Psychology Research and Behavior Management

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ORIGINAL RESEARCH

Social distance modulates the process of uncertain decision-making: evidence from event-related potentials

This article was published in the following Dove Press journal:
Psychology Research and Behavior Management

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Purpose: Social distance affects risk perception in uncertain decision-making, but how this effect works and the mechanism of how social distance influences the early processing stages of uncertain decision-making are still unclear. This investigation aimed to explore how social distance influences risk-taking during uncertain decision-making using the Iowa Gambling Task with recording of event-related potentials.

Methods: A total of 57 healthy subjects (36 female) participated in the modified single-choice Iowa Gambling Task when they gambled based on three quantified social distances (self, friend, and stranger). The social distance between participant and beneficiary was quantified on a scale of 0–100 points, with 0 representing self, 5 representing a close friend, and 100 representing a stranger.

Results: Three stages of uncertain decision-making were analyzed. Behavioral results showed that social distance worked interactively with choice frame, and high social distance made people choose a more advantageous deck and a less disadvantageous deck than low social distance. The P300 in the choice-evaluation stage, which reflects stimulus discrimination, directly proved this result by showing that gambling for a stranger caused higher P300 when evaluating an advantageous deck and lower P300 when evaluating a disadvantageous deck than for others. Decision preceding negativity in the response-selection stage represents the anticipation of risky choices: this was larger with high social distance when choosing a disadvantageous deck. Feedback-related negativity and feedback-related P300 had motivational significance, showing smaller amplitudes when gambling for a stranger than for oneself.

Conclusion: These results provide evidence that social distance works interactively with choice frames of uncertain decision-making. People at high social distance are more risk-taking in an advantageous frame and more risk-avoid ant in a disadvantageous frame.

Keywords: uncertain decision-making, social distance, risk-taking, Iowa Gambling Task, event-related potential, ERP

Introduction

Uncertain decision-making is a situation where an individual's knowledge about the likelihood of a choice's outcome is imperfect.[1] People make uncertain decisions consistently, not only for themselves but also for others, and not only in personal but also in different social, economic, or health-care situations, such as giving advice to a friend in job hunting or making medical decisions for an incapable patient. Exploring difference in self vs others regarding decisions is important to the understanding and improvement of human decision-making. Social distance

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DovePress
http://doi.org/10.2147/PRBM.S210910

describes the affective closeness between self and others, in-groups, and out-groups.[2] It affects individuals' risk-taking preferences and thus is an important influencing factor in uncertain decision-making.[3] Even though studies have demonstrated that self vs other regarding decision-making differentiates from each other, the existing findings are conflicting about whether social distance increases or decreases individuals' risk-taking.[4]

Research has shown that as social distance increases, people seek more risk.[5–7] Participants are more risk-tolerant for others than for themselves when making decisions about romantic relationships,[7] gambling,[5] and in scenarios where losses are possible.[6] On the contrary, other studies have found that those making decisions for others were more risk-averse than for themselves. Not only general populations but also doctors made more conservative decisions for others than for themselves in physical safety scenarios.[8–10] Those studies used different value-based decision-making scenarios, which might have caused their inconsistent results. Other research further showed that deciding for others was based primarily on perceived value with regard to risk: riskier decisions were made for others where risk-taking was valued (relationship scenarios), but when risk aversion was valued (physical safety scenarios), participants made more risk-averse decisions for others than for themselves.[9,11] For gain and loss frames of choice, research found that individuals were more risk-averse in the gain frame and more risk-seeking in the loss frame when deciding for themselves than for others.[3] People became more rational, seeking desirable consequences and avoiding undesirable consequences more as social distance increased.[12,13]

The social-distance effect in different choice frames of uncertain decision-making can be explained by construal level theory (CLT). According to CLT, social distance interacts with construal level: the greater the distance between the individual and the object, the more abstract the object will be construed, and thus the higher the individual's construal level.[14,15] High construal–level individuals devote more cognitive deliberation to the task and focus mainly on the desirability (eg, attractiveness of the outcome) of an action, while low construal–level individuals focus mainly on the feasibility (eg, probability of a positive outcome) of an action.[2,16] Research on CLT has found that in the gain frame, individuals with high construal levels were more risk-tolerant than those with low construal levels, but this effect in the loss frame was not found.[17,18] However, another study on CLT and social distance produced inconclusive results.[19] It found that in a disadvantageous (long-term loss-leading) choice frame, high construal–level individuals were less risk-tolerant than those with low construal levels. The same manipulation worked differently with regard to social distance, wherein high social distance made people more risk-tolerant, as opposed to low social distance, in the disadvantageous frame.[19] As such, the choice frame of decisions has to be considered in exploration of the social-distance effect on uncertain decision-making.

Unlike previous behavioral studies, event-related potentials (ERPs) enable us to explore the real-time influencing process of social distance on uncertain decision-making. Uncertain decision-making can be divided into three temporal stages — choice evaluation, response selection, and feedback evaluation — which can be analyzed through measuring the P300, decision preceding negativity (DPN), feedback-related negativity (FRN), and feedback-related P300 (fP300), respectively.[20,21]

P300 is an important component in decision-making research.[22] It is a positive-going component that peaks 300–600 ms after stimuli onset, and mainly originates in central and parietal regions. The amplitude of P300 is reversely correlated with memory load.[23,24] P300 is a sign of motivational/emotional significance and stimulus discrimination.[23,25] Higher P300 is found when individuals choose riskier options.[22,26,27] DPN is a slow, negative potential that occurs approximately 500 ms before choice selection, and is mainly recorded in the right anterior region. DPN reflects the anticipation of choices.[28] FRN is a negative-going potential that emerges approximately 250 ms after feedback and originates in the medial frontal cortex.[29] FRN and fP300 have been used to compare motivational differences between the self and others in gambling tasks.[30–32] Previous studies focused mainly on the influence of social distance on feedback-related potentials. They found that social distance modulated the process of feedback evaluation in gambling tasks, gambling for friends induced significantly greater FRN and fP300 amplitudes than for strangers,[33] and that this modulation effect diminished in loss situations and was also affected by the self-engagement of the participant.[30] The mechanism of how social distance influences the early processing stages of uncertain decision-making is still unclear.

