Running Head: PEER COMPETITION AND RISK-TAKING BEHAVIOR

**Neural Underpinnings underlying the Influence of Peer Competition on Risk-Taking Behavior
among Adolescent Girls: An Event-Related Potentials (ERPs) Study**

Ming-Chen Zhang

*Research Center of Adolescent Psychology and Behavior, School of Education, Guangzhou
University, Guangzhou China*

Jian-Bin Li

*Department of Early Childhood Education, The Education University of Hong Kong, Hong Kong
Special Administrative Region*

Kai Dou*

*Research Center of Adolescent Psychology and Behavior, School of Education, Guangzhou
University, Guangzhou China*

***Corresponding author:** *Kai Dou*

E-mail address: psydk@gzhu.edu.cn (Kai Dou)

Phone: +86-18819349858

Address: Guangzhou University, Guangzhou Higher Education Mega Center, 230, Waihuan Road
West, Panyu District, Guangzhou, China 510006

Abstract

Peer plays an important role in adolescent risk-taking. The existing studies have examined the effects of peer competition, an intensive form of peer influence, on adolescent risk-taking behavior, but the temporal neural underpinnings underlying this effect remain unclear. To fill this gap, the current study used Event related potentials (ERPs) technique in a 2 (condition: single vs. peer competition) $\times$ 2 (feedback: gain vs. loss) within-subject experiment to investigate the effects of peer competition on adolescent risk-taking behaviors and its neural process. Twenty-four late adolescent girls ($M_{\text{age}} = 19.83$ years, $SD = 1.49$) completed the Balloon Analogue Risk Task (BART) under the single and peer competition conditions with gain and loss feedbacks. ERPs were used to record the neural process when participants were working on the BART. Behavioral results revealed that participants showed more risk aversion in the peer competition condition than in the single condition. ERPs results found that during the decision-making phase, N2 component was elicited more negatively in the peer competition condition than in the single condition. During the feedback evaluation phase, a larger P300 was observed in the single condition than in the peer competition condition, while a higher amplitude of feedback-related negativity (FRN) difference wave was observed in the peer competition condition than in the single condition. This study contributes to the literature of adolescent risk-taking by identifying the effect of peer competition and its nuanced neural underpinnings.

Key words: peer competition; risk-taking; N2 component, feedback-related negativity; P300; youth

Neural Underpinnings underlying the Influence of Peer Competition on Risk-Taking Behavior among Adolescent Girls: An Event-Related Potentials (ERPs) Study

Risk-taking behaviors are a commonplace in adolescents (Arnett, 1992; Sherman et al., 2018). It refers to those behaviors that involve voluntary choices for behaviors where outcomes remain uncertain (Aklin et al., 2005; Crone et al., 2016). The negative forms of risk-taking behaviors (e.g., smoking, substance use, and crime) during adolescents may cascade into other poor outcomes in later life stages (Ben-Zur & Zeidner, 2009; Feeney et al., 2018). Identifying the etiological sources of adolescent risk-taking behavior is helpful in designing tailor-made strategies to mitigate negative risk-taking. Among other sources, peers play a critical role in adolescent risk-taking behaviors (Gardner & Steinberg, 2005; Smith et al., 2015). Hitherto, a number of studies have examined the effect of the gentle form of peer influence (e.g., peer presence, peer information) on adolescent risk-taking behavior (Chein et al., 2011; Kessler et al., 2016), but comparatively much less research has examined the effect of the intensive form of peer influence (e.g., peer competition) and its the underlying temporal neural underpinnings. Given the exceptional time resolution of event-related potentials (ERPs), the current study aims to adopt ERPs to disclose the precise timing of neural processes underlying the effect of peer competition on adolescent risk-taking behaviors.

Peer Influence on Risk-Taking Behaviors among Adolescents

Peers Influence during Adolescence

During adolescence, young people gradually spend less time with the family and invest more time with peers, which reflects adolescents' desire for autonomy and their development of social relationships (Collins & Laursen, 2004; Larson et al., 1996). Peers play an essential role in adolescents' many developmental outcomes, including externalizing, internalizing and academic problems (Giletta et al., 2021), and of course risk-taking behavior

(Liu et al., 2017). A main explanation of the high propensity of adolescents' risk-taking behaviors is the pursuit of potentially rewarding stimuli and the increasing social reinforcement (Forbes & Dahl, 2010). Studies have found that peers may strengthen adolescents' sensitivity to social rewards and therefore peer factors may predict their risk-taking behavior (Lorenz & Kray, 2022; Reiter et al., 2021; van Hoorn et al., 2016).

According to the *dual systems model*, the socio-emotional system develops rapidly during adolescence whereas the cognitive control system develops relatively slowly (Shulman et al., 2016; Steinberg, 2008). The imbalance between the socioemotional and cognitive control systems may contribute to the increase in risk-taking behaviors (Burani et al., 2019; Duell et al., 2018). Furthermore, the *dual systems model* also highlights that the influence of peers may "prime" a reward-sensitive motivational state that frequently outweighs adolescents' immature inhibitory control capacity, thereby causing a higher propensity for risk-taking behavior (Albert & Steinberg, 2011; Freeman et al., 2020). It is worthwhile to note that peer influences may take different forms, and previous research has suggested two forms of peer influence, namely *gentle* and *intensive* forms of peer influence (Laursen & Veenstra, 2021). These two forms of peer influences play different role in adolescent risk-taking behavior.

Gentle Peer Influence Plays an "Social Facilitation" Role in Risk-Taking Behavior

The gentle form of peer influence refers to the enhancement or impairment of performance engendered by the mere presence of others (Allport, 1927; Tricoche et al., 2020). This form of peer influence implies that adolescents are preoccupied to view the actual or imaginary presence of peer as "social facilitation". From this perspective, gentle peer influence serves as a specific social cue which provides adolescents with a strong sense of belonging and acceptance (Albert et al., 2013). Under gentle peer influence, adolescents prefer risky choices with short-term benefits rather than the safe choices with long-term value (O'Brien et al., 2011), and adolescents are also more motivated to take risks to show personal

attributes to gain admiration and popularity from peers (Baumeister & Leary, 1995; Chein et al., 2011, Knoll et al., 2015). This view is congruent with the studies which found that adolescents' risk-taking behavior is sensitive to the gentle form of peer influence, such as peer presence (Gardner & Steinberg, 2005), peer information (Tomova & Pessoa, 2018), and peers' risky choices (Osmont et al., 2021).

A long tradition of neural cognitive research also pointed out that the association between adolescents' risk-taking behaviors and gentle peer influence is particularly prominent. For instance, Chein et al.'s (2011) study indicated that the ventral striatum (VS) and orbitofrontal cortex (OFC) were activated more greatly under peer presence and higher engagement in risk-taking behavior occurred in peer presence condition. In event-related potentials (ERPs) studies, Kessler et al. (2017) used a Balloon Analogue Risk Task (BART) and found that adolescents assigned to the peer presence condition showed greater negative FRN than those assigned to the single (i.e., peer absence) condition after they received failure feedback. In a similar vein, Willoughby et al. (2021) suggested that adolescents were sensitive to peer observation and showed larger loss-feedback neural responses in the peer observation condition than in the single condition.

