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Context-based interpersonal relationship modulates social comparison between outcomes: an event-related potential study

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Abstract

Social comparison is a common behavior that largely determines people's experience of decision outcome. Previous research has showed that interpersonal relationship plays a pivotal role in social comparison. In the current study, we investigated whether the manipulation of context-based relationship would affect participants' comparison of self-outcome and other-outcome. Participants first finished a trust game with likeable (dislikeable) partner and then they were involved in a gambling task and observed the outcomes for themselves and for partners. According to self-reports, participants were more satisfied with likeable partner's gains than losses only when they received gains, but they were always more satisfied with dislikeable player's losses compared to gains. Event-related potentials including the feedback-related negativity (FRN), P3 and late positive component (LPC) were sensitive to context-based relationship. Specifically, the prediction error signal (indexed by the FRN) was largest when participants received losses but dislikeable player received gains. Meanwhile, the P3 indicates that participants had stronger motivation to outperform dislikeable player. Finally, the LPC was larger when participants received the same outcomes with dislikeable players. In general, our results support the key point of the self-evaluation maintenance model that personal closeness modulates subjective sensitivity when drawing a comparison of one's outcomes with other's outcomes.

Key words: social comparison; interpersonal relationship; outcome evaluation; feedback-related negativity (FRN); P3; late positive component (LPC)

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Introduction

One would probably be happy to hear that his/her salary will increase by 10%. However, he/she might be disappointed with the same fact when learning that his/her colleague's salary will increase by 20%. This process of considering other people's information in relation to the self is called social comparison (Wood, 1996). Social comparison helps people understand themselves and modulates self-evaluation based on their similarities and differences with others in various dimensions (Festinger, 1954; Gerber *et al.*, 2018). As indicated by the abovementioned example, when one engages in social comparison, his/her experiences of a certain phenomenon are affected by other people's relative outcome, the effect of which could even be stronger than the absolute outcome being received (Ball and Chernova, 2008). From a cognitive perspective, upward comparison (comparing oneself with those whose abilities and attributes are better than one's own, such as a colleague with higher salary) sometimes leads to more negative self-evaluations but could also be self-enhancing, as it represents a desire for self-improvement (e.g. trying to get a higher salary in the future) (Collins, 1996); meanwhile, downward comparison might be regarded as a strategy to enhance one's subjective well-being and protect self-esteem (Wills, 1981; Gibbons and McCoy, 1991). From an emotion perspective, social comparison induces envy (upward comparison) or schadenfreude (downward comparison), both of which are important social emotions and could be long lasting (Smith *et al.*, 1996; Fiske, 2010). Of specific interest to this study, the influence of social comparison on subjective feeling is modulated by interpersonal relationship (Zhang *et al.*, 2020). That is to say, our feelings toward a raise in colleague's salary might be more complex when that colleague happens to be our close friend: on the one hand, we might be proud of our friend's outstanding performance; on the other hand, the enlarged income difference may adversely affect our self-esteem. These two psychological processes have opposite effects on ones' self-evaluation (Tesser *et al.*, 1988; Major *et al.*, 1993). An investigation into the above issue would advance our knowledge pertaining to the impact of modern-day social media on mental health (Nesi and Prinstein, 2015; Appel *et al.*, 2016) and would be of substantial benefit to organizational behavior research (Greenberg *et al.*, 2007).

Literature concerning social behavior has witnessed various accounts of social comparison (e.g. Wills, 1981; Tesser *et al.*, 1988; Taylor *et al.*, 1990; Collins, 1996; Zell and Alicke, 2010; Gerber *et al.*, 2018). Among these accounts, we consider the self-evaluation maintenance model (SEM) (Tesser *et al.*, 1988) to be most relevant to the research area of this study. Compared to other mainstream theories such as the downward comparison theory (Wills, 1981) and selective accessibility model (Mussweiler, 2003), the SEM pays more attention to the modulating factors of social comparison, particularly psychological closeness with the comparison target (which is determined by interpersonal relationship). According to this theory, an individual's response to social comparison is strongly influenced by psychological/emotional closeness. To be more specific, a comparer may bask in the reflected glory of close others and experience an increase of self-esteem and positive emotions (i.e. the 'reflection process'); meanwhile, the success of a close other could cause one's own performance to pale by comparison and becomes a threat to self-evaluation (i.e. the 'comparison process'), especially when the comparison dimension is related to the comparer's self-concept (Tesser *et al.*, 1988). In this regard, the SEM focuses more on other-dependent variables, such as perceptions of others and closeness to others, rather than self-dependent variables (Gerber *et al.*, 2018). Consistent with the key idea of the SEM, Liu *et al.* (2016) found that high self-esteem individuals felt happy when scanning positive information from close friends on Facebook, but felt unhappy when scanning such information from distant friends (see also Morry *et al.*, 2018). Likewise, Lubbers *et al.* (2009) found that Dutch students prefer comparing themselves with friends and show reciprocal behaviors when comparing themselves with friends *vs* non-friends. However, the number of social comparison studies that have directly examined the reliability of the SEM is still limited (Gerber *et al.*, 2018).

The investigation of neural activity associated with social comparison could help unravel its underlying mechanisms (Swencionis and Fiske, 2014). By using functional magnetic resonance imaging (fMRI), Fliessbach *et al.* (2007) first reported that the ventral striatum (VS: a key region in the dopaminergic reward system) is sensitive to social comparison, such that a lower income relative to others led to reduced blood oxygen level–dependent (BOLD) signals in this area. Taking a step further, Dvash *et al.* (2010) found that even when participants were losing money, their VS activation was increased by another player's greater loss, indicating an effect of schadenfreude (see also Takahashi *et al.*, 2009). Further, the VS responses associated with social comparison are more pronounced in a public (e.g. each person's outcome could be observed by other people) than in a private environment (Bault *et al.*, 2011; Grygolec *et al.*, 2012). A recent coordinate-based meta-analysis on neuroimaging data showed that neural representations of social comparison resemble those for non-social reward processing (Luo *et al.*, 2018). However, fMRI and other hemodynamic-based brain-imaging techniques suffer from limited temporal resolution and might not be able to unfold adjacent processes temporally (Deshpande *et al.*, 2009). Researchers point out that different cognitive processes (e.g. outcome appraisal, self-evaluation, emotion regulation, and reward processing; see Jankowski and Takahashi, 2014) involved in social comparison might overlap in time domain. Employing neuroscience techniques with exquisite temporal resolution would help distinguish various cognitive processes that are involved during social comparison. Therefore, the current study mainly relies on event-related potentials (ERPs) derived from time-locked electroencephalogram (EEG) signals to investigate social comparison. This technique has been proven to be a powerful tool for tracking the precise timing of neural processes and serves as an informative platform on psychological mechanisms (Amodio *et al.*, 2014). The use of ERP technique would also be helpful in avoiding the potential influence of the social desirability response bias, because envy and schadenfreude are undesirable emotions and might be denied by participants in their self-reports (Cikara and Fiske, 2013).