The current study extends previous research in three major respects. Firstly, most previous research on social distance has used different ways to define "others" (beneficiaries of gamble, such as family, friends, or strangers) without unifying the social distance level of each beneficiary.[8,19,30,33,34] This difference might be behind their inconsistent results. To overcome this problem, we quantified "others" using the social-distance measurement.[35–38] Secondly, previous research on CLT and social distance led to inconsistent results.[17–19] To clarify how the social-distance effect works in the different choice frames of uncertain decision-making, we measured the behavioral results of participants when they gambled for three quantified social distances (self, friend, and stranger) in advantageous and disadvantageous choice frames. Thirdly, to fully measure the three information-processing stages (choice evaluation, response selection, and feedback evaluation) of uncertain decision-making, we adopted the modified single-choice Iowa Gambling Task (IGT) during ERP recording.[39] The IGT has been widely used by clinicians and researchers to simulate uncertain decision-making in real-life situations,[40] and is a rule-learning task that contains advantageous and disadvantageous deck frames wherein participants learn the rules after repeated trials.[41,42] Unlike the original IGT, mixing the first two stages of uncertain decision-making, the modified single-choice IGT allows us to measure the three stages separately.[20]

Based on previous research,[3,12,13] we speculated that the social-distance effect on the IGT would differ by deck-choice frame: high social distance would make people choose more from the advantageous decks (ie, approach) and choose less from the disadvantageous decks (ie, avoidance). Considering that the P300 is inversely related to memory load,[24] we hypothesized that disadvantageous decks, which need more attention, would elicit larger P300 values than advantageous decks. We also speculated that social distance worked interactively with decks: when gambling for high social distance, the P300 amplitude would be smaller in evaluating disadvantageous decks and larger in evaluating advantageous decks compared to gambling for close social distance. Larger DPN is associated with better ability to evaluate choices.[28] According to CLT, higher social distance is connected with higher ability to distinguish short-term from long-term outcomes.[2] Therefore, we hypothesized that making decisions for high social distance would cause larger DPN amplitude than for low social distance. Along with previous research on FRN and fP300,[30–32] we hypothesized that making decisions for low social distance would cause higher FRN and higher fP300 amplitudes than for high social distance, especially after win feedback.

Methods

Participants

A total of 57 individuals were recruited from the population of college students in Guangzhou, China. There were 36 women and 21 men. All were right-handed and had corrected-to-normal vision, without any history of mental or neurological disorders. The mean age of participants was 20.263±1.987 years. Every participant received basic monetary compensation of CN¥40 and a bonus of ¥0–¥20 based on their task performances. This study was conducted in accordance with the Declaration of Helsinki, and was approved by the Research Ethics Review Board of the South China Normal University in Guangzhou, China. Prior to participation in the study, written informed consent was obtained from all participants.

Task materials

Induction of social distance

We quantified social distance between participants and beneficiaries with a measurement applied in previous research.[35–38] This quantified social distance on a 100-point scale: 0 representing oneself,[38] 1 a dear friend or family member,[36,37] 50 a remote acquaintance whose name was not familiar,[35,38] and 100 a stranger.[35–38] To distinguish social distance between oneself and a friend, we quantified the social distance of a friend as point 5. Identities of beneficiaries were indicated by the participants through the following procedure. First, participants were told they were going to gamble for three beneficiaries with different social distances. They were asked to imagine their social network and mentally assign their social relationships by closeness on the 0–100 scale. Then, we instructed participants to imagine point 0 on the scale to represent themselves, 5 to represent a close friend, and 100 to represent a stranger. The social distance of each beneficiary was the same across participants. To keep the image of decision beneficiaries clear and fresh in participants' minds, we asked them to imagine and write down three thoughts associated with the three beneficiaries (self, friend, and stranger) at the present moment below the corresponding points.[36] Participants were allowed to complete the task in 3 minutes. No participants reported misunderstanding the induction and quantification of social distance.

Modified Iowa Gambling Task

The modified single-choice IGT was adopted from previous research to measure the ERP responses of three stages of uncertain decision-making separately.[20,39,41] It allowed participants to make a play/pass decision on one of four decks preselected randomly by computer on each trial, rather than choosing freely from four decks as in the original IGT, and thus the choice-evaluation stage was able to be separated from the response-selection stage.[20] The modified IGT had four decks: A–D. The presentation of the decks did not convey any indication of advantageous or disadvantageous outcomes, and they were presented in two rows on the screen to reduce eye movement.

The deck-value arrangement in the modified IGT was simplified, but retained the same structure in our study: two decks (A and B) were disadvantageous and led to a net loss after repeated play, while the other two decks (C and D) were advantageous and produced a net gain after being chosen repeatedly. The expected values after six consecutive choices of A, B, C, and D were −150, −150, 120, and 150, respectively. Additionally, the probability of win was 1/2 for A and C and 5/6 for B and D. Consequently, there were four possible combinations in each deck: low win probability with disadvantageous outcome (deck A), high win probability with disadvantageous outcome (deck B), low win probability with advantageous outcome (deck C), and high win probability with advantageous outcome (deck D). The payoff ranges of these four decks are listed in Table 1.

Procedure

Following completion of the social-distance induction task, participants sat at a distance of 70 cm in front of a 22-inch monitor (160 Hz refresh rate) in a quiet laboratory room. Participants' brain responses were recorded during the IGT. The task was designed and presented with E-Prime 1.1 (Psychology Software Tools, Sharpsburg, PA, USA). Figure 1 illustrates the procedure used in the study. Participants were asked to make a decision on the IGT for the three beneficiaries identified with the social-distance scale (self, friend, and stranger). The experiment comprised 432 trials, with 18 blocks of 24 trials. Each block was arranged to gamble for a different social distance. The order for social distance of each block was prearranged to balance the order effect. At the beginning of the gambling task, each participant received a loan of 2,000 tokens. After each block, the participant received a break, during which the running total of the participant's earnings appeared on the screen for 30 seconds.