Intensive Peer Influence Plays an “Interpersonal Threat” Role in Risk-Taking Behavior

As mentioned above, although significant studies have investigated the effects of gentler form of peer influence (e.g., peer information, peer presence, peer observation) on adolescent risk-taking, understanding the influence of a more intensive peer influence condition (e.g., peer competition) on adolescents' behaviors would be also necessary. As a common form of aggressive peer interaction, peer competition refers to one's mental state and behavior of attempting to surmount others (Brickley et al., 2000; Garling et al., 2021). In line with *social comparison theory* (Festinger, 1954), individuals may evaluate themselves by comparing with others, which may induce their upward motivations and further promote

competition with peers. That is, adolescents may react differently to risk-taking behavior due to consideration of potential social evaluations in competition (Toelch et al., 2014). The high propensity of adolescents to take risky choices in competition condition is to surpass and outperform their opponents or acquire a better peer status and approval under competition (Crocker et al., 2003). Given that risk-taking is commonly viewed as an attractive strategy to promote individuals' chances of success (Hangen et al., 2016), adolescents are more likely to engage in risky behaviors with a high propensity of victory when the conservative decisions may not help them win the competition, even with a high probability of cost (Mishra et al., 2014).

Empirical research suggests that adolescent risk-taking behavior may be influenced by the desire to enhance social status in the competition context (Op de Macks et al., 2017), while similar conclusions were found in the effect of multiplayer competition context on risk-taking behaviors (Foo et al., 2017). In addition, Liu et al.'s (2020b) study suggested that male adolescents are more likely to show risk-taking behavior in peer competition condition when they are working on the BART. Habib et al.'s (2017) study revealed that the promotive effect of competition condition on adolescent risk-taking behavior is due to weakened regret under competition. From neurocognitive perspectives, Vorobyev et al.'s (2015) functional Magnetic Resonance Imaging (fMRI) study found that peer competition condition increased the activation in the right caudate head only for the rewarding outcome. Given that few studies have examined the temporal neural process underlying the effect of peer competition on adolescent risk-taking behavior. Filling this gap will contribute to the bigger picture of the neural underpinnings of why adolescents commit to risk-taking behavior. .

Event-Related Potential Components

As our previous elaborates, although studies involving fMRI have contributed to identifying brain regions related to adolescents' responses to peer competition (Fliessbach et

al., 2007; Luo et al., 2018; Vorobyev et al., 2015), little is known about the temporal characteristics of decision making and feedback evaluation processing among individuals in the competition condition. Event-related potentials (ERPs) could reveal important insights about the precise timing of processes underlying cognitive functions given the measure's excellent time resolution. Therefore, we aimed to examine the time characteristics of peer competition in modulating risk-taking behavior. Specifically, we consider both the decision-making phase and the feedback evaluation phase in risk-taking behavior. According to Luck (2005, 2014), difference wave of FRN could be better to describe the conflict degree of processing of the current feedback in a "gain and loss" dimension and achieve a better understanding of the specificity of loss processing, because the weaknesses of general FRN is that it does not accurately represent the underlying source waveforms that are summed together.

N2 Component in the Decision-Making Phase

The conflict related N2 component has often been used as biomarkers for decision making phase (Folstein & Van Petten, 2008). The N2 approximately occurs 250-350 ms following stimulus onset (Hajcak et al., 2006) and it indicates an index conflict detection during stimuli processing. The potentially conflicting pieces of information should be associated with N2 amplitude (Dennis et al., 2015). Following this idea, Clayson & Larson's (2011) study suggested that the degree of inconsistency of the experiment may modulate the N2 amplitudes during decision-making. Similarly, Li et al. (2021) found that decision-making under different conditions may activate the dorsal anterior cingulate cortex response correlated with conflict and error monitoring, which can be reflected in different amplitudes of N2. In a similar vein, Wang et al. (2016) found that a more negative going N2 reflected a greater cognitive effort to inhibit cognitive conflict elicited by making distrusting decisions.

Given that there is more conflict information that individuals need to consider under competition condition, a larger N2 component may be manifested.

Feedback-Related Negativity (FRN) in the Feedback-Evaluation Phase

Apart from N2 in decision-making phase, the FRN at the frontocentral sites is a commonly computed ERPs component after the onset of feedback (Gehring & Willoughby, 2002), presumably generated in the ACC (e.g., vertex electrode Fz). The FRN is a negative-going component, whose maximum elicited in approximately 250–350 ms after the onset of outcome presentation (Gehring & Willoughby, 2002; Walsh & Anderson, 2012). Considering that FRN is greater in response to negative than positive outcomes, previous research have commonly linked this component to the monitoring of individuals' unfavorable events (Miltner et al., 1997; Sambrook & Goslin, 2015). Previous research has highlighted that FRN is sensitive to the feedback of risk-taking behavior (Wang et al., 2014; Valt et al., 2019). In addition, FRN is also modulated by the losses and gains of decision-making feedback in social comparison condition (Van Meel & Van Heijningen, 2010; Yu et al., 2019).

P300 in the Feedback-Evaluation Phase

Following the FRN, the P300 is a centro-parietal positivity appearing in the 300–600 ms time window (Holroyd & Coles, 2002; San Martín, 2012; Yeung & Sanfey, 2004). On one hand, P300 is generally considered to reflect attentional resource allocation in outcome evaluation (Gray et al., 2004). Specifically, P300 encodes the valence and magnitude of an outcome, marked as a greater amplitude for affectively positive, larger outcomes than for affectively negative, smaller outcomes (Yeung & Sanfey, 2004; Yeung et al., 2005). Moreover, P300 reflects allocation of attentional resources and the subjective importance of the desired outcome (Polich, 2007; Pornpattananangkul et al., 2017). On the other hand, P300 component also is sensitive to social conditions in the outcome evaluation (Cui et al., 2017; Leue & Beauducel, 2019). For instance, evidence from Zhang et al.'s (2021) study indicated

that P300 is modulated by peer condition. Participants had stronger motivation to outperform dislikeable opponents. In addition, Valt et al.'s (2019) research found that P300 is associated with the feedback processing of social comparison, when participants' performance was not as good as the performance of others, a greater P300 component elicited. Also, Barker et al.'s (2021) research used a non-social and social conditions flanker task and found that female individuals exhibited a larger P300 in social condition as compared to nonsocial condition.

The Present Study

Although the effect of peer influence on adolescent risk-taking behavior is well documented, two issues remain unsolved. First, previous studies focused primarily on how *gentle* peer influence on adolescent risk-taking behavior, but comparatively less research has examined the effect of *intensive* peer influence (i.e., peer competition) directly. Second, despite a small number of studies that have examined the effect of peer competition on adolescent risk-taking, no ERPs studies have investigated the temporal neural underpinnings. To address these gaps, the current ERPs study sought to examine the neural correlates for the effect of peer competition on adolescent risk-taking behavior. BART (Lejuez et al., 2002) is a classical dynamic sequential risky-taking task under uncertainty. The performance in the BART task has been examined to be related to certain risky behaviors (e.g., smoking and drug use) in reality (Aklin et al., 2012; Lauriola et al., 2014). Here, we combined BART with electroencephalography (EEG) recording to answer two research questions. First, how does peer competition influence risk-taking behavior? Second, what is the temporal neural process for the said effect? For the behavioral outcomes, we hypothesize that individuals in peer competition condition will engage in more risk-taking behavior compared to those in the single condition. For the ERPs outcomes, we hypothesize that the N2 may be elicited higher in peer competition condition rather than in single condition; (2) the difference wave of FRN (dFRN) amplitude will be greater under the peer competition condition than the single

condition. (3) P300 is more induced in the peer competition condition, regardless of the gain and loss feedback participants receive.

