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Agreeableness modulates group member risky decision-making behavior and brain activity☆

Fang Wang [a,1], Xin Wang [a,b,1], Fenghua Wang [a], Li Gao [a], Hengyi Rao [a,c,*], Yu Pan [a,**]

[a] Laboratory of Applied Brain and Cognitive Sciences, School of Business and Management, Shanghai International Studies University, People's Republic of China
[b] Postdoctoral Research Station, Shanghai International Studies University, People's Republic of China
[c] Center for Functional Neuroimaging, Department of Neurology, University of Pennsylvania Perelman School of Medicine, Philadelphia, PA, 19104, USA

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ABSTRACT

When facing difficult decisions, people typically believe that "two heads are better than one". However, findings from previous studies are inconsistent regarding the advantages of decision-making in groups as compared to individual decision-making. We hypothesize that personality traits may modulate risk-taking behavior and brain activity changes during group decision-making. In this study, we used event-related potentials (ERP) with a well-validated balloon analogue risk task (BART) paradigm to examine the relationships between personality traits, decision-making behavior, and brain activity patterns when a cohort of male participants make decisions and take risks both in groups and in isolation. We found significantly increased risk-taking behavior and reduced P300 component during group decision-making as compared to individual decision-making only for participants with high Agreeableness, but not for those with low Agreeableness. Moreover, Agreeableness scores correlated with risk-taking behavior and P300 amplitude changes in group decisions. These findings suggest that Agreeableness personality modulates risk-taking behavior and brain activity when people make decisions in groups, which have implications for future group decision research and practice.

1. Introduction

People need to make a number of decisions under some risk or uncertainty every day. Understanding how people take reasonable risk and make appropriate decision posits a challenge across many disciplines including psychology, economics, management, and neuroscience (Rushworth et al., 2011; Sirigu and Duhamel, 2016). Although a certain amount of risk-taking may be essential for human survival and advancement, excessive risk-taking behavior is linked to a range of disorders such as addiction and pathological gambling (Bechara and Damasio, 2002; Timmeren et al., 2018). In real life, people generally believe that "two heads are better than one" and would usually ask for help from others when facing difficult decisions. Conventional wisdom assumes that group decision-making may help people explore all possible states that the world could be in and all possible actions that one could take, therefore are more likely to lead to better choices than individual decision-making. Indeed, previous studies have provided some evidence supporting the benefits of decision-making in groups versus individual decision-making in isolation (Bang and Frith, 2017; Bose et al., 2017; Galton, 1907; Kerr and Tindale, 2004; Marshall et al., 2017; Navajas et al., 2018; van Dolder & van den Assem, 2018). However, group decision-making situations could also give rise to individual's inappropriate behavior and resulting in disadvantages, for example as illustrated by the bystander effect in which people's intention to help others decreases when passive bystanders are present in an emergency situation (Fischer et al., 2011; van Bommel et al., 2012).

A number of studies have examined the changes of people's risk-taking behavior and preference from individual decision-making to

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* Corresponding author. University of Pennsylvania Perelman School of Medicine, USA.
** Corresponding author. Laboratory of Applied Brain and Cognitive Sciences, School of Business and Management, Shanghai International Studies University, Shanghai, People's Republic of China.
E-mail addresses: hengyi@pennmedicine.upenn.edu (H. Rao), 13311887777@163.com (Y. Pan).
[1] The first two authors contribute equally to this work.

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group decision-making, only to obtain inconsistent findings. For example, earlier studies demonstrated a higher level of risk-taking in group decisions (Dion et al., 1970), whereas later studies showed that joint decisions were associated with more risk averse and greater ambiguity averse (Bateman and Munro, 2005; Keck et al., 2014; Keller et al., 2007; Masclet et al., 2009). Further studies suggested that several group factors may affect the changes of risk-taking behavior and preference in group decisions, such as the size of the group (Shupp and Williams, 2008), the age of group members (Reynolds et al., 2013), the communication pattern in the group (Baillon et al., 2016), the probability of winning (He et al., 2012), and the rules of decision (Levati et al., 2017).

In addition to group factors, other individual factors may also contribute to the differences in risk-taking behavior and preference, such as personality traits (Gullone and Moore, 2000), gender (Charness and Gneezy, 2012), age (Figner et al., 2009), social culture (Kreiser et al., 2010), risk-taking history (Cameron and Shah, 2015), parental background (Dohmen et al., 2011), financial status (Griskevicius et al., 2013), and genetic variations (Cesarini et al., 2009; Kuhnen and Chiao, 2009). Among these factors, personality traits constitute a comprehensive factor that might reflect other individual differences. In fact, the five-factor model (FFM) of personality traits have been shown to affect risk-taking preferences and propensity (Gullone and Moore, 2000; Nicholson, Soane, Fenton-O'Creevy and Willman, 2005; Soane and Chmiel, 2005; McGhee et al., 2012), entrepreneurial status (Zhao and Seibert, 2006), ethical leader behavior (Kalshoven et al., 2011), as well as academic achievement (Komarraju et al., 2011). FFM personality traits also modulate individual cooperation behavior in groups, with high Agreeableness and low Extraversion associated with more self-restraint when the common resource was severely threatened in an experimental resource dilemma (Koole et al., 2001). Furthermore, personality traits modulate decisions in an incentivized game, with low Neuroticism and high Openness to Experience predicting more cooperative transfers (Lönnqvist et al., 2011). A review on teammate personalities found that Agreeableness had the strongest relationships with team performance in field settings (Bell, 2007). Recent study further suggested that Agreeableness may affect performance through communication and cohesion and that communication precedes cohesion in time (Bradley et al., 2013). However, the associations between personality traits and potential changes of individuals' risk-taking behavior in group decisions remain unclear. Furthermore, few studies have been able to examine the relationships between personality traits and individuals' brain activity changes during group decision-making.

In the present study, we used the electroencephalography (EEG) to measure event-related potential (ERP) responses to sequential risk-taking and decision-making during an individual-based and a group-based balloon analogue risk task (BART), in order to examine the correlation between personality traits, risk-taking behavior change and brain activity changes when people move from individual decisions to group decisions. ERP provides a non-invasive electrophysiological measure of brain response, consisting of a series of positive and negative voltage deflections induced by a specific cognitive or sensorimotor process. The BART is a computerized dynamic risk decision-making task which provides an ecologically valid model for the objective assessment of risk-taking behavior and propensity (Lejuez et al., 2002, 2007; Lejuez et al., 2003a,b; Rao et al., 2008). During the BART, participants are required to repeatedly make decisions regarding whether to continue or discontinue inflating a virtual balloon that could either grow larger or explode (see Fig. 1A). In individual decision condition, participants perform the typical BART alone, while in group decision condition, two participants sit side by side to make decisions for the same balloon alternately. Risk in the BART is ecologically defined as the probability of explosion for each balloon. A larger balloon is naturally associated with a greater risk of explosion as well as a larger amount of potential monetary reward. The average number of inflation pumps participants made for the unexploded winning balloons, also referred to as average pumps, has been suggested to be a predictor of real life risk-taking behavior in various populations including risky driving (Ba et al., 2016), smoking (Lejuez et al., 2003a,b), drug and alcohol use (Bornovalova et al., 2005; Skeel et al., 2008), gambling (Mishra et al., 2010), and psychopathy (Hunt et al., 2005; Swogger et al., 2010).

