

Stimulus-preceding negativity represents a conservative response tendency

Takahiro Hirao^a, Timothy I. Murphy^c and Hiroaki Masaki^b

Humans tend to be conservative and typically will retain their initial decision even if an option to change is provided. We investigated whether the stimulus-preceding negativity (SPN), an event-related potential associated with the affective-motivational anticipation of feedback in gambling tasks, represents the strong response tendency to retain an initial decision. We compared SPNs in three different card-gambling tasks wherein the participants were given the opportunity to change their initial decision after they chose one of three cards. In two of these tasks, the winning probability was equiprobable (1/3 and 1/2, respectively) whether or not the participants changed their initial decision. However, in the Monty Hall dilemma task, changing the initial decision stochastically doubled the probability of winning (2/3) compared with retaining (1/3). In this counterintuitive probabilistic dilemma task, after the participant chose an option among three cards, a nonreward (losing) option is revealed. Then, the participants are offered a chance to change their mind and asked to make their final decision: to retain their initial choice or change to the alternate option. In all tasks, maintenance of previous

behaviors was observed, although the rate of retaining earlier choices tended to be lower in the Monty Hall dilemma task than in the other two tasks. The SPNs were larger on retain trials than on change trials irrespective of task. These results suggest that underlying brain activities associated with the strong tendency to retain the initial decision can be observed by the SPN and thus it reflects expectancy of outcomes in terms of self-chosen behaviors. *NeuroReport* 27:80–84 Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.

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^aGraduate School of Sport Sciences, ^bFaculty of Sport Sciences, Waseda University, Tokorozawa, Saitama, Japan and ^cDepartment of Psychology, Brock University, St. Catharines, Ontario, Canada

Correspondence to Hiroaki Masaki, PhD, Faculty of Sport Sciences, Waseda University, 2-579-15, Mikajima, Tokorozawa, Saitama 359-1192, Japan
Tel/fax: +81 4 2947 6909; e-mail: masaki@waseda.jp

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Introduction

The stimulus-preceding negativity (SPN) is a negative slow wave [1] observed between an action and its outcome in decision-making tasks [2] wherein the feedback signal is informative for behavioral adaptations [3] or includes affective-motivational aspects [4]. Recent studies have emphasized that the amplitude of the SPN increases in negativity over frontal regions, reflecting affective-motivational anticipation of outcomes that is induced by either monetary reward or punishment [4,5]. In addition, the SPN shows a right hemisphere preponderance [1,4] because of activities of the right insula cortex [6]. Other event-related potential studies confirmed an association between the SPN and the feedback-related negativity [4,7] that is widely believed to reflect affective-motivational processes [8]. Further, a neuroimaging study has confirmed that the right anterior insula underlies the affective-motivational aspects of the SPN [9]. Therefore, the SPN can be considered a neuronal index of affective-motivational anticipation of outcomes.

Previous neuroimaging studies showed that both caudate and anterior insula were more activated when the participant could intentionally choose an option and had a sense of control, reflecting a stronger action–outcome contingency (AOC) [10,11]. In agreement with this finding, the SPN also represented an AOC [12], raising an intriguing question: is a larger SPN observed for a conservative response tendency associated with decision making?

If given a choice, individuals typically retain (stay with) their initial decision [13], changing only if convinced that it is advantageous [14], perhaps because of an avoidance strategy to minimize regret. The feedback-related negativity elicited by negative feedback became larger when participants lost money after changing their initial decision [13]. Thus, regret might be enhanced by experiencing a negative outcome after changing one's mind.

We tested whether the SPN also becomes larger, representing a strong AOC associated with behavioral maintenance of initial choices using three different card-gambling tasks, namely, the 33% winning task, 50% winning task, and the Monty Hall dilemma (MHD) task (we refer to these tasks as 33%, 50%, and MHD, respectively) where the participants could change their

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initial decision after choosing one of three cards. In both the 33% and the 50% tasks, the winning probability was not influenced by whether or not the participants changed their initial decision. However, in the MHD task, a counterintuitive probabilistic dilemma, the optimal solution was to discard the initial decision, which doubled the probability of winning (2/3) compared with retaining (1/3) [15]. In this scenario, most participants fail to learn the solution (switching is better) even if they explicitly understood the underlying logic and still tend to retain their initial decision [16].

We predicted larger SPN amplitudes on retain trials, representing the strong tendency of conservative behaviors especially observed in both the 33% and the 50% tasks and smaller SPN amplitudes on the retain trials in the MHD task, especially over frontal regions, because the retain behavior should be weaker once the MHD solution has been learned.