Method

Participants

To examine the adequacy of the sample, we conducted a priori power analysis (G*Power 3.1) and suggested that at least 24 participants would be needed to ensure .80 power with an expected effect size (i.e., f) of 0.25 and an alpha level of 0.05 (Faul et al., 2007). Twenty-nine dextral college students participated in this study. They 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 24 female participants ($M_{\text{age}} = 19.83$ years, $SD = 1.49$, age range: 18-23 years). All procedures involving human participants were reviewed and approved by the research ethics committee of the corresponding author's institution. Participants provided written consent prior to participation.

Experimental Design

The experiment conducted a 2 (conditions: Single vs. Competition) $\times$ 2 (Feedback: Gain vs. Loss) within-participant factorial design. The order of the conditions was counterbalanced across participants.

Task and Procedure

In this study, we used the BART (Lejuez et al., 2002) to measure participants' risk-taking behavior. This task requires participants to make tradeoffs between low-risk, small-reward options, and high-risk, large-reward options (Canning et al., 2021). Previous studies have been confirmed that the risk-taking propensity on the BART is correlated with real-life risk-taking behavior in adolescents (Qu et al., 2015; Telzer et al., 2015). During the task, participants were required to pump balloons to get monetary rewards. Each pump not only

raises the size of the balloon and thus increases the reward, but also increases the explode propensity for the current balloon. For non-exploded balloons, a monetary reward was offered. For exploded balloons, participants' accumulated rewards would be forfeited from the current balloon as a punishment. The maximum pump of balloons was 128 in the origin version of BART (Lejuez et al., 2002). Therefore, in the origin BART, the probability that the balloon would burst after the first pump was $1/127$ while the probability climbed to $1/10$ after the second pump; and the burst probability of the balloon was 1.00 at the 128th pump. Here, we used an adapted version of the BART, which was well validated to assess risk-taking behavior in ERP studies (Xu et al., 2019). We modified the maximum pumps to 12 for each balloon. In each balloon, participants would win 10 cents for each pump in the balloon as long as the balloon does not burst. The BART was programmed with E-prime 2.0 (Psychology Software Tools; Figure 1) running on a Windows 10 PC.

Before the experiment, each participant sat comfortably in front of a computer screen in the laboratory, and all participants were asked to minimize their eye blinks and head movements while performing the task. The BART included 144 formal trials in each condition. All participants first saw a fixation for 800ms. After an 800-1200ms random delay blank, they were instructed to pump each balloon in the counting of 5 seconds. After another 800-1200ms random blank, participant received feedback. To start with, participants were given clear instructions and a practice block of 10 trials prior to the official test to ensure that they understood the task and the procedure. Participants completed the BART in two conditions (i.e., two blocks). For the single condition, participants were told that they would complete the BART alone and their total rewards would be based on their performance. In the peer competition condition, participants were told that they would be competing with an age-matched opponent who was impersonated by the researcher. The opponent was in another room outside the EEG cabin during the task, and they were competing in real time.

Participants were told that the final scores determined who would win or lose in the BART. The winner would get not only her own reward, but also half of the total reward of the loser. The order of single and competition condition was randomized. The experiment lasted about 20-25 minutes for each condition. All participants were given a 10-minute break between the two conditions. They received a total reward of roughly 80 Chinese yuan (about 12.5 dollars) based on their performance in the two conditions.

[Insert Figure 1 in here]

Manipulation Check and Behavioral Measures

Participants were asked to provide a self-reported manipulation check, which included (a) emotion under two conditions by using the 10-items positive and negative affective scale (PNAS; Watson et al., 1988); (b) the intensity of the task (i.e., “How intense you perceived in the task you just performed”) under two conditions 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).

We analyzed the following behavioral indices in this study: average pumps and average pumps after different feedback was given under the two conditions. The average pumps index refers to averaging all the balloon trials, including the exploded and non-exploded balloons. We also calculated participants’ average pumps in the current trial after receiving the gain and loss feedback respectively in the previous trial.

Psychophysiological Recordings

EEG was recorded from 64 scalp sites BrainAmp Standard amplifier and BrainVision Recorder software (Brain Products, Munich, Germany) at a sampling rate of 500 Hz. Ag/AgCl electrodes were fitted to an elastic cap according to the International 10-20 system. Additional electrodes were placed at the FCz for offline reference and at Afz as connection to

ground. All electrode impedances were kept below 10 k Ω throughout the experiment. Offline data were processed with BrainVision Analyzer 2 software (Brain Products, Munich, Germany). EEG channels were re-referenced to an average of the activity at the mastoids, and data were filtered at cutoffs of 0.01 and 40 Hz. All data were visually inspected and artifacts (e.g., muscle movement, horizontal eye movement) were removed. Eyeblinks were removed with the independent component analysis (ICA, Lee et al., 1999; Jung et al., 2000). ERPs segments ranging from 200 ms before to 800 ms after feedback onset were created, and baseline correction was performed based on the average signal in the 200 ms directly preceding feedback. Segments containing maximum amplitudes that exceeded an absolute value of 100 μ V or a voltage step from one sample to the next of 50 μ V were excluded by means of automated artifact rejection.

EEG Analysis

The N2 component was utilized to examine the group differences in the decision-making phase, while the FRN and P300 components were used to examine the feedback evaluation phase. Given the overlap of FRN waveform, the current study conducted the peak-to-average-peak method to compute the general FRN (Osinsky et al., 2012; Xu et al., 2019). Specifically, this study estimated the largest amplitudes of the negative peak during 250-350ms following the feedback onset. Furthermore, we detected the most positive going electrical potential during 150-250ms before negative peak as left largest positive peak (Wischnewski & Schutter, 2018) and the most positive peak during 350-450ms after negative peak as right largest positive peak (de Groot & van Strien, 2019). Then, individuals' mean amplitudes for the 25ms time windows around these positive and negative peaks were computed (e.g., Osinsky et al., 2012), and the difference in voltages between the mean

amplitudes of the most negative feedback and the average of the mean amplitudes of the preceding and succeeding peaks was used to calculate the general FRN. The N2 and P300 were estimated by peak voltage measurements. To be specific, the P300 was calculated as the mean waveform (time window: 25ms) of the maximum positive amplitude during 300-450ms after the presentation of feedback (Polich, 2007), while N2 was also calculated as the mean waveform (time window: 25ms) of the maximum negative amplitude during 250-350ms after the decision-making stimuli presented (Folstein & Van Petten, 2008).

Data Analysis Strategies

For the behavioral data, a 2 (condition: single vs. competition) $\times$ 2 (feedback¹: gain vs. loss) repeated measures ANOVA was conducted on the average pumps² in BART. For the decision-making phase of EEG data, we analyzed the N2 component using single factor two levels (condition: single vs. competition) repeated measures ANOVA. For the feedback evaluation phase, we used a 2 (condition: single vs. competition) $\times$ 2 (feedback: gain vs. loss) repeated measures ANOVA to analyze the FRN amplitudes during the feedback phase of EEG data and the mean P300 amplitudes. We employed a Greenhouse-Geisser correction to account for the violations of the assumption of sphericity when necessary. We utilized Bonferroni correction for post hoc comparisons, and we also reported the partial eta squared as a measure of the proportion of variance explained by the independent variable.

Results

Manipulation Check Results

The results of the manipulation check showed that there were no significant differences in positive or negative emotions between single and competition condition ($ps = 0.09\sim 0.54$). However, the paired sample t-tests showed that the intensity of the task was higher for the competition condition ($M = 6.50, SD = 1.75$) than for the single condition ($M = 4.38, SD =$

¹ For the behavioral data, feedback refers to the previous feedback of last trial.

