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Whose loss is it? Human electrophysiological correlates of non-self reward processing

Hirokata Fukushima and Kazuo Hiraki

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To recognize whether another person's action results in a good or bad outcome is imperative for social learning, as well as for understanding the behavior of others in a broad context. Recent studies have reported that a scalp-surface event-related potential (ERP) called medial-frontal negativity (MFN), considered to be an index of negative reward processing, is generated when perceiving not only one's own losses, but also those of others. This suggests that the same neural mechanisms operate in monitoring one's own actions and in perceiving the consequences of the actions of others. To further elucidate the properties of this "observational" MFN, this study examined whether its amplitude differs with different observational targets. In a gambling task, participants observed the performances of non-self agents: a human friend and PC programs. The outcomes of the decisions of these agents were not associated with the participants' own benefits. ERP results showed that the MFN-like pattern was significantly elicited only when observing the outcomes of decisions made by human agents. Furthermore, self-reported measures of empathy were positively associated with the magnitude of the observational MFN. These findings suggest that the neural activity in non-self reward processing reflects a socioemotional state generated by the target of observation, as well as an empathetic trait of the individual.

Keywords: Empathy; Reward processing; Performance monitoring; Gambling task; Event-related potentials (ERPs).

INTRODUCTION

This study was performed to examine the neural activity involved in perceiving the consequences of non-self behavior. In any given context, the consequences of our decisions are categorized as either a success or a failure in a teleological and affective sense. This categorical perception, often termed performance monitoring or behavior evaluation, is important to guide our daily behavior. Moreover, human behavior is developed and guided in social environments largely by observing the behavior of others. Thus, observing the consequences of other people's actions is imperative for understanding others, for social learning, and for organizing appropriate social behavior.

However, investigations on the neurocognitive mechanisms underlying the monitoring of others' performances have been limited until recently.

Previously, investigating the mechanisms of behavioral monitoring was achieved by analyzing self-generated actions. In particular, the neural response to an unfavorable self action and its negative consequence has been intensively examined. Such neural processing is thought to be central in performance monitoring of motor execution, learning, and decision-making. Findings from neurophysiological studies in monkeys (see for example Gamba, Sasaki, & Brooks, 1986; Shima & Tanji, 1998) and functional neuroimaging studies in humans (see for example Carter et al., 1998; Kiehl, Liddle, & Hopfinger, 2000;

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Menon, Adelman, White, Glover, & Reiss, 2001; Ullsperger & Von Cramon, 2003) have strongly implicated the medial and lateral prefrontal areas in the detection of both execution error and negative reward to a self action. In parallel with these studies, investigation of event-related potentials (ERPs) using surface-scalp electroencephalography has revealed a particular pattern at the front-central scalp sites that is present at the moment of an incorrect motor response, or during perception of feedback stimuli informing the negative outcome of a preceding action (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990; Gehring, Coles, Meyer, & Donchin, 1990; Gehring & Willoughby, 2002a; Miltner, Braun, & Coles, 1997). Whether those ERP components that are differentially elicited (response-locked or feedback-locked) by various types of tasks (those featuring error, conflict, reward, or stimuli prediction) are identical has not been fully elucidated (for a debate on this issue, see for example Gehring & Willoughby, 2002b, 2004; Holroyd, Coles, & Nieuwenhuis, 2002; Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004b). Many studies have suggested that the source of such ERP components is the anterior cingulate cortex (ACC) (Garavan, Ross, Kaufman, & Stein, 2003; Gehring & Willoughby, 2002a; Luu, Tucker, Derryberry, Reed, & Poulsen, 2003; Miltner et al., 1997; Nieuwenhuis, Holroyd, Mol, & Coles, 2004a), and most researchers (often implicitly) consider these components to reflect an approximately identical function. In this paper, all these negative components related to performance monitoring are referred to as the medial-frontal negativity (MFN).

There are several functional models for the MFN; the most prevalent is based on a reinforcement learning (RL) theory (Holroyd & Coles, 2002; Nieuwenhuis et al., 2004a). It is known that mesencephalic dopaminergic neurons mediate reward prediction error, and this is thought to guide action selection by the ACC (Schultz, 1998). This phasic dopaminergic signal influences several cortical regions, including part of the ACC (Picard & Strick, 1996; Paus, 2001), either disinhibiting or inhibiting the apical dendrites of the neurons there. This processing evokes differential activity in response to favorable and unfavorable trials, which is manifested at the scalp as the MFN (Nieuwenhuis et al., 2004a). Based on this assumption, the RL-MFN theory predicts that the amplitude of the MFN is associated with the

RL process (Holroyd & Coles, 2002). This prediction has been partly confirmed (Frank, Woroach, & Curran, 2005; Holroyd, Larsen, & Cohen, 2004; Holroyd, Nieuwenhuis, Yeung, & Cohen, 2003), although some reports have been contradictory (see for example Donkers, Nieuwenhuis, & van Boxtel, 2005; Yeung, Holroyd, & Cohen, 2005).