Table 1 Arrangement of deck value and probability in modified Iowa Gambling Task

	Decks			
	A	**B**	**C**	**D**
Payoff range	90 90 120 −125 −150 −175	90 90 90 110 120 −650	40 40 70 −5 −10 −15	40 40 40 60 70 −100
Probability of win	1/2	5/6	1/2	5/6
Probability of loss	1/2	1/6	1/2	1/6
Expected value	−150	−150	120	150

Note: Outcomes of deck A were 90, 90, 120, −125, −150, and −175. Outcomes of deck B were 90, 90, 90, 110, 120, and −650. Outcomes of deck C were 40, 40, 70, −5, −10, and −15. Outcomes of deck D were 40, 40, 40, 60, 70, and −100. The design of the payoff schedules followed two rules: first, the probability of wins from decks B and D was 5/6, whereas from the other two decks it was 1/2; second, the win magnitudes of decks A and B were 100 and decks C and D 50. Therefore, the expected value of deck C was set to 120 to comply with these rules.

Each block began with the presentation of a picture of a cross with a random duration of 400–600 ms. Subsequently, a cue appeared on the screen to communicate to the person for whom they were going to make a decision. To keep the participant reminded of beneficiary they were going to gamble for in each block, they had to circle on the scale at the corresponding points of each person's social distance. Social distance remained the same within each block. Each trial in every block included three processing stages. During the stimulus-presentation (choice evaluation) stage, four decks appeared on the screen for 800 ms. One of these was outlined with a yellow square for the participant to decide whether to play it or pass. During the response stage, a question mark was presented. Participants were instructed to make a choice by pressing a button on the keyboard within 2,000 ms. The left key (Z) represented "play", and the right (M) represented "pass". The cues for response keys were simultaneously presented on the computer in black to limit participants' response preference. After the choice had been made, a delay of 800 ms followed. Finally, during the feedback stage, the real-time payoff of the participant's choice appeared on the center of the screen for 1,000 ms, and the payoffs of each deck (see Table 1) were arranged to appear randomly as the feedback of each trial. A win outcome was presented with a red positive value, a loss outcome was blue with a negative value, and a pass was a black zero. Then, the next trial began after a pause of 400–600 ms.

After participants had completed the IGT, the computer would randomly choose a block from the task outputs. The amount of a bonus was determined according to this

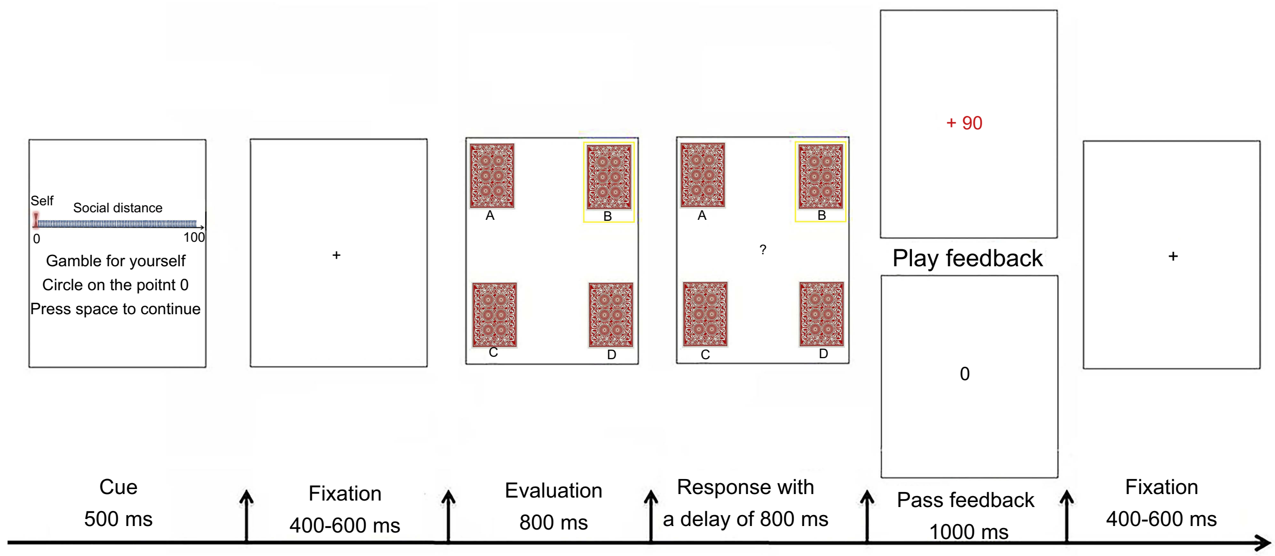

Figure 1 Experimental flow of the IGT.
Abbreviation: IGT, Iowa Gambling Task.

block's net earnings. The beneficiary of the bonus was the person for whom the participant made the decision during that block. The participant would ultimately receive monetary compensation of ¥40 plus a bonus of ¥0–¥20 based on their task performances. The other two beneficiaries would also have a chance to receive the bonus earned by the participant. Bonuses to strangers were given to the next anonymous participant.

EEG recordings

EEG data were recorded with a band pass of 0.05–100 Hz and a sampling rate of 500 Hz from 32 Ag/AgCl electrodes (Easycap; Brain Products, Munich, Germany). Electrodes were arranged according to the international 10–20 system with a ground electrode placed at AFz, online reference to the FCz site, and offline algebraic rereference to the average of the left and right mastoids.[43,44] The vertical EOG was placed at the infraorbital of the right eye and a horizontal EOG was positioned laterally to the outer canthi of both eyes. Impedance at or below 10 kΩ for all electrodes was considered acceptable.