² The average pump in BART refers to participants' average pumps after receiving the feedback of the previous trial.

1.93), $t = -5.43$, $p < .001$, Hedges' $g = 1.15$. In addition, the average score of the participants on the question of task authenticity was 5.00 ($SD = 1.38$), which indicated that participants believed they were in a real competition in general.

Behavioral Results

As indicated in Figure 2a, participants pumped less in the peer competition condition ($M = 5.36$, $SD = 1.02$) relative to the single condition ($M = 5.65$, $SD = 0.72$), $F_{(1, 25)} = 7.36$, $p = .012$, partial $\eta^2 = 0.242$.

[Insert Figure 2a and 2b in here]

To investigate the effect of the previous balloon explosion on the current risk-taking behavior, we conducted further ANOVA on the average pumps of balloons with the factors of previous trial feedback (gain or loss) and condition (single or peer competition). As indicated in Figure 2b and Table 1, there was a significant main effect of condition, $F_{(1, 25)} = 6.77$, $p = .016$, partial $\eta^2 = 0.227$. Participants pumped more in the single condition than in the peer competition condition regardless of the feedback of the previous trial. However, we did not find a significant main effect of feedback ($F_{(1, 25)} < 1$, $p = .341$, partial $\eta^2 = 0.039$) and there was no interaction between condition and feedback ($F_{(1, 25)} = 1.45$, $p = .242$, partial $\eta^2 = 0.059$).

[Insert Table 1 in here]

ERPs Results

Decision-Making Phase

The mean N2 component amplitudes are summarized in Table 2 and the grand average ERPs waveforms for positive and negative feedback for the channel Fz across conditions are presented in Figure 3. The peak voltage measurements determined through a repeated measure ANOVA revealed a significant and main effect of the condition (single vs. peer competition), $F_{(1, 25)} = 8.36$, $p = .008$, partial $\eta^2 = 0.266$. Specifically, a more negative

N2 occurred in the competition condition ($-5.78 \pm 3.89 \mu\text{V}$) than in the single condition ($-4.27 \pm 3.57 \mu\text{V}$).

[Insert Figure 3 in here]

Feedback Evaluation Phase

Grand average ERPs of FRN and P300 waveforms in feedback evaluation phase are presented in Figure 4 and 5. For FRN, the mean voltage measurements determined through a repeated measure ANOVA revealed a significant and main effect of the feedback (gain vs. loss), $F_{(1, 25)} = 25.15, p < .001$, partial $\eta^2 = 0.52$. Specifically, a more negative FRN was observed after loss feedback ($-6.99 \pm 4.91 \mu\text{V}$) than after the gain feedback ($-3.96 \pm 3.23 \mu\text{V}$). However, the results did not observe a significant main effect of condition ($F_{(1, 25)} < 1, p = .746$, partial $\eta^2 = 0.005$) or interaction effect between condition and feedback ($F_{(1, 25)} = 2.32, p = .142$, partial $\eta^2 = 0.091$).

[Insert Table 2 in here]

In the current study, the difference wave of FRN was calculated by subtracting the wave of gain from the wave of loss (Figure 4). A significance main effect was found between the two conditions, $F_{(1, 25)} = 6.83, p = .016$, partial $\eta^2 = 0.229$. The difference wave induced in the single condition ($-4.55 \pm 4.33 \mu\text{V}$) was larger than competition condition ($-7.17 \pm 4.47 \mu\text{V}$).

[Insert Figure 4 in here]

Contrary to the FRN, repeated-measure ANOVAs of P300 amplitude (Figure 5) revealed a significant effect of condition ($F_{(1, 25)} = 8.387, p = .008$, partial $\eta^2 = 0.267$), such that larger positive peaks were induced in the single condition ($12.05 \pm 5.07 \mu\text{V}$) than in the peer competition condition ($9.44 \pm 5.75 \mu\text{V}$). Also, a significant main effect of the feedback ($F_{(1, 25)} = 4.35, p = .048$, partial $\eta^2 = 0.159$) was observed. The gain feedback ($11.53 \pm 5.22 \mu\text{V}$) elicited larger positive peaks than the loss feedback ($9.96 \pm 5.36 \mu\text{V}$). However, the

interaction effect between condition and feedback ($F_{(1, 25)} < 1$, $p = .422$, partial $\eta^2 = 0.028$) did not reached significance.

[Insert Figure 5 in here]

Discussion

How gentle peer influence on adolescent risk-taking has been widely examined at behavioral and neural levels (Chein et al., 2011; Kessler et al., 2016; Tricoche et al., 2020; van Hoorn et al., 2016). A few studies have also investigated intensive peer influence on adolescent risk-taking behavior (Liu et al., 2020; Mishra et al., 2014) and adopted fMRI to examine its underlying neural processes (Op de Macks et al., 2017; Polosan et al., 2011; Vorobyev et al., 2015). However, little is known about the temporal neural process. To fill this gap in the literature, the current study used the ERPs technique to analyze the effect of peer competition situation on adolescent risk-taking behavior in the BART. Our results indicated that, adolescents were less likely to inflate the balloon in the competition condition than in single condition. At the decision-making phase, a more negative going of N2 amplitude elicited in the peer competition condition was larger than that in the single condition. At the feedback evaluation phase, our results revealed the difference wave of FRN was larger in the peer competition condition than in the single condition while P3 amplitude was more pronounced in the single condition than in the peer competition condition.

The Influence of Peer-Competition on Risk-Taking Decision at the Behavioral Levels

The behavioral result of the current study has replicated that, participants had a higher propensity for risk-taking behavior under single condition rather than peer competition condition. This finding is inconsistent with the previous studies which commonly found that adolescents may ignore the negative outcomes and engage in more risk-taking behavior to win the competition so that they could acquire potential social praise and peer recognition (Liu et al., 2020b; Vorobyev et al., 2015). Of note, our punishment setting was “lose 50

percent of participants' reward to their opponent in the competition" while Liu et al.'s (2020b) setting was "receive nothing if participants lose in the competition". We speculate that such inconsistency of reward or punishment judgments in competition may lead to individuals' inconsistent behavioral outcomes.

According to the *prospect theory* (Kahneman & Tversky, 1979), individuals are more risk-seeking when facing with losses, but they are more risk-averse when facing rewards. Liu et al.'s (2020b) setting implies that participants are more willing to make risky choices to win because they will lose 100 percent of reward if they lose the competition. By contrast, the manipulation of losing 50% of reward in our study may urge adolescents to use rational strategies to make conservative decisions, because participants can still obtain 50% of the reward even if they lose. Another possible explanation is that Liu et al.'s (2020b) study only found the facilitative effect of peer competition on risk-taking behavior among male adolescents, whereas our study focused on adolescent girls. The gender differences in risk preference may help explain the inconsistency. Future research should broaden the scope of the binary competition outcome of winning or losing by using computational modeling measures, such as using the drift diffusion model (Ratcliff & McKoon, 2008) from an information accumulation of decision-making perspective. It may better clarify the boundaries of changes in risky behavior under competition.

According to the *social comparison theory*, individuals frequently evaluate themselves through comparison with 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, participants' gains and losses are solely borne by themselves in the single condition,

so they are more willing to take risks to maximize their own benefits without worrying about the potential negative repercussions of their decision (Jiao et al., 2015).

