Research Proposal

How competition modulates risky decision making? Evidence from event-related oscillations (EROs) and event-related potentials (ERPs)

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1. GENERAL INTRODUCTION

Risk-taking behaviors are commonly found in adolescents (Sherman et al., 2018), and may set in motion a series of negative developmental cascades in later life stages (Feeney et al., 2018). The high propensity of adolescents' risk-taking behaviors can be explained in terms of pursuit of potentially rewarding stimuli and the increasing importance of social reinforcement (Forbes & Dahl, 2010). In line with the dual system model (Steinberg, 2008), the synaptic pruning that occurs in the prefrontal cortex (PFC) during adolescence and causing individuals' socio-emotional system to develop more rapidly than the cognitive control system (Duell et al., 2018). The lack of self-control and the increase of reward-seeking lead to a high incidence of risk-taking behaviors (Burani et al., 2019). More importantly, peer factors may strengthen the sensitivity of adolescent socio-emotional system to novel stimuli. Given the core of social relations shifted from family to peer among adolescents (Collins & Laursen, 2004), numeral of studies improved evidence that peer influence is crucial for risk-taking behaviors among adolescence (Gardner & Steinberg, 2005; Reiter et al., 2021; Smith et al., 2015; van Hoorn et al., 2016). However, previous studies focused primarily on those "gentler" peer contexts, such as peer presence (Chein et al., 2011; Tomova & Pessoa, 2018) or peer observation (Kessler et al., 2017), these "peer factors" are not directly related to the individuals' potential behavioral outcome (e.g., peers may suggest individuals take more risks, but individuals can still take a conservative decision). In order to draw conclusions about the intended behavior in different complex peer contexts, it is

necessary to validate that the more influential peer context (e.g., peer competition) has similar effects on guiding adolescents' choices.

As a common form of peer interaction, peer competition refers to one's mental state and behavior of attempting to surmount others (Liu et al., 2020). According to the social comparison theory (Festinger, 1954), individuals may compare with others to conduct their self-evaluation. Thus, adolescents may react differently in risky decision-making due to consideration of potential social evaluations under competition (Toelch et al., 2014). More specifically, in order to surpass opponents or acquire a better peer status and peer approval under competition (Crocker et al., 2003), individuals may occur in higher risk-prone. For instance, Foo et al. (2017) used a rank setting to induce participants' competitive experience and found that adolescents with low ranks had a higher propensity of risk-taking than those not presented with ranks and high ranks adolescents. In a similar vein, by using Balloon Analogue Risk Task (BART), Z. L. Liu et al. (2020) suggested that male adolescents are more risk-prone in competition context. Meanwhile, N. Liu et al. (2021) used a two-round BART and indicated that individuals are more likely to occur risky decisions making when they compete with a former winner while showing a risk-aversion when competing with a former loser. On neurocognitive level, Vorobyev et al. (2015) used a driving task conducted with functional Magnetic Resonance Imaging (fMRI) to measure risky decision making and found that adolescents with higher resistance to peer influence took more risks in peer competitive context, and suggested that peer competition increased the activation in the right caudate head but only for the rewarding outcome.

Although studies involving fMRI have contributed greatly to identifying brain regions related to individuals' responses to peer competition (Vorobyev et al., 2015), little is known about the temporal characteristics of decision making and feedback evaluation processing among individuals in competition context. The event-related potential (ERP) could reveal important insights about the precise timing of processes underlying cognitive functions given the measure's excellent time resolution. Therefore, the present study aimed to examine the time characteristics of peer competition in modulating risky decision-making processing by using ERP.

Consistent with this idea, the FRN is a commonly computed ERP component at frontocentral sites, such as at the vertex electrode Fz, and peaks between 250 and 350 ms after the feedback onset (Gehring & Willoughby, 2002), which is more negative for negative feedback than for positive feedback (Miltner et al., 1997). According to the reinforcement learning theory of the error-related negativity, a negative reward prediction error is generated in the midbrain dopamine system and is conveyed to the anterior cingulate cortex (ACC), where it elicits the FRN and guides the action or learning (Holroyd & Coles, 2002). FRN has been proved to be related to expectation violation of decision-making feedback and is regulated by social comparison context (Luo et al., 2015; Wagemaker et al., 2020). Following the FRN, the P3 is a centro-parietal positivity appearing in the 300–600 ms time window (Holroyd and Coles, 2002; Yeung & Sanfey, 2004; San Martín, 2012). The P3 encodes the valence and magnitude of an outcome, with greater amplitude to an affectively positive than negative outcome and to a larger than smaller reward (Yeung & Sanfey, 2004; Yeung et al., 2005; Glazer et al., 2018). The P3 reflects the allocation of attentional resources and the

subjective importance of the desired outcome (Polich, 2007; Mussel et al., 2018). ERP studies in risky decision-making have found that the P300 is sensitive to the interpersonal variables in competition (Wang et al., 2014). More importantly, risky decision-making under competition should include not only the outcome evaluation phase but also the decision-making phase. Based on this idea, the N200 is a negative deflection that approximately occurs 200-350 ms following stimulus onset (Hajcak et al., 2006), and it indicates an index conflict detection during stimuli processing. Larger N200 amplitudes suggested participants perceived stronger conflicts during decision-making (Li et al., 2021). For instance, Enriquez-Geppert et al. (2010) revealed the association between N200 and the impulsiveness inhibition while Folstein and Petten.'s study (2008) shared the similar conclusion.

Given that the potential cognitive mechanism of competition on risky decision making remains unclear, I have designed an ERP experiment in my master thesis in order to investigate the differences in risky decision making under single and competitive contexts among late adolescents. I am very honored to introduce my research on this field which is one sub-study of my master thesis study. This research is entitled "*How does peer competition modulates risk-taking behavior: Evidence from brain activity in the Balloon Analogue Risk Task (BART)*" as shown in the *PREVIOUS RESEARCH PROGRESS OF APPLICANT* section.