In parallel with the processing above, affective processing is often implicitly considered to be another important modulator of the MFN (Luu & Tucker, 2004; Yeung, 2004). This affective factor has been evidenced by two lines of research: motivational factors in subjects and affect-related personality traits. In the first line of research, the response-locked MFN (called the error-related negativity) is larger when accuracy is emphasized over speed (Gehring, Goss, Coles, Meyer, & Donchin, 1993), whereas the feedback-elicited MFN amplitude in a gambling task is larger after a participant experiences a larger loss (Gehring & Willoughby, 2002a; Masaki, Takeuchi, Gehring, Takasawa, & Yamazaki, 2006). It was also demonstrated that the MFN amplitude is correlated with participants' subjective ratings of interest in a gambling task (Yeung et al., 2005). This suggests motivational modulation to the MFN. Secondly, studies have shown that the amplitude of the MFN is greater in participants who score highly on psychological tests assessing negative affect (Hajcak, McDonald, & Simons, 2004; Luu, Collins, & Tucker, 2000; Yasuda, Sato, Miyawaki, Kumano, & Kuboki, 2004), anxiety (Hajcak, McDonald, & Simons, 2003), and obsessive-compulsive disorders (Gehring, Himle, & Nisenson, 2000; Hajcak & Simons, 2002; Johannes et al., 2001; Santesso, Segalowitz, & Schmidt, 2006). These reports suggest that the MFN reflects not only the cognitive processing of performance monitoring, but also affective processing.

Building on this knowledge of the mechanisms underlying self-performance monitoring, two studies investigated whether the ERP component involved in performance monitoring is also present when individuals observe errors committed by others, and not just their own (Miltner, Brauer, Hecht, Trippe, & Coles, 2004; van Schie, Mars, Coles, & Bekkering, 2004). Miltner et al. (2004) used a four-choice reaction time task on a PC monitor. Although the participants performed all tasks by themselves, they also observed a virtual player perform the same tasks. The results showed that the participants (observers) had a negative ERP deflection in response to feedback

stimuli derived from non-self performances that was similar to the MFN in terms of latency and scalp distribution. Similarly, van Schie et al. (2004) examined the ERP responses of subjects observing both erroneous and correct lever-pressings by a human model. They showed that a negative potential was elicited upon seeing an inappropriate motor execution performed by someone else, and that such potentials had a similar distribution to those evoked by self-errors. These two reports showed that the ACC is the likely source of these negative components, similar to the MFN for self-performance. Therefore, these reports consider the MFN-like components in the observation of non-self performances to be homologues of the MFN observed during monitoring of self-performance (Miltner et al., 2004; van Schie et al., 2004). In other words, the mechanism of monitoring is probably the same for self and non-self performance. Below, we refer to the MFN component generated by observation of non-self performance as 'o-MFN', meaning other- or observation-MFN. Since these initial reports, a couple of studies have further examined the o-MFN. These have shown that the processing of a negative reward to another person in a simple gambling task also elicits the o-MFN (Fukushima & Hiraki, 2006; Hewig et al., 2008; Itagaki & Katayama, 2008; Yu & Zhou, 2006).

Most previous reports on the o-MFN interpret it as a form of observational learning reflecting the RL process (Hewig et al., 2008; Itagaki & Katayama, 2008; Miltner et al., 2004; van Schie et al., 2004; Yu & Zhou, 2006). By contrast, we previously demonstrated that the o-MFN is possibly associated with another aspect of mental processing oriented to the target of observation (Fukushima & Hiraki, 2006). The putative factor under the modulation of the o-MFN was empathy, the phenomenon and function of sharing the affective experiences of others. This previous study employed a "competitive" two-person gambling task, in which two players alternately performed a task, and the rewards for each player were directly inverse; each player's gain meant the other's loss. We examined whether the o-MFN was elicited in such a contradictive context. As a result, a large variation in ERPs between individuals was found for the latency of the MFN component. There was a significant gender difference: Most females showed the o-MFN, whereas most males did not, or they showed polarity inversion of the o-MFN.