The Influence of Peer Competition on Risk-Taking Behavior at the Neural Levels

The ERPs results demonstrated that individuals responded differently to risk-taking behaviors in the BART and revealed the neural underpinnings under different conditions. Electrophysiologically, the decision-making and outcome evaluation phases perspective (Wang et al., 2016) provides support for our research and three ERPs components (the N2, FRN, and P300) revealed group differences in neural processing under risk-taking behavior. Early-stage of decision-making processing to risky choices was reflected in the N2 while outcome evaluation processing to different feedback under single and competition conditions was reflected in the FRN and P300.

As expected, we observed a negative going between 250 and 350ms, which may be identified as an N2 component (Hajcak et al., 2006). To be specific, participants' N2 was modulated by the condition. A larger N2 amplitude occurred in the peer competition condition. This finding is in line with our hypothesis, which indicates that participants consider additional factors (e.g., extra punishment) in their decision-making process under the peer competition condition which increases the level of cognitive conflict in the early stage of decision-making process (Li et al., 2021). Research has shown that greater N2 is associated with increased conflict adaption (Clayson & Larson, 2011). Previous evidence also suggested that N2 is thought to be an index of cognitive control (Enriquez-Geppert et al., 2010). Combining our behavioral results, we assume that the setup of peer competition is a contextual social cue. The conflict willingness between receiving an extra reward from opponents and preventing one's own reward from being "snatched" by opponents alters the N2 amplitude, and thus participants engage in more conservative decision-making at the behavioral level.

Following the N2, a significantly different general FRN amplitude was found in the feedback condition, while no significant difference was detected in the single and peer competition condition. This finding is 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 conditions, participants' goal to accomplish BART is to gain benefits. Hence, their expectation violation would be activated more when perceiving loss feedback and thus a larger general FRN would be generated. According to Luck (2014), difference wave of FRN could be better to be described as the conflict degree of processing of the current feedback in a 'gain and loss' dimension. In this study, the amplitude of loss minus gain was used to calculate the FRN difference wave, which may conduct a better understanding of the specificity of loss processing (Xu et al., 2021). Based on this perspective, we observed a significant difference in difference waves of FRN between the single and peer competition conditions. Specifically, the FRN difference waves under the competition condition were larger. The results revealed that late adolescents seem to have a stronger sensitivity to loss-aversion under the competition condition rather than those in the single condition. This could also explain why they behave more conservatively (as measured by lower average pumps) under the social pressure context (Lin et al., 2021).

Of note, the P300 also represented the processing of feedback evaluation (Wang et al., 2014; Yeung & Sanfey, 2004). Our results showed that P300 amplitude was modulated by conditions while no significant effects were found in the feedback. 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 the peer competition condition, a larger P300 was elicited in the single condition, which may indicate that

individuals took all benefits themselves in the single condition and, as a result, they prefer to invest more psychological resources in the evaluation of outcomes (Hajcak et al., 2010). Prior fMRI studies revealed that individuals who reacted to peer condition with a decision response were associated with reward-based regions of the brain including the ventral striatum (VS), ventromedial prefrontal cortex (vmPFC) and orbitofrontal cortex (Pei et al., 2020; Polosan et al., 2011; Vorobyev et al., 2015). Therefore, compared with those in the peer competition condition, the higher inflation pumps appeared more rewarding and desirable for participants in the single condition because the reward is entirely up to them. This may place greater subjective importance on such outcomes and provided neurological explanation for the behavioral result of risk-seeking tendency in the single condition.

Limitations and Future Research

The current study has several limitations. First, this study focuses only on female adolescents. Yet, according to the male-warrior hypothesis (Vugt et al., 2007), cognitions and behaviors among males are more responsive to social interaction than females. Such effect was also confirmed by Liu et al.'s (2020b) study. In addition, evidence showed that males are more likely to engage in risk-taking behaviors (Lewis et al., 2021; Van Leijenhorst et al., 2008). Future studies may benefit from recruiting larger samples and investigating the gender differences in how peer competition predicts risk-taking among adolescents. Second, there are other factors that require continued empirical inquiries. For instance, our research focused primarily on how competition modulates risk-taking behavior in monetary-driven condition. The same effect should be clarified in social-driven condition (e.g., by using the island getaway task (Kujawa et al., 2014)). Third, the current study did not examine how the size of reward and the influences of different peers (e.g., strangers vs. friends) on participants' risk-taking behavior, future research should aim to uncover the effect of peer competition on risk-taking with more sophisticated research designs.

Conclusion

This study contributes to the understanding of the temporal neural process of the influence of peer competition on adolescent risk-taking. At the behavioral level, adolescents acted more cautiously when being alone than when playing with a peer. At the neural level, our study indicated that in the decision-making phase, a more negative going of N2 related to cognitive conflict was observed in the peer competition condition than in the single condition. In the feedback evaluation phase, a larger difference wave of FRN was elicited in the peer competition than in the single condition, whereas a more positive P300 amplitude was found in the single condition rather than in the peer competition condition. In sum, these findings together suggest that adolescent girls are more likely to make risk-adverse decision under peer competition context (vs. single context). The results also provide further behavioral and neural evidence for the intensive peer influence on adolescent risk-taking behavior.

References

- Allport, F. H. (1924). *Social Psychology*. Boston: Houghton Mifflin.
- Aklin, W. M., Lejuez, C. W., Zvolensky, M. J., Kahler, C. W., & Gwadz, M. (2005). Evaluation of behavioral measures of risk taking propensity with inner city adolescents. *Behaviour research and therapy*, 43(2), 215–228.
<https://doi.org/10.1016/j.brat.2003.12.007>
- Aklin, W. M., Severtson, S. G., Umbricht, A., Fingerhood, M., Bigelow, G. E., Lejuez, C., & Silverman, K. (2012). Risk-taking propensity as a predictor of induction onto naltrexone treatment for opioid dependence. *The Journal of Clinical Psychiatry*, 73(8), 1056–1061. <https://doi.org/10.4088/JCP.09m05807>
- Albert, D., & Steinberg, L. (2011). Peer influences on adolescent risk behavior. In M. T. Bardo, D. H. Fishbein, & R. Milich (Eds.), *Inhibitory control and drug abuse prevention: From research to translation* (pp. 211–226). New York, NY: Springer
- Barker, T. V., Buzzell, G. A., Troller-Renfree, S. V., Bowman, L. C., Pine, D. S., & Fox, N. A. (2021). The influence of social motivation on neural correlates of cognitive control in girls. *Developmental Psychobiology*, 63(5), 1611–1625.
<https://doi.org/10.1002/dev.22086>
- Boudewyn, M. A., Luck, S. J., Farrens, J. L., & Kappenman, E. S. (2018). How many trials does it take to get a significant ERP effect? It depends. *Psychophysiology*, 55(6), Article e13049. <https://doi.org/10.1111/psyp.13049>
- Brain Products. (2013). *Ocular correction ICA* (Vol. 49). Brain Products Press Release.
- Brown, B. B., & Larson, J. (2009). Peer relationships in adolescence. In R. M., Lerner & L., Steinberg, (Eds.), *Handbook of adolescent psychology: Contextual influences on adolescent development* (pp. 74–103). Hoboken, NJ: John Wiley & Sons, Inc.
<https://doi.org/10.1002/9780470479193.adlpsy002004>

