Accurate Response Selection and Inhibition in Healthy Aging: An ERP Study

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Abstract

Inhibitory control is thought to be critical for appropriate response selection in an ever-changing environment and to decline with age. However, experimental paradigms (e.g., go/no-go) confound stimulus frequency with demands to respond or inhibit responding. The present study eliminated that confound by using a modified go/no-go task controlling for stimulus frequency differences (using frequent go, infrequent go, and infrequent no-go types of stimuli) in healthy older and young adults. Event-related potential (ERP) components related to detection of response conflict (N2) and response evaluation (P3) were also examined. Behaviorally, older and young adults were sensitive to stimulus frequencies indicated by significant slowing for the Infrequent compared with the frequent go stimuli observed in both groups. Furthermore, older adults were characterized by reduced commission errors and overall slowing, suggesting that they could take advantage of their slower performance. Increase of N2 amplitude was evident for correctly inhibited no-go stimuli in both groups. In contrast, no-go stimulus-related increase in P3 amplitude could be observed only in the young. Stimulus frequency-related ERP amplitude differences were not significant either in the young or in the old. These results suggest preserved behavioral control over inappropriate responses in older adults and indicate that efficient response inhibition is related to compensatory mechanisms. The age-related decrease in the P3 amplitude suggests that the evaluation of response inhibition could be 1) independent of the detection of response conflict, and 2) support the notion of strategic differences in performance with age.

Keywords: age differences; inhibition; control functions; response selection; ERP

Accurate Response Selection and Inhibition in Healthy Aging: An ERP Study

Inhibitory control is essential for the selection of the most suitable responses and thought to be reduced in older adults compared with young adults (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Miyake et al., 2000; Paxton, Barch, Racine, & Braver, 2008; Reuter-lorenz & Park, 2010; West, 1996). However, frequently used paradigms that measure inhibitory control often confound stimulus frequency with demands to respond. Particularly, in the go/no-go task, streams of identical stimuli (go) are presented, which is supposed to build up pre-potent response priming that must be overcome when a given specific rare stimulus (no-go) occurs and the response must be withheld. This paradigm confounds novelty or saliency effects with response conflict. Therefore, it might not be clearly measured how aging influences processes underlying inhibitory control. To address this issue, the present study used a modified go/no-go task that counterbalanced stimulus frequencies while maintained the pre-potent response priming. Furthermore, to more precisely identify the stages at which older adults might have had inhibitory control deficits, we also examined age differences in ERP components. We focused on early-stage processes, such as detecting stimulus frequency-related conflict, and later-stage response conflict, indicated by the changes of the N2 and P3 components, respectively.

The N2 and the P3 have been frequently studied in relation to inhibitory control (Eimer, 1993; Greenhouse & Wessel, 2013; Kok, 1986, 1999; Pfefferbaum, Ford, Weller, & Kopell, 1985). The N2 is a frontocentral negative ERP component peaking between 200-400 ms after a stimulus is presented with larger amplitudes when a stimulus is relatively rare or unexpected and/or stimulus-response conflict is present (Beste, Willemssen, Saft, & Falkenstein, 2010; Botvinick, Braver, Barch, Carter, & Cohen, 2001; Folstein & Van Petten, 2008; Kropotov, Ponomarev, Tereshchenko, Müller, & Jäncke, 2016; Smith, Jamadar, Provost, & Michie, 2013). The P3 component is a positive wave with a maximum peak occurring between 300-

600 ms after stimulus onset, and is thought to be the ERP marker of response-related evaluation processes (Benikos, Johnstone, & Roodenrys, 2013; Pires, Leitão, Guerrini, & Simões, 2014; Smith, Johnstone, & Barry, 2008). In go/no-go paradigms, both the N2 and the P3 components are characterized by larger amplitudes in no-go trials compared with go trials; this is labeled as the *no-go effect*. Furthermore, the N2 no-go effect has been found to be sensitive to the no-go stimulus probability, while the P3 no-go effect has been found to be dependent on whether the required response involves motor action (movement) (Burle, Vidal, & Bonnet, 2004; Smith et al., 2013, 2008; Thomas, Gonsalvez, & Johnstone, 2009; Wang, Tian, Wang, Cui, & Zhang, 2002). Overall, these No-go effects seem to be related to different aspects of inhibitory control; particularly, the detection of response conflict and the evaluation of the motor response (Huster, Enriquez-Geppert, Lavallee, Falkenstein, & Herrmann, 2013).