Inspired by previous studies on outcome evaluation and social comparison (Wu *et al.*, 2012; Luo *et al.*, 2015; Hu *et al.*, 2017), we focused on three ERP components: the feedback-related negativity (FRN), P3 and late positive component (LPC). The FRN is a negative-going frontal waveform that reaches its peak at around 250–300 ms after an event presentation (Miltner *et al.*, 1997; Gehring, 2002). This component is widely considered as one of the most important ERP indexes of outcome evaluation (San Martín, 2012; Sambrook and Goslin, 2015), though it is also sensitive to incentive cues (Walsh and Anderson, 2012). Although the cognitive implication of the FRN is still debated, most studies interpret this component as a prediction error signal that becomes more negative-going for negative feedback (e.g. performance errors and monetary losses) than positive feedback (Holroyd and Coles, 2002; Nieuwenhuis et al., 2004). Alternatively, the same phenomenon could be understood as a more positive-going FRN for positive feedback than negative feedback (Talmi et al., 2013; Proudfit, 2015; Heydari and Holroyd, 2016). Following the FRN, the P3 (or P300) is a positive-going centro-parietal waveform that reaches its peak between 300 and 500 ms post an event presentation. The P3 has been linked to various cognitive functions depending on task design (Donchin and Coles, 1988; Polich and Criado, 2006; Polich, 2007). With respect to outcome evaluation, the P3 amplitude is most frequently associated with the motivational significance of an ongoing event, such that it becomes larger for outcomes with a higher motivational value (e.g. outcomes that indicate the necessity to make behavioral adjustment: see Nieuwenhuis et al., 2005; San Martín et al., 2013; Zhang et al., 2013; Gu et al., 2018). Finally, the LPC (or late positive potential) is a positive-going central waveform that peaks after 500 ms in response to an event presentation (Hajcak et al., 2009). While the LPC is most often associated with emotional processing and emotion regulation (Hajcak et al., 2010; Leng et al., 2017), this component is also involved in outcome evaluation (Bland and Schaefer, 2011; Gibbons et al., 2016; Sun et al., 2017). One possible explanation of the LPC is that it reflects sustained emotional experience to outcome feedback (Jiang et al., 2009). One of our recent researches has demonstrated that the LPC amplitude increases as a function of incentive; specifically, the LPC was larger than other conditions among individuals with a higher level of impulsivity in high reinforcement trials, indicating that these individuals are more likely to be emotionally affected by rewards (Gu et al., 2017b).

Many ERP studies have been devoted to investigate the time course of social comparison. Wu et al. (2012) asked participants to finish a dot estimation task with an anonymous partner and found that both P3 and LPC had become more prominent when participants received a larger outcome (indicating stronger motivational salience) than another partner (see also Qiu et al., 2010; Wu et al., 2011). Luo et al. (2015) improved this knowledge by asking participants to compare with multiple partners and found that the FRN amplitude was also sensitive to other-outcome. According to the ERP data, Luo et al. proposed a multi-stage temporal model of social comparison, wherein the individuals first detect whether they are different from any other person, then evaluate whether they belong to the majority or minority among comparison targets, and finally focus on the situations in which they are the minority. A recent study conducted by Hu et al. (2017) also confirmed that the FRN, P3 and LPC are the three major ERP indexes of social comparison, but their effects were modulated by individual level of social value orientation; specifically, while these components differentiated between self-gain and self-loss in the whole sample, they differentiated between other-gain and other-loss only in the 'prosocial' group, but not in the 'proself' group.

Based on these findings, researchers move on to explore the potential role of interpersonal relationship. Leng and Zhou (2010) reported that the P3 was larger when participants gambled with friends in comparison to strangers. Meanwhile, Campanha et al. (2011) discovered that the FRN is also sensitive to the difference between the comparison of participants gambling with friends and participants gambling with strangers (see also Zhang et al., 2020). Zhu et al. (2018, 2020) found that the FRN amplitude was comparable for the self and for mother/friend under interpersonal self-construal priming.

These findings provide support to the SEM that social comparison could be sensitive to the effect of interpersonal relationship. Nevertheless, studies using real-life relationships might be obstructed by the familiarity effect, witnessing that relatives and friends are more familiar than strangers. In this regard, an alternative approach is to manipulate psychological closeness in the laboratory; for instance, confederates who play fairly would be perceived as more likeable and emotionally closer than those who play unfairly (Singer et al., 2006). Previous studies investigating passive observation and social competition have confirmed that the ERP components related to outcome feedback (e.g. the FRN and P3) are sensitive to this manipulation (Wang et al., 2014a,b; Chen et al., 2017; Qi et al., 2018).

In this study, we modulated the context-based interpersonal relationship between a participant and another player, and then observed whether this change would affect the participant's feelings and attitudes toward social comparison with that player in accordance with the self-reports and ERP signals collected in a follow-up task. In accordance with the SEM, we hypothesized that participants would evaluate other-gain in a similar way as to self-gain under the close relationship condition, but not under the distant relationship condition. With regard to the ERP data, our analysis focused on the FRN, P3 and LPC. We hypothesized that the influence of interpersonal relationship on social comparison would manifest on these components. Most notably, compared to a dislikeable player's losses, his/her gains should elicit a larger prediction error (indexed by a larger FRN), be more motivationally significant (indexed by a larger P3) and more emotionally salient (indexed by a larger LPC). Regarding the likeable player condition, however, it remained to be determined whether the effects of the reflection process would counteract with that of the comparison process.

Methods

Participants

Thirty healthy college students (20 females; aged 21.56 ± 3.20 years, mean ± s.d.) from Liaoning Normal University were recruited as participants. All of them reported normal or corrected-to-normal vision and were right-handed, without known cognitive or neurological impairments. No one was colorblind according to self-reports. Each participant received a based payment (¥50, ∼$7 US dollars) and extra earnings (¥0–10, ∼$0–1.4 US dollars; depending on their task performance). This study was carried out under the Declaration of Helsinki, and written informed consent was obtained from all participants. The protocol was approved by the institutional ethics committee of Liaoning Normal University.

Procedure

In this experiment, we used the trust game (TG for short; see Berg et al., 1995) to manipulate each participant's interpersonal relationship with another person, and observed whether the process of social comparison with that person in a follow-up gambling task (Hu et al., 2017) would change accordingly. Using the TG to modulate context-based relationship and social comparison preference has been proven to be effective in previous studies (Singer et al., 2006; Wang et al., 2014a; Qi et al., 2018). Consistent with the experimental procedure of Singer et al. (2006), there were two identical runs in total (Figure 1A), such