- Burani, K., Mulligan, E. M., Klawohn, J., Luking, K. R., Nelson, B. D., & Hajcak, G. (2019). Longitudinal increases in reward-related neural activity in early adolescence: Evidence from event-related potentials (ERPs). *Developmental Cognitive Neuroscience*, 36, Article 100620. <https://doi.org/10.1016/j.dcn.2019.100620>
- Buunk, A. P., Groothof, H. A. K., & Siero, F. W. (2007). Social comparison and satisfaction with one's social life. *Journal of Social and Personal Relationships*, 24(2), 197–205. <https://doi.org/10.1177/0265407507075410>
- Chein, J., Albert, D., O'Brien, L., Uckert, K., & Steinberg, L. (2011). Peers increase adolescent risk taking by enhancing activity in the brain's reward circuitry. *Developmental Science*, 14(2), 1–10. <https://doi.org/10.1111/j.1467-7687.2010.01035.x>
- Clayson, P. E., & Larson, M. J. (2011). Conflict adaptation and sequential trial effects: Support for the conflict monitoring theory. *Neuropsychologia*, 49(7), 1953–1961. <https://doi.org/10.1016/j.neuropsychologia.2011.03.023>
- Collins, W. A., & Laursen, B. (2004). Changing Relationships, Changing Youth: Interpersonal Contexts of Adolescent Development. *Journal of Early Adolescence*, 24(1), 55–62. <https://doi.org/10.1177/0272431603260882>
- Crocker, J., Luhtanen, R. K., Cooper, M. L., & Bouvrette, A. (2003). Contingencies of self-worth in college students: Theory and measurement. *Journal of Personality and Social Psychology*, 85(5), 894–908. <https://doi.org/10.1037/0022-3514.85.5.894>
- Crone, E. A., van Duijvenvoorde, A. C., & Peper, J. S. (2016). Annual Research Review: Neural contributions to risk-taking in adolescence—developmental changes and individual differences. *Journal of Child Psychology and Psychiatry*, 57(3), 353–368. <https://doi.org/10.1111/jcpp.12502>

- Cui, F., Zhu, X. R., & Luo, Y. J. (2017). Social contexts modulate neural responses in the processing of others' pain: An event-related potential study. *Cognitive Affective & Behavioral Neuroscience*, 17(4), 850–857. <https://doi.org/10.3758/s13415-017-0517-9>
- Defoe, I. N., Dubas, J. S., Figner, B., & van Aken, M. A. G. (2015). A meta-analysis on age differences in risky decision making: Adolescents versus children and adults. *Psychological Bulletin*, 141(1), 48–84. <https://doi.org/10.1037/a0038088>
- de Groot, K., & van Strien, J. W. (2019). Event-related potentials in response to feedback following risk-taking in the hot version of the Columbia Card Task. *Psychophysiology*, 56(9), Article e13390. <https://doi.org/10.1111/psyp.13390>
- Dennis, T. A., Amodio, D. M., & O'Toole, L. J. (2015). Associations between parental ideology and neural sensitivity to cognitive conflict in children. *Social Neuroscience*, 10(2), 206–217. <https://doi.org/10.1080/17470919.2014.968290>
- Duell, N., Steinberg, L., Icenogle, G., Chein, J., Chaudhary, N., Di Giunta, L., Dodge, K. A., Fanti, K. A., Lansford, J. E., & Oburu, P. (2018). Age patterns in risk taking across the world. *Journal of Youth and Adolescence*, 47(5), 1052–1072. <https://doi.org/10.1007/s10964-017-0752-y>
- Duell, N., & Steinberg, L. (2020). Differential correlates of positive and negative risk taking in adolescence. *Journal of Youth and Adolescence*, 49(6), 1162–1178. <https://doi.org/10.1007/s10964-020-01237-7>
- Elkind, D., & Bowen, R. (1979). Imaginary audience behavior in children and adolescents. *Developmental psychology*, 15(1), 38–44. <https://doi.org/10.1037/0012-1649.15.1.38>
- Enriquez-Geppert, S., Konrad, C., Pantev, C., & Huster, R. J. (2010). Conflict and inhibition differentially affect the N200/P300 complex in a combined go/nogo and stop-signal task. *Neuroimage*, 51(2), 877–887. <https://doi.org/10.1016/j.neuroimage.2010.02.043>

- Ertac, S., & Gurdal, M. Y. (2012). Deciding to decide: Gender, leadership and risk-taking in groups. *Journal of Economic Behavior & Organization*, 83(1), 24–30.
<https://doi.org/10.1016/j.jebo.2011.06.009>
- Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39(2), 175–191. <https://doi.org/10.3758/bf03193146>
- Feeney, A., Travers, E., O'Connor, E., Beck, S. R., & McCormack, T. (2018). Knowing when to hold "em: regret and the relation between missed opportunities and risk taking in children, adolescents and adults. *Cognition & Emotion*, 32(3), 608–615.
<https://doi.org/10.1080/02699931.2017.1326373>
- Festinger, L. (1954). A theory of social comparison processes. *Human Relations*, 7(2), 117–140.
- Fliessbach, K., Weber, B., Trautner, P., Dohmen, T., Sunde, U., Elger, C. E., & Falk, A. (2007). Social comparison affects reward-related brain activity in the human ventral striatum. *Science*, 318(5854), 1305–1308. <https://doi.org/10.1126/science.1145876>
- Folstein, J. R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, 45(1), 152–170.
<https://doi.org/10.1111/j.1469-8986.2007.00602.x>
- Foo, J. C., Nagase, K., Naramura-Ohno, S., Yoshiuchi, K., Yamamoto, Y., & Morita, K. (2017). Rank among peers during game competition affects the tendency to make risky choices in adolescent males. *Frontiers in Psychology*, 8, Article 16.
<https://doi.org/10.3389/fpsyg.2017.00016>
- Forbes, E. E., & Dahl, R. E. (2010). Pubertal development and behavior: Hormonal activation of social and motivational tendencies. *Brain and Cognition*, 72(1), 66–72.
<https://doi.org/10.1016/j.bandc.2009.10.007>

- Furman, W., & Buhrmester, D. (1992). Age and sex differences in perceptions of networks of personal relationships. *Child Development*, 63(1), 103–115.
<https://doi.org/10.2307/1130905>
- Hajcak, G., MacNamara, A., & Olvet, D. M. (2010). Event-Related Potentials, Emotion, and Emotion Regulation: An Integrative Review. *Developmental Neuropsychology*, 35(2), 129–155. <https://doi.org/10.1080/87565640903526504>
- Gehring, W. J., & Willoughby, A. R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science*, 295(5563), 2279–2282.
<https://doi.org/10.1126/science.1066893>
- Hajcak, G., Moser, J. S., Holroyd, C. B., & Simons, R. F. (2006). The feedback-related negativity reflects the binary evaluation of good versus bad outcomes. *Biological Psychology*, 71(2), 148–154.
- Holroyd, C. B., Pakzad-Vaezi, K. L., & Krigolson, O. E. (2008). The feedback correct-related positivity: Sensitivity of the event-related brain potential to unexpected positive feedback. *Psychophysiology*, 45(5), 688–697. <https://doi.org/10.1111/j.1469-8986.2008.00668.x>
- Holroyd, C. B., & Coles, M. G. H. (2002). The neural basis. of human error processing: Reinforcement learning, dopamine, and the error-related negativity. *Psychological Review*, 109(4), 679–709. <https://doi.org/10.1037//0033-295x.109.4.679>
- Jung, T. P., Makeig, S., Humphries, C., Lee, T. W., McKeown, M. J., Iragui, V., & Sejnowski, T. J. (2000). Removing electroencephalographic artifacts by blind source separation. *Psychophysiology*, 37(2), 163–178. <https://doi.org/10.1111/1469-8986.3720163>
- Kahneman, D., & Tversky, A. (1979). Prospect theory of decision under risk. *Econometrica*, 47(2), 263–291.