Studies investigating age-related changes in inhibitory control using various go/no-go tasks suggest that the N2 and P3 no-go effects differ between young and older adults, even in the absence of behavioral performance decline. Falkenstein et al. (2002) found comparable no-go effect in both N2 and P3 in the older adults using a visual and an auditory go/no-go task; however, the N2 no-go effect was slightly decreased in the visual modality in the older adults. Barry et al. (2016), in contrast, found in an equiprobable go/no-go task that only the P3 no-go effect was decreased in the older adults but the N2 no-go effect was observed in both groups. The results of Niessen et al. (2017) also showed that the N2 no-go effect was present in both the young and the older adults; however, the amplitude of the P3 was found to be decreased in the older adults for the No-go stimuli. On the contrary, Kropotov et al. (2016), by manipulating expectancy using a cued version of the go/no-go task, found that the N2 no-go effect was decreased but the P3 no-go effect was increased in the older adults.

The above studies used stimulus probability distributions that favoured responding over withholding reponse. When testing inhibitory control by promoting this pre-potent response priming, these paradigms confounded the no-go effect with novelty or saliency. To address this confound, Albert et al. (2013) controlled the stimulus probability differences between go and no-go stimuli while the relative infrequency of the no-go stimuli was preserved: An additional infrequent stimulus type was inserted in the stimulus stream, for which participants had to give exactly the same response as for the frequent (go) stimulus. These three stimulus categories, the frequent go, the infrequent go, and the infrequent no-go were presented with a probability distribution of 60%-20%-20%. The authors found that the N2 was indeed sensitive to the stimulus frequency differences but not to inhibition, while the P3 showed the opposite pattern. In other words, the "pure" no-go effect could only be observed in the P3 amplitudes but not in the N2 amplitudes that were sensitive only to stimulus probabilities.

Although Albert et al. (2013) handled the confounding factors in the go/no-go task, they investigated inhibitory control only in young adults and the effect of age was not tested. Therefore, in the present study, the go/no-go task described in the study of Albert et al. (2013) was used to investigate the age-related changes in inhibitory control processes. It was assumed that by comparing infrequent go and no-go stimuli, the no-go effect could be analyzed separately from the effect of stimulus frequency differences. It was also hypothesized that dealing with two types of infrequent stimuli could increase the load on inhibitory control because of the higher level of uncertainty, i.e., expectations could be developed for the infrequent stimuli (40% of probability in sum) but not for no-go itself. Regarding that the N2 was found to be related to the tracking of stimulus probability, the N2 no-go effect was assumed to be diminished in both groups. Meanwhile, the tracking of stimulus probability could be evidenced by larger N2 amplitudes for infrequent go stimuli compared with frequent go stimuli. Based on the assumption of increased load on inhibitory control, the P3 no-go effect (i.e., the increased P3 amplitude for No-go stimuli) was expected to be diminished in the older adults.

Methods

Participants

Twenty-three young adults and 22 older adults participated in the present study. The data of three young and four older adult participants had to be excluded from the analysis due to low performance level (one young adult and one older adult participant produced commission error rates above 45%) and EEG technical issues (two young adults and three older adults). Thus, the data of 20 young (10 female, age range = 21-28 years) and 18 old (13 female, age range = 62-72 years) adults was analyzed. According to an a priori power analysis conducted using the G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007), a total sample size of (at least) 18-24 participants is required to achieve the desired power level of 80% in case of a 0.3 effect size for the inhibition effect and its interaction with age (see Barry et al., 2016).

All participants provided written informed consent and received financial compensation to take part in the experiment. All participants were right-handed and had normal or corrected-to-normal vision. None of them reported any kind of neurological or psychiatric diseases, nor did any of them reported the use of medications which are known to influence the EEG. The IQ of all participants was tested by the Hungarian standardized version of Wechsler Intelligence Scale (WAIS-R) (Wechsler, 1955) prior to the experimental session. The demographic data and the IQ scores of the two groups are shown in Table 1. The study was approved by the relevant institutional ethics committee of Hungary (United Ethical Review Committee for Research in Psychology) and was conducted in accordance with the Declaration of Helsinki (Williams, 2008).

Table 1. Descriptive characteristics of participants.