Analyses

EEG data were analyzed offline using EEGLab 13.6.5b in MatLab (MathWorks).[45] Data were resampled at 250 Hz and filtered digitally offline by high- (0.1 Hz) and low-pass filters (30 Hz, slope 24 dB/oct). ERP components were acquired by segments of 1,000 ms units according to stimulus markers, and the mean of the first 200 ms served as baseline. Epochs with signals >±100 μV were rejected. Then, these epochs were screened for further eye movement–related artifacts by applying independent-component analysis.[46,47] The trials remaining were considered artifact-free (gambling for oneself in deck A, 30.0±6.0 trials; gambling for oneself in deck B, 28.7±6.4; gambling for oneself in deck C, 28.9±6.4; gambling for oneself in deck D, 28.8 ±6.2; gambling for friend in deck A, 28.2±7.0; gambling for friend in deck B, 28.3±7.0; gambling for friend in deck C, 28.4±7.3; gambling for friend in deck D, 28.3±6.7; gambling for stranger in deck A, 29.2±6.4; gambling for stranger in deck B, 28.5±5.9; gambling for stranger in deck C, 30.3±7.9; gambling for stranger in deck D, 29.0±6.3).

EEG-data processing was divided into three stages according to the process of decision-making. In the choice-evaluation stage, the time window for P300 was 300–600 ms after stimulus. P300 components were analyzed to examine whether the perceived deck value and social distance would evoke different P300 patterns. Mean amplitudes of P300 at 300–600 ms on nine electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4) were analyzed. In the response-selection stage, previous research and participants' average reaction times were taken into account to establish the DPN 1,300 ms segments. The baseline time window was set at 500 ms preceding the response markers and the 600–800 ms following the response.[20,48] The same nine electrodes from the previous stage were used for analysis. In the feedback-evaluation stage, FRN and fP300 were analyzed to determine whether or not different feedback and social distance would produce differences in components' valence or magnitude. For FRN, the mean amplitude of the time window was 240–300 ms following the onset of feedback.[49,50] Additionally, for fP300, the mean amplitude of the time window was 300–420 ms following the onset of feedback.[23,51] The average amplitude of Fz, FC1, FC2, and Cz in the fronto central area for FRN and the average amplitude of Cz, CP1, CP2, and Pz in the centroparietal area for fP300 were analyzed.[52,53]

All data analyses were performed using SPSS 20.0. Repeated-measure ANOVAs were used to analyze behavioral and ERP results. The Greenhouse–Geisser method was used for correction when the sphericity assumption was not satisfied. Bonferroni correction was used for multiple comparisons. Effect sizes of all data analyses were estimated by partial eta squared (η^2_p).

Results

Behavioral results

Deck-choice frequency

Repeated-measure ANOVA was used to gauge IGT deck selections, with social distance (self, friend, and stranger) and deck (A–D) as the repeated-measures variable. The main effects of deck and the interaction between deck and social distance were significant ($F_{3, 168}$=37.543, P<0.001, η^2_p=0.401 and $F_{6, 336}$=52.517, P<0.001, η^2_p=0.108, respectively). When gambling for oneself, participants chose deck A more than for a friend or stranger (for oneself, mean 25.053±0.977; friend, mean 23.649±1.059; stranger, mean 22.754 ±0.882; P<0.05). When gambling for oneself, participants chose deck C less than for a friend or stranger (for oneself, mean 28.035±0.626; friend, mean 29.825 ±0.695; stranger, mean 29.947±0.633; P<0.01). The deck choices of each social distance are presented in Figure 2.

Net gain

To gauge the net gain of each social distance across IGT, the whole task was divided into three stages according to time. Repeated-measure ANOVA was used with social distance and stage as the repeated-measure variables. The interaction of deck and stage was significant ($F_{4, 224}$=2.508, P=0.043, η^2_p=0.043). When gambling for oneself (mean 40.439 ±48.183) participants gained less than for a stranger (mean 207.544±52.997, P=0.048) in stage 1. Differences in later stages were not found.

ERP results

Social distance interacted with deck frame of P300 amplitude

Repeated-measure ANOVA was conducted on P300 amplitude, with social distance, deck, region (frontal, central, parietal) and laterality (left, middle, right) as the repeated-measure variables. The main effects of region, laterality, and deck were significant ($F_{2, 112}$=15.679, P<0.001, η^2_p=0.219, $F_{2, 112}$=29.414, P<0.001, η^2_p=0.344, and $F_{3, 168}$=41.721, P<0.001, η^2_p=0.427, respectively). P300 amplitudes of decks A and B were larger than decks C and D (P< 0.001), as shown in Figure 3A. The interaction of deck, social distance, region, and laterality was significant ($F_{24, 1,344}$=6.201, P< 0.001, η^2_p=0.100). Evaluation of deck A showed that gambling for oneself was associated with a larger P300 amplitude than for a stranger in the left frontal and central regions (P<0.05). Evaluation of deck C showed that gambling for oneself was associated with smaller P300 amplitude than for a stranger in the right frontal, central, and parietal regions (P<0.05) and gambling for oneself with a smaller P300 amplitude than for a friend and stranger in the middle parietal region (P<0.05). Evaluation of decks B and D showed that no interaction among the three social distances was found. Figure 3B illustrates the topographical maps of the four decks for the different social distances.

Social distance interacted with deck frame of DPN amplitude

Repeated-measure ANOVA was conducted on the mean amplitude of DPN, with choice (play and pass), deck, social distance, region, and laterality as within-subject factors. The main effects of social distance, region, and laterality were significant ($F_{2, 112}$=3.275, P<0.05, η^2_p=0.055, $F_{2, 112}$=22.271, P<0.001, η^2_p=0.285, and $F_{2, 112}$=5.639, P<0.01, η^2_p=0.091, respectively). Gambling for a stranger produced larger DPN amplitude than when gambling for oneself (P=0.053), as shown in Figure 4A. The interaction of social distance, deck, laterality, was significant ($F_{12, 672}$=2.879, P=0.001, η^2_p=0.049). When choosing deck A, gambling for a stranger produced larger DPN amplitude than for oneself or a friend in left and right literalities (P<0.05), and when choosing deck B, gambling for a friend produced larger DPN amplitude than for oneself in left, middle, and right literalities (P<0.05, Figure 4B).