2. PREVIOUS RESEARCH PROGRESS OF APPLICANT: How does peer competition modulates risk-taking behavior: Evidence from brain activity in the Balloon Analogue Risk Task (BART)

2.1 Participants

To examine the adequacy of the sample, the current research conducted a priori power analysis for a 2×2 within-subjects, repeated measures analysis of variance (ANOVA) using G*Power 3.1 software with 80% statistical power for detecting a small-to-medium effect size (Faul et al., 2007). Thus, the current research recruited 29 college students (mean age in years = 20.14, $SD = 1.42$) in this study. All participants are dextral and gave their informed consent to participate in this experiment and reported no history of neurological or psychiatric disorders or head trauma. Data from 3 participants were excluded due to excessive artifacts in EEG data. The final sample for analysis consisted of 26 participants (mean age in years = 19.69, $SD = 1.38$). All procedures involving human participants were reviewed and approved by the research ethics committee at Guangzhou University (Protocol Number: GZHU2019017), and written informed consent was obtained from all participants.

2.2 Manipulation check

Participants were required to provide a self-reported manipulation check, which included (a). emotion under two contexts by using the 10-items positive and negative affective scale (PNAS; Watson et al., 1988); (b). the intensity of the task (i.e., “The intensity you perceived in the task just performed”) under two contexts with a 9-point Likert scale ranging from 1(not at all) to 9 (extremely); and (c). the authenticity of the tasks (i.e., “I

believe that I was playing with a real student in the lab next door”) with a 7-point Likert scale ranging from 1(not at all) to 7 (extremely).

2.3 Task and procedure

In order to elicit brain activity, participants completed two conditions in a Balloon Analogue Risk Task (BART; Lejuez et al., 2002). Each participant sat comfortably in front of a computer screen in a laboratory and completed the BART with 144 balloons (trials) in each condition (single vs. peer competition). Participants were asked to minimize their eye blinks and head movements although performing the task. For the single condition, participants were told that they complete the BART alone and their total rewards are all up to their performance. In the peer competition condition, participants were told that they would be competing in a BART mission with a peer (who was impersonated by the researcher). Peer was in another room outside the EEG cabin during the game, and they were competing in real time. Participants were also told that the final scores of the players determined whether they were victorious or defeated. The winner will get not just his or her BART awards, but also half of the entire benefits of the loser. (see Figure 1). The order of different conditions was randomized between participants.

Figure 1. Schematic diagram for the BART. The order of single condition and competition condition is random in the experiment

Participants were required to pump 144 balloons in each condition in order to get a reward during the task and they were given clear task instructions and a practice block of 10 trials prior to the official test to ensure that they understood the task and procedural. A pump might either raise the size and value of the balloon (positive feedback) or burst it, resulting in the loss of the collected rewards (negative feedback). For the feedback phase, the current research chose a red and green text color to present loss and gain feedback, respectively.

The current research implemented the BART with E-prime 2.0 (Psychology Software Tools; see Figure 1) running on a Windows 10 PC. During each trial, the probability that the balloon would burst increased with each pump, and the maximum pump was set to 12. When each trial (balloon) begins, the program chooses a number between 1 and 12 at random and sets that number as the bursting point. If the number of participants inflated exceeds the bursting point, the balloons will explode and they loss the reward in this trial, but if the number of participants inflated is less than the popping point, the pump will work properly (i.e., the balloon will not explode and get rewards from the current trial). This investigation modified an experimental setting of actual incentives instead of virtual points, according to Xu et al. (2019). For each pump in non-exploded trials, a monetary award of 10 cents of Chinese Yuan was offered (e.g., If the balloon does not explode, 6 pumps can get 0.6 yuan). All participants in the experiment were instructed to pump the balloon in the counting of 5 seconds. When participants successfully pump the balloon, they may receive the matching reward, or they forfeit all prior earnings from the current balloon as a punishment if the balloon is inflated past its particular popping point. The tasks in two conditions took roughly 60 minutes to complete the experiment. Each participant received a total reward of roughly 80 Chinese yuan based on their performance under two conditions.

2.4 Psychophysiological recording and pre-processing

EEG data were sampled at a rate of 500 Hz from 64 Ag/AgCl electrodes mounted in a cap (Brain Products GmbH, Gilching, Germany) according to 10-20 international placement system connected to two amplifiers with an offline re-reference to the averaged mastoid electrodes. The electrooculogram (EOG) was recorded from electrodes placed 1.5 cm below

the right eye. Electrode impedances were kept below 10 k Ω during recording. All EEG data were recorded online utilizing the vertex FCz reference and re-referenced offline to the mean value of the bilateral mastoids. After the record was completed, the current research export offline EEG data into BrainVision Analyzer 2.2(Gilching, Germany: Brain Products GmbH) and use it as well as custom scripts for time-domain analysis.

To remove electronic artifacts (e.g., blanking and movement), this study conducted independent component analysis (ICA; Jung et al., 2000; Lee et al., 1999) for EEG data. Second, the data was filtered using a 0.1-40 Hz band-pass filter and a 48-52 Hz notch filter. Third, EEG data was segmented into epochs that began 200 ms before stimulus onsets and ended 800 ms after onset, and further be baseline-corrected based on the 200ms pre-offer period. Moreover, the present research excluded epochs that contained artifacts exceeding $\pm 100\mu\text{V}$ from subsequent analyses.

2.5 Data analysis strategies

For the behavioral data, a 2 (context: single, competition) $\times$ 2 (feedback of last trial: gain vs. loss) repeated measures ANOVA was conducted on the average pumps in BART. For the decision-making phase of EEG data, the present study analyzed the N2 component using single factor two levels (context: single competition) repeated measures ANOVA. The current work used a 2 (context: single, competition) 2 (feedback: gain vs. loss) repeated measures ANOVA to analyze the FRN amplitudes during the feedback phase of EEG data, as well as the same ANOVA model to analyze the mean P300 amplitudes.