Previous EEG studies (e.g. A. S. A. Euser et al., 2013; Holroyd and Coles, 2002; Lei et al., 2017; Nieuwenhuis, 2004; Polezzi et al., 2010; Schuermann et al., 2012; Xu et al., 2016; Yau et al., 2015) have consistently identified several specific ERP components involved in risk-taking and decision-making, including the early feedback-related negativity (FRN)/reward positivity (RewP) components, and the late P300 component (see Chandrakumar et al., 2018 for a review). The P300 component is a positive deflection peaking around 300–450 ms post-feedback, commonly maximal in amplitude at centro-parietal electrodes, and reflects a later, attention-sensitive, more elaborate appraisal of outcome sensitivity to the reward magnitude (Hajcak et al., 2005; Sato et al., 2005; Wu and Zhou, 2009; Yeung, 2004), often associated with the evaluation of the functional and motivational significance of feedback stimuli (Gu et al., 2011; Luo et al., 2014; Wu and Zhou, 2009). The FRN peaks around 200–300 ms post feedback onset at medio-frontal sites (Fukunaga et al., 2012) and reflects a neural response to outcomes worse than expected and has been found to mirror rapid feedback evaluation and reflect salience prediction errors (Bellebaum et al., 2010; Cohen and Ranganath, 2007; Holroyd and Coles, 2002; Nieuwenhuis, 2004). In decision-making studies, the FRN is typically obtained by the difference between negative feedback and positive feedback to examine the processing of different outcomes from risky choices (Euser et al., 2011; Kiat et al., 2016; Kóbor et al., 2015; Takács et al., 2015). However, increasing evidence suggest that the FRN may overlap with the reward positivity

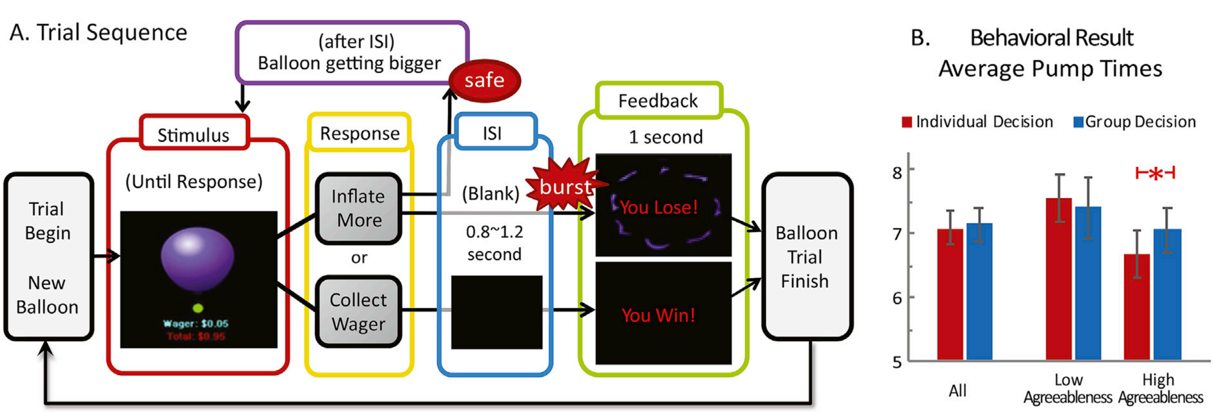

Fig. 1. Balloon Analogue Risk Task (BART, A) and behavioral result (B) in current study. In Individual Decision mode, subjects performed the task by their own. In Group decision condition, two subjects would sit side by side in front of the monitor and performed the task as a group, each response were made by the two partners alternately. The behavioral measurement were the average pump times of the winning bolloons.

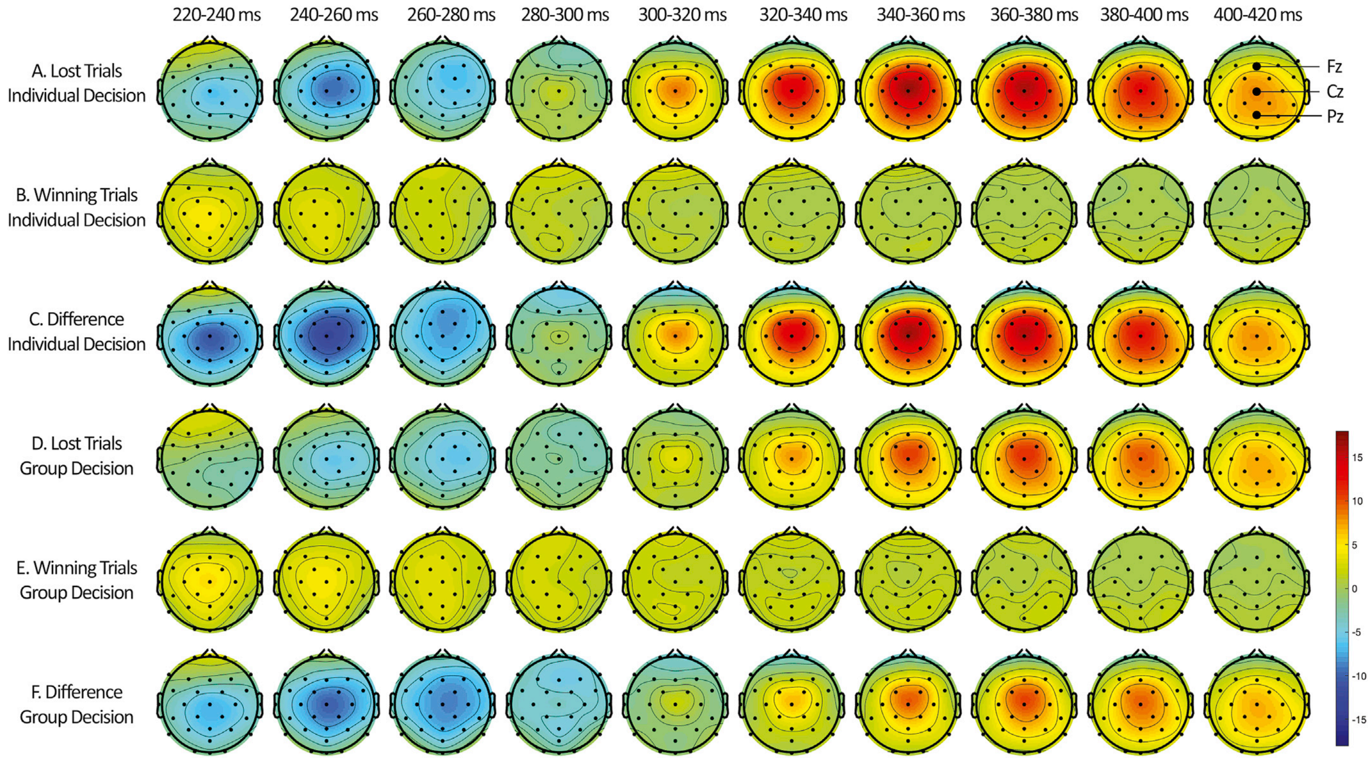

Fig. 2. Topography of grand averaged ERP waveforms. A, B, C: Individual decision condition; D, E, F: Group decision condition. A, D: Lost trails; B, E: Winning Trials; C, F: Difference of lost trials and winning trials. Each topography was the averaged potential of corresponding time window and time-locked to the onset of feedback.