Furthermore, the amplitude of the o-MFN correlated linearly with the participants' subjective ratings concerning their affective feelings on the other's outcomes, as well as their scores of Empathy Quotient (EQ), a trait measurement known to be sensitive to gender differences (Baron-Cohen & Wheelwright, 2004). We interpreted this data as suggesting a possible association between the MFN and social and affective processing, particularly empathy.

In the current study, we aimed to support the finding of our previous report that the o-MFN is associated with the degree of empathetic processing. To this end, we set different types of non-self agents: a human player and computer-generated players. Specifically, we investigated whether differences in the o-MFN depend on observational targets. In social cognitive neuroscience, this "human vs. machine" comparison is often utilized to examine the effect of one's counterpart in social interactions (see for example Gallagher, Jack, Roepstorff, & Frith, 2002; Gazzola, Rizzolatti, Wicker, & Keysers, 2007; McCabe, Houser, Ryan, Smith, & Trouard, 2001; Rilling, Sanfey, Aronson, Nystrom, & Cohen, 2004; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004). In the present study we assumed that a difference in an observational target could manipulate an observer's internal state and attitude toward non-self performance, and that this would be reflected in the amplitude of the o-MFN. While our previous study examined a situation where the rewards of players were competitively engaged (Fukushima & Hiraki, 2006), the current study set rewards among players independently; that is, there was no association between an observer and the observed agents. This was done to remove any possible effects of self-benefit on the o-MFN. Therefore, any difference in the amplitude of the o-MFN could be interpreted as being caused by a difference in socio-motivational processing.

In addition to examining intra-individual modulation of the o-MFN in terms of difference of target, this study also examined an inter-individual difference: the possible association between the MFN and participants' traits concerning empathy. We utilized two sets of self-report questionnaires. One was the Interpersonal Reactivity Index (IRI; Davis, 1983), one of the most popular scales for empathy studies in social neuroscience (see for example Gazzola, Aziz-Zaadeh, & Keysers, 2006; Jackson, Meltzoff, & Decety, 2005; Lawrence et al., 2006; Singer et al., 2004, 2006). The other set was the EQ, developed

by Baron-Cohen and colleagues (Baron-Cohen & Wheelwright, 2004). Both the IRI and EQ scales are categorized into several subscales corresponding to different aspects (for example, cognitive or emotional aspects) of empathy (Davis, 1983; Lawrence, Shaw, Baker, Baron-Cohen, & David, 2004; Muncer & Ling, 2006). Thus, it was expected that a possible correlation between the MFN amplitude and these measurements would further contribute to the elucidation of the nature of individual differences in non-self performance monitoring.

In summary, this study aimed to further elucidate the properties of the o-MFN and examine a possible association with the empathetic nature of the individual. We examined whether the amplitude of the o-MFN is different in responses to different observational targets, and the association between this difference and the measured personality trait.

METHODS

Participants

Gender-matched friend pairs were recruited from local Japanese universities. Twenty-three pairs (13 male and 10 female pairs, aged 18–32 years, mean 19.5) of healthy, right-handed Japanese undergraduate and graduate students participated in the experiment. Handedness was assessed using an abridged version of the Edinburgh Inventory (Oldfield, 1971). Participants were paid approximately 2000 yen, with additions or subtractions depending on the scores on the gambling task. Written informed consent was obtained from each participant before the experiment. The ethics committee of The University of Tokyo approved this study.

Apparatus and procedures

The methodology was based on our earlier study (Fukushima & Hiraki, 2006). In an electrically shielded room, each participant pair was seated ~1 m in front of a 14-inch CRT display, and ~0.8 m apart from each other (Figure 1A). Each participant held a response box, on which there were two buttons to select the left and right “cards” in the display. They were instructed to

use the left hand to press the left button (left card), and the right hand for the right button (right card). The task sequence (shown in Figure 1B) was based on that of Gehring and Willoughby (2002a). Two possible betting cards, in denominations of 5 yen and 25 yen, were displayed (each card was 6.5° high, 7.5° wide, and each printed number was 2° high), and a player selected one of them. Approximately 1 s (uniformly varied from 800 to 1200 ms) after the choice, the color of the selected card changed to cyan or magenta. One color indicated a gain for the player, while the other indicated a loss; this was assigned randomly across participant pairs.

