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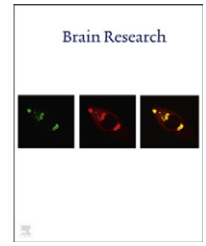

Research Report

Electrophysiological evidence for the importance of interpersonal curiosity

Chunhui Han[a,1], *Peng Li*[b,1], *Christopher Warren*[c], *Tingyong Feng*[a], *Jordan Litman*[d], *Hong Li*[b,*]

[a]*School of Psychology, Southwest University, Chongqing 400715, China*
[b]*Research Center of Psychological Development and Education, Liaoning Normal University, Dalian 116029, China*
[c]*Department of Psychology, University of Victoria, Victoria British Columbia, BC, Canada V8W 3P5*
[d]*Department of Psychology, University of South Florida, Tampa, FL 33613, United States*

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ABSTRACT

Interpersonal curiosity (IPC) is an important intrinsic motivation in social interaction, yet studies focused on its neural mechanism are rare. In a three-agent (Self, Other, or Computer) interactive gambling task, we recorded event-related potentials (ERPs) to a cue stimuli indicating whether participants will be informed of their own, of another participant's or the computer's outcomes such that curiosity will be satisfied (CWS) or curiosity will not be satisfied (CWN). The results showed that relative to the CWS cue stimuli the CWN cue evoked a larger late positive component (LPC) between approximately 400 ms and 700 ms after cue onset in both the Self and Other conditions, but not in the Computer condition. Additionally, participants reported stronger curiosity in the Other's outcomes than in the Computer's outcomes. Most importantly, participants' subjective rating of curiosity was significantly correlated with the amplitude of the LPC elicited by the CWN cue. Furthermore, scores in the "curiosity about emotion" subscale of the IPC Scale was significantly correlated with the LPC amplitude when the participants learn they will not be informed of the Other's outcomes. We suggest that (1) interpersonal information is of great significance to individuals and IPC is an important social motivator, and (2) LPC amplitude is sensitive to IPC.

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1. Introduction

Curiosity is the intrinsic desire for unknown and novel information (Berlyne, 1954; Loewenstein, 1994; Collins et al., 2004). Previous studies have investigated a range of categories of curiosity such as epistemic curiosity (i.e., the desire for knowledge that motivates individuals to learn new ideas and solve intellectual problems), sensory curiosity, perceptual curiosity and interpersonal curiosity (IPC) (Berlyne, 1954; Collins et al., 2004; Litman et al., 2005; Festinger, 1954). Interpersonal curiosity (also termed social curiosity) (cf. Renner, 2006) is the desire for information about other people, and is of great importance in social interaction and in human relationships (Festinger, 1954; Snyder and Ickes,

*Corresponding author. Fax: +86 23 6825 2309.
E-mail addresses: lihong@swu.edu.cn, lihongwrm@vip.sina.com (H. Li).
[1]Denotes the shared first author.

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1985, Litman and Pezzo, 2007). Generally, the object of IPC is unknown information about other individuals (i.e., public or private behavior, experiences, thoughts, and feelings). This kind of information has been termed “people-information” (Litman and Pezzo, 2007).

In a 2004 multidisciplinary review of gossip research, Foster claimed people need to obtain as much people-information as possible to cope effectively with a complex social environment. Similarly, social cognition neuroscientists (e.g., Swann et al., 1981) and evolutionary psychologists (e.g., Dunbar, 2004), have argued that people-information is a valuable resource that is pursued, and that can be exploited for a degree of control over the social and even physical environment. In a previous study (Han et al., 2012), participants were asked to play a two-person gambling task with a stranger and were able to choose to receive information about the other participant's outcome on any given trial. On average, participants chose to see the other person's outcomes on 78% of the trials, demonstrating the perceived value of this information.

There have been two major theoretical accounts of curiosity associating the satisfaction of curiosity with a rewarding affective state: the reduction view (e.g., Berlyne, 1954; Loewenstein, 1994) holds that the reward arises from the reduction of an undesirable state such as uncertainty. In contrast, the induction view (e.g., Spielberger and Starr, 1994; Litman, 2005) holds that the reward comes from the induction of a positive experience such as interest. Recently, Litman and Jimerson (2004) proposed the interest/deprivation (I/D) model reconciling the two theories. They suggested that curiosity had two aspects—curiosity as a feeling of deprivation (CFD) and curiosity as a feeling of interest (CFI). CFD refers to curiosity about information that people need, while CFI refers to curiosity about information that is just interesting. This viewpoint presents a more complex and intuitive description of curiosity, but has not been tested empirically.

People-information plays an important role in many prominent and well-studied social-cognitive phenomena, such as cultural transmission and language development (Baumeister et al. (2004); Dunbar, 2004). Recently, social cognitive neuroscientists have begun to investigate these kinds of phenomena with neuroimaging methods. For example, another theoretical framework intimately linked to people-information is social comparison theory (Festinger, 1954; Snyder and Ickes, 1985). It is important for people to determine their position in society relative to the positions of others through social comparison. In an fMRI study, Fliessbach et al. (2007) found that social comparison modulated the activation of the ventral striatum, a brain area strongly implicated in reward processing . Further to this, Zink et al. (2008) investigated the neural mechanisms associated with processing the status of individuals within a social hierarchy. They demonstrated that status information significantly affected the dorsolateral prefrontal cortex in an interactive, simulated social context and the involvement of DLPFC in processing hierarchical information is specifically social. Taken together these imaging studies suggest people-information has a special significance in certain situations and clearly influences brain activity. In this and similar contexts people-information might be used to develop and enhance friendship, or to better compete with others (Rosnow, 2001; Galen and Underwood, 1997).