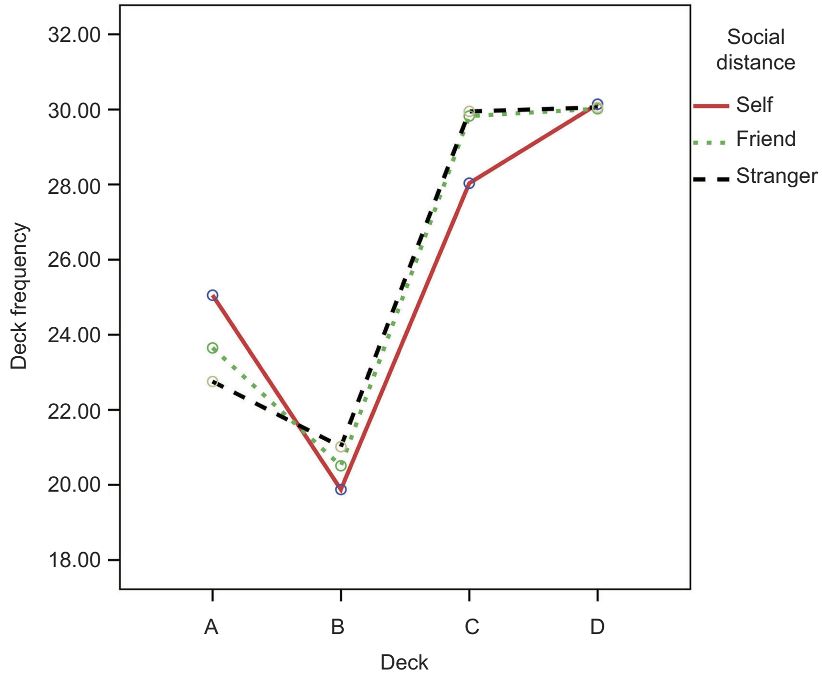

Figure 2 Deck-choice frequencies when participants gambled for three social distances (self, friend, and stranger) during the IGT.
Abbreviation: IGT, Iowa Gambling Task.

Social distance modulated FRN and fP300 amplitudes

FRN and fP300 data were analyzed using two repeated-measure ANOVAs, with valence (win and loss) and social distance as within-subject factors. For FRN, the main effect of social distance was significant ($F_{2,\ 112}$=11.809, P<0.01, η^2_p=0.081). When gambling for oneself, the FRN amplitude was more negative than for a stranger (P<0.05), as shown in Figure 5A. For fP300, the main and interactive effects of social distance and feedback were significant (social distance, $F_{2,\ 112}$=10.721, P<0.001, η^2_p=0.161; feedback, $F_{1,\ 56}$=5.195, P<0.05, η^2_p=0.085; interaction, $F_{2,\ 112}$=7.420, P=0.001, η^2_p=0.117). The fP300 amplitude of gambling for a stranger was smaller than for oneself and a friend in the win-feedback condition (P<0.001), whereas loss feedback displayed no such difference between social distances, as shown in Figure 5B.

Discussion

In this study, we aimed to explore the influence of social distance on uncertain decision-making with advantageous and disadvantageous choice frames. To overcome the method limitations and result inconsistencies of previous research,[5–10] we investigated the impact of social distance on uncertain decision-making by quantifying social distance, as well as adopting a modified single-choice IGT.[35–37,39]

Behavioral

Behavioral results of net gain and deck choice were consistent with each other and also corroborated the hypothesis that IGT performance differs significantly between different levels of social distance. The participants earned less when they gambled for close social distance (self) than for high social distance (stranger) in the early stage of the IGT. Individuals demonstrated more risk avoidance in a disadvantageous choice frame (deck A) and risk tolerance for an advantageous choice frame (deck C) when gambling for a stranger than when gambling for oneself or a friend. Our results are partly inconsistent with previous research on CLT, as they only found a social-distance effect on risk preference for uncertain decision-making in the gain frame.[17,18] This inconsistency might have been caused by the task difference we applied to measure decision-making. Our results indicate that when gambling for high social distance, individuals are more likely to distinguish advantageous decks from disadvantageous decks, which in turn results in better decision performance and gambling outcome.

This deck-choice discrepancy in different social distances could be explained by the decks' frame and manipulation of social distance on participants' construal level. According to CLT, making decisions on distant situations requires self-control and long-term planning.[14,54,55] A high construal–level