Variables	Young adults (*n* = 20; 10 male)		Older adults (*n* = 18; 5 male)		
	Mean	SD	Mean	SD	Difference (*t*)
Age	22.45	± 1.96	65.83	± 3.58	-46.93**
Years of education	12.90	± 1.41	13.50	± 3.97	-0.63
IQ	118.20	± 8.06	120.30	± 8.77	-0.78
Verbal IQ	112.70	± 8.80	117.94	± 8.08	-1.91^{+}
Performance IQ	121.70	± 12.88	122.00	± 12.88	-0.08

Note. $^{+}$ $p < .1$; * $p < .05$; ** $p < .01$

Stimuli, Task, and Procedure

The present study was based on the modified go/no-go paradigm used by Albert et al. (2013). The stimuli were made up of three capital letters ("N", "M", and "W") that were presented individually in yellow color against black background (font style: Arial, font size: 12 pt). The participants were instructed to respond as fast and as accurately as possible with a right-handed button press (with their index finger) on a gamepad when the letters "N" or "M" appeared on the screen but to withhold their response when the letter "W" was presented. The session consisted of 400 experimental trials. A trial began by the appearance of the letter "N", "M", or "W" shown at the center of the screen for 400 ms. After stimulus offset, a blank screen was presented for 700 or 900 ms (randomly selected); then, the next trial began. Responses were expected during the whole trial from stimulus presentation until the end of the trial. In 60% of the trials, the letter "N" occurred (frequent go stimulus), whereas both the letter "M" (infrequent go stimulus) and "W" (infrequent no-go – hereafter referred to as no-go – stimulus) were presented with the same probabilities (20-20%). The trials were presented according to a semi-randomized sequence, which was based on five, pre-generated lists of stimulus order. The repetitive presentation of infrequent trials (infrequent go as well as no-go) was avoided. Five different pre-defined stimulus lists were administered in a counterbalanced manner.

EEG Data Collection

Participants were seated in an electrically shielded and acoustically attenuated room in front of a 19” CRT screen at a distance of 125 cm. The EEG was recorded with 62 Ag/AgCl electrodes, placed according to the international 10-20 system, using Synamps amplifiers and Neuroscan software (4.5; Compumedics). Vertical and horizontal eye movements were recorded by additional electrodes that were attached above and below the left eye, and also in the left and right outer canthi. The tip of the nose was used as a reference and an electrode placed between Cz and FCz was used for ground (AFz). The sampling rate was 1000 Hz and the signals were filtered on-line (DC-70 Hz, 24dB/octave roll-off). The impedance of the electrodes was kept below 10 kΩ.

Data Analysis

Behavioral data. The percentage of commission errors (false alarms for no-go stimuli) and omission errors (misses for go stimuli) were used to measure accuracy. The *log transformed response times* (logRT) of the correctly responded go trials (frequent and infrequent) was calculated to measure response speed. To eliminate the possible effect of posterror slowing (Dutilh, Vandekerckhove, et al., 2012) on response time (RT) data, posterror correct trials were not taken into consideration.

Electrophysiological data. The analysis of EEG data was performed by Matlab 7.9.1 (Mathworks) using the EEGLab 11.0.3.1b toolbox (Delorme et al., 2011). The continuous EEG signal was filtered to 0.5-45 Hz (digital FIR filter with 24dB/octave roll-off). Independent Component Analysis (ICA) was performed on continuous datasets with the help of ADJUSTS Version 3 plugin (Mognon, Jovicich, Bruzzone, & Buiatti, 2011) in order to exclude artifacts caused by blinking or other eye-movements.

For stimulus-related ERP analysis, all of the correct trials were considered. The artifact free data were epoched from -500 ms before to 800 ms after a given stimulus, and a 200-ms-long pre-stimulus interval was defined for baseline correction. Based on the topographical distribution of the ERPs, a central region of interest (ROI) was defined as the average of the data recorded by the FC1, FCz, FC2, Cz, CP1, CPz, CP2 electrodes. The ERPs were quantified on this central ROI. The time windows for the ERP analysis were selected based on visual inspection and in accordance with previous studies (Falkenstein et al., 2002; Niessen et al., 2017). The N2 component was analyzed as the mean amplitude ERP occurring between 200-350 ms after stimulus onset, whereas the P3 was measured as the mean amplitude between 350-500 ms. To eliminate stimulus frequency-related bias in the statistical comparisons, every third trial of the frequent go condition was taken into consideration. The average stimulus-related trial numbers per condition were $M_{\text{Frequent Go}} = 73.11$ (range: 39-79), $M_{\text{Infrequent Go}} = 71.89$ (range: 41-79), $M_{\text{No-go correct}} = 61.92$ (range: 34-74).The trial numbers per condition did not differ significantly between the age groups ($F(3, 34) = 1.75$, $p > .1$).