Observational learning is another social-cognitive phenomenon intimately linked to people-information (Bandura et al., 1966). ERP studies of observational learning have revealed that, just as self-committed errors produce negative deflections in the ERP known as the error-related negativity (ERN) and the feedback error-related negativity (fERN), observing strangers commit errors likewise impacts the ERP. This suggests that similar neural mechanisms are involved in monitoring one's own action and the actions of others (van Schie et al., 2004; Yu and Zhou, 2006). Perhaps even more interesting in the context of this article, in further studies the amplitude of the ERN and the fERN was modulated by the social relation between participants and their observed subjects (Itagaki and Katayama, 2008; Fukushima and Hiraki, 2006, 2009; Leng and Zhou, 2010; Kang et al., 2010). These works provide evidence of an impact of the relative value of a social relationship on personal outcome assessment.

In studying IPC, self-reported psychological measurement has been the primary method employed, but some neuroimaging has been applied in this area as well. Kang et al. (2009) tried to explore the neural mechanisms of epistemic curiosity using fMRI. They found that the satisfaction of epistemic curiosity induced increased activity in reward-related brain regions, such as the caudate regions and lateral prefrontal cortex. Kang and colleagues provided the first imaging evidence that satisfaction of curiosity is a reward, and curiosity itself is a type of reward anticipation.

In the present study, we conducted an exploratory experiment using event-related potential (ERP) technique to examine the neural mechanisms that distinguish between curiosity with the prospect of having the curiosity satisfied (CWS), and curiosity that will never be satisfied (CWN). More specifically, we manipulate curiosity about people-information using a multi-agent (Self, Other, Computer) interactive gambling task. We compare electrophysiological activity to a cue that tells the participant whether or not they will be provided information about the outcome each agents' decisions. By comparing the CWS cue with the CWN cue across the three levels of agent we can also examine the electrophysiological differences associated with curiosity about people-information (curiosity about the Other's outcome versus Self and/or Computer information). Following from the Kang et al. (2009) work, we reasoned that some late ERP components (such as the fERN) would be observed when comparing the CWS cue with the CWN cue, and the amplitude of these components would be modulated by the relationship between the subject and the object of their curiosity (Self, Other, Computer). In addition, the ERPs elicited by the feedback stimuli were also examined in order to replicate the classic fERN effect. Finally, we administered the IPC scale developed by Litman and Pezzo (2007) to participants to allow comparison relative levels of curiosity with the electrophysiological data.

2. Results

2.1. Behavioral results

The Self-report scores of curiosity (state curiosity) for the outcomes of different agents in CWN condition were significantly different [$F(2,34)=13.35$, $p<0.001$, $\eta^2=0.44$]. Curiosity for Self outcomes was stronger than that for Other's outcomes ($p=0.039$), and curiosity for Other's outcomes was stronger than for Computer's outcomes ($p=0.010$). No significant difference was observed in the subjective ratings of happiness [$F(2,34)=1.35$, $p=0.274$, $\eta^2=0.07$]. The detailed scores were showed in Table 1.

2.2. ERP results

As shown in Fig. 1, the main effect of agent on the LPC amplitude was significant [$F(2,34)=30.52$, $p<0.001$, $\eta^2=0.64$]. Additionally, the main effect of cue type was significant [$F(1,17)=21.75$, $p<0.001$, $\eta^2=0.56$], and the interaction between these two factors was also significant [$F(2,34)=16.32$, $p<0.001$, $\eta^2=0.49$]. Simple effects analysis revealed that in the conditions of Self and Other, the CWN cue elicited a more positive LPC than the CWS cue ($p<0.001$, $p=0.006$). However, the amplitude of LPC induced by the two cue stimuli was not significantly different in the Computer condition ($p=0.642$). The main effect of electrode position was also significant [$F(3,57)=17.07$, $p<0.001$, $\eta^2=0.50$]. Further analyses showed that the LPC amplitude at FCz was significantly larger than at all other electrodes ($p<.01$) except Cz ($p>.05$). The LPC amplitude at Cz was significantly larger than all other electrodes ($p<.05$) except Fz, F3 and FCz. There was no significant interaction between electrode position and agent [$F(2,61)=1.61$, $p=0.19$, $\eta^2=0.087$], however, the interaction between electrode position and cue type was significant [$F(4,66)=5.61$, $p<0.001$, $\eta^2=0.25$].