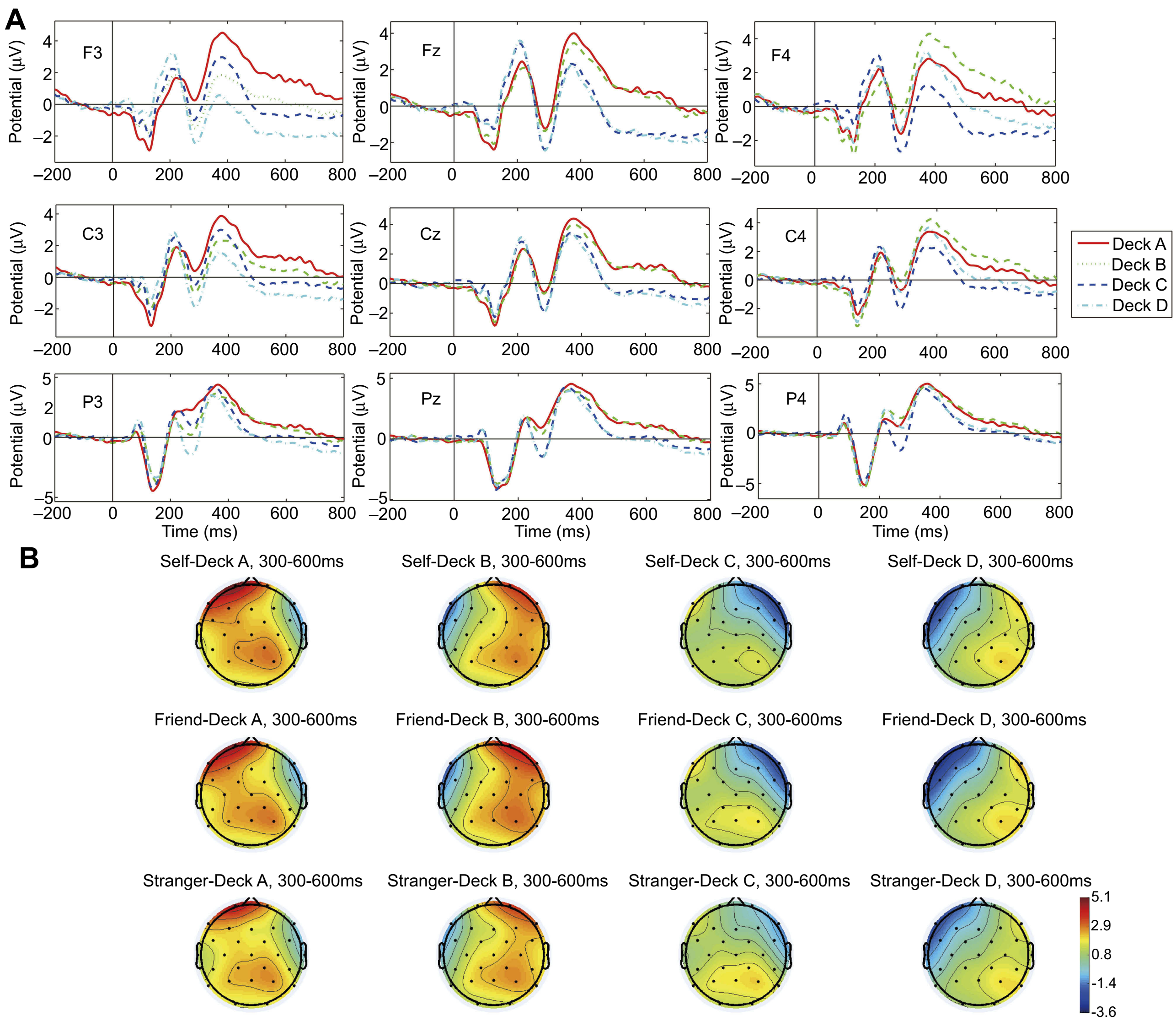

Figure 3 Event-related potential (ERP) results for the choice evaluation stage.
Notes: (**A**) Grand mean ERP wave forms of decks from F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4 electrodes. (**B**) Topographical maps of four decks when participants gambled for three social distances (self, friend, and stranger [µV]).

mind-set increases individuals' level of elaboration on decision-making, which in turn shifts their focus from short-term to long-term outcomes.[2,56] With increased social distance, individuals are more risk-tolerant for desirable results and risk-avoidant for undesirable results.[3,12,13] Research has shown making decisions for others is riskier in situations where risk-taking is valued than making decisions for oneself, but in situations where risk aversion is valued, making decisions for others is more conservative.[9,11] We speculate that since risk-taking in advantageous choice frames and risk aversion in disadvantageous choice frames were valued: people gambling for high social distance (high construal level) were more likely to avoid the disadvantageous deck A and approach the advantageous deck C. Most of our participants were able to distinguish the advantageous/disadvantageous frames of decks B and D more easily than decks A and C because of their deck-value arrangement,[19,57] and thus no social-distance effect was found on decks B or D in our study.

Research suggests that the gain–loss frame of each deck has an important impact on performance in the IGT.[58] Our results contribute to previous research by indicating that people with high social distance are more rational in their decision-making: they are more risk-taking in advantageous frames and more risk-averse in