Participants and methods

Participants

Thirty-two right-handed participants (16 female, 18–25 years, $M \pm SD$: 20.4 ± 1.4) were recruited from Waseda University and given a fictitious instruction that they could maximize their monetary reward on gambling tasks, but were actually all paid 3600 yen (~US\$ 36). This study was approved by the Waseda University Ethics Committee.

Stimuli and procedure

We tested three types of card-gambling tasks with differing winning probabilities. In all tasks, the participant first chose a card, the computer offered an alternate option, and they were asked to retain, or change, their initial option (Fig. 1). Feedback was shown 2.5 s after the final decision and only one card was rewarded (10 yen, ~10 cents). The task was programmed with Presentation (Neurobehavioral Systems, Inc., Berkeley, California, USA) and stimuli were presented centrally on a cathode ray tube monitor placed 1 m away.

In the 33% task, after the first decision, one of the unselected options was inactivated, resulting in a 33% equiprobable winning rate on either the initially chosen or alternate card. In the 50% task, a losing card was disclosed before the first decision, resulting in a 50% equiprobable winning rate on either card. In the MHD task, after participants chose a card, one unrewarded card was disclosed from the two unselected and they were asked to either retain or change to the other card.

Participants chose by pressing one of three buttons corresponding to left, center, and right cards with the right index, middle, and ring fingers, respectively. The visual angle of the stimulus display was $2.9^\circ \times 1.4^\circ$. Intertrial intervals varied from 2 to 4 s in 1 s increments. Each task consisted of two (60 trial) blocks and task order was

counter-balanced across participants. After the experiment, participants were asked the winning probability of each task.

Recordings and data analysis

The electroencephalogram (EEG) was recorded from 128 sites. Vertical and horizontal electrooculograms were recorded from left supraorbital and infraorbital sites and left and right outer canthus, respectively. These were recorded with a sampling rate of 1024 Hz (bandwidth of DC to 205 Hz, 3 dB/octave) using a Biosemi Active Two System (Biosemi, Inc., Amsterdam, Netherlands).

EEGs were processed using Brain Vision Analyzer 2 (Brain Products, Gilching, Germany), re-referenced to averaged mastoids, and low-pass filtered with a 30 Hz cut-off (roll-off: 24 dB/octave). EEG epochs ranging from –3 to 1 s relative to the feedback onset were extracted for averaging. Ocular movements were corrected using an algorithm [17]. Artifact-free trials were averaged to obtain SPNs. Because of insufficient trials for averaging (<16 acceptable trials/task), 12 participants were excluded, leaving 20 participants (eight female, 18–25 years, $M \pm SD$: 20.6 ± 1.5). SPN amplitudes (F3/4, C3/4, P3/4) were scored within a window extending 100 ms before the onset of feedback relative to baseline (–2700 to –2500 ms) and subjected to an analysis of variance (ANOVA) with repeated measures on Caudality (frontal/central/parietal), Hemisphere (left/right), Task (33%/50%/MHD), and Choice (retain/change) with Bonferroni's correction on post-hoc comparisons.

For behavioral analysis, the rate of retaining was subjected to a one-way ANOVA with repeated measures on Task after applying the inverse sine transformation.