The task included four “players”: two human participants and two computer-generated players. Each of the four players performed 20 consecutive trials in turn, then one agent played 20 trials successively, then another agent played 20 trials (Figure 2). Because there were four players, this experiment contained four trial types for each human participant: a self-performance trial and three observation trials in which he or she observed three kinds of non-self agent performance (a human counterpart and two types of computer-generated counterparts). The participants were given two instructions for each task: (1) “maximize your individual outcome using any strategy”; and (2) “pay as much attention to the other players’ performances and outcomes as you do to your own.” The choices of PC programs were set to be random. The probability of gain/loss for each of the four players was 50%.

Each human player was paired with one of the two computer-generated players and took turns playing in an experimental block. Each of the four players was assigned a letter with which to display their turns and scores. Human participants were assigned “A” or “X” randomly, and the computer-generated players were labeled “B” or “Y” (Figure 2A). The whole recording session consisted of four blocks, in which two blocks were performed by the A (human) and B (computer) pair and the other two by the X (human) and Y (computer) pair. The aim of this design was to ensure there were periods where the human players could participate as a stable observer, and not always as a next or former player. During the blocks for the A–B pair, player X could concentrate on observing the performances of A and B without having to immediately prepare for or reflect on their own performance. During the

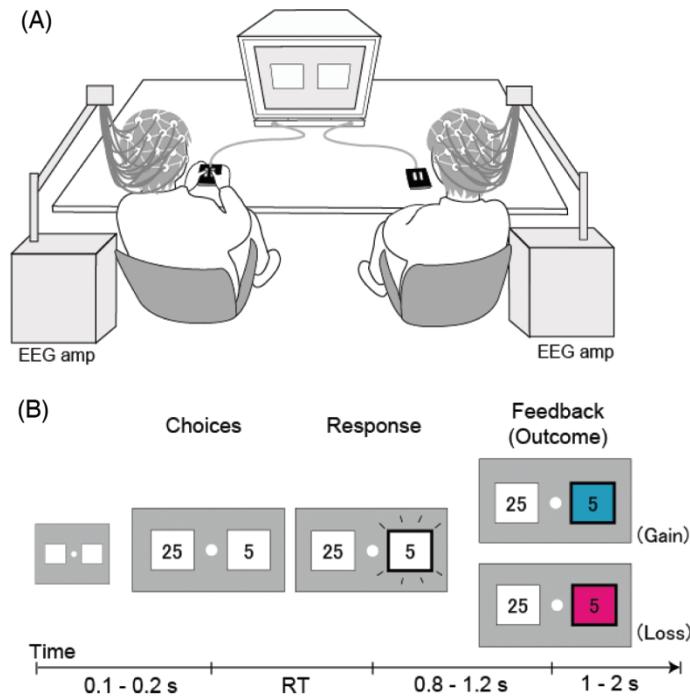


Figure 1. Experimental setup (A) and task sequence (B) of the experiment. (A) Two players sat in front of a display and played a game. EEG recordings were taken from both players. (B) In each trial, 5 yen or 25 yen betting cards were displayed and the performer selected one of the cards (the example illustrates the selection of a 5 yen card). After choosing, the selected card changed into one of two colors, either cyan or magenta. In this example, cyan indicated a gain, while magenta indicated a loss for the performer.

X–Y blocks, conversely, player A was able to simply observe. Using two types of computer-generated players would also enable us to examine any possible effect of temporal proximity with self-performance, by comparing neural activity between human–human and human–computer pairings.

After each turn of 20 trials, the scores of each player were displayed to help maintain motivation (Figure 2B). A short rest period was then inserted during which the display informed the players who was next, namely, “A’s turn” or “Y’s turn.” This display disappeared to start the next 20 trials at the press of a button by one of the human players (that is, the players controlled the lengths of the rests). The actual trials were preceded by 10 practice trials for each human player. An interval of 3–5 min was inserted between blocks. The first and second blocks were initiated by human players; the third and fourth blocks were initiated by the computer-generated players. When the second and fourth blocks ended, participants filled out questionnaires, which are described later in this section.

The entire experimental session consisted of 640 trials and lasted for 70–90 min.

For the subsequent data analysis, the measurements corresponding to the four players were labeled as follows: Self-performance was labeled “self,” the human partner was “human,” the computer-generated player who partnered the participant in a task block was “PC1,” and the other computer-generated player (that is, the other participant’s partner) was “PC2.”