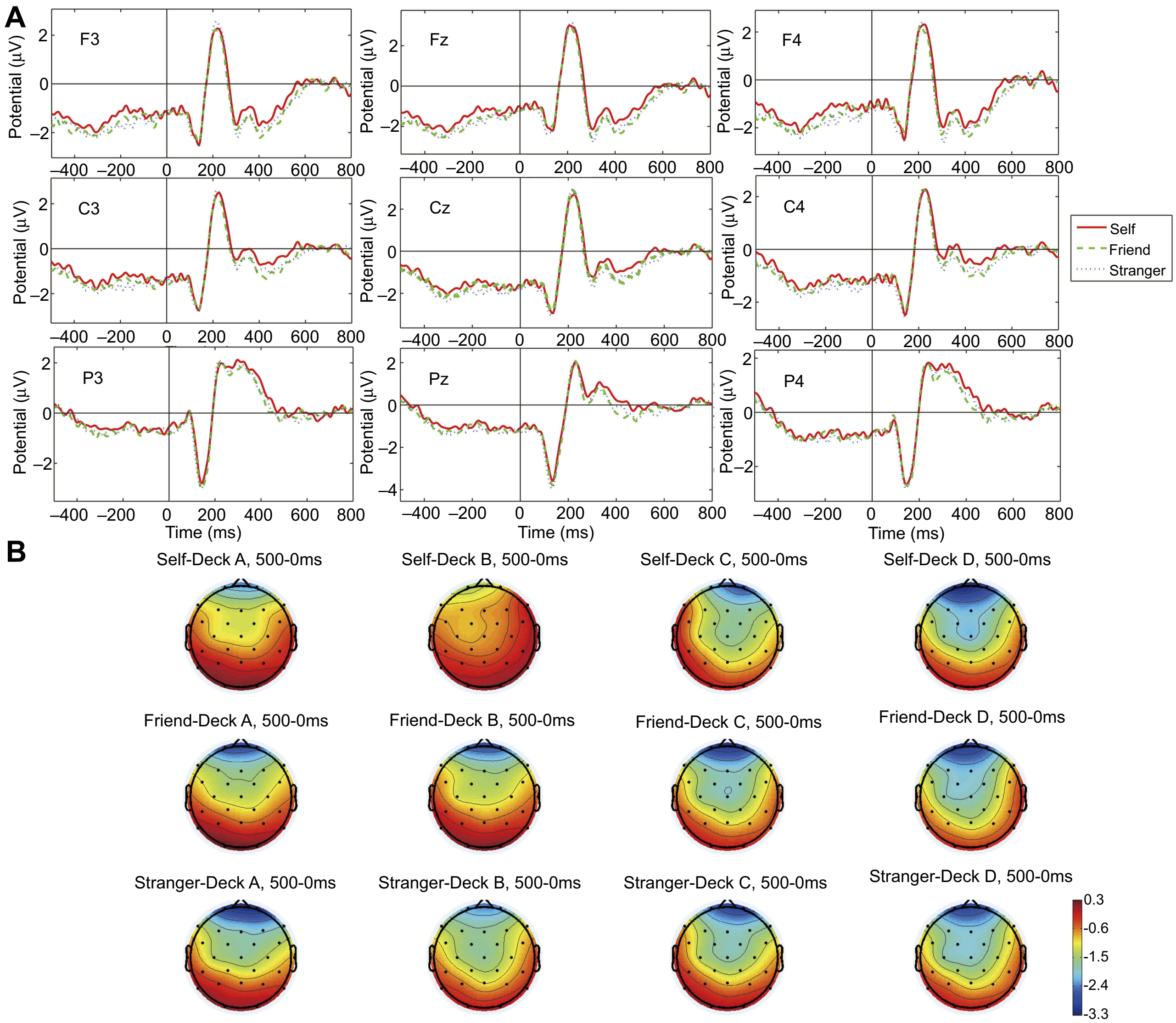

Figure 4 Event-related potential (ERP) results for the response-selection stage.
Notes: (**A**) Grand average ERP wave forms of three social distances from F3, Fz, F4, C3, Cz, C4, P3, Pz, and P4 electrodes. (**B**) Topographical maps of four decks when participants gambled for three social distances (μV).

disadvantageous frames.[3,12,13] According to frame-effect theory, people tend to avoid risks when a positive frame is presented, but seek risks when a negative frame is presented.[59] Our results extend this view by suggesting that frame effect reverses when people make decisions for a stranger (high social distance).

ERP

P300 in choice-evaluation stage

Our ERP results in the choice-evaluation stage directly support the behavioral results by proving that the effect of social distance on the P300 amplitude works interactively with the frame of choice: gambling for low social distance caused larger P300 when evaluating the disadvantageous deck A, while smaller P300 when evaluating the advantageous deck C than high social distance. We also found lower P300 amplitude when evaluating advantageous decks than disadvantageous decks.

These results replicate previous research and are also consistent with the motivational significance of the P300.[20,41] Recent theory has assumed that the P300 comes from locus coeruleus–norepinephrine system activity. This system indicates that the amplitude of P300 is closely related to the motivational significance of the given stimulus.[60,61] Emotionally valent stimuli are motivationally significant and associated with larger P300.[62,63] We

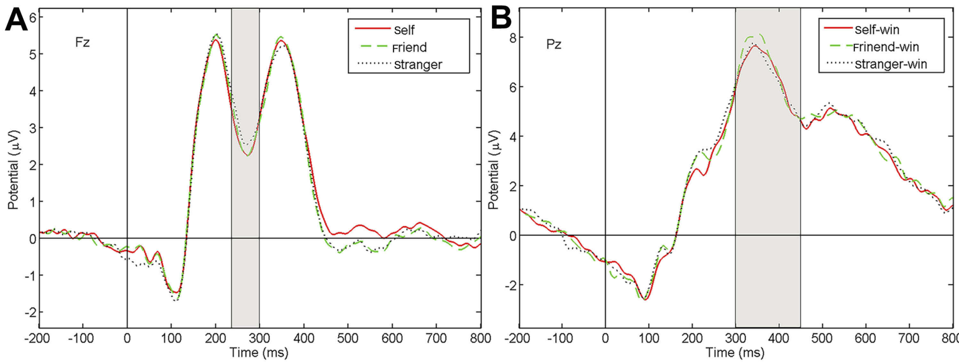

Figure 5 Event-related potential (ERP) results for the feedback stage.
Notes: (**A**) Grand average ERP wave forms of feedback-related negativity for three social distances from Fz electrode. (**B**) Grand average ERP wave forms of fP300 for three social distances after gains feedback from Pz electrode.

speculate that disadvantageous choices are more emotionally valent when individuals gamble for high social distance, while advantageous choices are more emotionally valent when individuals gamble for low social distance.

P300 amplitude has been considered a representation of working memory,[23] and has been widely demonstrated to be inversely proportional to working memory.[64–66] Our results indicate that participants pay more attention on the disadvantageous deck when they gamble for a stranger, while they pay more attention on the advantageous deck when they gamble for oneself. The manner in which participants construed the task may contribute to this working memory–load difference. People with high construal levels mainly focus on the attractiveness of outcomes and devote more attention to the task,[2,16,56] and thus they may discriminate long-term reward choices from short-term reward ones, while low construal levels make people focus more on the feasibility of a positive outcome and less on the task,[2,16,56] and thus they may choose more short-term reward choices. No social distance effect was found with decks B or D. This result corresponds with our behavioral deck-choice result. It suggests that when choices are easy to value, social-distance manipulation might not work.[18]

P300 amplitude was also found to be correlated with perceived risk: it was enhanced in high-risk choices and smaller when people showed more aversion in decision-making.[22,26,27] Our results indicate that the social-distance effect on the risk-taking of uncertain decision-making distinguishes between advantageous and disadvantageous choice frame: low social distance makes people more risk-tolerant in disadvantageous situations and more risk-averse in advantageous situations. Our results extend previous research on self–other regarding decision-making that did not take the choice frame into account and thus got inconsistent results.[5–10,17]