Fig. 2 presents the difference waves constructed by subtracting the CWS ERP from the CWN ERP in each of the three agent conditions (Self, Other, Computer) and the corresponding scalp distributions at electrode FCz, where LPC peaked. The figure shows that the observed LPC in the present study has a frontal-central distribution. A two-way ANOVA had been conducted with agent and electrode as variable on the difference wave. The results showed that the main effect of agent was significant [$F(2,28)=16.32$, $p<.001$, $\eta^2=0.49$], pairwise comparison indicated that the Self difference wave was significantly larger than both the Other difference wave ($p=0.003$) and the Computer difference wave ($p<0.001$); and the Other difference wave was significantly larger than the Computer difference wave ($p=0.036$). The results also showed that the main effect of electrode position was significant [$F(4,66)=5.61$, $p=.001$, $\eta^2=0.25$] and the interaction with agent reached significant [$F(5,81)=3.6$, $p=<.01$, $\eta^2=0.18$]. Further analyses revealed that all of the electrodes showed three types of trends among three agent conditions: the Self difference wave was significantly larger than Other difference wave and the Other difference wave was significantly larger than Computer difference wave at Fz (all $p<.05$). There was no significant difference between the Other and Computer difference waves, however both were significantly smaller than Self difference wave at F3, FCz, FC3, Cz, C3 and C4 (all $p<.005$). Finally, there was no significant difference between the Self and Other difference waves, however both were significantly larger than the Other difference wave at F4 and FC4(all $p<.05$).

Table 1 – Mean and standard deviation of the subjective rating (M±SD).

	Self	Other	Computer
Degree of curiosity (state curiosity)	4.44±1.29	3.61±1.42	2.56±1.42
Degree of happiness	3.83±0.92	4.22±0.65	4.06±1.00

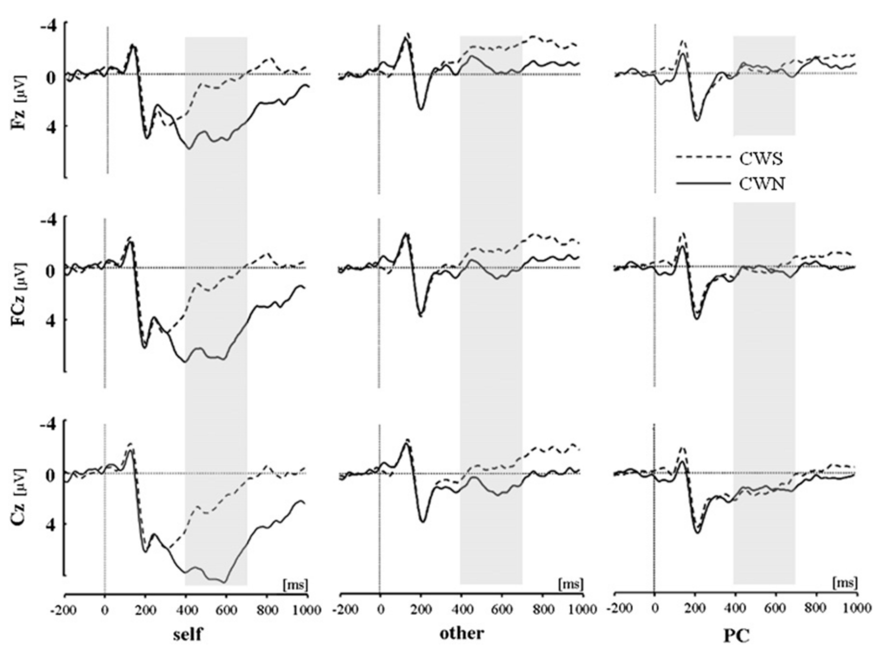

Fig. 1 – The grand average of LPC locked at the cue stimuli onset.

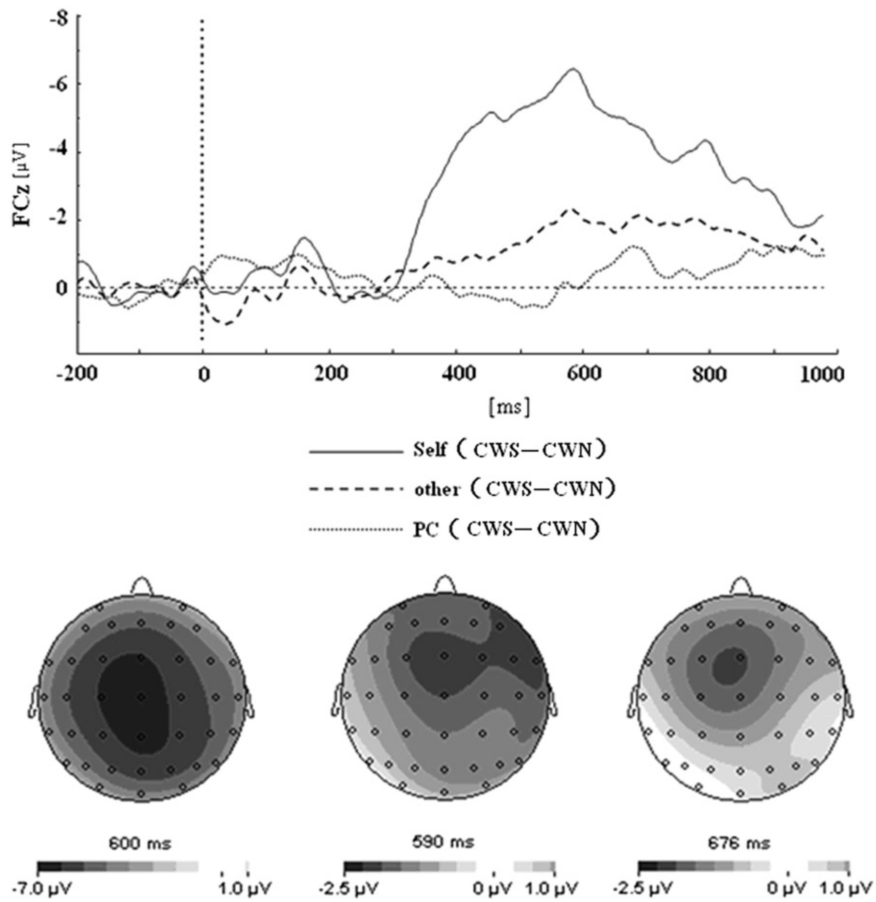

Fig. 2 – Difference waves between CWS and CWN of three agents and the scalp distribution (PC: computer condition).