The present study employed a Greenhouse-Geisser correction to account for the violations of the assumption of sphericity when necessary, and we applied a Bonferroni

correction for post hoc comparisons; we also report the partial eta-squared as a measure of the proportion of variance that is explained by the independent variable.

2.6 Results

2.6.1 Competition manipulation check

The results of the manipulation check showed a nonsignificant difference in all positive and negative emotion between single and competitive context ($ps = 0.12\sim 0.68$). However, the paired sample t-tests showed that the intensity of the task was higher for the competitive context (4.42 ± 2.10) than for the single context (6.30 ± 2.07 ; $t = -4.30$, $p < 0.001$ cohen's $d = 0.901$). In addition, the average score of the participants on the question of task authenticity was 4.77 ($SD = 1.66$), which indicated that Participants assume they were in a real competitive context.

2.6.2 Behavioral results

As indicated in Figure 2a, participants made less balloon inflation pumps in the peer competitive condition ($M = 5.40$, $SD = 1.10$) relative to the single condition ($M = 5.73$, $SD = 0.88$), $F(1, 25) = 11.10$, $p = .003$, partial $\eta^2 = 0.31$.

Figure 2. Violin plot of behavioral results. (a) demonstrate the average pumps under two conditions in BART. (b) demonstrate the average pumps following gains and losses in the previous trials

To investigate the effect of the previous balloon explosion on the current decision-making behavior, we conducted further ANOVA on the average pumps of balloons with the factors of previous trial feedback (gain or loss) and context (single or peer competition). As indicated in Figure 2b, there was a significant main effect of context, $F(1, 25) = 10.42$, $p = 0.003$, partial $\eta^2 = 0.294$. Participants pump more in the single condition than peer competition condition regardless of the feedback of the previous trial. However, we did not find a significant main effect of feedback ($F(1, 25) < 1$, $p = 0.74$) and there was no interaction between context and feedback ($F(1, 25) = 1.08$, $p = 0.31$).

2.6.3 ERP results

In decision-making phase, the mean N2 component amplitudes and the grand average ERP waveforms for positive and negative feedback for the channel Fz across contexts is presented in Fig. 3, respectively. The mean voltage measurements determined through a repeated measure ANOVA revealed a significant and main effect of the context (single vs. peer competition), $F(1, 25) = 7.13$, $p = .013$, partial $\eta^2 = 0.222$. Specifically, a more negative N2 in the competition condition ($-3.97 \mu\text{V}$) than in the single condition ($-2.58 \mu\text{V}$).

Figure 3. Grand-averaged waveforms at electrode Fz across single versus peer competition conditions. A and B are topographic maps corresponding to the respective peak of the waveforms, A: competition condition (308ms after decision making phase presented). B: single condition (316ms after decision making phase presented). The negativity is more pronounced (blue) in the competition condition.

In the outcome evaluation phase, the mean FRN amplitudes and the grand average ERP waveforms for positive and negative feedback for the channel Fz in the gain and loss feedback across single and peer competitive contexts are presented in Fig. 4, respectively. The mean voltage measurements determined through a repeated measure ANOVA revealed a significant and main effect of the feedback (gain vs. loss), $F(1, 25) = 9.81, p = 0.005$, partial $\eta^2 = 0.30$. Specifically, a more negative FRN after loss feedback ($-4.21 \mu\text{V}$) than after the gain feedback ($-2.86 \mu\text{V}$). However, the results did not observe a significant main effect of context ($F(1, 25) = 1.28, p = 0.27$) as well as a none significant interaction between context and feedback ($F(1, 25) < 1, p = 0.38$). Moreover, a significance was found in difference wave (i.e., loss amplitude minus gain amplitude) between two context, $F(1, 25) = 5.091, p =$

0.034, partial $\eta^2 = 0.181$. The difference wave induced in single condition ($-4.98 \pm 0.49 \mu\text{V}$) was larger than competitive condition ($-6.84 \pm 4.13 \mu\text{V}$).

Figure 4. Grand-averaged waveforms for gains, losses, and the loss-minus-win difference at electrode Fz across single versus peer competition conditions, A and B are topographic maps corresponding to the respective peak of the difference waveforms, A: single condition (276ms after feedback). B: competition condition (292ms after feedback). The negativity is more pronounced (blue) in the competition condition.

Contrary to the FRN, repeated measure ANOVAs of P300 amplitude (see Figure 5) mainly revealed a significant effect of context ($F(1, 25) = 5.811, p = 0.024$, partial $\eta^2 = 0.189$) on the single condition ($12.23 \pm 1.065 \mu\text{V}$), which elicited larger positive peaks than the peer competitive condition ($10.29 \pm 1.289 \mu\text{V}$). Neither the main effect of the feedback ($F(1, 25) = 3.47, p = 0.07$) nor the interaction effect between context and feedback ($F(1, 25) < 1, p = 0.47$) reached significance.

Figure 5. Grand-averaged waveforms for gains, losses at electrode Pz across single versus peer competition conditions, A, B, C and D are scalp topography corresponding to the respective peak of the waveforms, A: single-gain (390ms after feedback). B: single-loss (368ms after feedback). C: competition gain (376ms after feedback). D: competition-loss (388ms after feedback). The positivity is more pronounced (red) in the single condition.