induced by positive feedback which may reflect the motivational value of specific reinforcers to particular individuals (Holroyd et al., 2008; Schmidt et al., 2019; Schmidt et al., 2017a,b). During the BART, there were three types of feedback after participants press a button: an unexpected negative feedback of balloon explosion, an expected positive feedback of winning the wager, and an expected feedback of larger balloon. A range of previous BART studies examined the differences between the unexpected negative feedback and the expected positive feedback (e.g., Ba et al., 2016; A. S. Euser et al., 2013; Gu et al., 2018; Xu et al., 2016). In the present study, we employed the same comparisons to examine difference between negative and positive feedbacks and our results showed a clear N200 component (Holroyd et al., 2008) rather than a typical FRN component. The aim of this study is to examine whether participants' personality traits would modulate their risk-taking behavior and brain activity changes when they making decisions in groups as compared to making decisions alone. Among the five personality dimensions in the FFM theory, Agreeableness measures one's tendency to be compassionate and cooperative rather than suspicious and antagonistic towards others, reflecting individual difference in their general concern for social harmony (Graziano and Eisenberg, 1997; Robinson, 2007; Thompson, 2008). Based on the literature that Agreeableness affects team performance and modulates cooperation behavior in groups (Bell, 2007; Koole et al., 2001), we hypothesize that Agreeableness would modulate risk-taking behavior and neural activity changes during group decision-making as compared to individual decision-making.

2. Materials and Methods

2.1. Participants

A total of 60 healthy male adults (mean age = 21.3 years) participated in this study. All participants known each other before the study and were recruited in 30 pairs. Participants reported no history of neurological or psychiatric disorders or head trauma, and reported no alcohol or tobacco smoking during the two weeks prior to the test. The present study was approved by the Shanghai International Studies University ethics committee. The entire experimental protocol was carried out according to the approved guidelines, which were in accordance with the Declaration of Helsinki. Each participant provided a written informed consent before enrollment and was compensated 200 Chinese Yuan (about US $30) for their time for participating in the study. Participants also received an additional bonus compensation (on average about 100 Chinese Yuan, $15) based on their earnings from the study.

2.2. The balloon analogue risk task

The BART paradigm (Fig. 1A) was modified from previous studies. During the task, participants were asked to inflate a balloon that could either grow larger or explode. Balloon stimuli were blue spheres with radii that increased proportionally to the amount of money added. The visual angle of the 1st balloon is 4.5°, which increased by 0.3–0.54° after each inflation. Participants were repeatedly given two options: to press a button to continue inflating the balloon or to press another button to discontinue inflation and collect the reward for the current balloon. If participants chose to stop inflation, they won the reward for the current balloon, which was added to their cumulative earnings. If they chose to continue inflation and the balloon exploded, a silent balloon burst graphic with text indicating the loss of money was presented, and participants lost the reward for the current balloon, which was subtracted from the cumulative earnings as a penalty. Delay between the participant's button press and feedback was randomized from 0.8 to 1.2 s.

To encourage participants to make multiple inflation attempts for a balloon, monetary rewards increased with the balloon size and the probability of explosion. The maximum number of inflations for each balloon was set to be 12. The probability of the balloon bursting after the first inflation was 1/11, after the second inflation 1/10, and so on, until the 12th pump. Monetary reward was 1 cent for the first balloon and doubled after each pump. Both reward values corresponding to each balloon size and cumulative earnings for the task were explicitly displayed on the screen, whereas the exact probability of explosion associated with a given inflation were kept unknown to participants. Prior to the formal experiment, participants practiced several balloon trials for each condition and experienced both loss and win for the balloons.

2.3. Experimental procedure

Participants sat comfortably in a chair and completed the BART under two conditions: Individual Decision and Group Decision. Before the study, participants were instructed to maximize the amount of monetary reward on all tasks. Except for the source of the decision, the two versions of the task were identical in all other respects. Participants took these two decision conditions in a counterbalanced order.

In individual decision condition, participants performed the BART in the traditional way: the inflate-or-collect choice were made by each participant, no other suggestions were given. During the individual decision condition, each participant perform the task by himself, and his partner were asked to watched passively. In the group decision condition, the two participants in each pair were asked to sit side by side in front of the single screen monitor, with brain activity simultaneously collected by two sets of EEG systems. Participants were instructed to performed the task in an alternate way: the inflate-or-collect choice would be first made by one participant, by pressing 1 or 2 using a numeric keypad, whereas the next choice would be given to the partner, by pressing 4 or 5 using another numeric keypad. Participants were asked not to discuss their choices while performing the task. Despite the decisions were allocated to both participants in the group decision condition, the task paradigm was exactly the same with the paradigm in the individual decision condition. The total earnings in the BART were were split equally and rewarded to each pair of the participants as a bonus compensation for the study.

Each participant completed 100 balloon trials in individual condition and 200 balloon trials in group condition. Similar to previous studies, risk-taking behavior on the BART in individual condition was measured by calculating the average inflation pumps of winning trials, in which participants successfully collected the wager. To measure each participants' risk-taking behavior in group condition, we calculated the similar measure for each member, by allocating the group's 200 balloon trials to the two participants according to which of the two made the final inflate-or-collect decision in the trial. As a result, participants also had an average of 100 balloon trials in group decision, which is similar to the balloon trials in individual decision.

For each participant, personality was measured by The NEO-Five Factor Inventory (FFI, Mccrae and Costa, 2004). It measured an individual on the Five Factor Model (FFM) of personality which included Extraversion (vs. introversion), Agreeableness (vs. antagonism), Conscientiousness (vs. lack of direction), Neuroticism (vs. emotional stability) and Openness to experience (vs. closeness to experience). The inventory consisted of 60 items, Each of the items is scored on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). The Chinese version of the FFI has been used in Chinese population and demonstrated good reliability and validity (Costa et al., 2004; Wang et al., 2015; Wang et al., 2012; Zhai, Yang, Zhai, O'Shea and Willis, 2012).