With regard to the feedback phase, only the fERN in the Computer condition was significantly different from 0 μV, $t(17)=3.9$, $p=.001$; the Self and Other conditions were not (all $p>0.05$). Surprisingly, the gain feedback elicited more negative deflection than the loss feedback in the computer condition (as showed in Fig. 3). The ANOVA showed that the main effect of agents was significant [$F(2,34)=3.44$, $p<.05$, $\eta^2=0.17$], pairwise comparison showed that the fERN in the Computer condition was significantly larger than that in the Other condition ($p=.03$) and the Self condition ($p<.02$). The 3×2 ANOVA on the P300 amplitude showed that the main effect of agent was significant [$F(2,26)=45.28$, $p<.001$, $\eta^2=0.73$], pairwise comparison showed a linear increased trend of P300 amplitudes among three agent conditions: largest P300 in the Self condition and medium size in the Other condition and smallest in the Computer condition (all $ps<.005$). No significant main effect of valence and no interaction between agent and valence were found on the amplitudes of P300 (all $p>0.05$). There was no significant effects on P300 peak latency (all $p>0.05$).

2.3. *The relationship between the behavioral data and ERP data*

wThe internal consistencies of all items in IPC scale is 0.795 and the alpha coefficient for the Sn subscale is 0.602; for the

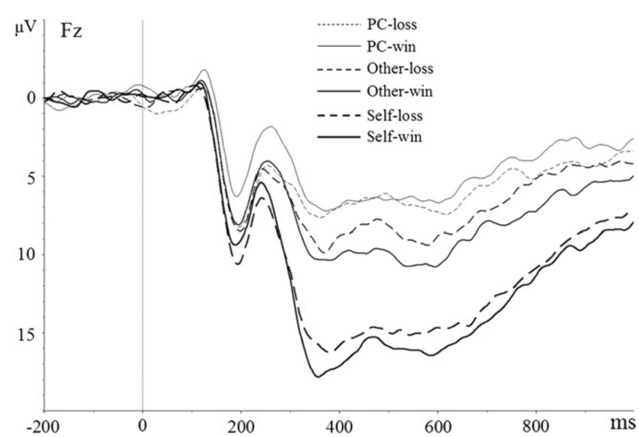

Fig. 3 – Grand average ERPs locked at the feedback stimuli for six conditions (PC: computer condition).

CE subscale is 0.591; and for SP subscale is 0.63. The first regression analysis was conducted with the LPC amplitude at FCz as dependent variable and with the scores of three IPC subscales as independent variables. As shown in Fig. 4, the CE dimension entered the regression equation with an explanatory rate of 24.5% ($p<0.05$), indicating that if the participant had a stronger CE score, the indication IPC would not be satisfied elicited a larger LPC deflection. No other significant

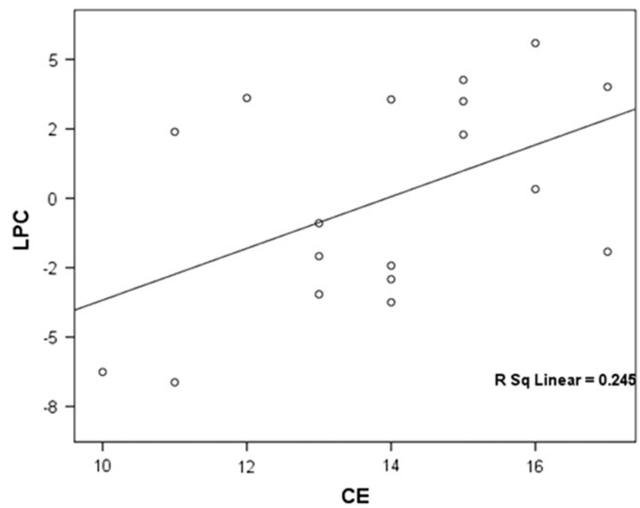

Fig. 4 – Regression effect of CE to the LPC in other-CWN condition.

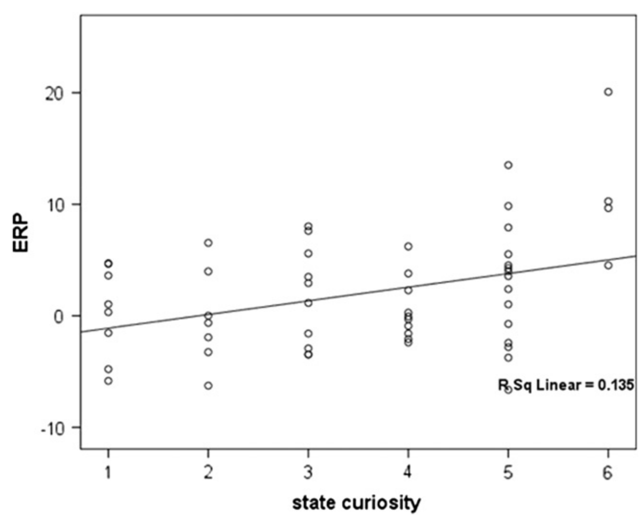

Fig. 5 – Regression effect of state curiosity to the ERP in CWN condtion.

results were found in this regression analysis. The regression weight for Sn score was −0.25 and for SP score was −0.23(all $p>.05$).

