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Research report

Age-related characteristics of risky decision-making and progressive expectation formation

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HIGHLIGHTS

- Age-dependent risk-taking behavior in sequential decision making was investigated.
- ERPs for the rewarding feedback were analyzed based on the forthcoming decisions.
- Reward positivity increased as a function of reward contingencies only in the young.
- Increased hesitation and deliberate decisions characterized the elderly.
- Reward contingencies had less effect on the elderly than on the young.

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ABSTRACT

During daily encounters, it is inevitable that people take risks. Investigating the sequential processing of risk hazards involve expectation formation about outcome contingencies. The present study aimed to explore risk behavior and its neural correlates in sequences of decision making, particularly in old age, which represents a critical period regarding risk-taking propensity. The Balloon Analogue Risk Task was used in an electrophysiological setting with young and elderly age groups. During the task each additional pump on a virtual balloon increased the likelihood of a balloon burst but also increased the chance to collect more reward. Event-related potentials associated with rewarding feedback were analyzed based on the forthcoming decisions (whether to continue or to stop) in order to differentiate between states of expectation towards gain or loss. In the young, the reward positivity ERP component increased as a function of reward contingencies with the largest amplitude for rewarding feedback followed by the decision to stop. In the elderly, however, reward positivity did not reflect the effect of reward structure. Behavioral indices of risk-taking propensity suggest that the performance of the young and the elderly were dissociable only with respect to response times: The elderly was characterized by hesitation and more deliberative decision making throughout the experiment. These findings signify that sequential tracking of outcome contingencies has a key role in cost-efficient action planning and progressive expectation formation.

1. Introduction

Whether we are aware of the fact or not, risk-taking behavior occurs more frequently during our everyday actions than generally thought. Besides those simple and common examples like taking only one more drink before driving, a temporary excursion from one's self-regulatory goals, i.e., risking the long-term goals for short-term advantages such as making a cheat in a diet, can be

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considered as a more complex form of 'gambling' [1]. Risk-taking behavior can be defined as a decision making propensity motivated by gain reward beside the possible opportunity to lose [2–4]. Since natural circumstances usually include continuous fluctuations in risk, the ability of making decisions based on the acquisition of action-outcome contingencies is an essential part of adaptive risk behavior [5]. In particular, old age represents a critical period due to substantial neurocognitive changes having an effect on both frontal cortical and subcortical brain areas known to be involved in decision making [6,7]. The question remains, however, whether there is a specific inability of the acquisition of relevant information behind the possibly reduced decision quality of the elderly.

From the perspective of self-report questionnaires, elderly are characterized by higher risk-avoidance tendency [8]. However, regarding risk behavior, results show evidence for both normal and altered patterns of decision making [6,9]. Both extremely cautious and hazardous decisions can be found when only partial information is available about the outcome structure of the task [8]. In these situations, participants are unaware of the possible outcome after a safe choice, and the exploration of the options and boundaries are necessary. These age differences can be eliminated, however, with experience with the task, especially when the task complexity is relatively low [8,10]. Nevertheless, providing partial information could jeopardize the chance of error correction, in particular in the elderly, who are generally less certain in ambiguous decision making situations [6,8].

The Balloon Analogue Risk Task (BART) developed by Lejuez et al. [11] is an experimental paradigm that requires sequential decision making without providing explicit information about outcome probabilities. This paradigm is specifically suitable for the investigation of the flexibility of risk attitudes and risk-avoidant behavior, since in the BART it is adaptive to take risks. However, adaptive risk-taking behavior cannot be acquired without exploring and learning the structure of the task. During task performance, participants are required to collect points by pumping up virtual balloons. Participants may pump as long as they decide to 'cash-out' (i.e., to collect the reward points) or until the balloon bursts and the points collected so far on that balloon are lost. Each additional pump on the balloon increases the likelihood of balloon burst and losing the accumulated reward but deciding to go on pumping increases the chance to collect more reward. The experience gained through the repeated sequential decision making process ensure the step-by-step acquisition of the reward structure of the task and supports progressive expectation formation about the outcome distribution.