2.4. EEG recording and analysis

For each participant, EEG was recorded using ANT Neuro *eego mylab* device (ANT B.V., Enschede, The Netherlands), from 32 channels of EEG sensors positioned using the 10–20 EEG standard montage, via ANT Neuro Waveguard caps (ANT B.V., Enschede, The Netherlands). Two separate EEG recording systems were used to acquire ERP from the two partners simultaneously. Event marks were sent simultaneously from the single experimental control PC two these two EEG recording systems, using an in-house adaptor. Horizontal and vertical Electrooculography (EOG) was also recorded. Electrode CPz was used for online EEG recording and EEG signal was offline algebraically re-referenced to the average of the left and right mastoids. Electrode impedance was kept below 5 kΩ. EEG was amplified with a band pass of 0.1–100 Hz, digitized online at a sampling rate of 1000 Hz, and then filtered offline with a digital low-pass of 40 Hz. Continues EEG was segmented into ERP epochs, which were time-locked to the onset of the feedback screen, from 200 ms of pre-feedback to 800 ms of post-feedback. Trials contaminated by eye blinks, eye movement or muscle potentials exceeding ±70 μv at any electrode were excluded before averaging. ERP were then averaged for winning trials and lost trials within each condition. The baseline for ERP measurements was the mean voltage over the 200 ms pre-feedback interval. All offline processes were performed using EEGLAB toolbox based on MATLAB 2016. On average, 4.1 trials (95% in 0–13 trails) were removed from following analysis due to artifacts, remaining 45.7 trials (95% in 24.0–69.5) for each condition. A participant would be removed from following analysis if any of the condition average were less than 20 trials (due to artifacts or collect the wager too often or too rare). 30 participants out of 60 participants entered into following analysis.

In line with previous EEG/ERP studies of feedback processing (Chandrakumar et al., 2018), we subtracted the winning trials from lost trail (lost/winning difference, Fig. 3A for individual decision and Fig. 3B for group decision) to identify our component of interest (Fig. 3C), chose the time window and electrode which showed the maximum of difference. Another important reason of using difference waveform to identify N200 and P300 was that, since participants were fully aware of their choices and consequences in winning trials, N200 and P300 could hardly be elicited by the winning feedback. The topography of 10 time windows (from 220 to 400, 20 ms interval and 20 ms length each) for all the 6 grand averaged ERP (lost trials, winning trials and the difference waveform for both individual condition and group condition) were shown in Fig. 2, which we could see that Cz had the largest N200 difference (N200-Diff) and P300 difference (P300-Diff). The ERP waveforms were shown in Fig. 3 (all 6 waveforms of Cz and the difference waveforms of Cz, Pz and Fz). As we can see, the N200-Diff peaks around 250 ms in electrode Cz. Following analysis of N200-Diff used mean amplitude of 240–260 ms of Cz, while the mean amplitude of 190–210 ms were subtracted from N200-Diff to eliminate the negative shift before 200 ms. Then, mean amplitude of 330–370 ms were used as the measurement of P300, as lost/winning difference peaks around 350 ms–360 ms in both conditions (solid lines in Fig. 3D) and the condition difference peaks around 340 ms–350 ms (dotted line in Fig. 3D). At the same time, according to previous studies (see Chandrakumar et al., 2018 for a review), N200 of Fz and P300 of Pz were also considered (Fig. 3E and F). A repeated measures ANOVA was used to examine the effects of decision condition and Agreeableness group on component amplitudes. Greenhouse-Geisser correction for repeated measures was applied for statistical analysis. The significance level was set as $p < 0.05$.

3. Results

3.1. Behavioral results

In the current study, the group condition did not significantly influence the outcome of participants' risk-taking behavior, as the balloon had similar pop ratio across these conditions (Paired t-test: $p = 0.76$, mean ± standard error: Individual decision 0.41 ± 0.02, Group decision 0.42 ± 0.02). When using the pump times of winning balloon as participant's risk-taking behavior measurement, average pump times of all participants were similar in group decision condition and in individual decision condition (paired t-test: $p = 0.73$, Individual 7.08 ± 0.25, Group 7.14 ± 0.27, Fig. 1B).

As this insignificant change of behavioral performance might be partly due to the individual difference, we performed correlation analyses to evaluate the relationship between pump times change and

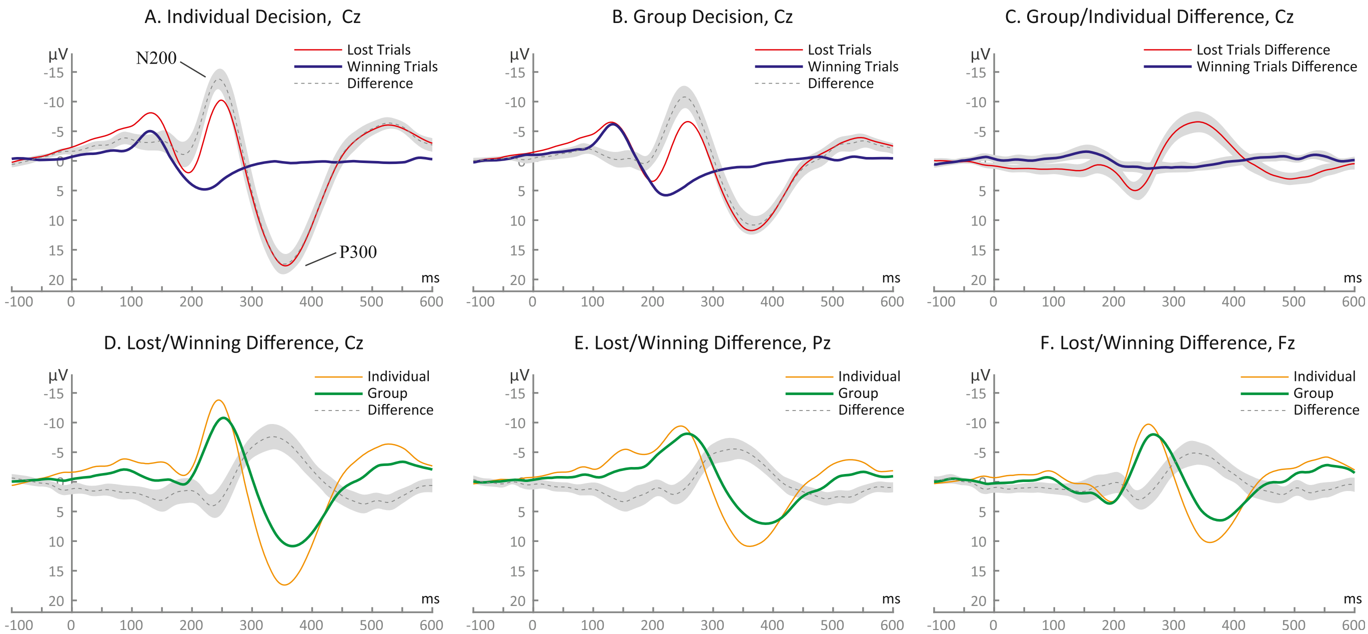

Fig. 3. Grand averaged ERP waveforms, time-locked to feedbacks. A, B, C: Waveforms of lost trials (red), winning trials (blue) and their difference, of Individual condition (A) and Group condition (B). C: The difference waveform of subtracting Individualt condition waveforms from Group condition waveforms. D, E, F: Lost/Winning different waveforms of Individual condition (yellow), Group Condition (green) in Cz (D), Pz (E) and Fz (F). Grey shadows marked the 95% confidence interval of difference between corresponding comparisons.

participants' personality. Results showed that participants with higher Agreeableness had more pump times increase in group decision condition (correlation between pump times increase and Agreeableness: r = 0.401, $p < 0.028$, Fig. 5A; correlation between pump times increase and other 4 personalities: all $p > 0.1$). However, this correlation could not survive the false detection rate (FDR) correction, if we consider the correlation between 5 personality traits as multiple comparisons.