Another regression analysis was conducted with state curiosity scores and happiness scores as the predicating variable and the LPC amplitude at FCz after the onset of the CWN cue across all of the three agent conditions as the dependent variable. As shown in Fig. 5, the results demonstrated that the self-report curiosity score could explain 13.5% of the variance in LPC amplitude in the CWN condition ($p<0.01$). In other words, the more curious about the outcome, the larger the amplitude of LPC when the participant was informed that he/she could not obtain the outcome.

In addition, a correlation analysis between the state curiosity and trait curiosity was also carried out. Interestingly, only the state curiosity was significantly (inversely) correlated with the scores on the SP subscale in the "Self" condition ($r=-0.48$, $p<.05$). This negative correlation indicated that the participants who reported high state curiosity about their own results have less interest in delving into other people's private affairs. Results also showed that the correlation between P300 and LPC reached significant ($r=0.43$, $p=.001$). Another correlation analysis between the P300 amplitude and state curiosity scores also reached significant ($r=.47$, $p<.001$). In contrast, we did not find any significant correlation between the IPC scale and P300 amplitude.

3. Discussion

3.1. *Effect of LPC*

In the present study, we exploited a novel paradigm and focused on the electrophysiological activity locked to a cue stimulus that informed participants whether they would or would not be informed of the gambling outcomes of the three agents (Self/Other/Computer). A robust LPC effect, but not the fERN component, was elicited by the cues. Since previous researchers found the fERN is related to reinforcement learning process (Holroyd and Coles, 2002), we suggest that the absence of the fERN might be due to the fact that there weren't direct reinforcement cues in our research (i.e., feedback about whether IPC would be satisfied or not did not directly relate to task performance). However, the results demonstrate that the CWN cue in both Self condition and Other condition induced a significantly larger LPC, with no effect in the Computer condition. This ERP pattern is consistent with our basic prediction that different levels of brain activity are provoked when curiosity can be satisfied compared to when it cannot, and this effect depended on whether the outcome information concerned the participant, a different person, or a computer. The ERP data was complimented by behavioral data demonstrating that participants reported a progressively reduced intensity of curiosity from information about their own outcome, to information about other's outcome, to information about the Computer's outcome. Regression analysis showed that the subjective rating of curiosity was significantly correlated with the LPC amplitude induced by the CWN cue. Thus we believe that the LPC is sensitive to the intensity of curiosity across three agent conditions in the present experiment.

Given the fact that the present task is a monetary incentive task, an alternative explanation of the LPC effect should be considered: Whether or not the LPC reflects a relationship between the cues and the participant's actual reward, rather than curiosity about the participant's reward. Normally, participants need external feedback to allow them to make optimal decision in such a gambling task (Holroyd and Coles, 2002). Thus, the cues might have a direct influence on the participant's own reward in the Self condition. However, compared to Self information, both Other's information and Computer's outcome are not related to the participants' personal reward directly, and yet the difference we have described occurs in those conditions as well. Even so, there is still the possibility that participants tried to increase their reward amount through observational learning in the other condition and the Computer condition. However, in this case the potential for observational learning is equal between

Other's and Computer's choices/outcomes, and yet the data show that LPC amplitude was significantly larger in the Other condition than that in the Computer condition. Therefore, the IPC effect exists independent of the relative utility of the reward information for the participant's goals.

Recently, the LPC has received much interest in the cognitive neuroscience literature. It appears about 300 ms after stimulus onset and has a broad distribution. Numerous studies have shown that the LPC is closely related to the allocation of attention (Schupp et al., 2004; Pastor et al., 2008; Hajcak et al., 2009). Hajcak et al. (2009) instructed participant's to control their attentional focus while they watched emotional pictures and found that when the participant was instructed to focus on the more neutral portion of a negative picture, LPC amplitude was significantly decreased. They proposed that this phenomenon demonstrates that emotional effects can be modulated by top-down attentional and cognitive processes. Additionally, two groups found that positive and negative pictures elicited larger LPC amplitudes compared to neutral pictures and this phenomenon gets stronger as the intensity of the emotional stimuli increases (Schupp et al., 2004; Pastor et al., 2008). These researchers argue that the LPC reflects arousal, not the valence of emotion. This position might explain the present results that no notable difference was observed in the self-report score of happiness between the three agent-conditions, even while differences in LPC amplitude were found. According to Fredrickson (1998), the experience of curiosity is integral to the ability to self-regulate attentional resources in pursuit of potentially rewarding activities. Taking these studies together, we suggest that the LPC is an index of automatic attentional arousal and further, reflects the motivational significance of curiosity. These cues may work as an early alarm which tells people more seeking behaviors are required.