Statistical analysis. Statistical analysis was performed with the Statistica software (Version 13.4; TIBCO Software). Bonferroni's post hoc test was used to assess p-values of the pairwise comparisons. Partial eta-squared values are provided as a measure for the proportion of variance explained by the independent variables.

Behavioral data. Independent samples *t*-tests were used to compare commission (false alarms for no-go trials) and omission (misses for go trials) error rates (percentage of errors) between the groups. Mixed design analyses of variances (ANOVAs) were used to assess logRT on the correct trials with group (young vs. old) and frequency (frequent vs. infrequent) as variables.

ERPs. Stimulus-related ERPs were analyzed by mixed design ANOVAs. The *no-go effect* on the N2 and P3 components was assessed in a group (young vs. old) by inhibition (infrequent Go vs. No-go) design using the correctly responded infrequent Go and No-go trials. *Stimulus frequency effect* on the N2 and P3 components was assessed in a group (young vs. old) by frequency (frequent go vs. infrequent go) design.

Results

Behavioral Results

Accuracy. Regarding commission errors (see Figure 1A), a significant difference was observed between the two age groups ($t(36) = 2.16$, $p = .037$), indicating that older adults made fewer commission errors ($M = 12.29$, $SD = 5.41$) than young adults ($M = 17.25$, $SD = 8.27$). There was, however, no participant who made any omission errors ($M = 0$, $SD = 0$ for both groups).

RT. Analysis of the effect of stimulus frequency on the logRTs (see Figure 1B) revealed a significant main effect of group ($F(1, 36) = 16.81$, $p < .001$, $\eta_p^2 = .32$), indicating faster responses in the young ($M = 5.78$, $SE = 0.02$) than in the old group ($M = 5.93$, $SE = 0.03$). A significant main effect of frequency was also observed ($F(1, 36) = 152.94$, $p < .001$, $\eta_p^2 = .81$), showing that responses were slower for infrequent ($M = 5.91$, $SE = 0.02$) than for frequent go ($M = 5.80$, $SE = 0.02$) stimuli in both groups. No significant interaction was found between the two factors. The mean logRT values of the groups are shown in Table 2.

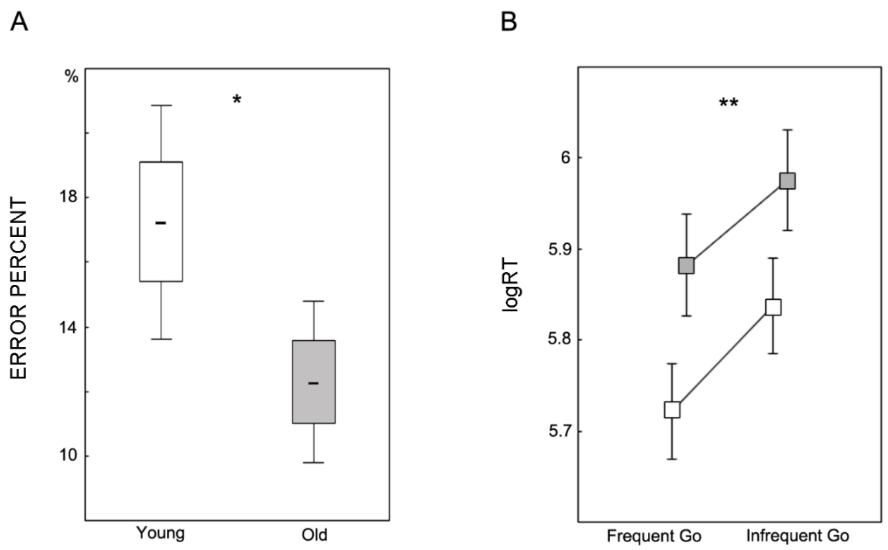

Figure 1 – Behavioral measures. Panel A denotes the mean percentage of commission errors. Panel B shows the frequency effect in the logRTs of correct responses by groups. Data of the old group is shown in grey. Vertical lines denote 95% confidence intervals. Significant statistical comparisons are indicated by asterisks. * $p < .05$; ** $p < .01$

ERP Results

Grand averages of stimulus-locked ERP waveforms are shown in Figure 2. Non-significant effects are shown in detail in Table 3. Table 2 shows the exact values and standard errors of the components by trial type.

