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Age-dependent characteristics of feedback evaluation related to monetary gains and losses

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Abstract

Monitoring the consequences of actions is of crucial importance in order to optimize behavior to the challenges of the environment. Recently the age-related aspects of this fundamentally important cognitive processing have been brought into the focus of investigation since behavioral monitoring and related control mechanisms are widely known to be affected by aging. Processing of feedback stimuli is a core mechanism for rapid evaluation of the functionally significant aspects of outcome, guiding behavior towards avoidance or approach. The aim of the present study was to analyze the age-related alterations in the most prominent electrophysiological correlates of feedback processing, the feedback-related negativity (FRN) and the P3 event-related potential components, using a two-choice-single-outcome gambling task with two amounts of monetary stakes. In terms of behavioral indices higher proportion of risky choices was observed after loss than after gain events in both groups. In the young the FRN component was found to be an indicator of the goodness of outcome (loss or gain), and the P3 showed a complex picture of feedback evaluation with selective sensitivity to large amount of gain. In contrast, in the elderly group outcome valence had no effect on the amplitude of the FRN, and the P3 was also insensitive of the complex outcome properties. As the ERP-correlates of feedback processing are not as pronounced in the elderly, it is suggested that normal aging is accompanied by an alteration of the neural mechanisms signaling the most salient feedback stimulus properties.

Keywords: aging; feedback processing; FRN; P3; gambling

Abbreviations [1]

[1] ERP – Event-related potential; FRN – Feedback-related negativity; MFN – Medial-frontal negativity; fERN – feedback error-related negativity; RT – response time; WAIS-R – Wechsler Intelligence Scale Revised ; IQ – Intelligence quotient; VQ – Verbal quotient; PQ – Performance quotient; ICA – Independent Component Analysis ; ROI – Region of interest

1. Introduction

Adequate feedback processing mechanisms based upon internal and external cues are crucial for optimizing goal directed behavior. Theories on feedback-related learning have a long history dating back to the 1920s (reviewed by Holroyd & Coles, 2002). Stimuli with reward or punishment valence normally regulate the motivational basis of future actions towards avoidance or approach behavior. Recently, more attention has been paid to the age-dependent aspects of this fundamental cognitive processing since behavioral monitoring and control mechanisms were shown to be affected by aging (Luszcz, 2011), although life experience could provide compensatory advantage in the elderly (Bäckman & Farde, 2005). Thus the present study is aimed to investigate the age-dependent neural and behavioral characteristics of feedback evaluation related to monetary gains and losses.

Neurocognitive mechanisms underlying behavioral monitoring are traditionally investigated by the electrophysiological correlates of feedback processing. Two event-related potential (ERP) components, the feedback-related negativity (FRN, also labeled as medial frontal negativity – MFN, or feedback-error-related negativity – fERN) (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Holroyd & Coles, 2002; Miltner, Braun, & Coles, 1997; Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004), and the P3 component were found to corresponding to various aspects of the feedback evaluation process.

The FRN occurs with about 200-300 ms post-stimulus latency and is usually seen with a fronto-central scalp distribution. The FRN is typically elicited by feedback stimuli indicating that the consequences of the response the experimental subject executed was erroneous; more specifically, that the outcome appeared to be worse than expected (Nieuwenhuis et al., 2002; Walsh & Anderson, 2012). In terms of generator regions and mechanisms, feedback-monitoring processes are considered to be mostly prefrontal and rostral cingulate cortical functions (Cohen, Wilmes, & Vijver, 2011; Gehring & Willoughby, 2002; Hauser et al., 2014; Mathalon, Whitfield, & Ford, 2003; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). According to the "dopaminergic theory", the FRN is considered to correspond to a negative signal from the mesencephalic dopaminergic system to the ACC and prefrontal cortex (Holroyd & Coles, 2002; Nieuwenhuis et al., 2002). It is important to note, however, that the FRN could be the result of an error-related suppression of the reward positivity component. Thus the magnitude and the occurrence of FRN are possibly influenced by specific reward-related factors as well (Holroyd, Krigolson, & Lee, 2011; Proudfit, 2015).

The feedback associated P3 can be defined as a positivity peaking between 300-500 ms post-stimulus (Kamarajan et al., 2009; West, Bailey, Anderson, & Kieffaber, 2014; Wu & Zhou, 2009; Yeung & Sanfey, 2004), and it represents the process of elaborative evaluation of outcome reflecting the functional significance of stimuli (Gu et al., 2011; Lole, Gonsalvez, Barry, & De Blasio, 2013; Zhang et al., 2013). Two subtypes of the P3 component (P3a and P3b) can be defined with different scalp distributions and generator mechanisms (Polich & Criado, 2006; Squires, Squires, & Hillyard, 1975). Whereas the P3a has a fronto-central scalp distribution and is associated with dopaminergic activation (Foti, Weinberg, Dien, & Hajcak, 2011; Holroyd, Pakzad-Vaezi, & Krigolson, 2008; Polich & Criado, 2006; West et al., 2014), the P3b is possibly generated in the temporo-parietal cortical regions and corresponds to norepinephrine-linked processes (Polich & Criado, 2006; West et al., 2014).

An often used experimental condition in which feedback-driven behavior is studied is simulated gambling, typically involving monetary gain and loss possibilities. A consistent finding was that the FRN recorded in these conditions reflected the evaluation of outcome events along a "good or bad" dimension (worse or better than expected) and was not sensitive to the magnitude of the error, e.g. amount of monetary loss (Gehring & Willoughby, 2002; Holroyd & Coles, 2002; Yeung & Sanfey, 2004). The P3 component, on the other hand, was found to correspond to an evaluative process reflecting on the magnitude of reward or punishment and the risk associated with a particular outcome, but was considered to be insensitive to the valence of outcome (Christie & Tata, 2009; Kamarajan et al., 2009; Yeung & Sanfey, 2004).