3.2. *Nature of curiosity*

Even though most researchers agree that the nature of curiosity is reward anticipation (Berlyne, 1954; Loewenstein, 1994; Kang et al., 2009), there is disagreement about the affect that comes from having curiosity satisfied: whether it involves a reduction of the negative emotional experience such as ignorance and uncertainty or whether it involves the induction of a positive emotional experience such as interest (Day, 1971; Kashdan et al., 2004). We interpret our results as being more consistent with the "reduction" view: Across the three levels of agent, the amplitude of the LPC was more impacted by the CWN cue than the CWS cue, suggesting that our effect is driven more by the prospect of remaining ignorant than by the satisfaction of IPC. In contrast, the "induction" view would predict that the CWS cue would most impact brain activity, inducing changes consistent with an emotional response to the impending reward. The present data provide the first ERP evidence in favor of the "reduction" view. However, the limitations of the present study lead us to be cautious of this conclusion. First, we focused only on IPC, which is a specific type of curiosity, and our results might not apply to more general curiosity. Second, we did not manipulate the CFD and CFI in the present study so that we could not test the interest/deprivation model suggested by Litman (2005) directly. Follow-up studies will be necessary to explore the neural mechanisms of curiosity in general. We submit that the LPC could be used as an index of curiosity in future studies. In addition, we propose that fMRI technology should be used in future studies in order to examine the prediction of these theories about curiosity. According to Kang et al. (2009) finding, curiosity is a type of reward anticipation. Thus, curiosity might provoke activity in reward-processing areas such as the ventral striatum and orbitofrontal cortex (Delgado et al., 2000; Costa et al., 2010; O'Doherty., 2004; Burgdorf and Panksepp, 2006). On the other hard, some regions in the brain, such as insula and amygdala might be activated by the negative experience of being curious without the prospect of having the curiosity satisfied (Liu et al., 2007; Morris et al., 1996).

3.3. *Significance of the IPC*

As discussed earlier, IPC works as an intrinsic motivator of seeking behaviors and is adaptive for a variety of reasons. Here, we suggest that IPC might have two potential benefits: for observational reinforcement learning and for social comparison. Several studies have reported that the brain activity of participants observing someone else perform an gambling task is similar to the brain activity of participants when they complete the task by themselves, which indicates an influence of observational learning on ERPs (van Schie et al., 2004; Yu and Zhou, 2006; Itagaki and Katayama, 2008; Fukushima and Hiraki, 2006, 2009; Leng and Zhou, 2010; Kang et al., 2010). Consistent with these findings, our study focused on the motivational level of acquiring other agents' information and showed that the LPC in the Other condition was significantly larger than that in the Computer condition. This demonstrates the importance of social observational learning through people-information.

In addition, the acquiring of people-information is a prerequisite of social comparison. The CE dimension of the IPC scale evaluates the extent of the desire to learn other people's feelings In our study, the CE dimension was significantly correlated with the amplitude of LPC induced by the CWN cue in the Other condition. This means that the stronger a participant's IPC, the larger the LPC would be when the participant's IPC was unsatisfied. Schachter (1959) extended social comparison theory to the domain of emotion. He argued that when people are uncertain about a situation, they turn to others who are in a similar situation for emotional comparison purposes. The implied motive for this sort of behavior is IPC, the purpose of which may be to understand one's own feelings and the environment better and to relieve anxiety, fear and the sense of uncertainty. The mental mechanism is just like the so-called proverb "misery loves company" (Wert and Salovey, 2004). In fact in a previous study, Litman and Pezzo (2007) found that the CE subscale showed a positive correlation with extraversion. They suggested that being curious about people's feeling is more likely to motivate social interaction. In the present study, the CE subscale scores are correlated with LPC amplitude in the Other condition. We propose that participants' IPC might be mainly driven by curiosity about other's feelings about the gambling task and they need this information for emotional comparison purposes in the task context.

3.4. *Effect of fERN and P300*

In the outcome evaluation phase after the CWS cue, a fERN and P300 were observed. Surprisingly, a fERN was only observed in the Computer condition, and even more surprising was that the fERN difference was in the opposite direction than is typical, with a more negative deflection to gains than to losses. This inverse fERN effect in the Computer condition might be due to the fact that people judge the outcome based on their own standpoint (Itagaki and Katayama, 2008): The gain of Computer may seem a waste to them. In the Other and Self condition, loss feedback did not show a larger negative deflection than gain feedback. According to the previous studies, the outcome evaluation system is binary and highly context dependent (Hajcak et al., 2006; Holroyd et al., 2004). In the present study, participants might process the outcome within the whole context, which means they took the CWN condition into consideration as well. Compared with no feedback, the loss and gain feedback are equally good for them. However, the null fERN effects observed here should be interpreted with caution. There were only 30 trials for generating the fERN component in each condition because the outcome evaluation was not the target phase of interest in the present study. Finally, the P300 showed a linear trend among the three agent conditions and was correlated with LPC and state curiosity. according to prior studies which demonstrated that the P300 might be related to context updating and allocating attention resource (Donchin and Coles, 1988; Wu and Zhou, 2009), the P300 effect observed here may reflect a feedback evaluation process after the curiosity was satisfied, in other words, the relative importance of the outcome to the participant, such that their own outcome is most important (larger P300), the Other's outcome is next important (intermediate P300), and the Computer's outcome is least important (smallest P300).