2.7 Brief discussion of results

Behavioral result of the current study has replicated that, participants occurred a higher propensity of risky decision making under single condition rather than competitive competition. This finding is inconsistent with the previous studies, which shared the premise that the potential positive social feedback, such as social praise and peer recognition, is conducive to young people's gaining good peer status and, as a result, adolescents may ignore the negative outcomes and take more risk for the win of the competition (Liu et al., 2020; Vorobyev et al., 2015). According to social comparison theory, individuals frequently evaluate themselves by comparing to others (Buunk et al., 2007). Considering that every loss feedback represents a negative social appraisal (McCormick et al., 2018), participants may be more concerned about being adversely assessed by others and choose more cautious decision

options because it represents a better chance of succeeding (Nockur et al., 2021). On the contrary, individuals' profits and losses are solely borne by themselves in the single context, so they are less likely to consider the potential negative repercussions of their decision and instead focus on immediate rewards in order to maximize their own benefits (Jiao et al., 2015).

For the ERP analysis, the present study selected N2, FRN, and P3 components to investigate the decision-making and outcome evaluation processing phase of risky decision-making under single and competitive context. The results showed that the N2 amplitude was higher in peer competitive context. Previous evidence suggested that greater N2 is associated with increased conflict adaption and cognitive control (Clayson & Larson, 2011; Wang et al., 2016). Given the extra punishment setting of peer competitive context, a more negative going N2 in competitive context than single context in this study may suggest greater cognitive effort to inhibit the conflict of greater gains and higher risk propensity.

Following the N2, a significantly different FRN amplitude was found in feedback, while no significant difference was detected in single and peer competitive contexts. These findings are consistent with reinforcement-learning theory (Holroyd & Coles, 2002), which predicts greater general FRN amplitudes following negative or unexpected events compared to positive or predicted outcomes. Regardless of the contexts, participants' goal to accomplish BART is to gain profit, and therefore, their expectation violation would be higher when perceiving negative feedbacks (i.e., loss) and thus a larger FRN would be generated. Furthermore, the present study also found a significant difference in difference wave of FRN between single and peer competitive condition. According to Luck (2014), difference wave

could be better to describe the conflict degree of processing of the current feedback in a ‘gain and loss’ dimension. The difference wave was calculated using loss minus gain in the current study, which conducts a better understanding of the specificity of loss processing (Xu et al., 2021). Based on this perspective, these findings indicated that late adolescents in the peer competitive context have a stronger sensitivity of loss-aversion than those adolescents in single condition, which could also explain why they behave more conservatively (indexed by a lower average pumps) under the social pressure context (Lin et al., 2021).

Regarding the P300 amplitudes, it was modulated by contexts but not by feedback types. Given that previous research shared the premise that the P300 component reflects the perceived relevance of individual attention resource allocation and expected outcomes, as well as the inhibitory control mechanism and the engaged motivation (Wischnewski & Schutter, 2018). Compared to peer competitive condition, a larger p300 was elicited in single condition, which may indicate that individuals governed all benefits on their own in single condition and, as a result, they prefer to invest more psychological resources in outcome evaluation (Hajcak et al., 2010). This also provided a neurological explanation for their more pumps in single context.

3. KEY DEBATES AND GAPS IN EXISTING KNOWLEDGE

Previous research (N. Liu et al., 2021; Z. L. Liu et al., 2020; Vorobyev et al., 2015) and my previous research progress have shown that competition has great implications for risky decision making. However, there are three gaps that have not been addressed properly. First, individual behavioral decision-making is subject to dual regulation of monetary rewards and social reinforcement (Dougherty & Cherek, 1994; Sanfey, 2007), in particular in a social context (Smith et al., 2015). According to van den Bos et al.'s (2013a, b) studies, winning and losing in competition are inherent social reward and punishment. Nonetheless, previous evidence focused primarily on how competition modulates risky decision making in monetary condition, few studies investigated the same effect on social condition. Therefore, it should be clarified the potential neural mechanisms of individuals processing rewards and losses under social and monetary competitive context.

Second, as per the adage 'everything is possible until the last minute in competition', peer competition should be known as a dynamic process, but prior scholarship paid relatively little attention to the tendency of adolescents' risky decision making under social dynamic competitive context, especially from the social reference point perspective (Lu et al., 2015). In line with this idea, two mainly type of social reference point, downward comparison and upward comparison may drive different levels of risky decision-making propensity. It will be necessary to examine the neural process of comparing individuals' own outcomes against their opponent, as well as the behavioral changes that ensue.

Third, according to the social comparison model of competition (see Garcia et al., 2013), number of competitors is a key situation factor to change one's competitiveness. To

put it another way, individuals' behavioral motivations and risk preferences may differ in multiplayer competition (or group competition) than in one-on-one competition (Mishra et al., 2014). Even more crucial, the relative ranking of individuals in a group may become a moderating element that alters their behavioral decision-making in the group competition (Bault et al., 2008). Nevertheless, to date, very little body of evidence have examined how the rank among peer competition affects adolescent risky choices (Foo et al., 2017; Kirchler et al., 2018; Shechter & Hardisty, 2020). Given the typically of multi-person competition in real society, to transfer the research on risk decision-making under one-on-one competition to the context of multiplayer competition will depict a more complete view of the effect of competition.

To verify these three questions, the current research proposal envisages to design three experiments (the flow chart see Figure 6). While both the experimental approach and the design have their strengths and limitations, they will complement one another. In study 1, I sought to investigate the rewards and losses sensitivity under monetary and social competitive context by using two edited versions of classic experimental paradigms (the doors task and the island getaway task) and manipulate two ambiguity competitive context in order to adapt the invisible competitive pressure in the real society (Levinson et al., 2017). In the study 2 and study 3, I intend to use the monetary and social BART to measure the risk preference under monetary-drive and social-drive competition. Study 2 will focus primarily on one-on-one competitive context while study 3 will replicate the similar influence in multi-people competition. In these two studies, social reference points will be considered as an important moderator in both monetary and social competition. The distance (far and near) of social reference points will also be included in these two studies.