Results

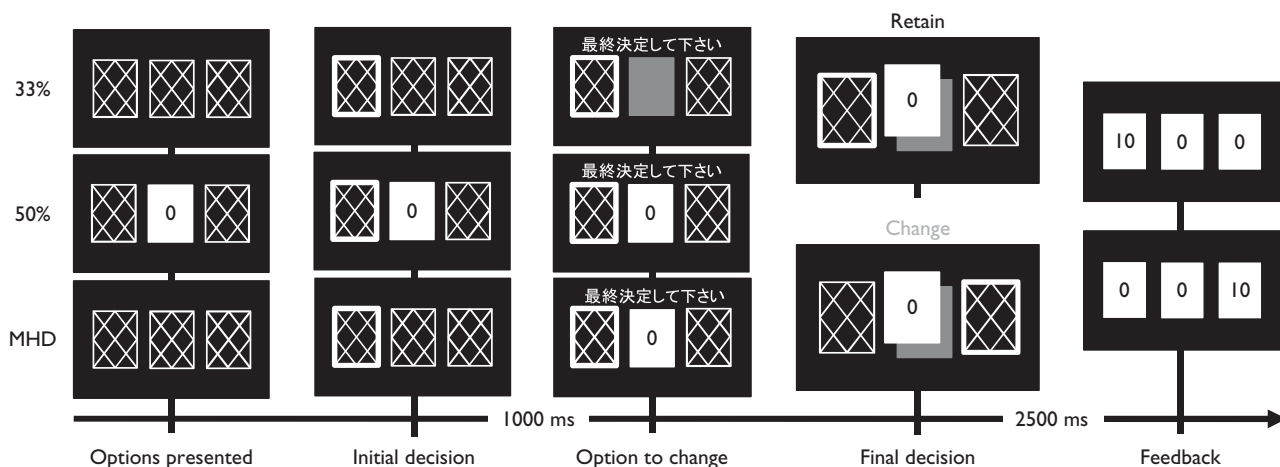
Behavioral data

The mean (SEM) rate of retaining for the 32 participants in the 33%, 50%, and MHD tasks were 63.8% (3.8%), 62.3% (3.3%), and 54.8% (3.5%), with a main effect of Task [$F(2, 62) = 4.81$, $P = 0.01$]; post-hoc tests showed a significantly lower rate of retaining in the MHD than the 33% task [$t(31) = 2.95$, $P = 0.02$]. For the 50% task, the result was in the expected direction, but not significant [$t(31) = 2.32$, $P = 0.08$]. No participants could report precise winning probabilities of the retain or change trials in the MHD task, suggesting that they implicitly recognized the advantage of change in the MHD task. When we excluded 12 participants from the SPN analysis who showed insufficient trials in a task (<16 trials), the mean rate of retaining for the 33%, 50%, and MHD tasks were 54.5% (3.8%), 53.9% (2.6%), and 51.8% (3.0%) and no longer differed ($P = 0.72$).

Stimulus-preceding negativity

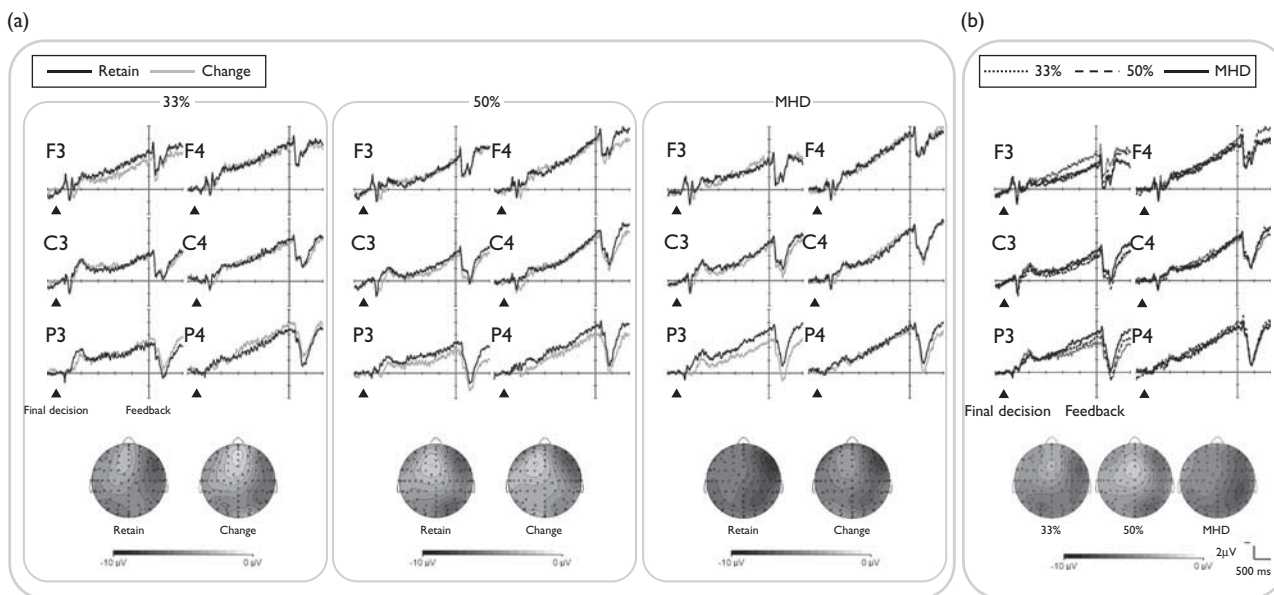
Figure 2a shows grand-averaged SPN waveforms and topographies in each task. The SPN developed over all electrode sites after the final-decision button press until feedback. The SPNs were distributed over right frontal

Fig. 1



Experimental paradigm. When participants make their choice (button press), the border of the chosen card was highlighted, then an option was offered to change the selection before a final decision was made and feedback was provided. MHD, Monty Hall dilemma.