We then performed more analysis to examine the effect of Agreeableness. Based on the median Agreeableness score (40), participants were divided into two groups, resulting 14 participants in higher Agreeableness group (HAG, mean Agreeableness ± standard error: 44.93 ± 0.95, same as below), 13 participants in lower Agreeableness group (LAG, 36.62 ± 0.92), while 3 participants with median Agreeableness score were excluded in Agreeableness group comparisons. Statistics showed that HAG pumped more in group decision ($p < 0.030$, Individual 6.66 ± 0.37, Group 7.05 ± 0.35, Fig. 1B) while LAG did not ($p = 0.61$, Individual 7.55 ± 0.39, Group 7.41 ± 0.49, Fig. 1B). This difference between Agreeableness groups can be confirmed by the interaction between decision condition and Agreeableness group (2 × 2 repeated ANOVA, main effect: decision condition, F = 0.666, $p = 0.422$, Agreeableness group: F = 1.336, $p = 0.26$; interaction F = 3.017, $p < 0.096$).

3.2. ERP results: N200

All-averaged N200-Diff were similar in individual condition and group condition (Cz: individual −10.80 ± 1.59, group −9.60 ± 1.00, $p = 0.49$; Fz: individual −11.99 ± 1.16, group −9.60 ± 1.24, $p = 0.068$). Further 2 × 2 repeated measures ANOVA analysis ('decision condition' as within-participant factor, 'Agreeableness group' as between-subject factor, bar plot of N200-Diff amplitudes see Fig. 4I) confirmed that group decision did not affected participant's N200-Diff (Cz: main effect of decision conditions: F = 0.221, $p = 0.64$, interaction F = 1.561, $p = 0.23$; Fz: main effect of decision conditions: F = 0.337, $p = 0.57$, interaction F = 0.762, $p = 0.48$).

Correlation analysis were also performed on N200. No significant correlation between pump times increase and N200-Diff change was found ($p = 0.14$, Fig. 5B). No significant correlation between Agreeableness and N200-Diff change was found ($p = 0.77$, Fig. 5D) either. N200-Diff change was marginally correlated with trait Openness to Experience (r = −0.4526, $p < 0.013$, $p = 0.063$ after FDR), while correlation between N200-Diff change and Conscientiousness/Neuroticism/Extraversion were not significant (all $p > 0.5$).

To be noted is, although the N200-Diff looks larger in the individual condition (Fig. 3F), it might be the result of negative shift before 200 ms. That is the reason of subtracting the mean amplitude of 190–210 ms from mean amplitude of 240–260 ms to compute the N200 amplitude.

3.3. ERP results: P300

P300-Diff were significantly different across decision conditions (individual 16.64 ± 0.82, group 9.61 ± 0.90; *t*-test: t = 7.086, $p < 0.001$). A 2 × 2 repeated measures ANOVA showed that decision condition affected participant's P300 across Agreeableness groups differently (Fig. 4, main effect of decision condition, F = 60.178, $p < 0.001$; main effect of Agreeableness group: F = 0.317, $p = 0.73$; interaction F = 10.658, $p < 0.001$). Following analysis showed that participants of HAG had significantly smaller P300-Diff in group decision condition than individual decision (individual 17.84 ± 1.31, group 7.55 ± 1.04; *t*-test: t = 12.40 $p < 0.001$), while this P300-Diff difference of LAG across decision conditions were not as larger as HAG (individual 14.73 ± 1.09, group 11.74 ± 1.38; *t*-test: t = 2.34, $p < 0.037$).

In accordance to typical studies examining P300 and in order to identify the main source of P300-Diff change, we further performed separate analysis to P300 of winning trials (P300-Win) and P300 of lost trails (P300-Lost) respectively. Results of two separate 2 × 2 repeated ANOVA (Agreeableness group × decision condition) showed that decision condition modulated P300-Lost differently in these two Agreeableness group (interaction: F = 9.877, $p < 0.002$; decision condition, F = 64.590, $p < 0.001$; Agreeableness group: F = 0.558, $p = 0.58$; Fig. 4I), while decision condition affect P300-Win similarly in these two agreeableness groups (interaction: F = 2.426, $p = 0.11$; decision condition, F = 6.263, $p < 0.02$; Agreeableness group: F = 0.075, $p = 0.93$). This means that the P300-Diff change between individual condition and group