Figure 6. The flow chart of the current research proposal

4. STUDY 1: The mechanism of processing reward and loss under competitive context: Evidence from neural oscillation

4.1 Introduction

Although previous experimental studies investigated the causal relation between competitive or social pressure context and individuals' risk-taking behavior (Starcke & Brand, 2016), the temporal characteristics of the underlying mechanism of specific process of rewards and losses under competition remain unclear. More importantly, despite my previous research exploring the ERPs process of risky decision-making under competition, the task I adopted (i.e., BART) may cause individuals to have certain anticipations (e.g., make profits in the task) during the experiment, while the no-gain setting (i.e., balloon exploded) in BART may not be able to induce loss related ERPs components. Therefore, the same effect should be investigated in a more balanced expectation task. It is noteworthy that not all competition in society is specific and thus human is often in a state of vague and ambiguous social competition (Starcke & Brand, 2016). However, few research separately examine the sensitivity of individuals' neural processing on gains and losses under monetary and social competition. The doors task and the island getaway task have been demonstrated to reliably elicit reward-related brain activity (Threadgill et al., 2020). Considering the good balance of monetary/social rewards and losses, these two tasks are also used to capture neural responsiveness, especially in ERPs research (Burani et al., 2019; Carlson et al., 2011). In line with this idea, the doors task and the island getaway task will be chosen to use in the present study.

One achievable measurement to monetary/social reward and loss sensitivity is the Feedback-related negativity (FRN) component (Sutubasi et al., 2018) and the difference wave of FRN can better express individuals' expectation violation by different subtraction of positive and negative feedback (Gu et al., 2010; Liao et al., 2011;). Specifically, FRN difference wave could be divided into Reward Positivity (RewP, which calculated by positive feedback minus negative feedback) and Feedback Negativity (FN, which calculated by negative feedback minus negative feedback). In particular, by transforming the ERP into time-frequency activities, the more specific cognitive functions may be explained by analyzing the neural oscillation in different frequency bands. For instance, FRN can be decomposed into frequency bands - activity in the delta (δ) frequency band (0.5–4 Hz) to gain (i.e., reward-related delta) and activity in the theta (θ) frequency band (4–8 Hz) to loss (i.e., loss-related theta) (Bernat et al., 2015). Therefore, besides time-domain analysis, I intend to use time-frequency analysis to further investigate the impact of the monetary and social condition on processing rewards and losses under competition. Evidence from brain oscillations, as opposed to ERPs, may provide more comprehensive information of individuals' cognitive processing (Cohen et al., 2007).

Therefore, I intend to conduct an experiment to examine that (a) whether individuals have different sensitivity to rewards and losses under social-driven competition and monetary-driven competition in cognitive neuroscience processing.

4.2 Method

4.2.1 Participants

G*Power (Faul et al., 2007) v.3.1 would be used to conduct prior sample size estimation for 2 (condition: social vs monetary) $\times 2$ (feedback: gain vs loss) within-subject repeated analysis of variance (ANOVA). The following parameters is that 80% power, expected effect size of at least 0.25(f), an alpha of 0.05, the default within-subjects measurement correlation of 0.5, and a nonsphericity correlation value (ϵ) of 1. This calculation suggested a total sample size of 24 participants. Thus, this study aims to recruit 30 college students (50% males). All participants need to be right-handed and had normal or corrected-to-normal vision while having no history of physical or psychiatric illness.

4.2.2 The Doors Task and the Island Getaway Task

The Doors task (see Proudfit, 2015) will be used to measure the monetary rewards and losses and it will consist of 100 trials. All participants will be told that “they will play with others player (No specific quantity provided) in a virtual society with limited resources. Only when they get more money from the doors task can they receive bonuses, otherwise they will receive nothing”. On each trial, participants were asked to choose one of two doors shown side by side on the monitor, using the “F” and “J” key. The “doors” will remain on the screen until participant make a choice. A jitter then appeared for 800-1200ms, followed by a feedback screen for 2000ms. Feedback consisted of either a green “↑”, indicating a win of 1 Yuan, or a red “↓”, indicating a loss of 0.5 Yuan; these amounts were chosen to give gains and losses equivalent subjective values (Tversky & Kahneman, 1992). After receiving feedback, an infinite presented screen will show the text “Press any key to open next door,” which remained on the screen until participants respond. All participant actually will receive

25 Chinese Yuan as a payment. Noteworthy, participants will not be told that the doors task is actually pseudo-random as their behavior had no influence on feedback outcomes.

Aside from the doors task, the island getaway task will be used to measure the social rewards and losses in this study. The number of trials in this task is the same as the doors task (i.e., 100). All participants will be told that “they and some other players (No specific quantity provided) now need to evacuate from a dangerous island. However, considering the capacity of the evacuation ship is limited. The more positive comments mean that more people have a good impression of you and so that you are more likely to have a chance to get on the evacuation boat. Therefore, all the people on the island need to pass a check by voting with each other to decide which people (No specific quantity provided) will have the chance to leave”. Before this task, participants first respond to some poll question (e.g., “The proudest thing you have ever done”) and then reviewed other players’ responses (Prepared in advance by the experimenter) in order to facilitate an exchange of personal information for the remaining voting and feedback phases. Participants and all other pretended players will appear in the form of virtual avatars. On each trial, participants were asked to watch the results of others’ votes on themselves in random order shown on the monitor. After a 500ms fixation, participants will see the people who voted for them in this trial. The voter represented by virtual avatars will remain on the screen until participant press the “Space” key. A jitter then appeared for 800-1200ms, followed by a feedback screen for 2000ms. Feedback consisted of either a green “thumb-up”, indicating a positive comment on you (i.e., social like), or a red “thumb-down”, indicating the negative impression of you (i.e., social dislike). After receiving feedback, an infinite presented screen will show the text “Press any

key to view the result of the next voter,” which remained on the screen until participants respond. The payment and the confidential setting of pseudo-random are the same as the doors task. The schematic for the doors task and the island getaway task is shown in Figure 7. The order between social and monetary conditions will be presented at random.