The results of several other studies, however, did not support the aforementioned conclusions. Hajcak et al. (Hajcak, Moser, Holroyd, & Simons, 2007) and Lole et al. (2013) found that the P3 was higher following rewards than non-rewards. In some studies the FRN was assumed to be a positive deflection, being larger following reward compared to non-reward outcomes (Foti et al., 2011; Holroyd et al., 2008). Based on more recent data it was suggested that the FRN and the P3 were both sensitive to the valence and also to the magnitude of the outcome in gambling conditions (West et al., 2014).

The electrophysiological investigation of age-related alterations in the process of feedback evaluation in probabilistic learning and gambling like conditions mostly concerned the FRN component which was consistently found to have reduced amplitudes in the elderly. Niuwenhuis et al. (2002) suggested that the impaired learning performance and reduced FRN were the consequences of dopaminergic dysfunction in old age. Wild-Wall et al. (2009) also concluded that the decreased FRN amplitude seen in the elderly was the consequence of a decline in the dopaminergic system, and that older adults could not utilize efficiently the negative feedback. Eppinger et al. (2008) also concluded that the elderly are less sensitive to negative feedback and rely more on positive feedback during reinforcement learning.

Most of these studies focused on various aspects of learning from feedback, but in conditions like gambling, the role of learning is not likely to play a role in shaping behavior. Although lifelong experience is in their favor, the decline of various aspects (memory, attention, etc.) of cognitive capacity (reviewed by Raz et al., 2005) is likely to jeopardize the chances of successful decision making with age.

The present study was aimed to investigate the age associated alterations of risky choice behavior and the related ERP correlates (FRN and P3 ERP components) of feedback processing. A modified version of the two choice single outcome gambling task used by Gehring and Willoughby (2002) was used, in which the participants had to choose between large and small amount of monetary stakes. The choices were followed by outcome stimuli indicating either monetary gain or loss that resulted from their choice. By the application of this experimental design processes related to evaluation of the outcome and its magnitude (large or small gain or loss) could be analyzed.

One of the main questions investigated was to determine which age group would be more likely to get involved in risky choice behavior (showing preference to lay large stakes), since life-long experience in the elderly would enable old subjects to use more rigorous control preventing excessive loss. However, because control mechanisms are known to decline with age a possible bias towards reward maximization may develop characterizing feedback related behavior.

It was also attempted to verify if the FRN corresponds only to the valence of reward (detection of erroneous outcome) and not to its magnitude, and likewise, if P3 is sensitive only to reward or non-reward magnitude and not to its valence. It was assumed that if the FRN indeed reflects expectation violation based on the simple evaluation of the correctness of outcome, larger FRN will characterize those outcomes that inform the participants about loss. In the case of the P3, if the assumption that it reflects higher level evaluative processes is tenable, sensitivity to both reward valence and magnitude can be expected, predicting larger amplitudes for larger amount of monetary gain. It was also investigated to what extent aging modifies the above correlations in the present gambling condition. It was expected that whereas the above correlations could differentiate between feedbacks associated with different outcome conditions in the young, smaller feedback-related changes would characterize the ERP indices in the elderly. More specifically, the amplitude of both the FRN and the P3 components were expected to be attenuated with age, and to show less differentiation between feedback types.

2. Methods

2.1. Participants

18 young (age range: 18-32 years, 15 female) and 17 old (age range: 62-72 years, 13 female) participants took part in the study (demographic data are shown in Table 1.). All of them had normal or corrected vision and were right handed. The participants had no history of neurological or psychiatric diseases and were not on any kind of medication (sedatives, tranquilizers, etc.) that are known to influence the EEG. The participants signed a written consent according to the Declaration of Helsinki, which was approved by the relevant institutional ethics committee (United Ethical Review Committee for Research in Psychology, Hungary). They received financial compensation for taking part in the study. The demographic data of the two groups (sex, years of education) were matched. Prior to the experiment the IQ of all participants was tested with the Hungarian standardized version of Wechsler Intelligence Scale (WAIS-R) (Table 1.). The analysis of the IQ measures (IQ, VQ and PQ) revealed no significant differences between the two groups.

--Table 1. --

2.2. Stimuli, task and procedure

The block design of the sequence of events during the gambling game was similar to that used by Gehring and Willoughby (2002). An example of an experimental trial is shown in Figure 1. At the beginning the participants viewed two roundish tokens in the left and right parts of the screen. The monetary value of each token was shown in yellow in their middle. The token of 50 HUF had a blue frame, was 7 cm diameter in size and appeared consistently in the left side of the screen. The frame of the 200 HUF token was black, was 11.5 cm diameter in size and was shown in the right. The participants were instructed to make a choice (to 'lay a stake') between these two items trial by trial and try to maximize their income throughout the game in order to gain an extra profit in addition to the participation fee. The tokens were visible on the computer screen as long as the participant made his/her choice by appropriate (left or right) button press on a gamepad. Then the chosen token changed its size (to 13.5 cm diameter), its location (to the center of the screen), and its frame (to yellow) for 300 ms followed by a blank screen for 1500 ms. After this, the chosen token re-appeared in the center of the screen with either red (meaning loss) or green (meaning gain) frame for 800 ms ('outcome event'). There was a 2200 ms delay interval after the offset of the outcome stimulus, during which a blank screen with a fixation cross was shown and then the process resumed. In every given trial four possible outcome events could be defined according to the amount of the chosen stake, representing the magnitude of the income/deficit: large gain, small gain, large loss and small loss. The experimental session for each participant consisted of 6 blocks of 32 trials (192 trials in sum). The participants started each block with 1000 HUF of stock, which was shown in the bottom of the screen during the first trial of the block, before the feedback was presented. The actual monetary status of the participant was shown after every 10 trials and also at the end of each block. Unbeknown to the participants, out of the six blocks two were programmed as ”gainers” (with an expected gain of approximately 4500 HUF), two blocks as “losers” (with expected gain of 500 HUF), and two in which the chances of losing and winning were balanced resulting with an expected gain of 2000 HUF in each. Thus the probabilities of outcomes were counterbalanced across the experiment and by randomizing the order of different blocks it was prevented that the participants would develop any kind of anticipation with respect to possible outcomes within or between the blocks.