4. Experimental procedures

4.1. *Participants*

Nineteen undergraduate and graduate students participated in the experiment as volunteers. One participant was excluded from the data analysis because of excessive movement artifacts during the EEG recording. Thus, we analyzed data from 18 participants (8 males) with ages ranging from 20 to 25 ($M=22.1$, $SD=1.4$). All the participants were healthy, right-handed, had normal or corrected-to-normal vision, and had not participated in similar experiments before. The participants were told that they would be paid in accordance with their performance in the experiment. However, the reward was random within a known range of US$ 3 to 5. This study was approved by the local Ethics Committee.

4.2. *Procedures*

The participants were seated comfortably in a dimly lit electromagnetically shielded room approximately 1 m in front of a computer screen with the horizontal and vertical visual angles below 6°. Prior to the experiment (experimental schematic figure shown in Fig. 6), the participant was informed that he/she would participate in a three-agent (Self, another participant called "Other", and a computer, called "Computer") gambling game via a local internet connection. The game would be played many times and both the participant and Other would be paid in accordance with the cumulative monetary gains at the end of the experiment. The participant was introduced to Other prior to entering their own shielded room to take part in the experiment, but Other was actually a research assistant and the choices of "Other were made by the computer program.

On each trial, two golden eggs with exactly the same appearance were shown on a black screen, and a signed number such as "+25" would be revealed when any one of the two eggs was cracked open (by making a selection). "+" meant monetary gain while "−" denoted monetary loss. The magnitude of money varied between 5¥ and 25¥ and the outcomes of the two eggs were independent of each other. The participant pressed either, "F" or "J" on the keyboard, corresponding to the left and right golden eggs, respectively. The golden eggs stayed on screen until the participant made a choice. When it was the turn of Other or Computer, the participants just waited and watched the stimuli on the screen. The decision time of Other and Computer varied

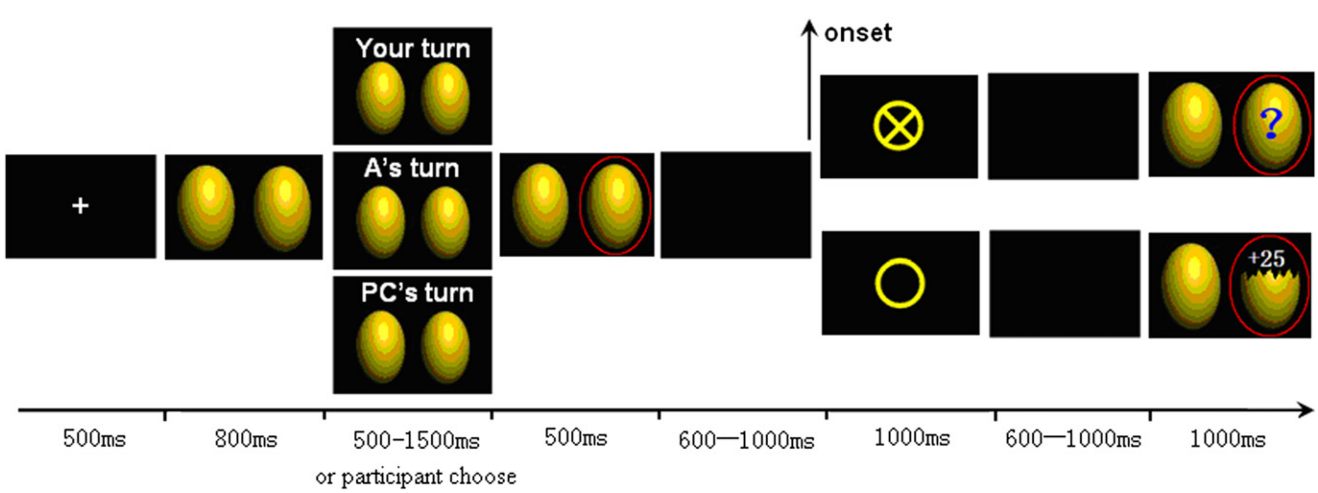

Fig. 6 – Experimental schematic.

randomly within the range of 500–1500 ms. The selected egg would be marked by an oval. Then the cue stimulus was presented: A hollow circle (CWS cue) denoted that the outcome would be presented in the screen at the end of this trial, while a hollow circle with a " × " inside (CWN cue) denoted that the outcome would not be presented. Prior to the experiment the participants had been told that whether feedback about the other players was given or not did not affect the cumulative monetary gain. After the CWS cue stimuli, the participant would get to know the outcome of that trial no matter which agent had chosen. After the CWN cue, the participant would not obtain the outcome and a "?" would appear on the selected golden egg.

Before the formal experiment there were 36 practice trials for the participants to familiarize themselves with the task. In the practice phase the explanatory sentences "you can look at the outcome this time" and "you cannot look at the outcome this time" were presented above the two cue stimuli denoting whether feedback would be provided (these sentences would not be presented in the formal experiment). After the practice trials, there were 360 critical trials, and the participants received all 6 experimental manipulations [2(CWS, CWN) × 3(Self, Other, Computer)], each of which was repeated 60 times. The order of the three agents' actions was randomized. The participants had a 1-min break at each interval of 72 trials. All the stimuli were presented by E-Prime version 1.1 on a computer.

4.3. *Post-task questionnaires*

After the experimental session, the participants were asked to fill out two questionnaires:

4.3.1 Participants were asked to rate their curiosity and happiness when they could not learn the outcomes of Self/Other/Computer using 7-point Likert scales, where scores were: 1—'not curious at all', 7—'very curious'; and 1—'not happy at all', 7—'very happy'.