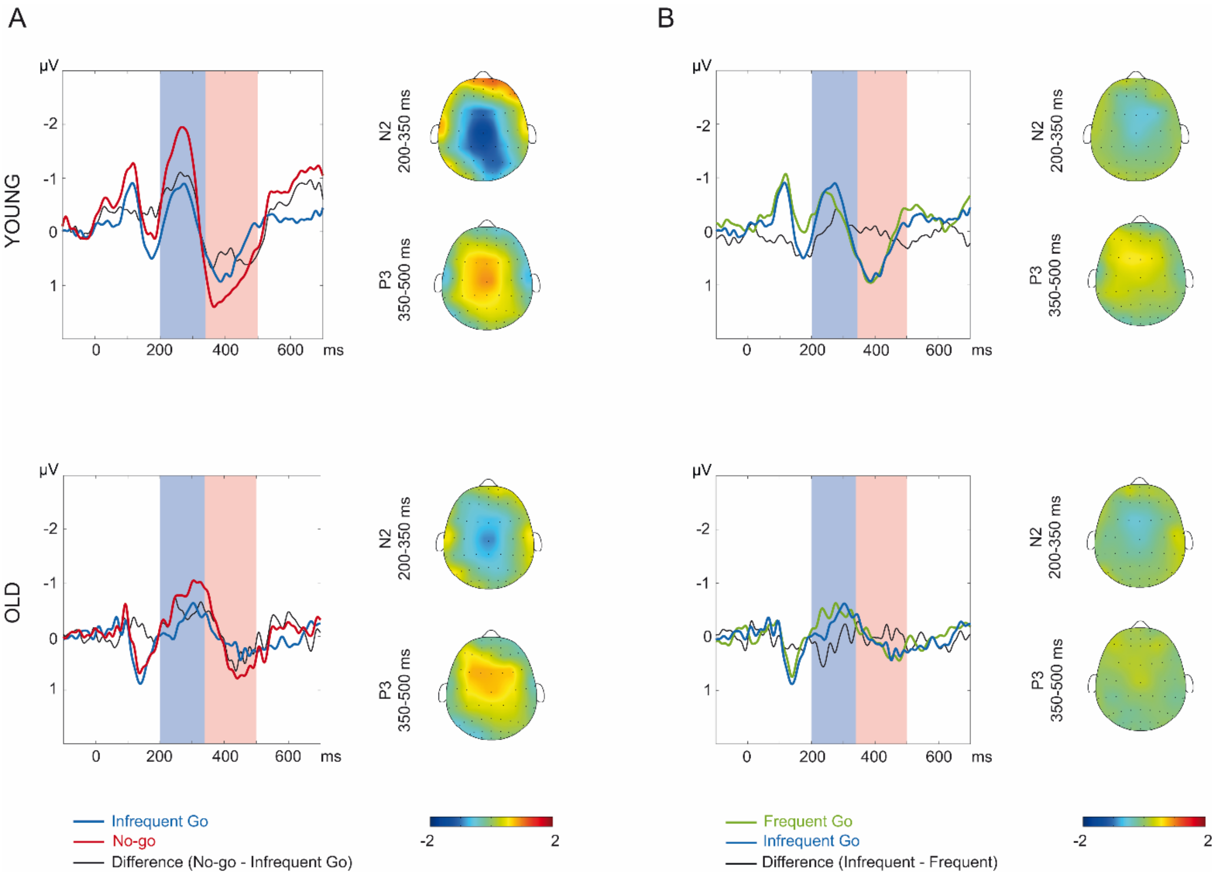

Figure 2 – ERP grand averages. Panel A: Inhibition effect. Stimulus-locked ERPs of the young (upper panel) and the old (lower panel) groups. Panel B: Frequency effects. Stimulus-locked ERPs of the young (upper panel) and the old (lower panel) groups. 0 ms indicates the presentation of the stimulus. Scalp maps show the topographic distributions of the inhibition

effect (Panel A) and frequency effect (Panel B). Scalp maps are plotted according to the local minimum/maximum values in the given time window.

Table 2.
Mean RTs and mean amplitudes of the ERP components.

	RT measures				**ERP**			
	RT (ms)		logRT		N2 (μV)		P3 (μV)	
Conditions	Young adults	Older adults	Young adults	Older adults	Young adults	Older adults	Young adults	Older adults
Frequent go	316 (8.53)	369 (8.99)	5.72 (0.03)	5.88 (0.03)	-0.28 (0.12)	-0.38 (0.13)	0.41 (0.10)	0.19 (0.10)
Infrequent go	353 (10.12)	407 (10.67)	5.84 (0.03)	5.98 (0.03)	-0.37 (0.12)	-0.26 (0.13)	0.48 (0.11)	0.18 (0.12)
No-go correct					-1.00 (0.15)	-0.78 (0.16)	0.99 (0.14)	0.39 (0.15)

Standard errors of the mean amplitude are in parentheses. RT = response time; ERP = event-related potential; logRT = log-transformed response time.