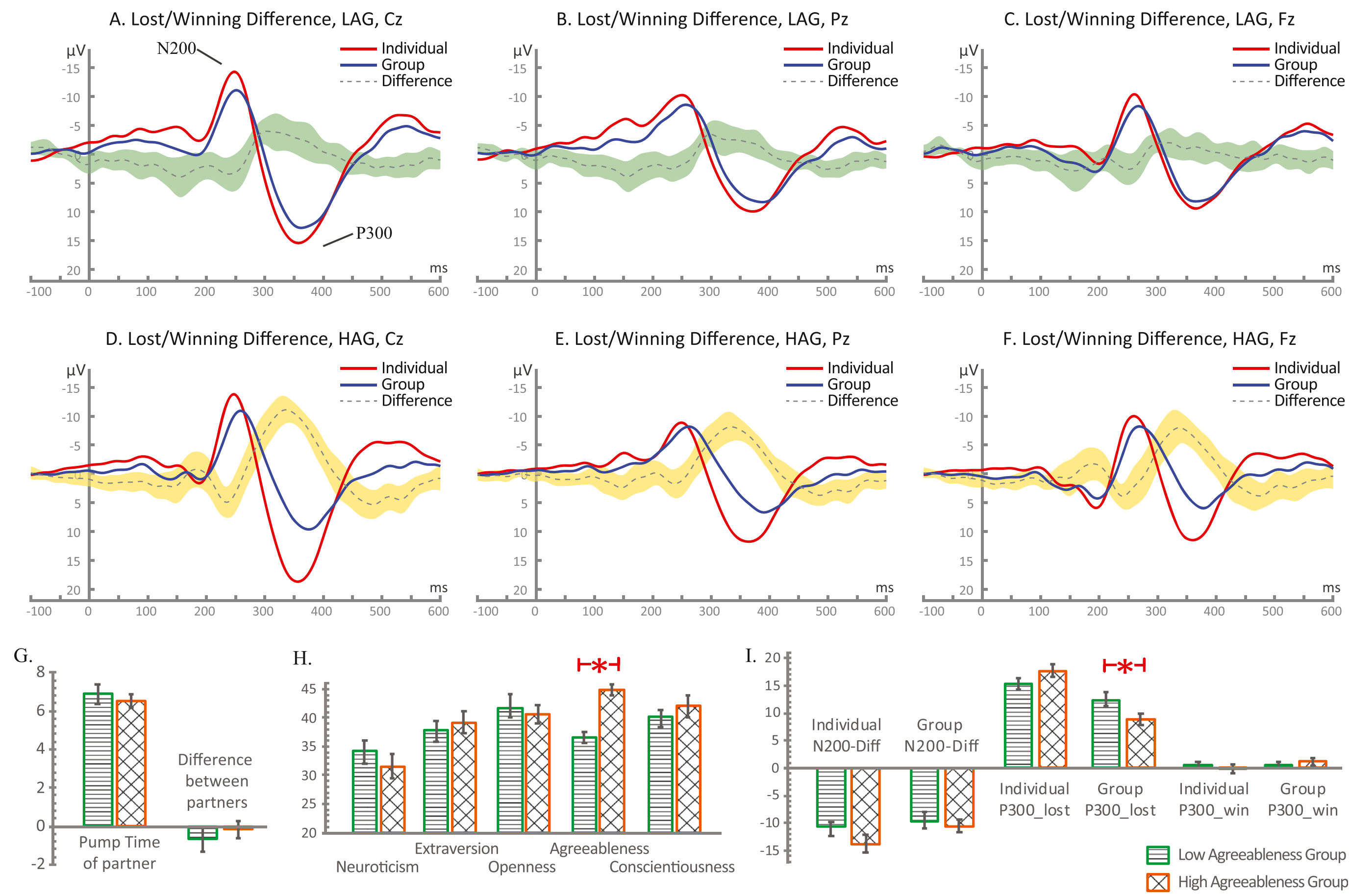

Fig. 4. Comparison of lower-agreeableness group (LAG) and higher-agreeableness group (HAG). A&D (Cz), B&E(Pz), C&F(Fz) showed the ERP waveforms of LAG and HAG, in two conditions and the condition difference. Shadows marked the 95% confidence interval of difference between corresponding lost trails and winning trials. G: Pump times of winning trials of participants' partners, in partner's own individual decision condition, and the difference between participant and his partner (error bar: standard error). H: Other personality traits were similar between LAG an HAG (error bar: standard error). I: N200-Diff, P300-Win and P300-Lost (Cz) amplitude of LAG and HAG in two decision conditions (error bar: standard error).

condition resulted from both P300-Lost decrease and P300-Win increase, while the interaction were mainly the result of the interaction effect of decision condition and Agreeableness group on P300-Lost.

Correlation analyses confirmed this result, as participants with higher Agreeableness have more P300-Lost decrease in group decision condition, which effect exists both in Cz ($r = -0.62$, $p < 0.0004$ before FDR and $p < 0.0015$ after FDR, Fig. 5F) and Pz ($r = -0.553$, $p < 0.002$ before FDR and $p < 0.008$ after FDR, Fig. 5H; no correlations between P300-Lost and other 4 personalities, all $p > 0.3$). No correlations between P300-Win change and 5 personalities survived FDR correction, although P300-Win change showed correlation between Neuroticism before FDR ($p < 0.023$, only in Cz, all other $p > 0.1$, Fig. 5E & G).

Although no direct correlation was found between pump-times-difference and P300-Lost ($p = 0.39$, Fig. 5C). The correlation between Agreeableness and pump-times-difference were partly the result of correlation between Agreeableness and P300-Lost difference, as removing P300-Lost difference in the correlation between Agreeableness and pump-times-difference would reduce the correlation (partial correlation between Agreeableness and pump-times-difference: $r = 0.354$, $p = 0.060$).

4. Discussion

To our knowledge, this is the first study using the well validated BART paradigm with ERP to examine risk-taking behavior and brain activity changes during group decision-making as compared to individual decision-making. In the literature of group decision-making research, there is an ongoing debate about whether people would become more risk-taking in groups or otherwise. In these studies, three domains may need to be taken into account.

First, characteristics of the group decision pattern, for instance, the size of the group (Shupp and Williams, 2008), communication (Baillon et al., 2016) and decision rules (Levati et al., 2017), played an important role in group decision making. Since these factors affect group decision making, they might affect groups' risk-taking in various ways. In this study, the group decision version of BART we executed in a two-participants group, while no discuss were taken and group decisions were made by each participant alternately. While in complicate group decision tasks, various environmental factors were perceived and comprehended by different people and result complex group-decision effect on each group member, this version of group-BART limits the group-decision effect to a simplified situation. In this study, almost nothing were changed in group decision condition, comparing to individual decision condition, except that half of their choice were made by their partners. In fact, the group interaction were so limited that one can hardly believe that participant's behavior would change in this group decision condition. This is almost the truth, as the behavior performance difference between these two conditions were not significant, until we separate the participants into two groups based on their Agreeableness personality. We noticed that this behavioral performance difference alone is not convincing, however, the more sensitive electrophysiological measure of brain activity also revealed that human cognition system processed quite differently in these two conditions.

Second, characteristics of group members were considered to at least

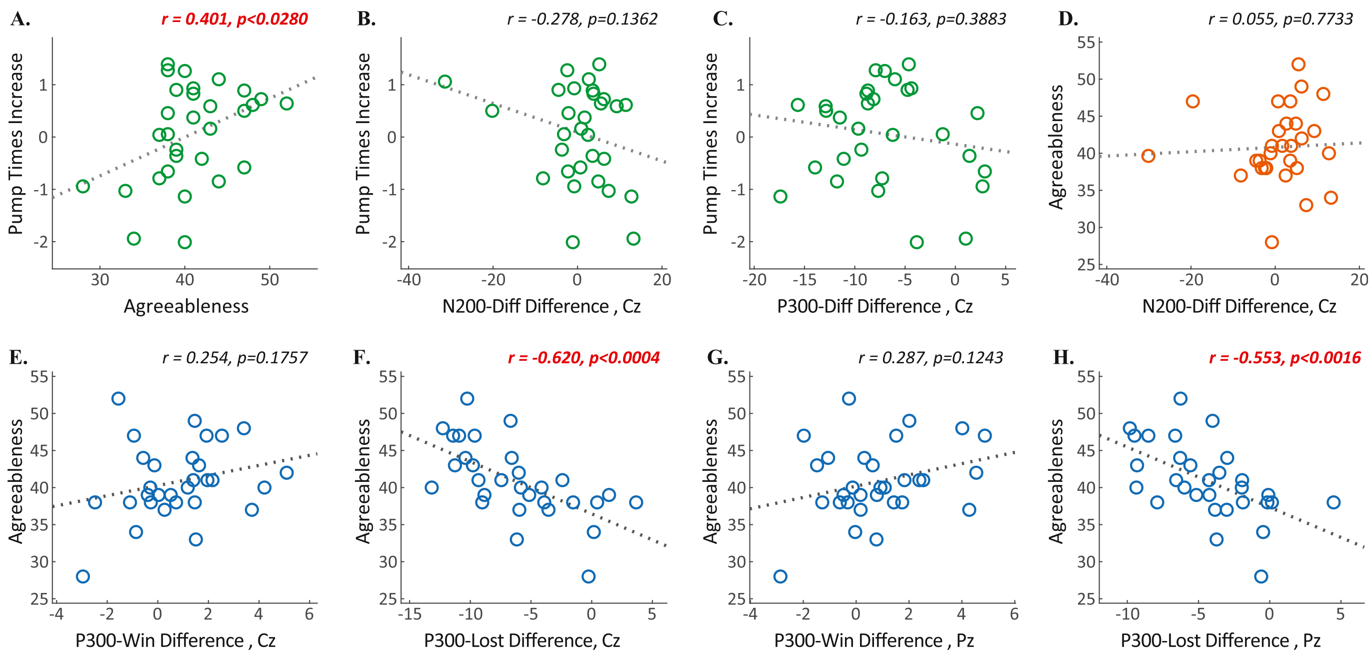

Fig. 5. Scatter plots and Pearson correlation coefficient analysis results. Correlation between pump times increase of winning trials in group condition and Agreeableness (A), N200-Diff (B) and P300-Diff (C). Correlation between Agreeableness and N200-Diff (D), P300-Lost (Cz in E, Pz in G) and P300-Win (Cz in F, Pz in H). Grey dotted lines represent estimated linear fitting curve of corresponding variables.