Fig. 2



(a) Stimulus-preceding negativity (SPN) waveforms and their topographies in each task. (b) SPN waveforms and their topographies on retain trials in each task. MHD, Monty Hall dilemma.

regions in all tasks. A four-way ANOVA showed larger SPNs when participants retained their initial decision ($M = -6.4$, $SEM = 0.8$) than when they changed ($M = -5.6$, $SEM = 0.9$) irrespective of task [$F(1, 19) = 8.06$, $P = 0.01$]. It also showed larger SPN amplitudes over the right hemisphere ($M = -7.2$, $SEM = 0.8$) than the left hemisphere ($M = -4.8$, $SEM = 1.0$) [$F(1, 19) = 25.49$, $P < 0.001$]. Contrary to our prediction, there was no interaction ($P = 0.99$).

It was likely that these participants in the SPN analysis preferred to change their initial decision more than participants who had to be excluded. Therefore, we re-averaged SPNs, focusing on retain trials ($n = 29$). Figure 2b shows SPN waveforms on retain trials. A repeated three-way ANOVA (Task, Caudality, and Hemisphere) showed larger amplitudes over the right hemisphere [$F(1, 28) = 30.3$, $P < 0.001$], but no main effect of Task

($P=0.94$) or Caudality ($P=0.35$) was obtained. No interactions were found (P 's = 0.34–0.59).

Discussion

We examined the SPN associated with a conservative response tendency by manipulating the retaining response tendency through different winning probabilities in three different gambling tasks. Behavioral data showed a higher rate of retaining with the initial decision, supporting our prediction of a retaining response tendency, and a relatively lower rate of retaining in the MHD task suggested implicit learning to recognize the advantage of change over time as in previous research [18,19]. As predicted, the SPNs on retain trials were larger, suggesting that the SPN increase represents the conservative response tendency of retaining behaviors. In the MHD task, participants should expect a monetary gain on the change trial after learning; however, SPNs on the retain trials were larger. There are several possible explanations for this.

The tendency to retain an initial decision has been explained conceptually as the illusion of control, a false belief that keeping an initial decision results in more success independent of stochastic probability [20]. During an explorative phase in decision-making tasks, the higher positive reward prediction error may result in increased activation of the insula, anterior cingulate cortex, and caudate [21]. Participants did not explicitly learn the proper strategy (i.e. change) in the MHD task, although rate of retaining was lower than in other tasks. Thus, these brain areas appeared to be involved in the increased SPN on the retain trials. It is plausible that the larger SPN on the retain trials might reflect a nonlearning behavior associated with the illusion of control.

Another possibility is that the larger SPNs on the retain trials were because of processes associated with an avoidance strategy to minimize regret [13,14] that has been known as the emotional-based choice bias [22]. Perhaps even after implicitly recognizing the proper strategy in the MHD task, they were still skeptical, and thus more explicit confidence was needed for the development of SPN. Previous studies showed that the SPN increased in negativity before affective-motivational feedback that was manipulated by monetary reward or punishment [4] and emerged only before informative feedback, but not before false feedback [3]. In our study, feedback following the final decision to retain could entail a strong affective-motivational anticipation in the MHD task.

A third possible explanation might be that SPN amplitudes reflected a sense of control over the outcome [12] that was induced by the initial decision, but not by changing behaviors. Previous fMRI studies have confirmed greater activations of the anterior insula (a generator of SPN) when participants felt control over the

outcome [10,23]. The AOC may be strengthened with the sense of control, inducing a strong conservative response tendency. In such situations, it is possible that the anterior insula is more active, receiving signals from other brain regions associated with both motivational and cognitive processes (e.g. striatum) [24].

To compare SPNs between retaining and changing behaviors, we excluded participants who rarely changed their initial decision. This procedure might have included participants with a weaker retaining tendency in SPN calculations. We reaveraged SPNs from 29 participants to obtain more rigorous waveforms, focusing on the retain trials. If the SPN represents the strength of retaining behaviors, smaller amplitudes were expected to be observed in the MHD task compared with 33% and 50% tasks, but this was not the case. Although this result did not support our hypothesis, it may be that our procedure was not sufficient for participants to learn the proper strategy in the MHD task to test the influence of changing behaviors on the SPN.

Conclusion

In all three-card tasks, a response tendency of retaining was observed. Humans seem to be conservative and retain initial decisions unless they have a convincing reason to change. This makes sense in a situation with equiprobable winning options because changing is not an advantage. Even in the MHD task where changing the initial decision would result in more successful outcomes, individuals are likely to retain their initial decision. The SPN amplitudes might represent our strong conservative tendency to retain initial decisions. Therefore, the SPN may be a useful tool in examining counterfactual decision-making processes.