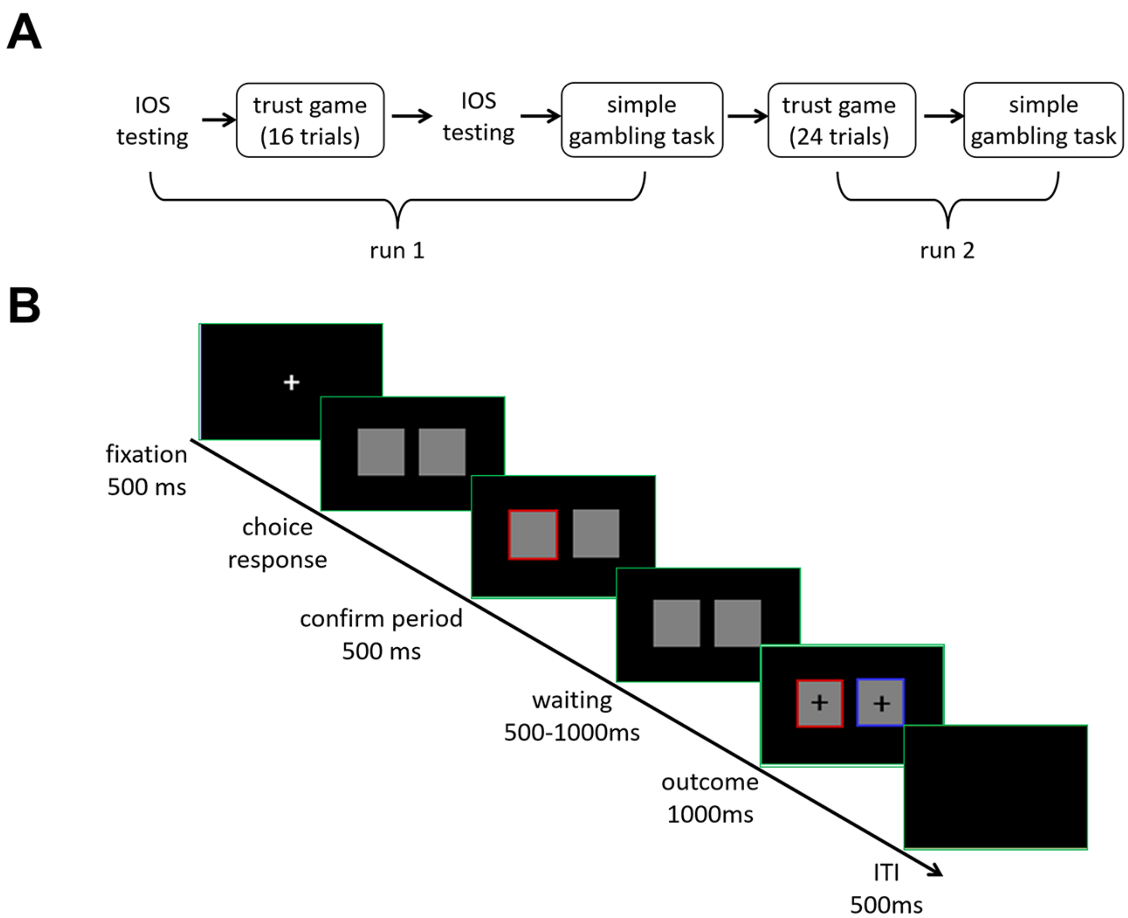

Fig. 1. The procedure of the present study. (A) All participants needed to finish the TG and simple gambling task twice each, and the sequence of the two players (likeable/dislikeable) in the gambling task was counterbalanced across participants. (B) The simple gambling task (Zhang *et al.*, 2020). Each trial began with a white fixation on a black background. Afterward, two gray squares ($1.9^\circ \times 1.9^\circ$ of visual angle) representing two options appeared on the left and right sides of the fixation point. The participants were required to choose the left or right square. The chosen option was highlighted by a thickening of red (or blue) border and, after an interval, the outcomes feedback corresponding to the chosen option for each participant and the other player (likeable or dislikeable) were displayed, respectively. In this example, the participant chose the left option while the other player chose the right option.

that each participant first finished the TG and then a simple gambling task with two same-gender players (A and B: both were actually confederates) in each run. There were 16 trials in the first TG and 24 trials in the second TG respectively, which was also consistent with the experimental setting of Singer *et al.* (2006). In both TG and gambling task, each participant interacted with players A and B in the same number of trials in each run.

Each participant sat ∼75 cm from a 19-inch LED screen (refresh rate: 60 Hz; resolution: 1440 × 900 pixels) during the experiment. Stimulus presentation and behavioral data acquisition were conducted with E-Prime 2.0 software (PST, Inc., Pittsburgh, PA, USA). Prior to the experiment, he/she was informed that other players were sitting in different rooms and would finish the tasks with him/her online. Unbeknownst to each participant, all the behavioral responses and corresponding feedback from other players were actually provided by the computer. The whole experiment lasted for ∼60 min. Each participant finished the Inclusion of Other in the Self (IOS) Scale (Aron *et al.*, 1992; Kang *et al.*, 2010) to indicate his/her context-based relationship with player A and player B twice, that is, before and after the first TG (see Figure 1). After the experiment, each participant was queried about the credibility of the task scenario and no one raised any doubts.

Experimental design

TG. In each trial of the TG, each participant interacted with either player A or B. The trials for player A and those for player B were in a pseudorandom sequence and were counterbalanced across participants. At the beginning of each trial, a photograph of player A or B appeared on the computer screen to allow the participant know whom he/she would play with. The participant was provided 10 initial tokens, from which he/she could decide to invest some (0–10) to player A or B by pressing the corresponding numeric button on the keypad. The amount of this investment would be tripled, then player A or B would return some tokens to the participant after waiting for 3500–5000 ms. Outcome feedback (4000 ms) was printed in black on a gray background, such that the number of tokens that the participant received and the number of tokens kept by player A/B appeared on the left and right side of the screen, respectively. The more tokens each participant received, the more extra earnings he/she would get at the end of the experiment. Previous research has confirmed the effectiveness of using tokens in social decision paradigms (van den Bos *et al.*, 2009; Wang *et al.*, 2014a).

Unbeknownst to each participant, the return ratio was predetermined by the computer: player A (a likeable fair opponent: see

Singer *et al.*, 2006) and player B (a dislikeable unfair opponent) would always return to each participant about 60–90% and 0–30% of the tripled investment, respectively (see also Qi *et al.*, 2018).

Gambling task. We used a simple gambling task from previous studies (Hu *et al.*, 2017; Zhang *et al.*, 2020). Before the experiment, each participant was encouraged to respond in a way that would maximize the final payment; also, the gambling outcome that the participant received and the outcome that player A/B received were independent of each other. Then the participant practiced for 12 trials. The formal task consisted of 256 trials divided into eight blocks, such that both the first run and the second run had four blocks. In each block, the participant finished the task with either player A or B. The sequence of the four 'player A' blocks and the four 'player B' blocks was randomized and was counterbalanced across participants. At the beginning of each block, a photograph of either player A or B appeared on the computer screen to make the participant know who he/she would play with. The participant was allowed to take a self-paced break in between adjacent blocks.

An example trial of the gambling task is illustrated in Figure 1B. Each trial began with a white fixation on a black background (500 ms) and then two gray squares (representing two options) appeared on the left and right side of the fixation point. The participant was required to choose the left or right option by pressing the 'F' or 'J' button on the keyboard with his/her left or right index finger, respectively. The chosen option would be highlighted by a thick red (or blue) border (1000 ms) and the participant waited for player A/B to finish the choice (500–1000 ms). Finally, the outcome feedback corresponding to the chosen option for the participant and that for player A/B [also highlighted by a thick blue (or red) border] were displayed simultaneously (1000 ms). The border color (red/blue) for the participant and that for player A/B were counterbalanced across participants. Outcome feedback was presented at the same position (left/right) with the corresponding chosen option. Each outcome was either a gain (indicated by the symbol '+', which means the final payment increased for ¥0.5) or a loss (indicated by the symbol '−', which means the final payment decreased for ¥0.5). From the perspective of each participant, there were four kinds of possible outcomes in the gambling task: self-gain and other-loss (hereinafter labeled as 'GL' for short), self-gain and other-gain ('GG'), self-loss and other-loss ('LL'), as well as self-loss and other-gain ('LG') (see also Zhang *et al.*, 2020). For both players A and B, each outcome condition (GL/GG/LL/LG) involved 64 trials. All conditions differed only in terms of outcome valence but not outcome magnitude. Unbeknownst to each participant, all kinds of outcome were presented randomly, and each participant received an equal number of trials for each kind of outcome throughout the task. After the experiment, each participant rated his/her level of satisfaction on a 7-point scale (1 = very dissatisfied and 7 = very satisfied) to each type of outcome (GL/GG/LL/LG).

IOS questionnaire. The IOS was used to examine whether each participant's context-based relationship with players A and B was modulated. The IOS has only one pictorial item, consisting of seven pairs of circles with a linear increasing degree of overlap to form a 7-point equidistant questionnaire (1 = no overlap and 7 = almost complete overlap). For each pair of circles, one of them represents the respondent and the other one represents another person. Each participant needed to select one of the seven options that appropriately represented the relationship between him/her and player A/B twice: before and after the TG in the first run.

ERP recording and analysis. EEG signals during the gambling task were recorded by a 64-channel amplifier (500 Hz sampling rate, Brain Products, Munich, Germany) according to the International 10–20 electrode system. Continuous online data were digitized using a bandpass filter of 0.01–100 Hz and referenced using the FCz electrode. In order to monitor ocular movements and eye blinks, vertical electro-oculogram recording was taken from an electrode placed below the right eye. The data were sampled at 500 Hz/channel with an impedance of lower than 10 kΩ.

EEGLAB toolbox for Matlab (Delorme and Makeig, 2004) was used to analyze the offline EEG data. Data was re-referenced offline to the average of the left and right mastoids. Major artifacts such as ocular movement, eye blinks and muscle-related potentials were corrected with independent component analysis (Jung *et al.*, 2000). Then the data were digitally filtered with a low-pass 30 Hz (24 dB/octave) and segmented from 200 ms before to 1000 ms after the onset of gambling outcome. After baseline correction (−200 to 0 ms), the trials with amplitude exceeding ±80 μV were excluded to eliminate the contamination of larger artifacts. After artifact rejection, the average numbers of survived trials was 49/49 (for the likeable/dislikeable player) in the GL condition, 50/48 in the GG condition, 48/47 in the LL condition and 49/47 in the LG condition. Across participants, the percentage of valid trial was between 73.4 and 78.1% and was sufficient to detect the mean amplitudes of ERP components (Cohen and Polich, 1997; Marco-Pallares *et al.*, 2011).