- Kessler, L., Hewig, J., Weichold, K., Silbereisen, R. K., & Miltner, W. H. R. (2017). Feedback negativity and decision-making behavior in the Balloon Analogue Risk Task (BART) in adolescents is modulated by peer presence. *Psychophysiology*, 54(2), 260–269. <https://doi.org/10.1111/psyp.12783>
- Kujawa, A., Arfer, K. B., Klein, D. N., & Proudfit, G. H. (2014). Electrocortical reactivity to social feedback in youth: A pilot study of the Island Getaway task. *Developmental Cognitive Neuroscience*, 10, 140–147. <https://doi.org/10.1016/j.dcn.2014.08.008>
- Kwon, S. J., Do, K. T., McCormick, E. M., & Telzer, E. H. (2021). Neural correlates of conflicting social influence on adolescent risk taking. *Journal of Research on Adolescence*, 31(1), 139–152. <https://doi.org/10.1111/jora.12587>
- Larson, R. W., Richards, M. H., Moneta, G., Holmbeck, G., & Duckett, E. (1996). Changes in adolescents' daily interactions with their families from ages 10 to 18: Disengagement and transformation. *Developmental Psychology*, 32(4), 744–754. <https://doi.org/10.1037/0012-1649.32.4.744>
- Lauriola, M., Panno, A., Levin, I. P., & Lejuez, C. W. (2014). Individual differences in risky decision making: a meta-analysis of sensation seeking and impulsivity with the balloon analogue risk task. *Journal of Behavioral Decision Making*, 27(1), 20–36. <https://doi.org/10.1002/bdm.1784>
- Lee, T.-W., Girolami, M., & Sejnowski, T. J. (1999). Independent component analysis using an extended infomax algorithm for mixed subgaussian and supergaussian sources. *Neural computation*, 11(2), 417–441. <https://doi.org/10.1162/089976699300016719>
- Lejuez, C. W., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., Strong, D. R., & Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology. Applied*, 8(2), 75–84. <https://doi.org/10.1037/1076-898x.8.2.75>

- Leue, A., & Beauducel, A. (2019). A meta-analysis of the P3 amplitude in tasks requiring deception in legal and social contexts. *Brain and Cognition*, 135, Article 103564. <https://doi.org/10.1016/j.bandc.2019.05.002>
- Lewis, G., Srinivasan, R., Roiser, J., Blakemore, S.-J., Flouri, E., & Lewis, G. (2021). Risk-taking to obtain reward: sex differences and associations with emotional and depressive symptoms in a nationally representative cohort of UK adolescents. *Psychological Medicine*, 1–9. <https://doi.org/10.1017/s0033291720005000>
- Li, M., Li, J., Tan, M., & Zhong, Y. (2021). Exposure to money modulates the processing of charitable donation: An event-related potentials study. *Neuroscience Letters*, 765, Article 136277. <https://doi.org/10.1016/j.neulet.2021.136277>
- Lin, Y. L., Gu, R. L., Luan, S. H., Hu, L., Qin, S. Z., & Luo, Y. J. (2021). The hierarchical sensitivity to social misalignment during decision-making under uncertainty. *Social Cognitive and Affective Neuroscience*, 16(6), 565–575. <https://doi.org/10.1093/scan/nsab022>
- Liu, Z., Liu, T., & Li, Y. (2020a). How does social competition affect true and false recognition? *Psychonomic Bulletin & Review*, 28(1), 292–303. <https://doi.org/10.3758/s13423-020-01807-7>
- Liu, Z., Liu, T., & Mu, S. (2020b). Gender differences in the effects of competition and cooperation on risk-taking under ambiguity. *Psych Journal*, 10(3), 374–383. <https://doi.org/10.1002/pchj.419>
- Luo, Y., Eickhoff, S. B., Hetu, S., & Feng, C. L. (2018). Social comparison in the brain: A coordinate-based meta-analysis of functional brain imaging studies on the downward and upward comparisons. *Human Brain Mapping*, 39(1), 440–458. <https://doi.org/10.1002/hbm.23854>

- Luo, Y., Feng, C. L., Wu, T. T., Broster, L. S., Cai, H. J., Gu, R. L., & Luo, Y. J. (2015). Social comparison manifests in event-related potentials. *Scientific Reports*, 5, Article 12127. <https://doi.org/10.1038/srep12127>
- McCormick, E. M., Perino, M. T., & Telzer, E. H. (2018). Not just social sensitivity: Adolescent neural suppression of social feedback during risk taking. *Developmental Cognitive Neuroscience*, 30, 134–141. <https://doi.org/10.1016/j.dcn.2018.01.012>
- Nockur, L., Pfattheicher, S., & Keller, J. (2021). Different punishment systems in a public goods game with asymmetric endowments. *Journal of Experimental Social Psychology*, 93, 1–10. <https://doi.org/10.1016/j.jesp.2020.104096>
- Osinsky, R., Mussel, P., & Hewig, J. (2012). Feedback-related potentials are sensitive to sequential order of decision outcomes in a gambling task: Feedback-related potentials and sequential outcome order. *Psychophysiology*, 49(12), 1579–1589. <https://doi.org/10.1111/j.1469-8986.2012.01473.x>
- Pei, R., Lauharatanahirun, N., Cascio, C. N., O'Donnell, M. B., Shope, J. T., Simons-Morton, B. G., Vettel, J. M., & Falk, E. B. (2020). Neural processes during adolescent risky decision making are associated with conformity to peer influence. *Developmental Cognitive Neuroscience*, 44, Article 100794. <https://doi.org/10.1016/j.dcn.2020.100794>
- Polich, J. (2007). Updating P300: An integrative theory of P3a and P3b. *Clinical Neurophysiology*, 118(10), 2128–2148. <https://doi.org/10.1016/j.clinph.2007.04.019>
- Polosan, M., Baci, M., Cousin, E., Perrone, M., Pichat, C., & Bougerol, T. (2011). An fMRI study of the social competition in healthy subjects. *Brain and Cognition*, 77(3), 401–411. <https://doi.org/10.1016/j.bandc.2011.08.018>
- Pornpattananangkul, N., Nadig, A., Heidinger, S., Walden, K., & Nusslock, R. (2017). Elevated outcome-anticipation and outcome-evaluation ERPs associated with a

- greater preference for larger-but-delayed rewards. *Cognitive Affective & Behavioral Neuroscience*, 17(3), 625–641. <https://doi.org/10.3758/s13415-017-0501-4>
- Ratcliff, R., & McKoon, G. (2008). The diffusion decision model: theory and data for two-choice decision tasks. *Neural Computation*, 20(4), 873–922. <https://doi.org/10.1162/neco.2008.12-06-420>
- San Martín, R. (2012). Event-related potential studies of outcome processing and feedback-guided learning. *Frontiers in Human Neuroscience*, 6, 304. <https://doi.org/10.3389/fnhum.2012.00304>
- Sherman, L., Steinberg, L., & Chein, J. (2018). Connecting brain responsivity and real-world risk taking: Strengths and limitations of current methodological approaches. *Developmental Cognitive Neuroscience*, 33, 27–41. <https://doi.org/10.1016/j.dcn.2017.05.007>
- Shulman, E. P., Smith, A. R., Silva, K., Icenogle, G., Duell, N., Chein, J., & Steinberg, L. (2016). The dual systems model: Review, reappraisal, and reaffirmation. *Developmental Cognitive Neuroscience*, 17, 103–117. <https://doi.org/10.1016/j.dcn.2015.12.010>
- Smith, A. R., Steinberg, L., Strang, N., & Chein, J. (2015). Age differences in the impact of peers on adolescents' and adults' neural response to reward. *Developmental Cognitive Neuroscience*, 11, 75–82. <https://doi.org/10.1016/j.dcn.2014.08.010>
- Steinberg, L. (2005). Cognitive and affective development in adolescence. *Trends in Cognitive Sciences*, 9, 69–74. <https://doi.org/10.1016/j.tics.2004.12.005>
- Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental review*, 28(1), 78–106. <https://doi.org/10.1016/j.dr.2007.08.002>