partly explain group risk-taking, such as age (Reynolds et al., 2013) and personality (Bell, 2007; Bradley et al., 2013). On one hand, various studies have suggested that personality traits are associated with an individual's risk-taking behavior, for instance, high Extraversion and Openness to Experience and low Conscientiousness were correlated with high risk-taking (McGhee et al., 2012). On the other hand, social psychology studies suggest personality traits are associated with people's behavior under social influence, as past research has found low Neuroticism and high Openness to Experience predicting more cooperative transfers (Lönnqvist et al., 2011). However, no relationship has been reported between an individual's personality and his risk-taking behavior change in group decisions. Our study provides two evidence that Agreeableness in the FFM might serve as a predictor of people's risk-taking behavior change in group decisions. First, by separating subjects into lower and higher group according to their Agreeableness, we found the higher group pumped the balloon more times in group condition until they collected the rewards. Then, the more convincing evidence is the correlation between Agreeableness score and the pump time increase (from individual decision condition to group decision condition). Though Agreeableness was not usually found to be related to risk-taking, it is the one reflect one's social traits. In order to fully understand this result and extend our conclusion to more scenes, we will elaborate on why agreeable people change their behavior in group decisions in next section.

Third, researchers have structuralized various group risk-taking environments into the model of motivated information processing in groups. As such, objective information-pooling and subjective information-interpretation are the two essential factors that decide if the group decision is going (Bang and Frith, 2017; Marshall et al., 2017). While information-pooling always helps groups make better decisions, biased interpretation of these information often leads groups to make varied decisions. Previous studies regarding group decision making have adopted research designs to involve participants in decision environments of varied combinations of objective information-pooling and subjective information-interpretation, resulting in mixed findings. Our current study employed BART and focused on the subjective factor of group decision making. As the probabilities of balloons blasting were kept unknown to the subjects and no discussions were allowed, the possibility of information pooling in group condition can be excluded. This means that it is the subjective interpretation of the information that changed and further affected participants' behavior in group decision. As a result, participants who have more positive attitude about group cooperation might pump the balloon more times. The experimental control in this study enabled us to understand how subjective interpretation of information leads people to behavior riskier in group decisions. In fact, the difference between objective information and subjective interpretation is so important that researchers are calling for proper distinguishing between them, naming them as decision-making under risk and decision-making under uncertainty, but not the mixture of risk-taking (De Groot and Thurik, 2018). Since that in real world the chances are almost always unknown, using BART as the measurement of risk-taking, which in fact studies the decision-making under uncertainty, would have good external validity.

Better decisions are usually dependent on full evaluation of both the likelihood and the outcomes of different choices. In this study, although the likelihood and the outcomes of different choices were kept the same in group and individual decisions, these information were unknown for the participants. When making decisions, an individual's tendency to take riskier choice can be attributable to a deliberate strategy of either weighting more about winning (increased risk-seeking) or weighting less about losing (reduced loss-aversion), which are made by people consciously and could be measured by questionnaires. In contrast to the slow deliberate strategy, there is a fast latent neural processing of the choices and their consequences. This latent processing affect people's feedback processing procedure by emotion and attention, played an important place in the formation of deliberate strategy, but are always unawarded to people. These two distinct process had different cognitive processing characteristics and contributes to people's behavior under risk. Reduced loss-aversion can be the result of latently feeling less bad about negative feedback or deliberately caring less about losing money, whereas increased risk-taking can be the result of latently feeling better about positive feedback, or blind cognitive optimism about the chance of winning, or false belief of 'my partner expects me to do so'. While the deliberate strategies could be reflected, and thus examined, by an individual's personality, examination of latent neural feedback requires neural techniques, such as the ERP method employed in the current study to reflect the first potential response of neurons to the feedback of risky behavior. Specifically, in the current study, we compared the ERP component difference between individual decision and group decision, using N200 and P300 elicited by positive feedback to reflect the changes in risk-seeking and those elicited by negative feedback to reflect the changes in loss-aversion.

In the current study, N200 was used to examine early processing of feedback in BART, found to be similar across individual-decision and group-decision conditions. Our N200 peaks in Cz around 250 ms, in consistent with the typical N200, which is a frontal-centrally distributed negative-going deflections that peak about 250 ms following stimulus onset, thought to be generated in the dorsal anterior cingulate cortex (ACC) (Folstein and Van Petten, 2007). Since N200 is associated with the unexpectedness of the event (Holroyd et al., 2008), the observed N200 difference between the winning feedback and the negative feedback in this study is not surprising. Numerous ERP studies on decision-making have consistently shown that the FRN/N200 may reflect an early, rapid evaluation of the affective or motivational impact of outcome events and its amplitude is related to the simple bad versus good appraisal of feedback (see Chandrakumar et al., 2018 for a review). Reinforcement learning theory posits that the FRN/N200 represents a reward prediction error "corresponding to the difference between the amount of reward obtained and the prior expected value of the reward" (Holroyd and Coles, 2002). Acting as a motor-control filter, the ACC uses the reinforcement signals to determine the most suitable behavior for the task at hand (Holroyd and Coles, 2002). However, because we did not compare the trials in which participants pumped the balloon and got a larger wager, our N200 did not include the feedback correct-related positivity, or reward positivity. The similar N200 amplitudes in the group and individual decision conditions suggests that participants did not anticipate that the balloon would be more or less likely to explode in group decision condition.

In contrast to the N200 component, the amplitude of P300 component was significantly reduced during group decision-making. The P300 component is also thought to be generated by the ACC as well as other regions involved in the circuit between frontal and temporal-parietal areas (Sander Nieuwenhuis, Slagter, von Geusau, Heslenfeld and Holroyd, 2005; Ryan et al., 2011). Unlike the N200 component, the P300 component reflects a later, attention-sensitive, more elaborate appraisal of outcome evaluation, in which factors affecting the allocation of attention resources come into play in a top-down controlled manner (Christie and Tata, 2009; Goyer et al., 2008; Hajcak et al., 2005; Leng and Zhou, 2010; Sato et al., 2005; Wu and Zhou, 2009; Yeung, 2004; Zhou et al., 2010). Previous study has shown that the P300 amplitude is linked to attention allocation and high-level motivational evaluation (Polich and Criado, 2006), it may likely reflect the evaluation of the functional significance of feedback stimuli in this study. Participants with higher Agreeableness showed greater P300 decrease for negative feedback in group decision condition, suggesting altered outcome evaluation during group decision-making. A potential explanation is that, similar unexpected negative outcomes may attract less attention from highly agreeable individuals and affect their emotion to a less extent during group decision-making, which was linked to less risk-averse and more risk-taking behavior.

