally standardized and, therefore, is not directly comparably to a standard questionnaire like the Mini-Mental State Examination (MMSE, Folstein et al., 1975).

4.2. *Stimuli and procedure*

The stimuli were 200 ms and 400 ms sinusoidal tones (generated offline with CoolEdit 2000) including rise and fall times of 10 ms each. Both short and long stimuli were presented as standard tones with 700 Hz (Standard) and as deviant tones with 770 Hz (Deviants). The tones were presented binaurally via head-phones (Sennheiser HD 25-1) with an intensity of around 70 dB SPL and with a stimulus-onset asynchrony of 3000 ms.

The participants were asked to perform a 2-AFC auditory duration discrimination task: for each tone presented, they indicated by pressing a button whether it was short or long. All subjects performed eight experimental blocks of 100 trials. Each block started with at least five standard trials to establish the memory trace of the standard frequency; these trials were excluded from data analysis. Short and long tones occurred with equal probability. Frequency Deviants were randomly interspersed with a probability of 12%. Moreover, a Deviant was always followed by at least three Standards. The infrequent changes in pitch were irrelevant for the duration discrimination task. Therefore, subjects were instructed to take note of the duration information only. RT relative to the onset of the duration difference, i.e. 200 ms after stimulus onset, and response accuracies were recorded.

An experimental session started with a short introduction to the experiment (including the information that the participant is free to stop the experiment if needed) followed by a short interview to assess the current mental and medical status of the subjects (e.g. hearing deficit, medication, etc.). Afterwards, subjects completed the WST and simultaneously were prepared for the EEG-recording (attachment of the electrodes). Subsequently, subjects were verbally instructed about the task in the experiment and were presented with some example trials. Importantly, subjects were instructed to react as fast and as accurately as possible, but accuracy of responses was stressed. Therefore, subjects were informed that they had enough time to give their reaction before a new stimulus would be presented in order to protect especially the older subjects from time pressure. Every subject performed a training block consisting of short and long standard trials only in order to practice the duration discrimination task. After the training block, subjects were asked about possible problems with the task or the stimuli, such as hearing problems. If the subjects felt comfortable with the task and had no further questions the experiment was started. The total experiment (including pauses between the blocks) lasted approximately 1 h. When all experimental blocks were performed subjects were debriefed about the task and their performance and the electrodes were removed. A complete session lasted for about 2 h.

4.3. *EEG-recording*

The electroencephalogram (EEG) was recorded continuously with a Synamps amplifier (Neuroscan, Virginia, USA) using

Ag/AgCl-electrodes placed at F3, Fz, F4, C3, Cz, C4, and Pz according to the international 10–20 system plus two electrodes at the left and right mastoids (LM and RM respectively); all electrodes were referenced to an electrode placed on the tip of the nose. To control for eye movements, vertical and horizontal electro-occulograms (EOG) were recorded. Impedances were kept below 5 kΩ. Data was digitized at 250 Hz and online filtered using a 0.1–40 Hz band-pass and a 50 Hz notch.

4.4. *Data analysis*

Mean RT and the percentage of correct responses for Standards and Deviants were computed separately for the three age groups. The first five trials of a block as well as the first and second trial after a Deviant were excluded from the computation of the response on Standards. Moreover, only correct responses that were given within a time window of 200 and 1000 ms were counted as correct and included in the RT calculation. The RTs were calculated from 200 ms after stimulus onset because this is the point in time when short and long stimuli could be distinguished from each other. The behavioral data were analyzed by means of a mixed model analysis of variance (ANOVA) with the between-subjects factor Age group (18–27 years, 39–45 years, 59–66 years) and within-subjects factor Stimulus type (Standard vs. Deviant). In addition, for each group a mean distraction effect was calculated by subtracting RT to Standards from RT to Deviants; the existence of the distraction effect was tested separately for the three groups by Students *t*-tests against zero.

The EEG was offline 20 Hz low-pass filtered. Grand-average ERPs within −200 to 800 ms relative to stimulus onset with the 200 ms pre-stimulus interval serving as a baseline were computed for Standards and Deviants separately for the three age groups. The first and second Standards after a Deviant were excluded from the computation of the Standard ERPs. Artifact rejection was performed prior to averaging in order to eliminate trials contaminated with extensive EOG activity (epochs exceeding a standard deviation of 30 μV within a sliding window of 200 ms).

Difference waves were formed by subtracting Standard ERPs from Deviant ERPs. After visual inspection group specific time windows for MMN, P3a, and RON were defined in order to calculate averaged ERP amplitudes separately for Standard and Deviant trials. These time windows were 40 ms centered on the group specific peak latency of the three components as depicted in the grand-average difference wave. In detail, the following time windows were applied for calculation of the average ERP amplitudes (all amplitudes were calculated at Fz): MMN: 186–206 ms (18–27 years), 144–184 ms (39–45 years), and 124–164 ms (59–66 years); P3a: 340–380 ms (18–27 years), 328–368 ms (39–45 years), and 360–400 ms (59–66 years); RON: 504–544 ms (18–27 years), 524–564 ms (39–45 years), and 580–620 ms (59–66 years). In accordance with the studies by Mager et al. (2005) and Horvath et al. (2009) we expected that Deviants in all groups will result in increased amplitudes in these three time windows; to test this hypotheses und to ascertain the existence of MMN, P3a, and RON in every group a series of one-tailed Students *t*-tests for paired samples was computed to test for significant differences between Standard and Deviant ERPs. Moreover, in order to test for an interaction of age with stimulus type the ERP data were analyzed by means of mixed model analysis of variance (ANOVA) with the between-subjects factor Age group (3 levels) and the within-subjects factor Stimulus type (2 levels) separately for the MMN, P3a, and RON time window.

To test for correlation of age effects in the whole sample, simple linear regression models were calculated for the behavioral distraction effect, the MMN component, the P3a component, and the RON component with RT costs, MMN amplitude, P3a amplitude, and RON amplitude as dependent and age as independent variable. The behavioral distraction effect were further modeled with multiple linear regression models with two independent variables (age plus either MMN amplitude, P3a amplitude, or RON amplitude); only the model with significant β coefficients is reported (i.e., age and P3a amplitude as independent variables). Prior to regression analyses the data set including the difference values were scanned for outliers in order to meet the linear model assumptions. In detail, a data set were classified as an outlier when the value of either the behavioral distraction effect, the MMN amplitude, the P3a amplitude, or the RON amplitude exceeded the mean value in the whole data set (i.e., in all subjects) by plus or minus the standard deviation. This criterion were met by three participants (one from each age group) in either one or two of the respective parameters and for better comparison of the results of the regression analyses these three participants were excluded from the regression analyses in general; the final data set comprised of 29 participants (14 female; age range 18–66 years; median 41 years). Estimated β coefficients and adjusted R^2s are reported. All statistical analyses were computed using the *base* and the *stats* packages of the *R* software package (version 2.15.1; R Core Team, 2012) and the *psych* R package (version 1.2.4; Revelle, 2012).

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