Figure 7. The schematic for (a) the doors task and (b) the island getaway task

4.2.3 EEG recording and preprocessing

EEG data were sampled at a rate of 500 Hz from 64 Ag/AgCl electrodes mounted in a cap (Brain Products GmbH, Gilching, Germany) according to 10-20 international placement system connected to two amplifiers with an offline re-reference to all the averaged electrodes. The electrooculogram (EOG) was recorded from electrodes placed 1 cm below the right eye. Electrode impedances were kept below 10 kΩ during recording. All EEG data were recorded online utilizing the vertex FCz reference and re-referenced offline to the mean value of the bilateral mastoids. After the record was completed, the current research export offline EEG data into Matlab and use EEGLAB toolbox (Delorme & Makeig, 2004) as well as custom scripts for time-domain analysis.

To remove electronic artifacts (e.g., blanking and movement), this study conducted independent component analysis (ICA; Chaumon et al., 2015; Lee et al., 1999) for EEG data. Second, the data was filtered using a 0.1-40 Hz band-pass filter and a 48-52 Hz (the filtering effect was better than 49-51 Hz) notch filter. Third, EEG data was segmented into epochs that began 200 ms before stimulus onsets and ended 800 ms after onset, and further be baseline-corrected based on the 200ms pre-offer period. Moreover, the present research excluded epochs that contained artifacts exceeding $\pm 100\mu\text{V}$ from subsequent analyses.

4.2.4 ERP waveform comparison

As I mentioned above, FRN difference wave could be divided into Reward Positivity (RewP) and Feedback Negativity (FN). The RewP is typically measured as the gain minus loss difference score (see Proudfit, 2015), with higher positive values indicating greater reactivity to reward, and the FN is typically measured as the loss minus gain difference score (see Crane et al., 2021), with higher positive values indicating greater reactivity to loss. To explore the difference of ERP waveform between different condition under competition, I will perform the t-test on amplitude at the most positive peak of RewP and the most negative peak of FN on p-value, which may demonstrate the time-window with significant difference.

4.2.5 Time-frequency transformation

To extract the time-frequency bands, the electrode with maximal power will then decompose into their time-frequency representation using Morlet wavelets. Combined with the spectrogram that will be generated in this study, the average power of the loss-related θ power (4-7 Hz) of 300 to 500ms and the reward-related δ power of 100 to 300 ms (<3 Hz) will be selected for statistical analysis (Webb et al., 2017).

4.2.6 Data analysis strategies

EEG data difference will be performed using SPSS version 26.0 (SPSS, Inc., Chicago, IL) and analysis the RewP and FN amplitudes using a 2 (context: monetary vs. social) $\times$ 2 (feedback: gain vs. loss) repeated measures ANOVA. The present study will employ a Greenhouse-Geisser correction to account for the violations of the assumption of sphericity when necessary, and we will apply a Bonferroni correction for post hoc comparisons; we also will report the partial eta-squared as a measure of the proportion of variance that is explained by the independent variable.

5. STUDY 2: That was so close! The roles of social reference points on risky decision making under competition

5.1 Introduction

As the Nobel Prize winner Simon (1990) once wrote, “*Human rational behavior is shaped by scissors whose two blades are the structure of task environments and the capabilities of the actor.*” Social comparison in competitive environment has been proven to play an important role in individuals’ behavioral decisions (Linde & Sonnemans, 2012; Mishra et al., 2014; Page et al., 2017). However, previous research focused primarily on the profound influence of social comparison in competition. For instance, Liu et al.’s (2021) used a BART mission to investigate the risk-taking propensity in competition with a former winner or loser. In a similar vein, Meng et al.’s (2021) study also reported that in the condition of defeat result in former mission, individuals’ behavioral motivation in the competition changes more.

What previous studies unspecified were the instant influence of dynamic social comparison in the relation between competition and risky decision making. Consist with this perspective, social reference points in the competitive context may be an important variable for exploring dynamic competition on risky decision making. Social reference points indicated that decision makers will make corresponding choices based on the results of comparison with the status of others (Xie & Lu, 2014). Furthermore, social reference points contain both upward and downward social comparisons and this can be exemplified in competition as leading and behind. Directional inference comes from Hill and Buss.’s (2011) study showing that, in the benefit situation, when the risk option offers the chance to surpass

others but the determined option does not, people are more likely to choose the risk option. Similar evidence from Mishra et al. (2014) also found that competitively disadvantaged are less likely to succeed in social competition and will consequently show elevated risk-taking in order to surpass their opponents.

Although the upward comparison and the downward comparison can express the leading and backward in the competition. It is worth noting that, as a next step, the levels of leading and behind should also be included in the scope of the impact of competition on risky decision-making. Specifically, the leading state during competition can further distinguish between far leading and narrow leading while the behind state could be divided into far behind and near miss. Previous research found that winning in a stronger competitive environment may inspire individuals' sense of satisfaction and thus affect their decision-making (Ruedy et al., 2013). However, to our knowledge, studies on how social reference points moderate the dynamic competition on risky decision making remain limited.

Taken together, the present study aims to investigate: (a) whether social reference points modulate adolescents' risky decision propensity under both social and monetary competition. (b) The difference in FRN and P300 amplitude of individuals in the evaluation of upward (i.e., far leading, narrow leading) and downward (i.e., far behind and near miss) social comparison. (c) Individuals' FRN and P300 amplitude in different leading (i.e., far leading and narrow leading) and behind states (i.e., far behind and near miss) in the evaluation of gains and losses feedback.

5.2 Method

5.2.1 Participants

G*Power (Faul et al., 2007) v.3.1 would be used to conduct prior sample size estimation for 2 (condition: social, monetary) $\times 2$ (feedback: gain, loss) $\times 4$ (social reference point type: Leading by large margin, Narrow leading, Far behind and Near miss) within-subject repeated analysis of variance (ANOVA). To ensure 80% statistical power for detecting a small-to-medium effect size (Vazire, 2016), and detect a reliable effect, this study intend to recruit 36 college students (50% males). All participants need to be right-handed and had normal or corrected-to-normal vision while having no history of physical or psychiatric illness.