The time window and electrodes for data analysis on each ERP component were determined according to visual detection on the grand-averaged data and the suggestion of previous studies (see below). Specifically, the mean amplitude of the FRN was measured in the time window of 280–340 ms across seven electrode locations (Fz, FCz, FC1, FC2, Cz, C1 and C2) (Sambrook and Goslin, 2015; Hu *et al.*, 2017; Chandrakumar *et al.*, 2018). The mean amplitude of the P3 was measured in the time window of 340–440 ms across 12 electrode locations (FCz, FC1, FC2, Cz, C1, C2, CPz, CP1, CP2, Pz, P1 and P2) (Ullsperger *et al.*, 2014; Wauthia and Rossignol, 2016; Hu *et al.*, 2017). Finally, the mean amplitude of the LPC was measured in the time window of 440–640 ms across nine electrode locations (Cz, C1, C2, CPz, CP1, CP2, Pz, P1 and P2) (Wauthia and Rossignol, 2016; Hu *et al.*, 2017). The amplitude value of each ERP component for statistical analysis was calculated as the arithmetical mean of all the corresponding electrodes. Our results showed that the FRN reached its peak at around the FCz site, while the P3 and LPC reached their peaks at around the CPz site (Figure 2).

Statistics

Behavioral and ERP data were statistically analyzed using SPSS software (version 22.0, SPSS Inc., Chicago, IL, USA). The FRN, P3 and LPC amplitudes, as well as the self-reported satisfaction scores, were analyzed separately using a three-way repeated measures ANOVA of 2(*Relationship*: likeable player *vs* dislikeable player) × 2(*Self-outcome*: self-gain *vs* self-loss) × 2(*Other-outcome*: other-gain *vs* other-loss). All of them were within-subject factors (Table 1 for details).

The significance level was set at $P = 0.05$ for all the analyses. The Greenhouse–Geisser correction was conducted to account

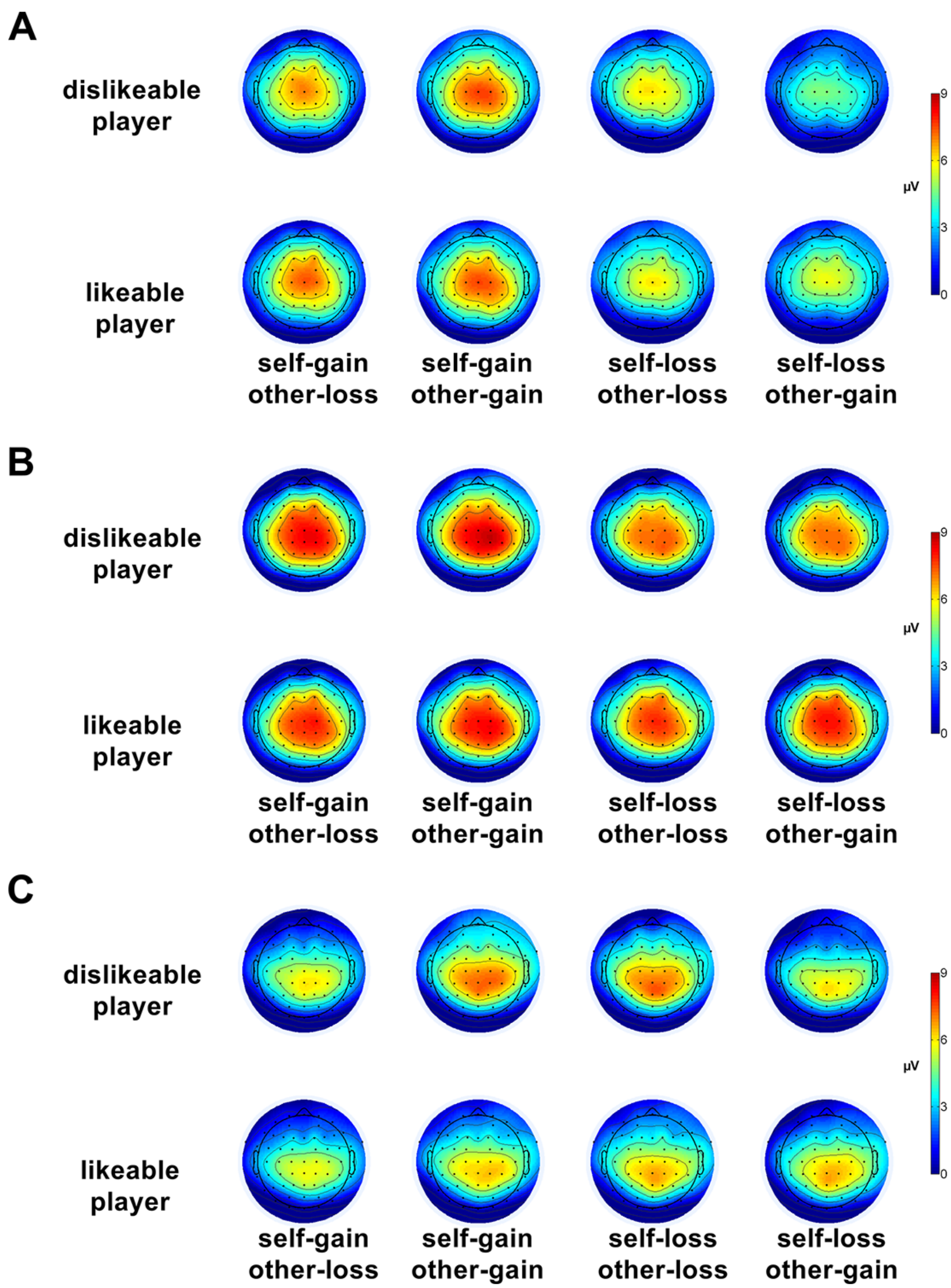

Fig. 2. The topographical distribution of each ERP component. Plane A–C represents the results of the FRN, P3 and LPC, respectively.

Table 1. Summary of the statistical analysis result of behavior and ERPs data

	Satisfaction score			FRN			P3			LPC		
Factor	*F*	*P*	$\eta 2\ p$	*F*	*P*	$\eta 2\ p$	*F*	*P*	$\eta 2\ p$	*F*	*P*	$\eta 2\ p$
S	**25.24**	**<0.001**	**0.47**	**18.04**	**<0.001**	**0.38**	**6.28**	**0.02**	**0.18**	1.02	0.32	0.03
O	**6.57**	**0.02**	**0.19**	2.02	0.17	0.07	0.72	0.40	0.02	0.80	0.38	0.03
R	**6.24**	**0.02**	**0.18**	0.02	0.90	<0.001	0.02	0.88	0.01	0.20	0.66	0.01
S × O	0.42	0.52	0.014	**4.84**	**0.04**	**0.14**	0.13	0.72	0.005	**8.97**	**0.006**	**0.24**
O × R	**23.24**	**<0.001**	**0.45**	1.92	0.18	0.06	1.05	0.31	0.04	1.38	0.25	0.05
S × R	**6.29**	**0.02**	**0.18**	0.29	0.59	0.01	**4.45**	**0.04**	**0.13**	1.54	0.23	0.05
S × O × R	**15.09**	**<0.001**	**0.34**	**6.50**	**0.02**	**0.18**	0.47	0.50	0.02	**9.53**	**0.004**	**0.25**

S: self-outcome; O: other-outcome; R: relationship. Degree of freedom is (1, 29); the significant results ($P < 0.05$) are shown in boldface.

for sphericity violations whenever appropriate. *Post hoc* testing of the significant main effects was applied using Bonferroni adjustments. Cohen's *d* and partial eta-squared ($\eta 2\ p$) were provided to demonstrate effect size when available (Cohen, 1973, 1988).