4.3.2 The 17-item IPC scale (Litman and Pezzo, 2007) was also administered. This scale expresses the IPC as a dimension of personality traits which comprises three 5-item subscales that assess dispositional tendencies to want and seek out different kinds of information about others: The *Curiosity about Emotions* (CE) subscale assesses desires to learn other people's feelings (e.g., "I pay attention to people's facial expressions to figure out how they feel"); the *Snooping* (Sn) subscale measures wishes to learn about people's interests and social behavior (e.g., "I like to know what other people do"); and the *Spying and Prying* (SP) subscale assesses intentions to delve into people's private affairs (e.g., "I feel comfortable asking people about their private lives"). For each item, participants indicate how often their behavior is consistent with the statement by rating it on a 4-point frequency scale ranging from "Almost Never" to "Almost Always". In past research (Litman and Pezzo, 2007), the scale and subscales have all exhibited acceptable internal consistency ($M\alpha = .775$).

4.4. *EEG recordings and data analysis*

Electrophysiological activity was recorded at 64 scalp sites using the electrodes mounted in an elastic cap (Brain Product, Munchen, Germany), with references on the left and right mastoids and a ground electrode on the medial frontal line. The impedance of all electrodes was kept below 10 kΩ. Vertical electrooculograms (EOGs) were recorded above and below the left eye. The horizontal EOG was recorded from the left and right orbital rim. The EEG and EOG were amplified using a 0.05–100 Hz band pass and continuously digitized at 500 Hz/channel for offline analysis. Ocular artifacts were corrected using the eye movement correction algorithm described by Gratton et al. (1983). Trials with EOG artifacts (mean EOG voltage exceeding ±80 μV) and those contaminated with artifacts due to amplifier clipping and peak-to-peak deflection exceeding ±80 μV were excluded from averaging. Less than 5% trials were excluded after artifact rejection.

Inspection of Fig. 1 reveals an obviously large late positive component (LPC) induced by CWN cue in the Self and Other conditions but not in the Computer condition. The evoked LPC by the cue were segmented (1200 ms epochs from −200 ms to 1000 ms) with a 200 ms baseline correction. In accordance with the scalp distribution (as shown in Fig. 2), these ERPs were analyzed within the time window of 400 ms to 700 ms after the cue stimuli onset at nine electrode positions (Fz, FCz, Cz, F3, FC3, C3, F4, FC4 and C4). The time window and electrode channels were chosen based on the ERP grand average (see Fig. 1) and scalp distribution of difference wave (see Fig. 2). A three-way analysis of variance (ANOVA) was conducted on the average amplitude of LPC with the agent (Self/Other/Computer), cue type (CWS/CWN), and electrode position (Fz, FCz, Cz, F3, FC3, C3, F4, FC4 and C4) as repeated factors.

To obtain a better understanding of the relationship between the behavioral data and the ERP data, we conducted a regression analysis with LPC amplitude at FCz (where LPC peaked) after the onset cue in the CWN condition as the dependent variable and with the three IPC subscales scores as independent variables for each of the three agent conditions separately. We also conducted another regression analysis with LPC amplitude at FCz as the dependent variable and with the state curiosity and the happiness scores as independent variables across the three agent conditions. In addition, a correlation analysis between the state curiosity and trait curiosity was performed. According to some literature, the P300 evoked by the feedback might be considered as a context updating process after the curiosity was satisfied in the present paradigm (Donchin and Coles, 1988). To test this assumption, some further correlation analysis were conducted to explore the relationship between P300 and LPC and the relationship between P300 and behavioral data, To measure the P300 amplitude, we averaged the P300 value in loss condition and gain condition because there was no significant difference between these two conditions. Then a correlation analysis had been conducted between the P300 amplitude and LPC difference waves across three agent conditions. Another correlation analysis was also conducted between the P300 amplitude and IPC subscale scores.

Additionally, inspection of Fig. 3, the fERN and P300 components were elicited by the feedback stimuli after the CWS cue. These two components were segmented (1200 ms epochs from −200 ms to 1000 ms) with a 200 ms baseline correction. To assess the fERN, we constructed a difference wave by subtracting the ERP to the gain condition from the ERP to the loss condition. We quantified measured the fERN as the mean amplitude of the difference wave between 200 ms and 300 ms post-stimulus onset at Fz, where the fERN was largest in this study. Then, we ran three *t*-tests to compare the fERN for each of the three agents with 0 μV separately. As well, a one-way ANOVA was conducted on fERN amplitude with agents (Self/Other/Computer) as the independent variable.

The amplitude of the P300 was also analyzed by measuring the peak point during 300 ms and 600 ms after the stimuli onset at Pz. Two 3×2 repeated measures ANOVA was performed on each of P300 peak amplitude and P300 peak latency with agent (Self/ Other/Computer), feedback valence (win/loss) as repeated factors. All the data analyses were carried out by SPSS 15.0. The Greenhouse–Geisser adjustment was used where appropriate.

5. Conclusion

In summary, individuals were more curious about the outcome of another person's decisions in a gambling task than the outcome of a computer's decision in the exact same task, and this relative curiosity was reflected in the amplitude of the LPC. This provides electrophysiological evidence for the significance of IPC. Moreover, the effect on the LPC is consistent with the "reduction" view concerning the nature of curiosity.

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