Table 3.
Mixed design ANOVAs.

	Group		**Frequency**		**Group*Frequency**	
Variables	*F*	*p*	*F*	*p*	*F*	*p*
logRT	16.81	< .001	152.94	< .001	1.75	.194
N2	0.00	.954	0.05	.825	2.64	.113
P3	3.47	.070	0.34	.562	0.41	.526
	Group		**Inhibition**		**Group*Inhibition**	
	F	*p*	*F*	*p*	*F*	*p*
N2	0.80	.378	52.10	< .001	0.40	.534
P3	7.31	.010	23.73	< .001	4.24	.047

Note. ANOVA = analysis of variance; logRT = log-transformed response time.

No-go effects. Investigation of the no-go effect on the N2 component revealed a significant main effect of inhibition ($F(1, 36) = 52.09$, $p < .001$, $\eta_p^2 = .59$), indicating that the N2 component was larger for the infrequent No-go ($M = -0.89$, $SE = 0.11$) than for the infrequent go ($M = -0.31$, $SE = 0.09$) stimuli.

Analysis of the No-go effect on the P3 showed a significant main effect of group ($F(1, 36) = 7.31$, $p = .010$, $\eta_p^2 = .17$), showing larger amplitudes in the young group ($M = 0.73$, $SE = 0.11$) than in the old group ($M = 0.28$, $SE = 0.12$). The main effect of inhibition was also significant ($F(1, 36) = 23.73$, $p < .001$, $\eta_p^2 = .40$), indicating that infrequent no-go stimuli elicited larger P3 amplitudes ($M = 0.69$, $SE = 0.10$) than infrequent go stimuli ($M = 0.33$, $SE =$

0.08). The interaction between the group and inhibition factors was also found to be significant (F(1, 36) = 4.24, p = .046, η_p^2 = .10). Post-hoc tests showed that the inhibition effect was present in the young group ($M_{infrequent\ Go}$ = 0.48, SE = 0.11; $M_{No\text{-}go}$ = 0.98, SE = 0.14; p < .001) but it was not observed in the old group ($M_{infrequent\ Go}$ = 0.18, SE = 0.12; $M_{No\text{-}go}$ = 0.38, SE = 0.15; p = .231).

Frequency effects. Investigation of the frequency effect did not reveal significant main effects or interactions either for the N2 or for the P3 components.

Discussion

The present study investigated the effect of age on inhibitory control by analyzing ERP components related to stimulus processing in a modified three-stimulus go/no-go task. Although both groups were characterized by accurate performance, older adults showed significantly less commission errors for the no-go stimuli and were characterized by slower responses for the go ones. The no-go effect was found to be significant in both age groups regarding the N2 component, but the P3 component showed an inhibition-related amplitude increase only in the young. Stimulus frequency effect in both age groups was found to be evident only in the response times but not in the ERPs. The comparable stimulus-locked N2 amplitudes and the decreased P3 amplitudes, together with the markedly accurate but slower performance of the older adults, support the assumption of strategic compensation in healthy aging.

Behavioral Performance

Older adults showed remarkably accurate performance with less commission errors compared with the young. The lower error rates of the older adults could be related to the age-related decrease in impulsivity, which is a critical factor in the go/no-go tasks. This kind of monotonous task requires long-lasting sustained attention to fight against automatized response priming (Staub, Doignon-Camus, Bacon, & Bonnefond, 2014a). In the study by Staub, Doignon-Camus, Bacon, & Bonnefond (2014b), young adults were characterized by higher level of subjective frustration and reported more mind-wondering thoughts and less motivation/interest during the task. Although the present study did not investigate the subjective task-related feelings and experiences, the effects of task involvement could be considered as a possible source of the group differences in accuracy.

The RTs varied significantly by stimulus frequency in both age groups: frequent go stimuli elicited faster responses than infrequent go stimuli. Infrequent go trials, however, can be considered as trials that involve a change in the stimulus but require exactly the same response. Studies investigating response repetition effects referred to these types of trials as equivalent trials (“different stimuli-same responses”) and found that the RTs on these trials did not differ significantly from the so-called identical trials (the term used for “same stimuli-same responses” combination) (Notebaert & Soetens, 2003). Thus, this frequency effect in the RTs – which did not interact with age – probably originates from stimulus frequency that had a significant influence on the processing speed and/or response selection regardless of the general age-related slowing of response speed.