Results

Behavioral results

IOS questionnaire. The IOS results reveal that participants' relationships with player A [3.53 ± 0.31 (mean ± standard error)] and that with player B (3.27 ± 0.31) were not significantly different before the TG [$t(58) = 0.61$, $P = 0.54$, Cohen's $d = 0.16$]. After the TG, participants felt closer than before with the likeable player A [4.80 ± 0.34, $t(58) = 2.75$, $P = 0.008$, Cohen's $d = 0.71$] and more distant than before with the dislikeable player B [2.00 ± 0.24, $t(58) = -3.25$, $P = 0.002$, Cohen's $d = 0.84$]. The difference between player A and player B after the TG was also significant [$t(58) = 6.73$, $P < 0.001$, Cohen's $d = 1.74$]. These result showed that participants' context-based relationship with other players had been successfully modulated by the TG.

TG performance. During the TG, participants invested a larger amount of money to the likeable player A than the dislikeable player B, in both the first run [6.52 ± 0.37 *vs* 1.61 ± 0.21; $t(58) = 11.53$, $P < 0.001$, Cohen's $d = 2.98$] and the second run [8.13 ± 0.37 *vs* 1.48 ± 0.38; $t(58) = 12.59$, $P < 0.001$, Cohen's $d = 3.24$].

Meanwhile, decision time in the likeable player condition showed no difference with that in the dislikeable player condition, in either the first run [4451.53 ± 289.41 ms *vs* 4203.67 ± 238.94 ms; $t(58) = 0.66$, $P = 0.51$, Cohen's $d = 0.17$] or the second run [2718.40 ± 162.80 ms *vs* 2435.44 ± 133.47 ms; $t(58) = 1.35$, $P = 0.18$, Cohen's $d = 0.34$].

Gambling performance. Decision time in the likeable player condition (622.59 ± 58.11 ms) and that in the dislikeable player (604.17 ± 45.67 ms) were not significantly different [$t(58) = 0.25$, $P = 0.80$, Cohen's $d = 0.06$].

Satisfaction to gambling outcome. According to the results of the *Relationship* × *Self-outcome* × *Other-outcome* ANOVA (Figure 3), the main effect of *Self-outcome* was significant [$F(1, 29) = 25.24$, $P < 0.001$, $\eta 2\ p = 0.47$], indicating that the satisfaction level was higher for self-gain (4.51 ± 0.14) compared with self-loss (3.16 ± 0.17). The main effect of *Other-outcome* was significant [$F(1, 29) = 6.57$, $P = 0.02$, $\eta 2\ p = 0.19$], indicating that the satisfaction level was higher for other-loss (4.03 ± 0.10) compared with other-gain (3.63 ± 0.12). The main effect of *Relationship* was also significant [$F(1, 29) = 6.24$, $P = 0.02$, $\eta 2\ p = 0.18$], indicating that the satisfaction level was higher when participants played with the likeable player (3.98 ± 0.11) compared with the dislikeable player (3.68 ± 0.09).

The interaction of *Other-outcome* × *Relationship* [$F(1, 29) = 23.24$, $P < 0.001$, $\eta 2\ p = 0.45$] was significant: the satisfaction level was higher when the likeable player received gains (4.25 ± 0.17) compared with losses (3.72 ± 0.14; $P = 0.03$), but lower when the dislikeable player received gains (3.02 ± 0.17) compared with losses (4.35 ± 0.15; $P < 0.001$). The interaction of *Self-outcome* × *Relationship* was significant [$F(1, 29) = 6.29$, $P = 0.02$, $\eta 2\ p = 0.18$]: in the self-gain condition, the satisfaction level was not significantly different between the likeable player (4.47 ± 0.15) and dislikeable player (4.55 ± 0.16; $P = 0.57$); in the self-loss condition, the satisfaction level was higher when playing with the likeable player (3.50 ± 0.23) compared with the dislikeable player (2.82 ± 0.19; $P = 0.007$). The interaction of *Self-outcome* × *Other-outcome* × *Relationship* was significant [$F(1, 29) = 15.09$, $P < 0.001$, $\eta 2\ p = 0.34$]: a simple-effect analysis showed that the satisfaction level was higher when the likeable player received gains (5.00 ± 0.23) compared to losses (3.93 ± 0.25; $P = 0.008$) in the self-gain condition, but it was insensitive to the likeable player's gains (3.50 ± 0.24) or losses (3.50 ± 0.25; $P = 0.99$) in the self-loss condition. In contrast, the satisfaction level was higher when the dislikeable player received losses compared with gains, regardless of self-outcome valence (GL: 5.40 ± 0.27, GG: 3.70 ± 0.21, $P < 0.001$; LL: 3.30 ± 0.21, LG: 2.33 ± 0.23, $P < 0.001$). Finally, the *Self-outcome* × *Other-outcome* interaction was insignificant [$F(1, 29) = 0.42$, $P = 0.52$, $\eta 2\ p = 0.014$].

ERP results

FRN. According to the results of the *Relationship* × *Self-outcome* × *Other-outcome* ANOVA (Figure 4), the main effect of *Self-outcome* was significant [$F(1, 29) = 18.04$, $P < 0.001$, $\eta 2\ p = 0.38$], indicating that the FRN was larger (i.e. more negative-going) in the self-loss (4.85 ± 0.83 μV) compared to the self-gain condition (6.44 ± 0.92 μV). Meanwhile, the main effects of *Other-outcome* [$F(1, 29) = 2.02$, $P = 0.17$, $\eta 2\ p = 0.07$] and *Relationship* [$F(1, 29) = 0.02$, $P = 0.90$, $\eta 2\ p < 0.001$] were insignificant.

Further, the interaction of *Self-outcome* × *Other-outcome* was significant [$F(1, 29) = 4.84$, $P = 0.04$, $\eta 2\ p = 0.14$]: in the self-loss condition, the FRN was larger in response to other-gain (4.41 ± 0.81 μV) compared with other-loss (5.28 ± 0.87 μV; $P = 0.004$); in the self-gain condition, the FRN was insensitive to the difference between other-gain (6.60 ± 0.94 μV) and other-loss (6.29 ± 0.94 μV; $P = 0.41$). Neither the interaction of *Other-outcome* × *Relationship* [$F(1, 29) = 1.92$, $P = 0.18$, $\eta 2\ p = 0.06$] nor that of *Self-outcome* × *Relationship* [$F(1, 29) = 0.29$, $P = 0.59$, $\eta 2\ p = 0.01$] was significant. Finally, the interaction of *Relationship* × *Self-outcome* × *Other-outcome* [$F(1, 29) = 6.50$, $P = 0.02$, $\eta 2\ p = 0.18$] was significant: a simple-effect analysis revealed that the FRN was larger for other-gain (3.95 ± 0.87 μV) than other-loss (5.55 ± 1.00 μV; $P < 0.001$) only when participants were playing with the dislikeable player in the self-loss condition (Figure 4).

P3. According to the results of the *Relationship* × *Self-outcome* × *Other-outcome* ANOVA (Figure 5), the main effect of *Self-outcome* was significant [$F(1, 29) = 6.28$, $P = 0.02$, $\eta 2\ p = 0.18$], indicating that the P3 was larger (i.e. more positive-going) in the self-gain (7.33 ± 0.81 μV) compared with the self-loss condition (6.73 ± 0.86 μV). Meanwhile, the main effect of *Other-outcome* [$F(1, 29) = 0.72$, $P = 0.40$, $\eta 2\ p = 0.02$] and *Relationship* [$F(1, 29) = 0.02$, $P = 0.88$, $\eta 2\ p = 0.001$] was insignificant.