Hence, all participants ended the experimental session as winners, albeit with different actual sums, in addition to the participation fee.

--Figure 1. --

2.3. EEG data collection

The participants were seated in an acoustically attenuated and electrically shielded room in front of a 19” CRT screen at a distance of 125 cm. The EEG was recorded with 62 Ag/AgCl electrodes (Fig. 2.), placed according to the international 10-20 system, using Neuroscan software (4.3) and Synamps amplifiers. Vertical and horizontal eye movements were recorded by electrodes attached above and below the left eye, and the left and right outer canthi. The tip of the nose was used as 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 rolloff). The impedance of the electrodes was kept below 10 kΩ.

2.4. Data analysis

2.4.1. Behavioral data

Behavioral results were analyzed focusing on the risk taking tendencies of the two groups. A ‘risky choice index’ was calculated by taking into account the proportion of risky choices (laying large stake) made in the trials after a distinct type of an outcome event (small or large gain/loss outcome). This was defined as the number of trials with large stakes after every given type of outcome event separately, divided by the sum of the trials that ended with that given outcome (e.g. sum of trials with large stake after large loss divided by the sum of the trials with large loss outcome, etc). In order to emphasize the willingness of the preference towards risk taking behavior, this risky choice index was corrected by a ’random response value' that would have occurred in case of responses given at chance level (50% distribution) between large and small stakes after every given type of outcome event.

The analysis of the time elapsing from the beginning of the trial (presentation of the two alternatives) to the indication of choice ("button press") allowed us to investigate the process of risky decision making. For this purpose response time (RT) was defined as the period starting by the presentation of the two tokens with alternative values and ending with the button press indicating the choice of the larger stake. RT was also analyzed by taking into account the outcome of the previous trial; RT needed to take large stakes was based on the above defined outcome events.

2.4.2. Electrophysiological data

The continuous EEG signal was filtered to 0.5-45 Hz (digital FIR filter with 24dB/octave roll-off) and epoched to the onset of the outcome stimulus from 500 ms before stimulus onset to 1500 ms post-stimulus by using the Neuroscan 4.3 software. All further analysis of EEG data was performed (by using custom written scripts) in Matlab 7.9.1 (Mathworks Inc.). In order to exclude EEG epochs biased by artifacts (blinking, movement, etc.) visual screening and Independent Component Analysis (ICA) were performed on the datasets using EEGLab 11.0.3.1b toolbox (Delorme et al., 2011) including ADJUSTS Version 3 plugin (Mognon, Jovicich, Bruzzone, & Buiatti, 2010). The minimum number of artifact free epochs per condition in every subject was 20 (see Supplementary Materials).

Event-related potentials (ERPs)

Before averaging to the outcome event types, baseline correction (from -200 to 0 ms) was performed on the artifact free EEG epochs. Based on the topographical distribution of the FRN and P3 ERP components, two non-overlapping regions-of-interest (ROIs) were defined for further analysis. Since the FRN occurs with the largest amplitudes over the fronto-central regions, a fronto-central ROI including electrodes F1, Fz, F2, FC1, FCz, FC2 and Cz was used for the analysis. The topographical distribution of the P3 (P3b) accounted for the use of a centro-parietal ROI, including the CP1, CPz, CP2, P1, Pz and P2 electrodes. For further analysis, ERPs recorded on these electrodes were averaged corresponding to the above mentioned ROIs.

The amplitudes of the ERP components were measured with respect to the 200 ms prestimulus baseline using mean amplitude measurement. The FRN was measured in the 225-275 ms post-stimulus interval. The P3 was analyzed by measuring the mean amplitude in the 350-400 ms time range.

--Figure 2. --

2.4.3. Statistical analysis

Statistical analysis was performed with the Statistica software (version 11.0). Repeated measures ANOVAs were performed to evaluate the behavioral and ERP results.

For the behavioral data (risky choice index and RT) the analysis was performed in a group (young vs. old as a between subject factor) * outcome valence (gain vs. loss as a within subject factor) * outcome magnitude (large vs. small as a within subject factor) design.

For the electrophysiological data repeated measures ANOVAs were performed in a group (young vs. old as a between subject factor) * outcome valence (gain vs. loss as a within subject factor) * outcome magnitude (large vs. small as a within subject factor).

When necessary, p-values were adjusted by using the Greenhouse-Geisser correction to avoid violations of the assumption of sphericity (if necessary, indicated by the epsilon value). Bonferroni's post hoc test was used to assess p-values of the pairwise comparisons, in order to avoid the multiple comparison errors. Partial eta-squared values are provided, as a measure for the proportion of variance explained by the independent variable.

3. Results

3.1. Behavioral results

The proportion of risky choices with respect to previous outcomes is shown in Fig.3. No significant main effect of group was found indicating that the total number of risky choices in the experiment did not differ between the two groups. The significant main effect of outcome valence (gain vs. loss; $F(1, 34) = 11.73$, $p = .001$, $\eta^2 = .26$) indicated higher proportion of risky choices after loss than after gain events in both groups, irrespective of the magnitude (large vs. small) of the outcome (gain $M = 2.82$, $SE = 2.5$; loss $M = 9.83$, $SE = 2.7$). No further significant main effects or interactions were observed.