DPN in response-selection stage

Consistently with hypothesis, our results showed that the influence of social distance on DPN amplitude in the response-selection stage mainly occurred when choosing disadvantageous decks, with high social distance causing larger DPN than low social distance. DPN is measured to reflect the anticipation of decisions on IGT. It is related to the integration of information, potential outcomes, and execution of motor responses and intuitive judgments.[67–69] Research has shown that DPN is associated with the anticipation of risky choices[48] and the avoidance behavior with disadvantageous choices.[70] Larger DPN amplitude has been found when giving up disadvantageous choices.[20,41] Our results correspond with research that showed low social distance made people more risk-averse in the gain domain and more risk-seeking in the loss domain.[3,12,13] Our results indicate that when gambling for high social distance, individuals are more likely to avoid disadvantageous choice frames than when gambling for low social distance. These results in response selection extend our understanding of brain activity before people make choices in uncertain situations.

FRN and fP300 in feedback-evaluation stage

Consistently with hypothesis, our results revealed that FRN in the feedback stage showed a social-distance effect: FRN was larger when gambling for a socially close person (self) than for a socially distant person (stranger). Our results correspond with previous studies in showing that FRN amplitude was modulated by social distance when people gambled for oneself or others.[30,33,34] Studies have found an FRN difference between gambling for a friend and a stranger, but we did not find this difference. Instead, we found FRN difference between gambling for oneself and a stranger. The motivation of making money for oneself is the most significant, and thus caused the largest FRN amplitude.[30–32] The social distance between oneself and a stranger was much farther than that with a friend.[35,71] The undifferentiated FRN between gambling for oneself and a friend might be caused by the relatively intimate social distance between the participant and the friend for whom they gambled. This explanation also sheds light on the results of research where early semiautomatic FRN was able only to distinguish participant's own outcomes from others', but when the participant was also engaged in the game, the difference between outcomes of a friend and outcomes of a stranger diminished.[33]

Consistently with previous research, the present study provides evidence that fP300 amplitude for a win is significantly larger than for a loss.[33,72–74] More importantly, we found that the social-distance effect on fP300 interacted with feedback valence. When gambling for a stranger, fP300 amplitude was lower than for oneself and a friend following gains feedback, whereas no difference was found in losses feedback. The influencing factors of P300 include the magnitude of rewards,[75] feedback valence,[76] some social factors, such as interpersonal relationships,[33,77,78] and the level of personal responsibility for the outcome.[52] It is widely believed that fP300 represents the motivational/emotional salience of stimulus.[25,50,61–63,79] Brain-imaging studies have identified that interaction with friends is associated with brain structures that are also linked to reward processing, empathy, and emotion regulation, such as the amygdala, hippocampus, nucleus accumbens, and ventromedial prefrontal cortex.[80,81] In our study, the lower fP300 when gambling for a stranger showed that personal gains resonated more with people than those for friends or strangers.

Our results indicate the motivation/emotional process represented by FRN and fP300 is modulated by interpersonal relationships (social distance in this study) between gamblers and beneficiaries. People are less emotionally involved when evaluating decision outcomes when they make decisions for others than making decisions for themselves. These findings suggest that when making decisions in reality, individuals should take a farsighted perspective to reduce the influence of emotion.

Limitations and future directions

Although the IGT has been widely used, it is easily affected by a number of contextual factors, such as personality,[82] age,[39] sex,[83] mood,[84] and motivation.[85] One limitation of this study is that we focused only on the influences of social distance and choice frame on uncertain decision-making. Research has shown that people in the first-person perspective tend to regard a behavior as situational, while people in the third-person perspective tend to regard the same behavior as dispositional.[2] This manifests that making decision for others could depend mainly on one's characteristic. Research has also shown bhat individual characteristics (such as risky/safe game strategy) modulate the effect of construal level on risk-taking.[17] Therefore, personality trait/state assessments, such as risk proneness and sensation-seeking among others, are needed to explain the social-distance impact on uncertain decision-making. Another limitation is the lack of gambling-severity scores for participants, as a gambling task like the IGT is sensitive to individuals' attitudes toward money.[40] Finally, our results are limited to normal adults with healthy ventromedial brain function. The ventromedial brain plays an important role in utilizing emotional information to guide decision-making,[42] and goes through a process of maturation from adolescence to young adulthood.[86] This process corresponds with IGT performance improving with age.[39] As such, the social-distance effect on uncertain decision-making in adolescent or mentally atypical people might be different, and more studies are needed to clarify this difference. We believe uncertain decision-making deserves further research, and intend to take other quantified social-distance levels into account to explore the possible linear regression of the social-distance effect on uncertain decision-making. Future studies should also consider other individual characteristics and demographic variables to help explain the mechanisms of the social-distance effect in the different choice frames of uncertain decision-making.

Conclusion

This study provides insights into behavior pattern with and time course of the social-distance effect on uncertain decision-making in advantageous and disadvantageous choice frames. Behavioral results indicate that uncertain decision-making is modulated by both social distance and the frame of choice: high social distance made people choose more advantageous decks and less disadvantageous decks than low social distance. ERP results supported this outcome by showing that higher social distance made people more discerning in advantageous and disadvantageous choices and less motivationally involved in outcome feedback. Our results extend the theory of frame effect and suggest that the social-distance effect on uncertain decision-making is different between advantageous and disadvantageous deck frames, high social distance makes people seek more desirable consequences and avoid undesirable ones than low social distance. These findings not only shed light on the neural mechanisms of uncertain decision-making but may also have broader implications for self–other regarding decision-making in reality.

Data availability

Data sets can be accessed at DOI:10.6084/m9.figshare.7836158.

Acknowledgments

The authors thank the reviewers for suggestions and Huilin Zhu for advice and guidance. This research was supported by the National Social Foundation of China (grant 16ASH009).

Disclosure

The authors report no conflicts of interest in this work.

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