Further, the interaction of *Self-outcome* × *Relationship* was significant [$F(1, 29) = 4.45$, $P = 0.04$, $\eta 2\ p = 0.13$], and follow-up simple-effect analysis revealed that the P3 was not significant between self-gain (7.09 ± 0.88 μV) and self-loss (6.84 ± 0.89 μV; $P = 0.38$) when playing with the likeable player; in contrast, the P3 was larger for self-gain (7.56 ± 0.98 μV) compared with self-loss (6.62 ± 0.98 μV; $P = 0.003$) when playing with the dislikeable player. Finally, the interactions of *Other-outcome* × *Relationship*

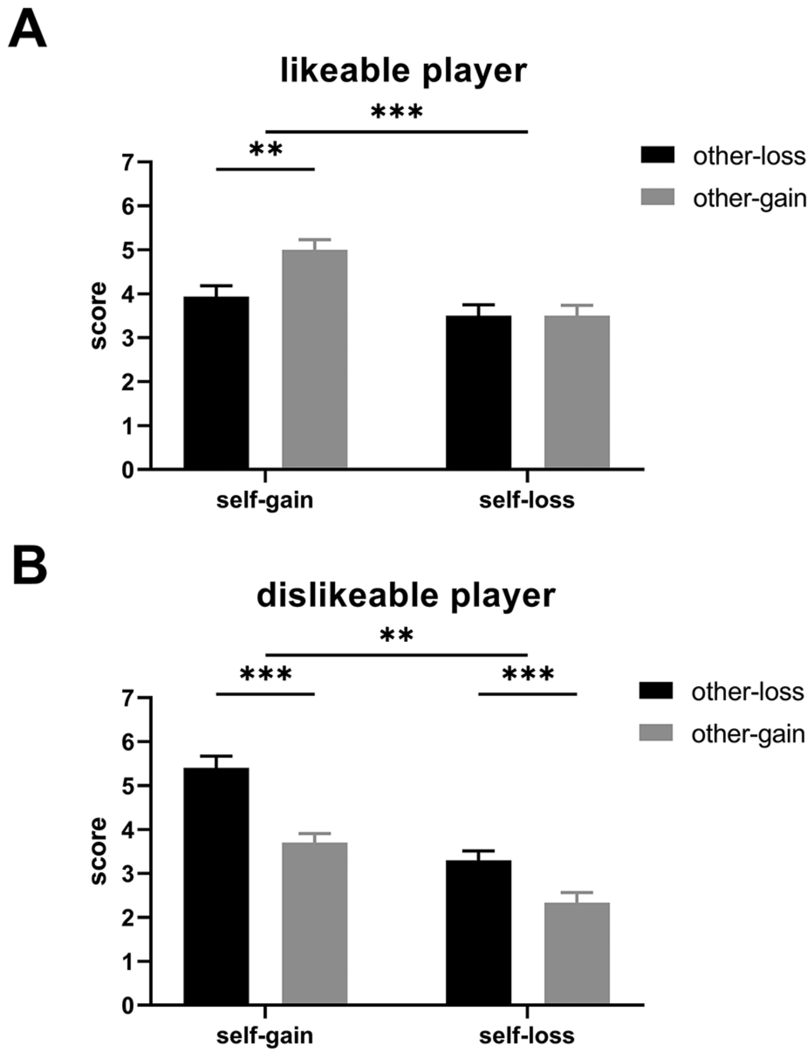

Fig. 3. The satisfaction scores analyzed by repeated measures ANOVAs. (A) The effect of self-outcome × other-outcome for a likeable player and (B) The effect of self-outcome × other-outcome for a dislikeable player. Error bars represent standard errors. (*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$).

[$F(1, 29) = 1.05$, $P = 0.31$, $\eta 2\ p = 0.04$], *Self-outcome × Other-outcome* [$F(1, 29) = 0.13$, $P = 0.72$, $\eta 2\ p = 0.005$] and *Relationship × Self-outcome × Other-outcome* [$F(1, 29) = 0.47$, $P = 0.50$, $\eta 2\ p = 0.02$] were insignificant.

LPC. According to the results of the *Relationship × Self-tionships on social comparison by askinoutcome × Other-outcome* ANOVA (Figure 6), all the main effects including *Self-outcome* [$F(1, 29) = 1.02$, $P = 0.32$, $\eta 2\ p = 0.03$], *Other-outcome* [$F(1, 29) = 0.80$, $P = 0.38$, $\eta 2\ p = 0.03$] and *Relationship* [$F(1, 29) = 0.20$, $P = 0.66$, $\eta 2\ p = 0.01$] were insignificant. The interaction of *Self-outcome × Other-outcome* was significant [$F(1, 29) = 8.97$, $P = 0.006$, $\eta 2\ p = 0.24$], indicating that in the self-gain condition, the LPC was larger for other-gain (6.20 ± 0.59 μV) compared with other-loss (5.20 ± 0.58 μV; $P = 0.001$); in the self-loss condition, the LPC was not significantly different between other-gain (5.60 ± 0.65 μV) and other-loss (6.25 ± 0.74 μV; $P = 0.11$). Meanwhile, neither the interaction of *Other-outcome × Relationship* [$F(1, 29) = 1.38$, $P = 0.25$, $\eta 2\ p = 0.05$] nor that of *Self-outcome × Relationship* [$F(1, 29) = 1.54$, $P = 0.23$, $\eta 2\ p = 0.05$] was significant.

Finally, the interaction of *Self-outcome × Other-outcome × Relationship* [$F(1, 29) = 9.53$, $P = 0.004$, $\eta 2\ p = 0.25$] was significant: a simple-effect analysis showed that in the self-gain condition, the LPC was larger when the dislikeable player received gains (6.61 ± 0.78 μV) compared with losses (5.31 ± 0.75 μV; $P = 0.001$); in the self-loss condition, the LPC was larger when the dislikeable player received losses (6.68 ± 0.88 μV) compared with gains (5.30 ± 0.79 μV; $P = 0.003$). However, the LPC was insensitive to the likeable player's outcomes in either the self-gain condition (likeable-gain: 5.78 ± 0.63 μV *vs* likeable-loss: 5.09 ± 0.68 μV; $P = 0.07$) or the self-loss condition (likeable-gain: 5.91 ± 0.69 μV *vs* likeable-loss: 5.83 ± 0.79 μV; $P = 0.88$).

Discussion

As described in Introduction, interpersonal relationship (e.g. friends *vs* strangers) plays an important role in social comparison (Zhang *et al.*, 2020). This study investigates the impact of context-based relationships on social comparison by asking participants to evaluate the outcomes of their choice and that of their respective anonymous partners during gambling. Here, the