The time taken for making risky choices in the young and in the elderly with respect to previous outcomes is shown in Fig.3. The analysis showed no significant main effects or interactions between the factors.

---Figure 3. --

3.2. Electrophysiological results

Grand averages of feedback-elicited ERPs of the two age groups according to the ROIs are shown in Fig.4.

---Figure 4. --

3.2.1. FRN amplitude

No significant main effect of group was observed for the FRN, suggesting that the mean amplitude values across conditions were not significantly different in the two groups. Significant main effect of outcome valence (gain vs. loss; $F(1, 34) = 12.47$, $p = .001$, $\eta^2 = .27$) was found, indicating larger negativity in the loss conditions. The outcome valence and group interaction was found to be significant ($F(1, 34) = 6.09$, $p = .018$, $\eta^2 = .15$). Post hoc tests showed that the effect of outcome valence on FRN amplitude was observed in the young (loss *M* = -1.99, *SE* = 0.85; gain *M* = 0.42, *SE* = 1.08; $p < 0.001$), but not in the elderly (loss *M* = -1.54, *SE* = 0.96; gain *M* = -1.11, *SE* = 1.21). Regarding the effect of outcome magnitude, no significant main effects or interactions were observed, suggesting that the magnitude of the outcome had no effect on the amplitude of the FRN component.

3.2.2. P3 amplitude

The analysis of the P3 amplitude revealed a significant main effect of group (young vs. old; $F(1, 34) = 36.75$, $p < .001$, $\eta^2 = .52$), indicating higher peak amplitudes in the young group compared to the old (young *M* = 13.18, *SE* = 0.88; old *M* = 5.2, *SE* = 0.98). The effect of outcome valence (gain vs. loss) also turned out to be significant ($F(1, 34) = 4.11$, $p = .050$, $\eta^2 = .11$), suggesting larger amplitudes in the case of gain than in the loss conditions (loss *M* = 8.72, *SE* = 1.06; gain *M* = 9.66, *SE* = 0.91). A significant three-way interaction was found between outcome valence, magnitude and group ($F(1, 34) = 6.34$, $p = .017$, $\eta^2 = .16$). The post-hoc comparisons showed that outcome valence-related amplitude differences could be observed because of the amplitude increase in the large gain condition, which, however, holds for only the young (large gain vs. large loss: $p < .001$; large gain vs. small loss: $p < .001$; large gain vs. small gain: $p = .009$), but not for the old group, where no such differences occurred (for mean amplitudes and SE-s see Supplementary Material).

4. Discussion

In the present study it was found that monetary outcome valence has only a subtle effect on the behavioral adjustment to the circumstances of the gambling paradigm in both age groups. Robust differences were found, however, between the young and elderly participants with respect to the electrophysiological indices observed in the present study. From a more general perspective this implies that whereas the willingness towards risk taking behavior in the two age groups are similar, the neural mechanisms related to feedback processing in risky decision making conditions are conspicuously age-dependent.

4.1. Risk taking behavior is affected by the valence of outcome

In agreement with the findings of Gehring and Willoughby (2002), we found that the occurrence of risky choices was higher following loss compared to gain and this relationship could be seen in both groups. The occurrence of risky choices did not differ between the two age groups. Thus, risk taking behavior may result from both approaching toward riskier choices following loss events and avoiding riskier choices following gain events, which is in line with the general result of the neuroeconomics literature (for a review see Heilbronner, Hayden, & Platt, 2010).

Unknown to the participants the present gambling situation was planned to result in a higher or lower but positive total monetary outcome. In these circumstances it would be a purposeful and sufficient strategy to take smaller and larger stakes in a roughly even proportion irrespective of the prior gain or loss outcome, even if the player was not in full possession of the outcome distribution. This suggests that the behavioral adjustment of the participants in the present study was moderately biased by the valence of the prior outcome. Another aspect in the process of decision making is the time it took the decision to be made. With respect to age, there were no significant differences in reaction times between the two groups suggesting that the elderly and young adults show similar patterns regarding the time spent on making decisions after gains and after losses.

Results of several studies using other gambling conditions (Denburg, Tranel, & Bechara, 2005; Fein & Chang, 2008; Zamarian, Sinz, Bonatti, Gamboz, & Delazer, 2008) , however, raise the possibility that older adults have to face more difficulties in ambiguous situations like the IGT, and they need to have exact information about the circumstances and the various possible outcomes (Mohr, Li, & Heekeren, 2010). Nevertheless, an important methodological aspect of the present experimental paradigm is that irrespective of the difficulty of being able to determine a promising strategy for maximizing the income, it still provides a 'sally-port' to reach advantageous outcome.

4.2. Age-related insensitivity to negative valence is reflected in the FRN ERP component

In the present study, group-related differences in the amplitude of FRN were found with respect to the gain-loss dimensions of outcome events. In the young group FRN had higher amplitude for losses than that for gains but it did not reflect the magnitude of the outcome, in agreement with the data of earlier findings according to which FRN was reported to be higher when the outcome of choices were worse than expected (Bellebaum, Polezzi, & Daum, 2010; Hajcak et al., 2007; Holroyd & Coles, 2002; Nieuwenhuis et al., 2004). In the old group FRN amplitude was found to be insensitive either to the valence of monetary outcomes or their magnitude, indicating that the rapid evaluative mechanisms of events with negative outcome reflected by this ERP component was evident only in the young.