Higher Agreeableness were also associated with more feedback-processing change in group decision. When associating personality to cognitive processing procedures, previous study (Robinson, 2007) suggested that Agreeableness, unlike Extraversion and Neuroticism, has hardly any priming effect on the target before its presence. Instead, Agreeableness is a trait closely linked to affect- and emotion-control processes, which resulted that agreeable individuals regulate their behavior in a socially acceptable manner. In this study, more agreeable individuals were less affected by the negative feedback in group decision (P300-Lost decrease), this is in line with the associations between affect- and emotion-control processes and Agreeableness. Moreover, this free-from-fear in groups might be the reason of their cooperative behavior and higher Agreeableness score.

Interestingly, among the five personality domains, only Agreeableness modulates risk-taking behavior and brain activity in group decisions. In the five-factor model, Agreeableness is the personality domain reflecting people social attributes and measuring their tendency to be compassionate and cooperative rather than suspicious and antagonistic towards others, reflecting individual difference in their general concern for social harmony (Graziano and Eisenberg, 1997; Robinson, 2007; Thompson, 2008). People who score high on the Agreeableness dimension are likely more empathetic and altruistic, while people with a lower agreeableness score often display more selfish behavior and a lack of empathy. Consequently, it is not surprising to find that high Agreeableness individuals were less affected by the negative feedback and adjusted their risk-taking behavior to a greater extent in group decisions.

Previous neuroimaging studies (DeYoung et al., 2010) have shown that Agreeableness may be associated with reduced volume in posterior left superior temporal sulcus (L-STS, involved in the interpretation of other individuals' actions and intentions on the basis of biological motion, Pelphrey and Morris, 2006), increased volume in posterior cingulate cortex (PCC, implicated in the process of understanding other individuals' beliefs, a sophisticated late-emerging component of theory of mind, Saxe and Powell, 2006) and fusiform gyrus volume (FG, specialized for perceiving faces, Kanwisher et al., 1997). Combing the brain associations of Agreeableness and their cognitive functions, we suggest that Agreeable individuals sensitively (larger PCC, larger FG) and mistakenly (smaller L-STS) perceived their partner's 'no signs of hard feelings in the quiet experiment situation for negative feedback' as the popped balloon were 'not so bad'. However, as studies using diffusion tensor imaging (DTI) were controversial in finding associations between DTI measures and Agreeableness (Bjørnebekk et al., 2013; Xu and Potenza, 2012), these interpretations were tentative and should be taken cautiously.

A number of important issues warrant further consideration when interpreting the results of the present study. First, when trying to predict participants' behavioral performance, we found neither P300 nor N200 amplitude was correlated with participants' pump times of winning balloon. This suggests that risk-taking is a complex social behavior such that even simplified BART cannot simplify it into pure output of neuronal processing. This might account for the rare reporting of direct correlation between N200 or P300 amplitude and behavioral performance in a voluminous literature employing BART, although N200 and P300 were reported to be different between groups of people and across experimental conditions (Euser et al., 2013; Kessler et al., 2016; Takács et al., 2015; Xu et al., 2016). However, as the current study found correlations both between Agreeableness and behavioral performance and between Agreeableness and P300, we suggest that P300 might be a factor important in the formation of individuals' personality in their early years but gradually dissipating in the late years. Further longitudinal studies are needed to test and verify this interaction between development, personality and ERP components.

When explaining risk-taking behavior change in groups in the current study, there are several other factors need to be considered. First, the risk-taking behavior change may not be the result of accumulating Balloon numbers, or learning, or fatigue, or any sequential effects, as the order of taking these two conditions were counterbalanced across participants. Second, in group decision condition, in addition to the participant's own decision, the partner's risk-taking tendency may also play an important role, as the balloon can be pumped larger by the partner when the participant himself would collect the reward, or the balloon can be collected by the partner when the participant was going to pump it more times. However, this effect seems not be able to account for the observed difference in our study, as both risky and conservative behavior of partners were included so that the effects were likely to be canceled out. We may still argue that agreeableness individuals tend to be more cooperative and consistent with their partners in group decision condition, this effect might be more robust for agreeableness individuals. To test the argument, we further examined whether partner behavior can have additional explanatory power over participant self-performance in group decisions. No difference was found either in the behavior measurements or in the personality traits between partners of low Agreeableness and high Agreeableness participants. Moreover, no correlations were found between pump-times-increase in group condition and partner-participant-difference ($r = -0.15, p = 0.43$). In addition, analysis of the effect of partner-participant-difference and agreeableness on group-pump-increase in group condition, confirmed that agreeableness modulates group-pump-increase ($p = 0.02$), while partner-participant-difference or their interaction have no significant effects on group-pump-increase (both $p > 0.4$).

Third, as mentioned above, while the experimental design in our study enjoys the merit of conciseness, contributing largely to the rigor requirement of scientific research, it might also carry the potential of limiting the validity of our findings across different situations, owing to such design elements as the BART paradigm, the alternate group decision mode, the male undergraduate students, the recruitment of paired participants, etc. However, with lower validity across different situation but higher reliability, accumulating these studies will provide increasingly solid evidence to solve the mystery of human behavior. Further studies shall build upon ours and take additional factors into consideration and explore deeper into the issue.

Finally, we borrowed from personality theory, ERP technique and personality neuroscience to make suggestions about why agreeable individuals behave riskier in group decisions. Further group decision studies shall endeavor to verify our findings and explanations so as to provide solid connections between people's behavior, personality, cognitive processing and brain mechanism. At the same time, we are fully aware that although there is evidence that the five factors are universal, it has been argued that these five factors may not be exhaustive, especially in non-Western cultures (Cheung et al., 2001). As a result, in a collective culture like China, the Big Five personality might not be an integrated and precise model to denoting the social and relational aspects of personality (Cheung et al., 2001; Cheung et al., 2011; Shao and Webber, 2006). Considering that current study focus on the common phenomenon and mechanism of group-decision effect on people, this usage of Big Five enabled further researchers to employ current experimental design into more group risk-taking studies and more cross-culture studies. Nonetheless, further study should consider more detailed measurement of lower facets of Agreeableness to examine how and why making decisions in a group would change individual's risk-taking behavior.

Taken together, here we examined the associations between personality traits and changes in risk-taking behavior and brain activity during group decision-making. We found that Agreeableness modulates risk-taking behavior and brain activity when people make decisions in groups as compared to decision-making in isolation. Only participants with high Agreeableness, but not those with low Agreeableness, increased their risk-taking behavior and reduced their P300 component during group decisions. These findings have implications for future group decision-making research and practice. For example, previous studies have consistently shown that individuals may make bad decisions when they are interacting with others, such that people may reduce willingness to help others in emergency situations when there are bystanders around (Fischer et al., 2011; van Bommel et al., 2012) and increase unethical acts in group market interaction (Falk and Szech, 2013). Based on findings from our study, we may need to emphasize more on individual's responsibility for the bad outcomes from group decisions to minimize the detrimental effects of group decision-making. Furthermore, our findings suggest that low agreeable individuals may be more suitable to be a group member for occasions where low-level risk-taking is desired, whereas highly agreeable individuals may be a good team player for occasions when high-level risk-taking is needed.

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