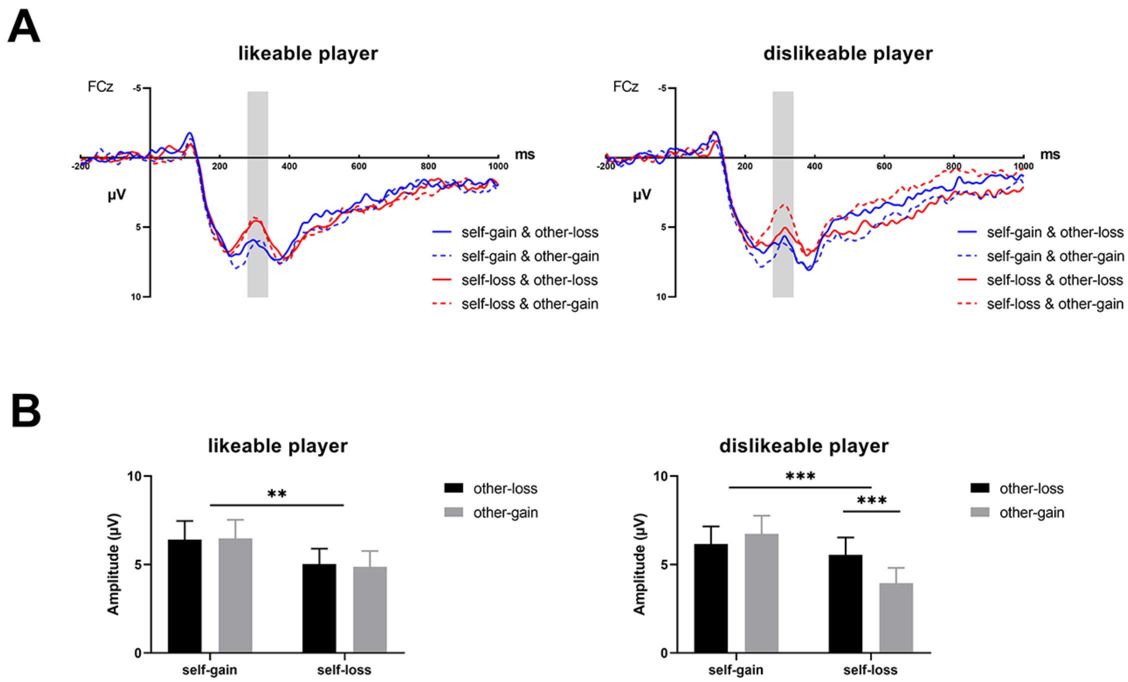

Fig. 4. (A) Grand-mean ERP waveforms elicited by outcome feedback at the FCz electrode, representing the FRN in each condition. (B) The FRN amplitude value analyzed by repeated measures ANOVA. Error bars represent standard errors. (*P < 0.05, **P < 0.01, ***P < 0.001).

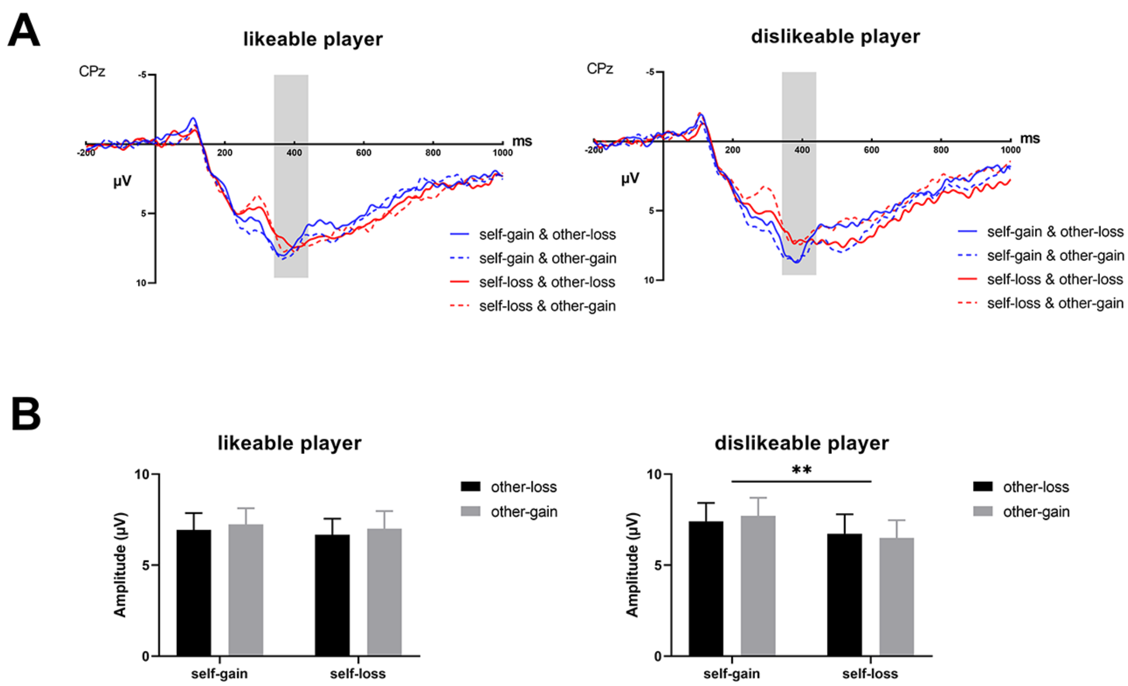

Fig. 5. (A) Grand-mean ERP waveforms elicited by outcome feedback at the CPz electrode, representing the P3 in each condition. (B) The P3 amplitude value analyzed by repeated measures ANOVA. Error bars represent standard errors. (*P < 0.05, **P < 0.01, ***P < 0.001).

context-based relationship was manipulated using a prior TG in which the partners behaved generously or not, and its effect has been confirmed by the IOS score. In the follow-up gambling task, the self-reported satisfaction level to outcome feedback revealed a social comparison effect modulated by the context-based relationship. That is to say, the participants were more satisfied with a likeable player's gains compared with losses when they also received gains, but they were not sensitive to a likeable player's outcomes when they received losses; in contrast, our participants were more satisfied with a dislikeable player's losses compared to his/her gains regardless of their own outcomes. In general, these results were in line with the SEM theory that the psychological closeness of other people modulates social comparison (Tesser, 1988).

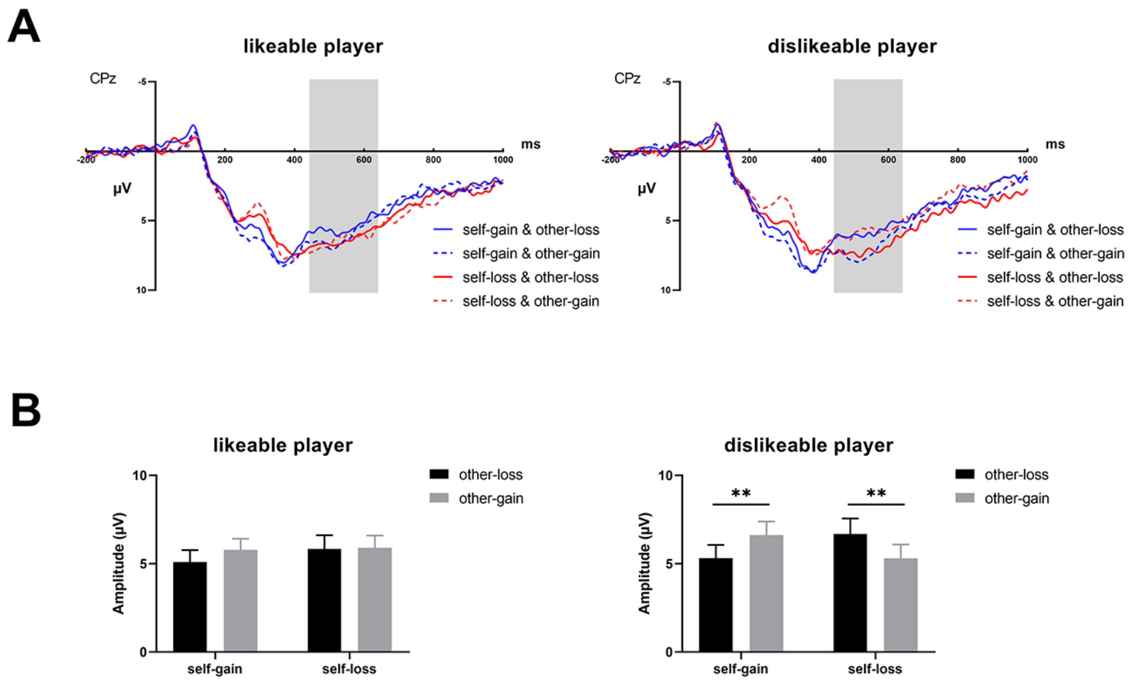

Fig. 6. (A) Grand-mean ERP waveforms elicited by outcome feedback at the CPz electrode, representing the LPC in each condition. (B) The LPC amplitude value analyzed by repeated measures ANOVA. Error bars represent standard errors. (*$P<0.05$, **$P<0.01$, ***$P<0.001$).