In general, negative events, like monetary losses, are more salient because they are important signals guiding approach-or-avoidance behavior (Tversky & Kahneman, 1981). In a gambling situation a loss is not just a negative event by itself, but based on the assumption that the subjects would choose the stake which they think is more likely to result in gain (Masaki, Takeuchi, Gehring, Takasawa, & Yamazaki, 2006), it could also be an unexpected one. Alternatively, choosing the lower stake could represent an expectation of forthcoming loss in that trial, assuming that the participant adopts the strategy of associate not the possible alternative choices themselves but the trials with forthcoming gain or loss. Since the FRN is considered to be the marker of expectation violation (Wu & Zhou, 2009), and other results also suggest that it reflects an affective evaluation process along a single good-bad dimension

(Kamarajan et al., 2009), if the subjects would have taken the smaller stake because of expected loss in a given trial, small gain outcomes should have elicited larger FRN than small losses. The present results, however, showing that the FRN was more sensitive to negative outcomes (large and small losses as well) in the young suggest that these negative events were reflected by an evaluation process along the good-bad (gain-loss) dimension.

The lack of evidence in our results for the reactivity of FRN in the old group probably indicates the impairment of the systems responsible for this fast monitoring process. Data obtained by Herbert et al. (2011) support the above hypothesis; in a reinforcement learning task these authors reported that the older adults failed to rely on the saliency of feedback which was observed both in their performance and also in the magnitude of the FRN. Nevertheless, they found that besides the reduced amplitudes of FRN in the elderly, a similar ERP pattern was observed for the positive and negative feedbacks in the two groups. Although the extremely reduced FRN amplitude change of the elderly observed in the present study could be the marker of inefficient signaling related to negative and positive outcomes, it cannot be defined to what extent this process manifests itself in their risk seeking or risk avoiding behavior.

4.3. P3 reflects complex evaluation of valence and magnitude

The amplitude of the P3 was significantly larger in the young which observation supports the well-known age-related amplitude decrease of the P3 (Polich & Criado, 2006). The higher amplitude of the P3 probably corresponds to more intense evaluative processes in the young, although it remains largely speculative as to what specific features of the gambling condition used it may apply. Some of the earlier findings supporting that only the magnitude of outcome guides the magnitude of the P3 response (Sato et al., 2005; Yeung & Sanfey, 2004), however, it was not verified by the data of the present study. Indeed, a complex interaction between the valence of monetary outcome and its magnitude was observed, namely that the P3 had a larger peak only in the large gain condition, which observation was, however, restricted to the young group. Contrary to this, in the elderly neither valence nor the magnitude of outcome elicited any differences in the P3 component.

The finding of the effects of both valence and magnitude on the P3 (larger amplitude for larger gains) is more or less consistent with some other previous studies (Hajcak, Moser, Holroyd, & Simons, 2006; Holroyd, Larsen, & Cohen, 2004; Wu & Zhou, 2009). Wu and Zhou (2009) argued that the integrative evaluation effect reflected by the P3 was made possible by using feedback stimuli that informed simultaneously both about the amount of gain or loss and also the valence of outcome. In the study of Yeung and Sanfey (2004) the P3 was sensitive to the valence of outcome only when the participant was already informed about the alternative outcome option as well (at the presentation of a second feedback about the alternative outcome). In another study, Gu et al. (2011) found that the amplitude of the P3 was sensitive both to the valence and to the magnitude of outcome, but it was also affected by the sequence of their presentation. They concluded that when the information about the possible outcome was not fully available, presentation style could influence the P3, suggesting that the distinct information about valence and magnitude activated different neuronal responses.

In our study participants were fully aware of the monetary choice options throughout the trial, and in the period of feedback they received information about both the outcome valence and its magnitude. Although the present study could not be conclusive from this perspective, it is possible that neural processes concerned with the evaluation of valence and that of magnitude, were simultaneously activated. Positive events and larger magnitudes both elicit amplitude increase of the P3 which probably explains why larger P3 response could be observed only for large gain events.

4.4. Feedback-related ERPs in the elderly imply altered neural mechanisms behind the decision making process

The fact that robust differences were observed between the two groups in the P3 amplitude suggests that the elaborative processing of feedback stimuli were less effective in old age. The complex evaluation of the current state starts with the evaluation of the feedback about the choice consequences, which is possibly the first step guiding the future actions towards the given goals. Brand, Labudda, & Markowitsch (2006) assume that the neural mechanisms recruited in the process of decision making are highly determined by the characteristics of known probabilities and rules required to the efficient task resolving, i.e. ambiguous and risky situations can also be differentiated by the recruited neural mechanisms. Ambiguous situations are more likely to involve the activation of limbic structures having a role in emotional processing whereas circumstances in which someone has to make decisions under risk, cognitive processing may become more dominant. Since the elderly are more likely to be characterized by emotionally driven decision making (Mohr et al., 2010; Zamarian et al., 2008), it is possible that they rely more on neural structures related to affective processing (like the limbic system) during gambling situations.

It needs to be emphasized, however, that the behavioral measures of risk taking should be considered as indices that correspond both to the early feedback evaluation and the late decision making processes, and imply those that are aimed at further action plans as well. Thus the possible relationship between characteristics of event-related neural responses (FRN and P3) and the subsequent consequences of choice behavior cannot be considered to be direct or straightforward.

4.5. Conclusions

In a two-choice-single-outcome gambling task substantial age-dependent changes were found to characterize the feedback-related electrophysiological responses. The behavioral adjustment patterns, however, were similar in the two groups, both showing higher probabilities of risk taking behavior after negative outcomes. Amplitude changes of the FRN and P3 ERP components influenced by outcome stimuli characteristics were observed only in the young group, where the FRN was found to be an indicator of the goodness of outcome (loss or gain). The P3, however, was supposed to be the marker of a complex evaluation process instead of being simply tied to the magnitude or to the valence of outcome. Contrary to this in the elderly no such ERP changes were observed. Given that the process of feedback evaluation can be defined as a rapidly emerging construct of neural responses to both simple and complex features of stimuli, the less robust neural signs of feedback processing in the elderly suggest that normal aging is accompanied by the decline of the efficiency of the neural mechanisms signaling the most salient stimulus feedback properties.