Slow RTs are usually attributed to general cognitive/response slowing and declined vigilance (Dutilh, Van Ravenzwaaij, et al., 2012; Salthouse, 1996). Maintaining high accuracy rate and giving slower responses is also in line with the increasingly apparent strategic/intentional speed-accuracy trade-off (SAT) process (Heitz, 2014; Salthouse, 1979). To assess whether a speed-accuracy trade-off can be detected in any of the age groups, a two-step post-hoc analysis was conducted. First, Pearsons’s correlation was calculated between accuracy (proportion of correct rejections for no-go stimuli) and RT (summarized logRT for go stimuli), irrespective of stimulus frequency and post-error status. This was conducted on the whole sample and for the two age groups separately. The correlational analysis revealed a significant positive correlation between the proportion of correct no-go rejections and the RT in the whole sample ($r(36) = .49$, $p = .002$) and in the young adult group ($r(18) = .49$, $p = .029$) but not in the old group ($r(16) = .27$, $p > 0.1$). Second, the balanced integration score (BIS) (Liesefeld & Janczyk, 2019) was used as a combined measure to assess performance independent of the possible speed-accuracy trade-off (SAT) differences between the two groups. The BIS score was computed by subtracting the z-score of the summarized logRT from the z-score of the proportion of correct responses, allowing these measures to be analyzed on the same scale. The independent samples *t*-test revealed no significant difference between the two age groups (BIS young group $M = 0.226$, $SD = 1.03$, BIS old group $M = -0.251$, $SD = 1.05$). Thus, while the SAT-independent performance measure could not reveal differences between the young and older adults, the pattern of RT and accuracy distribution points towards a higher decision criterion in the older adults, possibly due to vigilance and sustained attention factors.

Sustained attentional functions are found to peak at around forty years of age, whereas other fluid cognitive abilities seem to reach their peak in- or before the thirties (Fortenbaugh et al., 2015). From this perspective, neither the young nor the old group would have had an advantage in the present study. These two age groups are, in fact, on the opposite edges of the spectrum of strategy ranging from “going faster and respond” to “going slower and withhold” (Fortenbaugh et al., 2015). One possible factor by which age could be a benefit in monotonous cognitive tasks is motivation or interest (Staub et al., 2014b). As it was found by Staub et al. (2014b), however, older adults have performance difficulties on those sustained attentional tasks that require responses only for rare stimulus occasions. The authors proposed that the lack of task-relevant frequent stimuli failed to enhance the arousal level in older adults making it more difficult to engage attentional processes. Alternatively, the bottom-up intrusion of irrelevant information could imply a top-down regulation of attention that also affects the processing of relevant information. Taken together, it could be that efficient response inhibition – which might be overactive in a task-irrelevant context – is a byproduct of the increased recruitment of cognitive control in response to the motivation to maintain optimal performance.

Stimulus-locked ERPs

Interpretation of the N2 results. Stimulus frequency did not have an effect on the N2 amplitudes; however, the N2 no-go effect was reliably observed in both age groups. This result contradicts that of Albert et al. (2013) reporting a stimulus-frequency effect in the N2 in the same paradigm. It is to be noted, however, that the study of Albert et al. (2013) used the principal component analysis method for the quantification of ERPs. According to the conflict theory, the increase of the N2 is an index of the ongoing monitoring processes tracking those salient object- or context-related parameters that result in the violation of expectations (e.g., change in the stimulus properties, discrepancy in the probability of occurrence or novelty; see Botvinick, Cohen, & Carter, 2004). Thus, in theory, based on their frequency of occurrence in the stimulus stream, both infrequent go and no-go stimuli could have elicited the N2 with larger amplitudes irrespective of response inhibition. The present results suggest, however, that stimulus-related conflict detection did not vary between the go stimuli with different stimulus frequency but it was influenced by the inhibitory requirements of the no-go stimuli.

As Gajewski and Falkenstein (2013) proposed, the N2 amplitude signals conflict emerging from the stimulus-response associations. Indeed, assuming a developing stimulus-response association, the conflict emerging from the decision of whether to respond to a no-go stimulus or not should be higher compared with the conflict emerging from the frequency differences of the two go trial types. Furthermore, the letters that function as go stimuli in the present design (N and M) could be strategically grouped under the “go” label against the letter

W which is semantically (but not visually) more distinct from them, accentuating the go/no-go category boundaries even more. Thus, it could be that in the present design, the stimulus frequency information was less salient or even insignificant in the absence of response-related conflict that would have originated from two competing go response representations.