5.2.2 Monetary and social Balloon Analogue Risk Task (BART)

Each condition of BART will consist of 200 trials and the flow chart of two conditions of BART is shown as Figure 8.

In the monetary condition of BART, participants will be told that they would be competing in a BART mission with a peer (who was impersonated by the researcher). Their opponent will be in another room outside the EEG cabin during the game, and they will compete in real time. Participants will be also told that the final scores of the players determined whether they were victorious or defeated. The winner will get not just his or her BART awards, but also half of the total benefits of the loser. During the task, a pump might either raise the size and value of the balloon (positive feedback) or burst it, resulting in the loss of the collected rewards (negative feedback) and the maximum pump will be set to 12. For the feedback phase, there will present a red and green text color to present loss and gain feedback with 1500ms, respectively. All participants in the experiment will be instructed to pump the balloon in the counting of 5 seconds. When participants successfully pump the

balloon, they may receive the matching reward, or they forfeit all prior earnings from the current balloon as a punishment if the balloon is inflated past its particular popping point. Each participant will receive a total reward of roughly 50 Chinese yuan based on their performance under conditions.

In the social condition of BART (McCormick et al., 2018), participants will be instructed that they will play a “trick-or-treat” game, where they would approach a series of 200 people at their houses. At each house, participants had to choose whether to successively knock on the door, which would earn them more points with a green thumb-up and grimace as feedback. However, with each knock, the resident would get angrier and angrier. Participants will be told that if the resident (present by emoji face) of the home became too angry, they would slam their door and beat participants up, and participants would lose all the points they had earned on that door with a red thumb-down and slam door icon. As the competitive manipulation, participants will be required to complete the “trick or treat” game with another opponent, and use the total score as the indicator of winner and loser. As a social reward, the winner will be awarded a “the king of teenagers (KOT)” certificate, while the loser will not get this certificate. Each participant will receive a total reward of 50 Chinese yuan at the end of this experiment.

Figure 8. The flow-process diagram of social and monetary BART under one-on-one competition

5.2.3 The manipulation of social reference point

There are four types of manipulation of social reference points in this study (see Figure 9), including leading by large margin, narrow leading, far behind and near miss. During the task, four types of cues will appear in every two trials. Therefore, four types of social reference cues will present $25 \left(\frac{200}{2 \times 4} \right)$ trials each. The leading position of participants will be shown as a green line while a red line will be used to show the behind position. The position of opponents will always show as a black line. Specifically, I intend to use the distance between the participants' and the opponents' line as the distinction of leading by a large margin vs narrow lead, and far behind vs near miss.

Figure 9. The definition of four types of social reference cues

Considering the randomness of participants' decision-making on the outcomes during BART (e.g., participants receive loss feedback in the first 2 trials, but social reference prompts show that they are leading), the first 4 trials will be fully manipulated in this study to increase the authenticity experienced by participants. Specifically, I intend to design two sets of experiments, where participants randomly start the task from completely behind or completely leading. For those participants who start the task from completely behind, their first 4 trials will always receive loss feedback (excluded from analysis), while those who start the task from completely leading will receive 4 gain feedback in the first 4 trials (excluded from analysis). Moreover, in order to eliminate the occurring of The Ending Effect in risky decision making (Xing et al., 2019), the last two social reference points at the end of the

experiment will be always presented to one narrow leading cue and one near miss cue (also excluded from analysis) in random order for participants.

5.2.4 EEG data acquisition and preprocessing

As the same as the *previous research progress*.

5.2.5 ERPs analysis

The following ERPs components will be used in the subsequent analysis: P300 components (time window: 300-450 ms; electrodes Pz) and FRN components (electrodes Fz). Considering the overlap of FRN and P300 waveform, I aim to conduct the peak-to-average-peak method to compute the FRN (Xu et al., 2020). Specifically, I estimate the largest amplitudes of the negative peak (LNP, time window: 25ms) during 200-300ms following the feedback onset. Furthermore, I will detect the most positive going electrical potential during 160-260ms before negative peak as left largest positive peak (LLPP, time window: 25ms) and the most positive peak during 300-450ms after negative peak as right largest positive peak (RLPP, time window: 25ms). Then, I will calculate participants' FRN as the following equation: The P300 will estimated by mean voltage measurements. In specific, the P300 is calculated as the mean waveform (time window: 25ms) of the maximum positive amplitude during 300-450ms after the presentation of outcomes (Polich, 2007).

5.2.6 Statistic

For the behavioral data, a 2 (condition: monetary, social) $\times$ 2 (social reference points: under Leading by large margin, under Narrow leading, under Far behind and under Near miss) repeated measures ANOVA will be conducted on the average pumps (knocks) in BART. The current work will use a 2 (condition: monetary, social) $\times$ 2 (social reference

points: under Leading by large margin, under Narrow leading, under Far behind and under Near miss) $\times$ 2 (feedback: gain, loss) repeated measures ANOVA to analyze the FRN amplitudes during the feedback phase of EEG data, as well as the same ANOVA model to analyze the mean P300 amplitudes.

The present study will employ a Greenhouse-Geisser correction to account for the violations of the assumption of sphericity when necessary, and I will apply a Bonferroni correction for post hoc comparisons; this study will also report the partial eta-squared as a measure of the proportion of variance that is explained by the independent variable.