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	Young N 18		Old N 17		Difference
	Mean	SD	Mean	SD	t/χ^2
Age	22.11	± 3.31	66.94	± 2.73	-44.36**
Male/Female	3/15		4/13		.34
Years of education	12.4	± 1.6	13.82	± 2.56	-1.72
IQ	117.9	± 6.5	117	± 6.53	0.27
Verbal IQ	110.9	± 8.69	115.65	± 6.76	-1.66
Performance IQ	124.17	± 10.09	118.35	± 8.64	1.77

Table 1. Descriptive characteristics of young adult and old adult groups

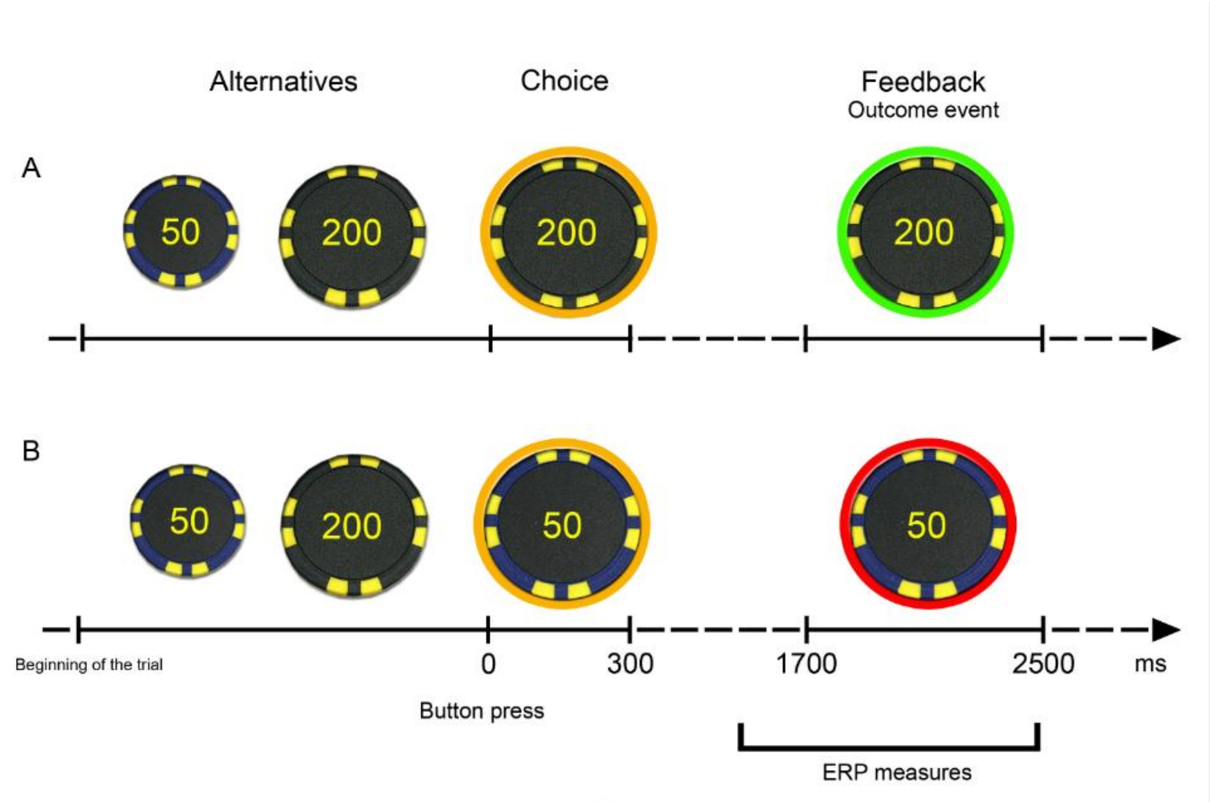

Figure 1. Layout of the experimental trials - The layout of the two-choice single-outcome gambling task involving large and small monetary stakes. Part A shows a trial resulting in a positive outcome (here in large gain). Part B represents a trial resulting in a negative outcome (here in small loss). The presentation period of the alternatives from the beginning of the trial until the response initialization ("button press") was self-paced. Timing (in ms) indicates the duration of the period starting from the response initialization lasting until the offset of the feedback stimulus. Dashed lines indicate periods of black screen with fixation cross. The period corresponding to the analyzed ERP is shown as "ERP measures".