- Tajfel, H., & Turner, J. C. (1979). An integrative theory of intergroup conflict. In W., Austin & S., Worchel, (Eds.), *The social psychology of intergroup relations*, Monterey, CA: Brooks/Cole, 33–47.
- Toelch, U., Jubera-Garcia, E., Kurth-Nelson, Z., & Dolan, R. J. (2014). Competition strength influences individual preferences in an auction game. *Cognition*, 133(2), 480–487.
<https://doi.org/10.1016/j.cognition.2014.07.010>
- Tomova, L., & Pessoa, L. (2018). Information about peer choices shapes human risky decision-making. *Scientific Reports*, 8, Article 5129. <https://doi.org/10.1038/s41598-018-23455-7>
- Tricoche, L., Ferrand-Verdejo, J., Pelisson, D., & Meunier, M. (2020). Peer presence effects on eye movements and attentional performance. *Frontiers in Behavioral Neuroscience*, 13, Article 280. <https://doi.org/10.3389/fnbeh.2019.00280>
- Van Leijenhorst, L., Westerberg, P. M., & Crone, E. A. (2008). A developmental study of risky decisions on the cake gambling task: Age and gender analyses of probability estimation and reward evaluation. *Developmental Neuropsychology*, 33(2), 179–196.
<https://doi.org/10.1080/87565640701884287>
- Valt, C., Sprengeler, M. K., & Sturmer, B. (2019). Feedback processing in the context of social comparison. *Psychophysiology*, 57(3), Article e13489.
<https://doi.org/10.1111/psyp.13489>
- Vorobyev, V., Kwon, M. S., Moe, D., Parkkola, R., & Hamalainen, H. (2015). Risk-taking behavior in a computerized driving task: brain activation correlates of decision-making, outcome, and peer influence in male adolescents. *Plos One*, 10(6), Article e0129516. <https://doi.org/10.1371/journal.pone.0129516>

- Vugt, M. V., Cremer, D. D., & Janssen, D. P. (2007). Gender differences in cooperation and competition: The male-warrior hypothesis. *Psychological Science*, 18(1), 19–23.
<https://doi.org/10.1111/j.1467-9280.2007.01842.x>
- Wagemaker, E., Huizenga, H. M., Dekkers, T. J., d'Escury-Koenigs, A. L. C., Salemink, E., & Bexkens, A. (2020). When Do those "Risk-Taking Adolescents" Take Risks? The Combined Effects of Risk Encouragement by Peers, Mild-to-Borderline Intellectual Disability and Sex. *Journal of Abnormal Child Psychology*, 48(4), 573–587.
<https://doi.org/10.1007/s10802-020-00617-8>
- Wang, Y. W., Yuan, B., Roberts, K., Wang, Y., Lin, C. D., & Simons, R. F. (2014). How friendly is a little friendly competition? Evidence of self-interest and empathy during outcome evaluation. *International Journal of Psychophysiology*, 91(3), 155–162.
<https://doi.org/10.1016/j.ijpsycho.2013.10.009>
- Wang, Y., Zhang, Z., Jing, Y., Valadez, E. A., & Simons, R. F. (2016). How do we trust strangers? The neural correlates of decision making and outcome evaluation of generalized trust. *Social Cognitive and Affective Neuroscience*, 11(10), 1666–1676.
<https://doi.org/10.1093/scan/nsw079>
- Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology*, 54(6), 1063–1070. <https://doi.org/10.1037/0022-3514.54.6.1063>
- Wischnewski, M., & Schutter, D. J. (2018). Dissociating absolute and relative reward-and punishment-related electrocortical processing: An event-related potential study. *International Journal of Psychophysiology*, 126, 13–19.
<https://doi.org/10.1016/j.ijpsycho.2018.02.010>

- Xu, S. H., Wang, H., & Wang, C. C. (2019). Paying out one versus paying out all trials and the decrease in behavioral and brain activity in the Balloon Analogue Risk Task. *Psychophysiology*, 57(3), Article e13510. <https://doi.org/10.1111/psyp.13510>
- Yeung, N., Holroyd, C. B., & Cohen, J. D. (2005). ERP correlates of feedback and reward processing in the presence and absence of response choice. *Cerebral Cortex*, 15(5), 535–544. <https://doi.org/10.1093/cercor/bhh153>
- Yeung, N., & Sanfey, A. G. (2004). Independent coding of reward magnitude and valence in the human brain. *Journal of Neuroscience*, 24(28), 6258–6264. <https://doi.org/10.1523/jneurosci.4537-03.2004>
- Zhang, H. Y., Gu, R. L., Yang, M., Zhang, M. M., Han, F. X., Li, H., & Luo, W. B. (2021). Context-based interpersonal relationship modulates social comparison between outcomes: an event-related potential study. *Social Cognitive and Affective Neuroscience*, 16(4), 439–452. <https://doi.org/10.1093/scan/nsaa167>

Table 1

The Average Pumps after Gain and Loss Feedback in Each Condition ($M \pm SD$)

Feedback	Single condition		Peer competition condition	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Gain	5.73	0.79	5.38	1.02
Loss	5.55	0.85	5.32	1.05

Table 2

Amplitudes of N2 (Fz) as a Function of Context and FRN (Fz) and P300 (Pz) as a Function of Feedback and Context ($M \pm SD$)

Feedback	<u>Single condition</u>		<u>Peer competition condition</u>	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
N2(μV)	-4.27	3.57	-5.78	3.89
FRN(μV)				
Gain	-4.25	2.98	-3.67	3.84
Loss	-6.85	4.76	-7.14	5.42
Difference wave	-4.55	4.33	-7.17	4.47
P3(μV)				
Gain	12.67	5.82	11.41	5.01
Loss	11.41	5.70	8.49	6.59

Figure 1. *The Schematic Diagram for the BART. Note: in the decision-making phase of peer competition condition, the position of the performing of BART (left vs. right) of participants was randomized.*

Figure 2. *Violin Plots of Behavioral Results. Note: left: Average pumps under two conditions in BART; right: Average pumps following gains and losses in the previous trials.*

Figure 3. Grand-averaged waveforms at electrode Fz across single versus peer competition conditions.

Note: A and B are Topographic Maps Corresponding to the Respective Peak of the Waveforms.

Note: A: competition condition (308ms after decision-making phase). B: single condition (316ms after decision-making phase).

Figure 4. Grand-averaged waveforms for gains, losses, and the loss-minus-win difference at electrode Fz across single versus peer competition conditions.

Note: A and B are Topographic Maps Corresponding to the Respective Peak of the Difference Waveforms. Note: A: single condition (276ms after feedback). B: competition condition (292ms after feedback).

Figure 5. Grand-averaged waveforms for gains, losses at electrode Pz across single versus peer competition conditions.

Note: A, B, C and D are Topographic Maps 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).