6. STUDY 3: The effect of “nip and tuck” on risky decision making under multiplayer competition

6.1 Introduction

Aside from one-on-one competitive context, recent evidence has pointed out that, during competition, awareness of low rank may be taken as a social punishment, and may make one eager to compensate by obtaining immediate reward even when the level of risk is high (Foo et al., 2017). Mishra et al.'s (2014) study share a similar premise and suggested that disadvantage in competition cause more risk-taking behaviors because attempting ‘longshots’ will be the only way to catch up to their opponents. On the contrary, both studies above showed that individuals may show higher risk aversion when they are ahead of the competition. It is noteworthy that, also as a manifestation of leading and lagging behind, the effect of “nip and tuck” (i.e., mutual bite between rankings) is common in the multiplayer competitive condition. Nonetheless, few studies have explored the role of such boundary conditions in competition on decision-making, in particular in neural cognitive level (Tharawadeepimuk & Wongsawat, 2017). In addition, there may be some potential process of change between leading by a large margin, fierce competitive state (e.g., stagger rankings between win and lose) and far behind.

Therefore, in this study, I will continue to use the far and near social reference point as the stimulus for investigating how far and near social reference points modulate the relation between monetary/social competition and risky decision making and the ERPs processing. I hypothesis that (a) there will be difference between the individuals’ risky decision-making level and ERPs amplitude in leading and behind position. (b) Leading and

lagging by a large margin and staggered rankings may have a certain relationship. Risky decision-making propensity may occur the highest level when participants are in staggered rankings between win and lose boundary position.

6.2 Method

6.2.1 Participants

G*Power (Faul et al., 2007) v.3.1 would be used to conduct prior sample size estimation for 2 (condition: social, monetary) $\times 2$ (feedback: gain, loss) $\times 2$ (social reference point type: Lead first, then approach vs. Fall behind first, then approach) mixed-subject repeated analysis of variance (ANOVA). To ensure 80% statistical power for detecting a small-to-medium effect size (Vazire, 2016), and detect a reliable effect, the total sample size will be required to at least 34 participants. Therefore, the current study intends to recruit 40 college students (50% males). All participants need to be right-handed and had normal or corrected-to-normal vision while having no history of physical or psychiatric illness.

6.2.2 Monetary and social Balloon Analogue Risk Task (BART)

Each condition of BART will consist of 240 trials and the flow-process chart of two conditions of BART is shown in Figure 10. The monetary condition and social condition of BART will be the same as STUDY 2. According to the settings of Zhu et al. (2016), the current study intends to conduct a 6 players group. Noteworthy, participants in both conditions (i.e., monetary and social) will be told that they will be regarded as winners in the competition when they place in the top 3 ranks.

Figure 10. The flow-process diagram of social and monetary BART under multiplayer competition

6.2.3 The manipulation of social reference point

As the same as the one-on-one competition, the multiplayer competition task also consists four types of manipulation of social reference points in this study (see Figure 11), including leading by large margin, narrow leading, far behind and near miss. During the task, four types of cues will appear in every two trials. Moreover, in multiplayer competitive missions, there are two more detailed settings of leading by large margin (i.e., rank the first and the second place) and far behind (rank in the fifth and sixth place) in order to increase the authenticity and intensity of the mission.

Figure 11. The introduction of (a) social reference point cues and (b) the presentation logic of social reference point in the current study

Considering the randomness of participants' decision-making on the outcomes during BART, the presented order of social reference points will be manipulated. Unbeknownst to

the students, ranks will be predetermined so that about half of the students will always leading by large margin in the first stage, then continuously presented with fluctuating the third of fourth ranks whereas the other half will always far behind in the first stage then continuously presented with the “nip and tuck” ranks (i.e., ranking the third of fourth place).

For the participants of “First lead, then approach”, they will receive 40 trials of “Leading by large margin” while “Narrow leading” and “Near miss” will be presented 40 trials each. For the participants of “First behind, then approach”, they will receive 40 trials of “Far behind” while “Narrow leading” and “Near miss” will be presented 40 trials each. The leading position of participants will be shown as a green tick icon while a red cross icon will be used to show the behind position. The position of opponents will always show as a black tick or cross. Specifically, rank the first and the second place are both defined as leading by large margin. The third rank and the fourth rank are respectively defined as narrow lead and near miss. Finally, the last two ranks refer to far behind.

6.2.4 EEG data acquisition and preprocessing

As the same as the **STUDY2**.

6.2.5 ERPs analysis

As the same as the **STUDY 2**.

6.2.6 Statistic

As the same as the **STUDY 2**.

7. POTENTIAL IMPLICATIONS AND CONTRIBUTIONS TO KNOWLEDGE

The current study has three potential important implications for developing the research field of competition on decision making. First, researchers will be better able to uncover the underlying mechanism of competition's impact on individuals' risky decision-making by distinguishing between the motivation by the reinforcement of social and monetary. Second, by examining the relation between competition and risk-taking behavior from a dynamic perspective, it will contribute to higher ecological validity in the research field of competition and extend the explanation boundary of social comparison theory. Third, the current research proposal will help promote the interpretation of the dynamic influence of competition on risky decision-making, and reveal the change in decision-making trends from leading or lagging behind by large margin state to a fierce state.

8. RESEARCH SCHEDULE (Unit: Quarter)

Research phase	Research objectives	2022			2023			
		2	3	4	1	2	3	4
Preliminary research	★ Literature review	√						
	★ Conduct a general research structure	√						
STUDY 1 The mechanism of processing reward and loss under competitive context: Evidence from neural oscillation	★ Literature review and experimental design	√						
	★ ERPs data collection	√	√					
	★ Data analysis and manuscript preparing		√	√				
STUDY 2 That was so close! The roles of social reference points on risky decision making under competition	★ Literature review and design of ERPs experiment		√	√				
	★ ERPs data collection		√	√				
	★ Data analysis and draft of manuscript		√	√	√			
STUDY 3 The effect of “nip and tuck” on risky decision making under multiplayer competition	★ Literature review and design of ERPs experiment		√	√	√	√		
	★ ERPs data collection				√	√	√	
	★ Data analysis and draft of manuscript				√	√	√	√

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