Nevertheless, the increased amplitude of the N2 in no-go trials could be observed in both the young and the older adults, which is in line with the findings of previous studies using the two stimulus go/no-go paradigms (Falkenstein et al., 2002; Niessen et al., 2017). As Czernochowski et al. (2010) summarized, age-related alterations in conflict monitoring and processing could be more likely detected under high task demands. In the present go/no-go design, task demands were moderate with a familiar stimulus set, slow inter-stimulus-interval, and simple response requirements; and the real difficulty was probably to keep up with the monotony of the task. Thus, it can be concluded that under monotonous but otherwise low-difficulty task conditions, inhibition-related conflict monitoring is preserved in the older adults, as shown by the N2 results.

Interpretation of the P3 results. The P3 was not sensitive to the stimulus frequency effect; and, in accordance with our predictions, the P3 no-go effect was observed only in the young but not in the older adults. The decreased P3 amplitude in the older adults for no-go stimuli is in line with the previous findings of Barry et al. (2016) and Niessen et al. (Niessen et al., 2017). Smith et al. (2013) in their combined EEG and fMRI study, associated the P3 no-go effect with active inhibition of the pre-potent motor movement in the successful no-go trials. In line with these findings, the present results suggest that the active inhibition of the response could not be observed in the ERPs of the older adults. The P3, however, is an ERP component that is thought to consist of several latent subcomponents, like the anterior P3a or the posterior P3b (Polich & Criado, 2006). Thus, it should be noted that the interpretation of the P3 functional significance could be a matter of ERP scalp topography (Vallesi, 2011).

Regarding its morphology, in the present study, the P3 occurred with a central peak for all stimulus conditions, probably reflecting evaluative rather than motor inhibition-related processes (Benikos et al., 2013).

Regarding the functional significance of the P3, a vast amount of literature associates larger P3 amplitudes with increased resource mobilization (see Polich & Criado, 2006). In contrast with the present results, Vallesi (2011) found an increased central no-go P3 component in older adults compared with younger adults, although they were using an equiprobable go/no-go design. The authors suggested that older adults allocated more resources to the irrelevant no-go stimulus than the young and associated it with higher distractibility. The authors raised the possibility, however, that the difficulty of the task could have influenced the amount of available resources, and, therefore, could have caused ambiguities in the age-related results. Benikos et al. (2013) found in a young adult sample that high level of task difficulty resulted in a decreased central P3 no-go effect. They concluded that beyond a certain point of difficulty, the efficiency of inhibitory mechanisms was "overwhelmed", and both go and no-go stimuli elicited larger P3 amplitudes. Thus, it could be that the lack of P3 no-go effect in the older adults was related to a (subjectively) higher perceived task difficulty.

Under uncertain circumstances where the type or appearance of the next event is less predictable, a proactive inhibition of an automatic/pre-potent response can be expected to preserve accurate performance (Criaud, Wardak, Ben Hamed, Ballanger, & Boulinguez, 2012). As it was demonstrated by Staub et al. (2014b) in a sustained attention go/no-go task, older adults were characterized by better proactive control engagement (increased pre-stimulus slow wave) and increased no-go sustained potential over the course of the task, which was associated with a stable performance level. Kropotov et al. (2016) found increased cue-related activity accompanied by increased P3 amplitudes for no-go stimuli in the older adults. In their task design, cues explicitly indicated whether the forthcoming go or no-go stimuli should be taken into consideration and, thus, emphasized the role of proactive control on the pre-motor response planning processes. In the present design, although the no-go trials always followed the frequent go trials, Frequent go trials could have been predictors of all three possible forthcoming stimulus types. In this regard, the lack of valid cue-target associations could have triggered proactive inhibition of responding in the older adults resulting in a decreased P3 inhibition effect and accurate performance.

Conclusions

In the present study, inhibitory control was investigated in healthy older and young adults. As revealed by their task performance, the present results suggested that despite the slower response times, older adults were able to perform on the same level as the young. ERP indices of stimulus processing indicated the successful detection of response conflict in both the young and the older adults; however, evaluative processing related to response inhibition was found to be altered with age. In conclusion, a dissociation between the detection of response conflict and the elaboration of response inhibition was found in the older adults, probably corresponding to neural changes related to aging. The preserved behavioral control over inappropriate responses in older adults presumably refers to a significant compensatory interaction of attention and inhibitory control and emphasizes the protective role of motivation under monotonic circumstances in healthy aging.

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