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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.

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 and 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 and 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 et al., 1991; Holroyd and Coles, 2002; Miltner et al., 1997; Nieuwenhuis et al., 2004), and the P3 component were found to correspond 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 and Anderson, 2012). In terms of generator regions and mechanisms, feedback-monitoring processes are considered to be mostly prefrontal and rostral cingulate cortical

Abbreviations: 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.

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functions (Cohen et al., 2011; Gehring and Willoughby, 2002; Hauser et al., 2014; Mathalon et al., 2003; Ridderinkhof et al., 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 and 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 et al., 2011; Proudfit, 2015).

The feedback associated P3 can be defined as a positivity peaking between 300 and 500 ms post-stimulus (Kamarajan et al., 2009; West et al., 2014; Wu and Zhou, 2009; Yeung and Sanfey, 2004), and it represents the process of elaborative evaluation of outcome reflecting the functional significance of stimuli (Gu et al., 2011; Lole et al., 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 and Criado, 2006; Squires et al., 1975). Whereas the P3a has a fronto-central scalp distribution and is associated with dopaminergic activation (Foti et al., 2011; Holroyd et al., 2008; Polich and Criado, 2006; West et al., 2014), the P3b is possibly generated in the temporo-parietal cortical regions and corresponds to norepinephrine-linked processes (Polich and 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 and Willoughby, 2002; Holroyd and Coles, 2002; Yeung and 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 and Tata, 2009; Kamarajan et al., 2009; Yeung and Sanfey, 2004).

The results of several other studies, however, did not support the aforementioned conclusions. Hajcak et al. (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. Nieuwenhuis 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
Descriptive characteristics of young adult and old adult groups.

	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		0.34
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

* $p < .05$.
** $p < .01$.

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