The basic properties of the BART implies a wide range of strategic processes that could possibly explain the behavior from the basic preconceptions of the decision maker to the extent the action-outcome representations can modulate the learning process [12]. Computational modeling works suggest that those models that take into account expectancy and outcome values (e.g., Bayesian Sequential Risk Taking Model) provide better fit with the behavior data instead of simple reinforcement learning models (e.g., the Target model) that do not rely on the sequential evaluation of gains and losses [12,13]. Hence, the context of pump-outcome pairs (i.e., action-outcome pairs) in the BART should be regarded in the light of extended action sequences and past experiences. Thus, probably there are some simple action-outcome contingencies that are more important in determining future behavior than others. The possible outcomes – gain (reinforcement) by cash-out or loss (punishment) by the balloon burst – represent the consequences of prior decisions, which are essential components of the outcome evaluation sub-process. Considering that these events have a subsequent effect on behavior, it would be plausible to propose that the evaluative processing of positive events (balloon increase) preceding cash-out or balloon burst would be more appropriate indices of the learning process.

Event-related potential (ERP) analysis is suitable to track feedback-evaluation processes related to these special events, which could give further insight to expectation formation during the task. These expectations are assumed to have an effect on behavior through neural processes constantly signaling not only whether the outcome of actions reached the task goals or not but also to what extent these could fit the participants' preconceptions/predictions [14]. According to the theories concerning the brain's reward prediction system, unexpected reward or punishment elicits brief bursts of phasic dopamine signaling originating from the midbrain dopamine system [15,16]. This reward prediction error (RPE) signal is thought to have an interplay with prefrontal cortical areas such as the prefrontal cortex (PFC) and the anterior cingulate cortex (ACC) [14,17,18]. This frontostriatal circuit with dopaminergic activation plays an essential role in reward seeking behavior and decision making [19,20], and the ERPs related to feedback evaluation, like the FRN and the reward positivity, are assumed to be the correlates of the activity of this dopaminergic circuit [17,21,22].

The FRN occurring at approximately 250 ms after feedback onset corresponds mainly to the erroneous nature of the outcome [22,23]. Contrary to this, the reward positivity (occurring in a similar time window as the FRN) is elicited by positive feedback informing about reward [24–26]. The reward positivity occurs with larger amplitude for unexpected than expected rewarding events [26]; thus, it can be regarded as a decisive index of outcome evaluation which reliably reflects the predictive processing. In addition, both the FRN and the reward positivity ERP components typically constitute a 'complex' with the following P3 component peaking at approximately between 300 and 500 ms [27–29]. The P3 is thought to reflect a more thorough evaluative process of the outcome events [30–32], including the local and global probabilistic properties, motivational significance of the stimuli, and also the amount of expended/invested attention [33].

Data collected in various experimental conditions in which inferences of reinforcement learning were addressed via feedback-related evaluation processes show an age-dependent decrease regarding the amplitudes of feedback-related ERP components [34–36]. Accordingly, imaging approaches suggest that the elderly have difficulties in representing outcome values during predictive processing due to decreased frontostriatal connectivity with age [5,20]. Furthermore, the activity of the dopaminergic system also declines during aging, which results in higher signal-to-noise ratio in the frontostriatal communication pathway [37–39]. The decreased reliability of prediction error processing may provide an explanation for the alterations in learning-dependent decision making situations in the elderly.

In the present study, our aim was to investigate age-related characteristics of feedback-related ERP correlates of predictive processing in the BART. Although the BART is a naturalistic experimental setting, it also has a hidden probabilistic structure requiring flexible adaptation and exploration, which results in an uncertain decision making condition [40]. As the most prominent indices of risk behavior, the number of pumps, as well as the number of balloon bursts allow the characterization of the progress of adaptation to the task structure at the behavioral level [11]. These indices are important to define whether or not learning occurred during task solving, and whether the patterns of risk taking can be categorized as typical. The decision time is also an informative index of uncertainty and deliberative decision making, which could be particularly important regarding the age-related aspects of risk taking. It was hypothesized that although experience with the task would likely boost the performance of the elderly, strategic differences would be detected in their decision times compared to that seen in the young.