Table 2. Summary of the simple-effect analysis result of behavior and ERPs data

	Conditions: relationship (F/D) and self-outcome (G/L) and other-outcome (G/L)			
Factor	Satisfaction score	FRN	P3	LPC
S	G > L	L > G	G > L	N.S.
O	L > G	N.S.	N.S.	N.S.
R	F > D	N.S.	N.S.	N.S.
S × O	N.S.	LG > LL	N.S.	GG > GL
O × R	F±G > F±L; D±L > D±G	N.S.	N.S.	N.S.
S × R	FL± > DL±	N.S.	DG± > DL±	N.S.
S × O × R	FGG > FGL; DLL > DLG; DGL > DGG	DLG > DGG	N.S.	DGG > DGL; DLL > DLG

S: self-outcome; O: other-outcome; R: relationship. F: likeable player; D: dislikeable player. G: monetary gains; L: monetary losses; ±: both gains and losses. N.S.: non-significant.

Notably, the influence of interpersonal relationship on social comparison manifested in not only the behavioral data but also the ERP components FRN, P3 and LPC (Table 2), which may help unravel the underlying mechanisms of social comparison. Overall, the impact of interpersonal relationship was more prominent in the dislikeable player condition, which was in line with our prior hypotheses. Below we discuss each ERP component in details.

First, the FRN amplitude elicited by self-loss was larger than that elicited by self-gain, replicating its classic pattern (Gehring, 2002; Holroyd *et al.*, 2004; Cohen *et al.*, 2011; San Martín, 2012). Most importantly, the three-way interaction of *Relationship* × *Self-outcome* × *Other-outcome* was significant, showing that the FRN elicited by 'self-loss, other-gain' (LG) became larger than 'self-loss, other-loss' (LL) in the dislikeable player condition, but not in the likeable player condition. To understand this finding, it is worth noting that the FRN is sensitive to expectancy violation, as its amplitude increases in response to unexpected *vs* expected feedback (Hajcak *et al.*, 2005, 2007; Holroyd *et al.*, 2006; Talmi *et al.*, 2013; Sambrook and Goslin, 2015; Heydari and Holroyd, 2016). According to the above knowledge, our participants may not expect that a dislikeable player's outcome would be better than their own outcome; consequently, 'self-loss, dislikeable player-gain' violated their prior expectation and thus elicited a larger FRN compared to the losses of both persons. This interpretation is supported by the observation that people are more likely to generate jealous thoughts toward a disliked person (van de Ven *et al.*, 2012) and a recent finding that the FRN was larger when facing an untrustworthy player than a trustworthy one (Li *et al.*, 2017a). In contrast, when comparing with a likeable player, the participants may not expect to get a relatively better or worse outcome, because neither way is desirable: performing better than a friendly and likeable person may result in negative emotions such as embarrassment and guilt (Muller-Pinzler *et al.*, 2016; Leng *et al.*, 2017), while performing worse than that person may be a burden to one's self-esteem (Major *et al.*, 1993; Brewer and Weber, 1994).

Following the FRN, we found that the P3 component was also modulated by interpersonal relationship. Specifically, the P3 amplitude was more pronounced for self-gain than for self-loss (see also Hajcak *et al.*, 2005; Zhang *et al.*, 2013), but this effect was only significant in the dislikeable player condition. In our opinion, the P3 finding could be understood from the perspective of motivational significance. That is to say, the participants had a stronger motivation to get favorable outcomes when they were comparing with a dislikeable player, possibly because they wanted to outperform that player (see also Lott and Lott, 1969). In line with our interpretation, individuals are particularly motivated to protect their self-interest when interacting with distrust people (Lewicki *et al.*, 1998).

Finally, the effect of interpersonal relationship manifested on the LPC amplitude in another way. That is, 'self-gain, dislikeable player-gain' elicited a larger LPC than 'self-gain, dislikeable player-loss'; meanwhile, 'self-loss, dislikeable player-loss' elicited a larger LPC than 'self-loss, dislikeable player-gain.' In short, an enhanced LPC amplitude was detected when the participants received the same outcome with a dislikeable player compared to different outcomes, while no significant LPC difference emerged in the likeable player condition. The implications of these findings are unclear to us, considering that (unlike the FRN and P3) the LPC was insensitive to the main effects of self-outcome, other-outcome or relationship type (likeable *vs* dislikeable). One possible explanation is related to interpersonal distance. People connect with others and establish close interpersonal distance when sharing similar experience with others (Baumeister and Leary, 1995; Heatherton, 2011). However, a close distance could also be intrusive and threatening, especially when interacting with disliked persons (Lloyd, 2009). A recent study found that distrust behaviors would enlarge interpersonal distance (Rosenberger *et al.*, 2020). In our opinion, the participants were willing to keep distance with a dislikeable player and therefore did not want to share similarities with that player, such as having the same decision outcomes (see also Banse, 2001; Mendes *et al.*, 2001). As a result, getting the same outcome with a dislikeable player evoked stronger emotional responses (indexed by the LPC) than getting different outcomes (see Introduction for the relationship between the LPC and emotional experience; see also Hajcak and Olvet, 2008; Hajcak *et al.*, 2009; Hajcak and Foti, 2020). This explanation is awaited to be tested further.

To conclude, manipulating interpersonal relationship significantly affects the comparison of self-outcome with other-outcome. Based on previous ERP research (Wu *et al.*, 2012; Luo *et al.*, 2015; Hu *et al.*, 2017), this study and one of our recent studies (Zhang *et al.*, 2020) show that all the major stages of social comparison could be modulated by both context-free and context-based relationships. From the perspective of cognitive psychology, our ERP results indicate that the evaluative (FRN), motivational (P3) and emotional (LPC) processes of social comparison are sensitive to the dislikeable player condition, such that the participants expected a dislikeable player to receive unfavorable outcomes, had stronger motivation to outperform that player and did not want to share similarities with that player. Broadly speaking, these results provide support to the SEM theory that emphasizes the association between personal closeness and social comparison. Regarding the likeable player condition, no ERP difference was detected. As mentioned above, we suggest that this was because the 'reflection' process and the 'comparison' process proposed by the SEM theory (see Introduction) counteract each other. Consequently, the participants did not hope a likeable player to play either better or worse than themselves. Further, the ERP results showed distinct patterns with the self-reported satisfaction score, indicating a deviation between implicit and explicit attitudes (Lust and Bartholow, 2009; Wu *et al.*, 2016; Gu *et al.*, 2020): although the participants explicitly claimed that they were more satisfied with a likeable player's gains compared to losses, their implicit attitude might be different. In short, we believe that the current findings have general implications beyond specific experimental manipulations, but the robustness of our viewpoint still needs to be examined with alternative tasks.

This study, however, is not free of limitations. It is necessary to point out the limitations to offer future direction to follow-up studies. First, the provision of different outcomes for participants and others simultaneously may lead to mixed effects, though this kind of outcome presentation has been applied in other studies (e.g. Qiu *et al.*, 2010; Boksem *et al.*, 2011; Luo *et al.*, 2015). Second, the self-outcome and other-outcome in this study were both randomly decided and were independent of each other, which might be different from the everyday experiences of social comparison and therefore have affected the ecological validity of our task. Third, this study did not take the facial attractiveness or trustworthiness of the putative players A and B into account. Previous research has indeed found a relationship between perceptions of attractiveness and trust building (Zhao *et al.*, 2015; Li *et al.*, 2017b). However, some other studies suggest that partner reciprocation is more important than physical appearance in economic games (Yu *et al.*, 2014). Follow-up research should consider controlling the confounding effects of facial attractiveness and trustworthiness. Lastly, further studies may examine the effect of individual difference (e.g. level of social comparison orientation) on our findings (Gibbons and Buunk, 1999). Indeed, some recent studies have confirmed the importance of individual difference in ERP signals related to social comparison (Hu *et al.*, 2017; Wang *et al.*, 2017; Qi *et al.*, 2018).

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Author contributions

H.Z. and W.L. conceived the research. H.Z., M.Y., M.Z. and F.H. designed and performed the experiment. H.Z. and M.Y. analyzed the data. H.Z., R.G., H.L. and W.L. wrote the manuscript.

Conflict of interest

There are no conflicts of interest to declare.

Declaration of ethics

All procedures performed in this study were in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

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