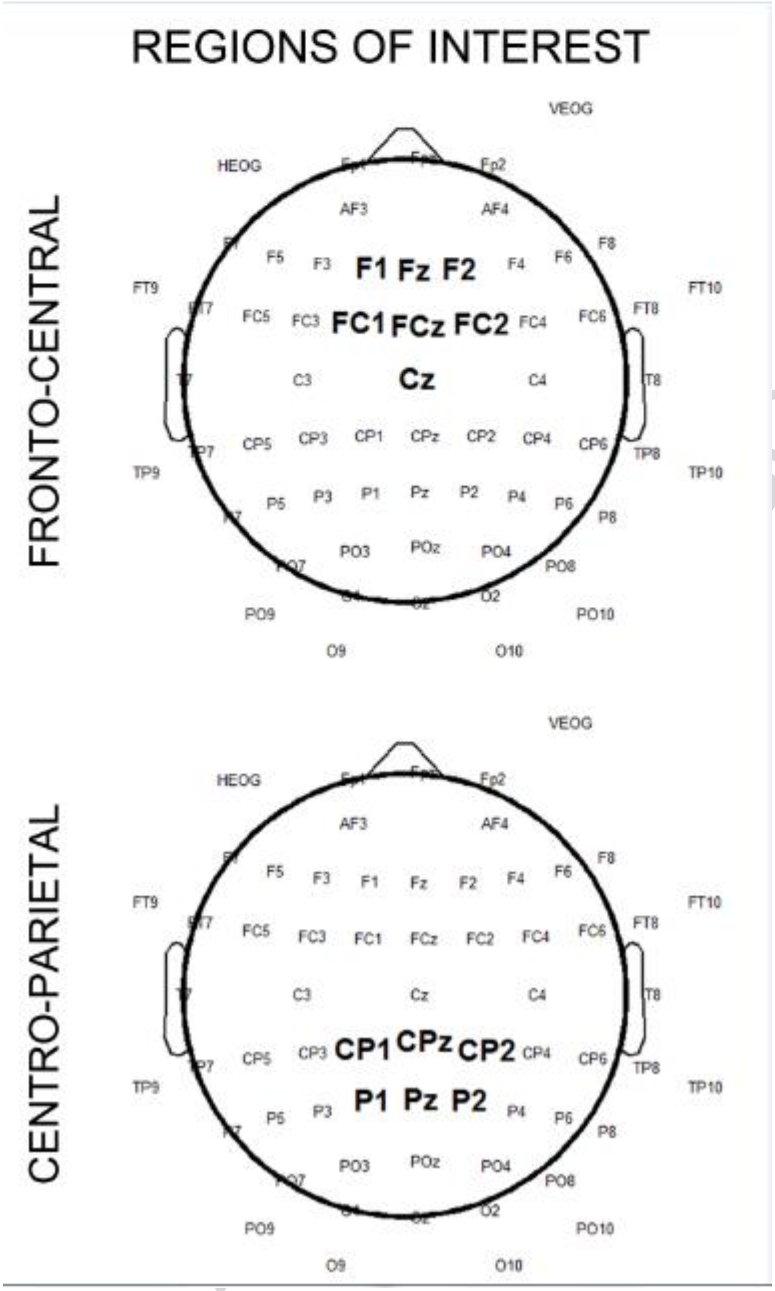

Figure 2. Regions of interest (ROIs) - Electrode locations and names. Bold styling indicates involvement of an electrode in the given ROI (fronto-central and centro-parietal).

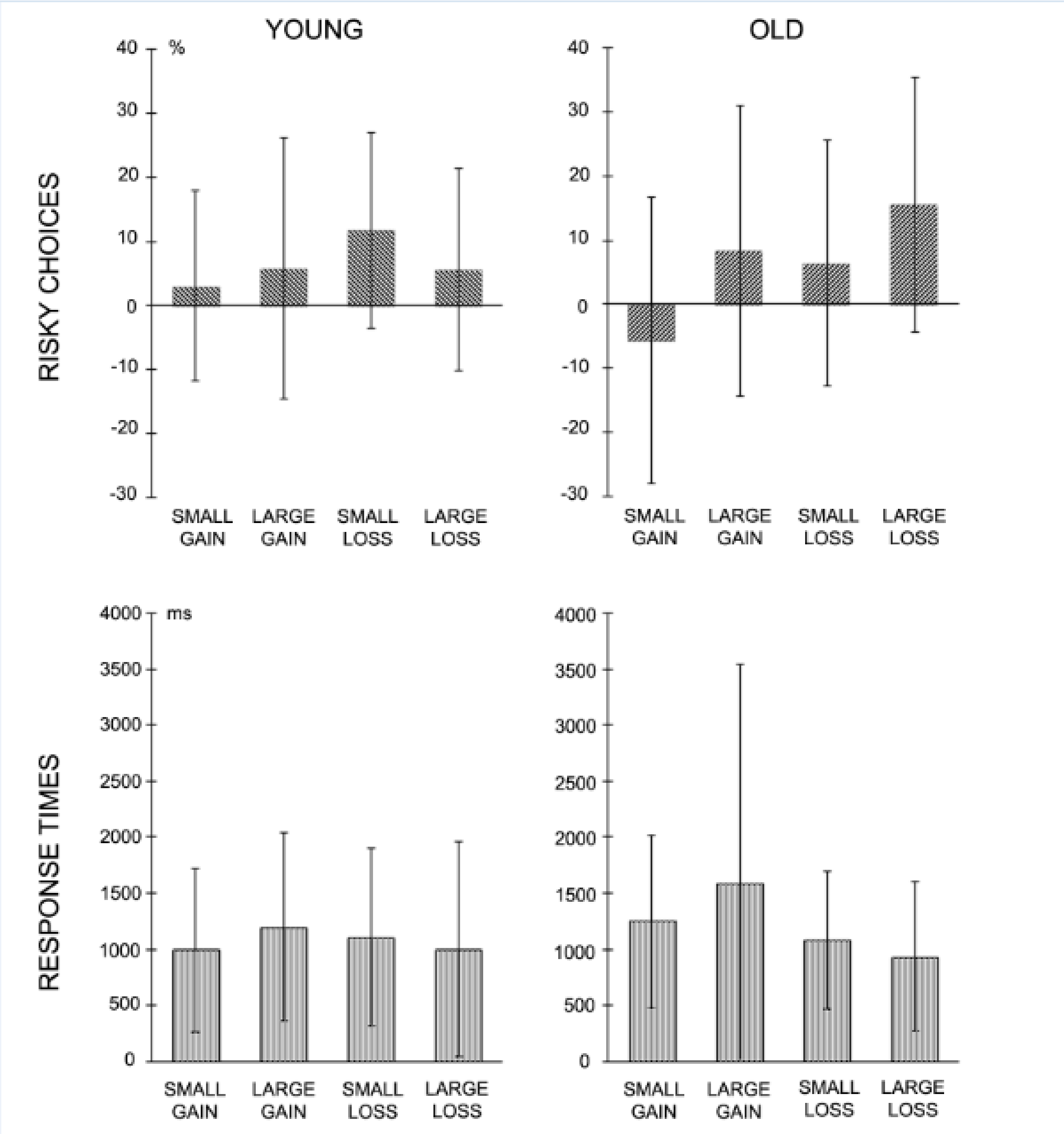

Figure 3. Behavioral indices - The upper part shows the mean proportion of risky choices (relative to the 50% random response distribution) in the four given outcome conditions in the young (right) and in the old group (left). The lower part indicates the average time that elapsed from the beginning of the trial to the response initialization resulting in risky choices (laying large stake) according to the previous outcome. Vertical lines upon the bars denote standard deviations (SD).