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Conflicts of interest

There are no conflicts of interest.

References

- 1 Brunia CH, Damen EJ. Distribution of slow brain potentials related to motor preparation and stimulus anticipation in a time estimation task. *Electroencephalogr Clin Neurophysiol* 1988; **69**:234–243.
- 2 Zheng Y, Li Q, Wang K, Wu H, Liu X. Contextual valence modulates the neural dynamics of risk processing. *Psychophysiology* 2015; **52**:895–904.
- 3 Chwilla DJ, Brunia CH. Event-related potentials to different feedback stimuli. *Psychophysiology* 1991; **28**:123–132.
- 4 Masaki H, Takeuchi S, Gehring WJ, Takasawa N, Yamazaki K. Affective-motivational influences on feedback-related ERPs in a gambling task. *Brain Res* 2006; **1105**:110–121.
- 5 Kotani Y, Hiraku S, Suda K, Aihara Y. Effect of positive and negative emotion on stimulus-preceding negativity prior to feedback stimuli. *Psychophysiology* 2001; **38**:873–878.

- 6 Brunia CH, de Jong BM, van den Berg-Lenssen MM, Paans AM. Visual feedback about time estimation is related to a right hemisphere activation measured by PET. *Exp Brain Res* 2000; **130**:328–337.
- 7 Donkers FCL, van Boxtel GJM. Mediofrontal negativities to averted gains and losses in the slot-machine task: a further investigation. *J Psychophysiol* 2005; **19**:256–262.
- 8 Gehring WJ, Willoughby AR. The medial frontal cortex and the rapid processing of monetary gains and losses. *Science* 2002; **295**:2279–2282.
- 9 Tsukamoto T, Kotani Y, Ohgami Y, Omura K, Inoue Y, Aihara Y. Activation of insular cortex and subcortical regions related to feedback stimuli in a time estimation task: an fMRI study. *Neurosci Lett* 2006; **399**:39–44.
- 10 Tricomi EM, Delgado MR, Fiez JA. Hemodynamic responses to anticipated and unanticipated reward relevant targets in an oddball task. Program No. 679.4, 2002. Neuroscience Meeting Planner. Orlando, FL: Society for Neuroscience; 2002.
- 11 Tricomi EM, Delgado MR, Fiez JA. Modulation of caudate activity by action contingency. *Neuron* 2004; **41**:281–292.
- 12 Masaki H, Yamazaki K, Hackley SA. Stimulus-preceding negativity is modulated by action–outcome contingency. *Neuroreport* 2010; **21**:277–281.
- 13 Zhou Z, Yu R, Zhou X. To do or not to do? Action enlarges the FRN and P300 effects in outcome evaluation. *Neuropsychologia* 2010; **48**:3606–3613.
- 14 Granberg D, Brown TA. The Monty Hall dilemma. *Pers Soc Psychol Bull* 1995; **21**:711–723.
- 15 Selvin S. A problem in probability. *Am Stat* 1975; **29**:67.
- 16 Tubau E, Alonso D. Overcoming illusory inferences in a probabilistic counterintuitive problem: the role of explicit representations. *Mem Cognit* 2003; **31**:596–607.
- 17 Gratton G, Coles MG, Donchin E. A new method for off-line removal of ocular artifact. *Electroencephalogr Clin Neurophysiol* 1983; **55**:468–484.
- 18 Franco-Watkins A, Derks P, Dougherty M. Reasoning in the Monty Hall problem: examining choice behaviour and probability judgments. *Think Reason* 2003; **9**:67–90.
- 19 Granberg D, Dorr N. Further exploration of two-stage decision making in the Monty Hall dilemma. *Am J Psychol* 1998; **111**:561–579.
- 20 Langer E. The illusion of control. *J Pers Soc Psychol* 1975; **32**:311–328.
- 21 Amiez C, Sallet J, Procyk E, Petrides M. Modulation of feedback related activity in the rostral anterior cingulate cortex during trial and error exploration. *Neuroimage* 2012; **63**:1078–1090.
- 22 Tubau E, Aguilar-Lleyda D, Johnson ED. Reasoning and choice in the Monty Hall dilemma (MHD): implications for improving Bayesian reasoning. *Front Psychol* 2015; **6**:353.
- 23 Zink CF, Pagnoni G, Martin-Skurski ME, Chappelow JC, Berns GS. Human striatal responses to monetary reward depend on saliency. *Neuron* 2004; **42**:509–517.
- 24 Craig AD. How do you feel – now? The anterior insula and human awareness. *Nat Rev Neurosci* 2009; **10**:59–70.