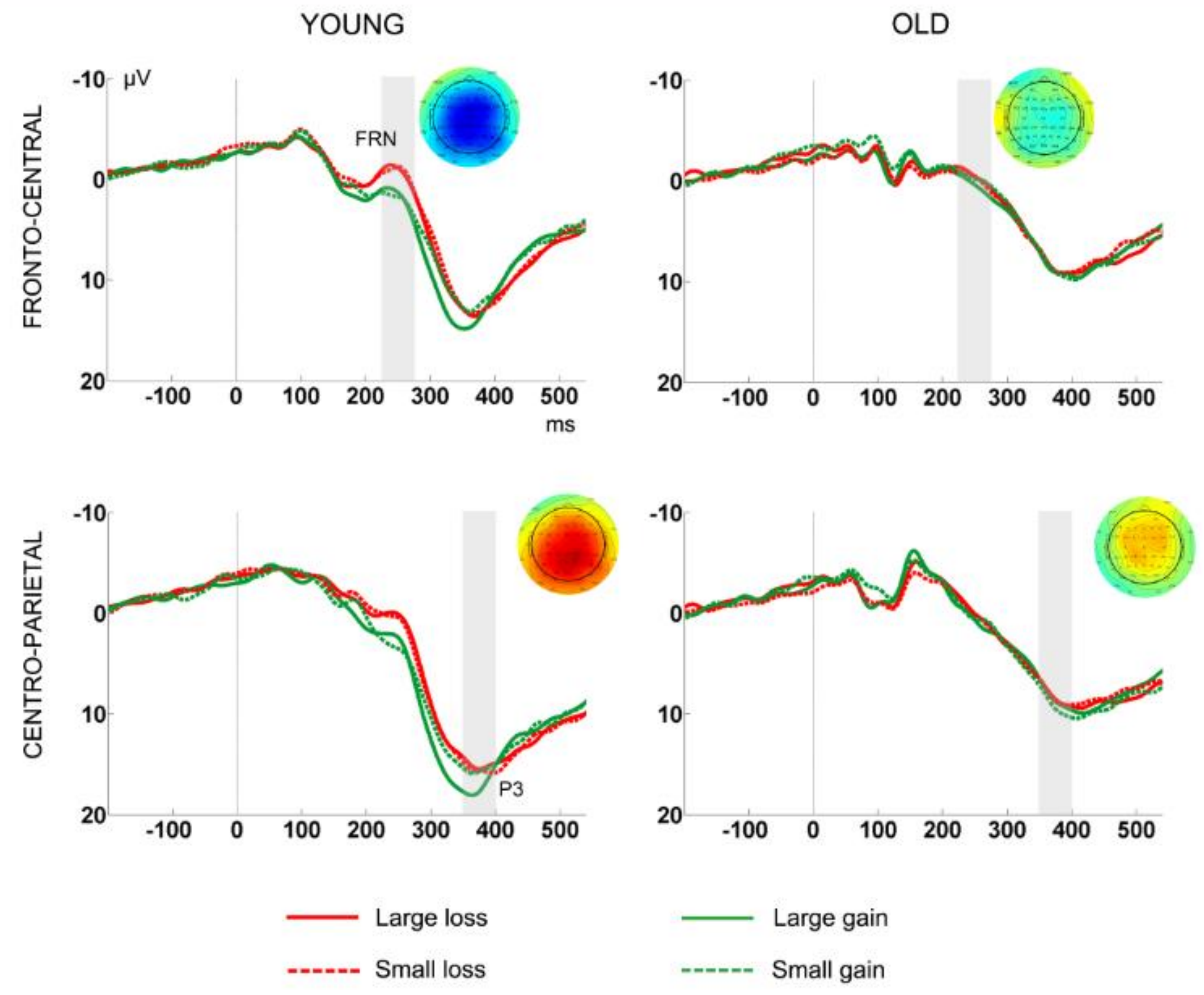

Figure 4. ERP waveforms - Grand average ERP waveforms in the two groups corresponding to the two non-overlapping ROIs. Waveforms recorded in gain and loss conditions are shown in green and red, respectively. Solid lines indicate large amount, whereas dashed lines denote small amount of stakes. The latency ranges for the measurement of the FRN and that of the P3 are shown with shaded areas. Scalp maps in the fronto-central part show the outcome related differences in the FRN resulting from the subtraction of loss-minus-gain conditions (same scale for the two groups). Scalp maps in the centro-parietal part correspond to the differences of the P3 distribution resulting from the subtraction of large gain-minus-small gain conditions (same scale for the two groups). Note that 0.5 – 25 Hz bandpass filter was used for the ERP waveform plots.

Highlights for the article „ Age-dependent characteristics of feedback evaluation related to monetary gains and losses” submitted by Kardos et al.

- characteristics of feedback related ERPs were analyzed in young and elderly subjects
- two-choice single-outcome gambling task provided feedbacks with different valence
- old adults were more influenced by the feedback valence and magnitude
- the ERPs were insensitive to the valence and magnitude of outcomes in the elderly