EEG recording

Each participant’s EEG was recorded from 65 electrodes with a Geodesic Sensor Net (Tucker, 1993), sampled at 250 Hz with a 0.1- to 100-Hz band-pass filter. All recordings were initially referenced to the vertex and later digitally re-referenced to the averaged mastoid’s reference. In the offline analysis, a 30-Hz low-pass filter was reapplied. All data were segmented into 1024-ms epochs, including a 200-ms prestimulus baseline period, based on time markers for the onset of the

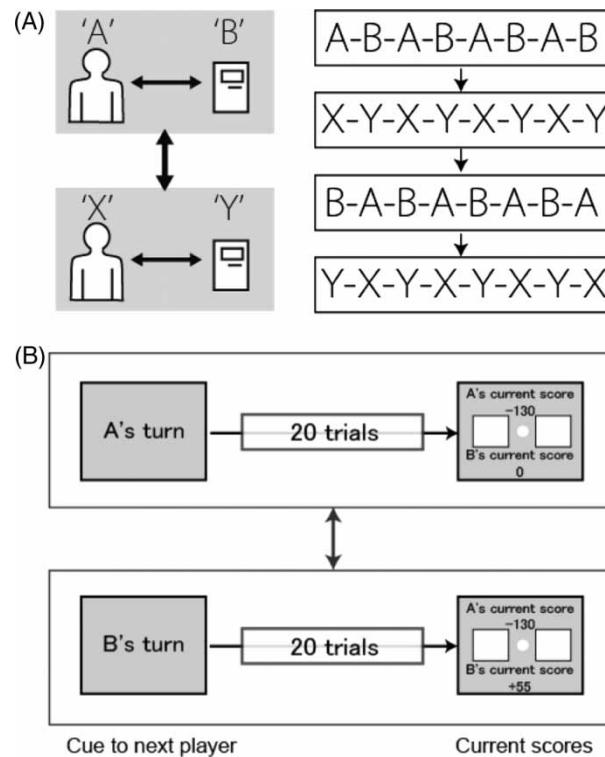


Figure 2. Procedural illustrations. (A) Assignment of player names and schematic of the hierarchical block design (left). The entire procedure consisted of four blocks (right). In each block, two assigned players performed 20 consecutive trials in turn. (B) Visual display during the rest period and at the end of the 20-trial unit. This illustrates the first and third blocks performed by players “A” and “B”. In the second and fourth blocks, it displayed the turn and scores for players “X” and “Y”.

feedback stimuli. Only segments less than ± 100 μV in each channel were analyzed and baseline-corrected.

Calculation of the ERPs

The data from one male participant was rejected during the subsequent analysis due to an insufficient number of artifact-free segments. Thus, the data from 45 participants (20 females) was used. The ERPs were calculated from EEG segments and time-locked to each type of feedback stimulus (gain or loss by each player).

Medial-frontal negativity

The MFN was defined as the negative component of the difference waveform between loss and gain for each player. The electrode site and time window for quantifying the MFNs for each subject were based on grand-averaged waveforms across subjects. On the grand-averaged data, the MFNs showed maximal amplitude at the FCz site, with peak latencies for each player shown in Table 1. Then, the mean amplitudes of the 40-ms time windows centered over these peak latencies were calculated for both the gain and loss of each agent at the FCz site. Although we considered the

TABLE 1
Area-mean amplitude and peak latency of each MFN

		<i>Self</i>	<i>Human</i>	<i>PC1</i>	<i>PC2</i>
Amplitude (μV)	mean	-3.287*	-1.252*	-0.608	-0.353
	SD	3.890	2.462	2.407	1.853
Latency (msec)	mean	256	236	220	228

Note: * $p < .05$.

MFN to be the negative component of the difference waveform for loss minus gain, the statistics described below dealt with ERPs of gain and loss trials separately to test the significance of MFN generation.

P300

The amplitude of the P300 component was determined as the most positive peak in the waveform at electrode location Cz, where the P300 showed maximal amplitude, in the period 200–600 ms post stimulus onset, after 4-Hz low-pass filtering (Yeung & Sanfey, 2004). The amplitudes were calculated for the gain and loss trials separately, and averaged between the gain and loss trials for each player.

Repeated-measures ANOVA analyzed the ERP components with two within-subject factors (outcome (gain/loss) and agent (self/human/PC1/PC2)) and one between-subject factor of gender (female/male). Greenhouse-Geisser epsilon correction of degrees of freedom for non-sphericity was applied where appropriate (Jennings & Wood, 1976).

Questionnaires

The task-related psychological states of the participants as well as their task-independent traits were measured using paper questionnaires.

Psychological state measurements

The participants rated their subjective states during the task concerning the task and players. The contents of the questionnaires were as follows.

1. Motivation: “How strongly did you feel ‘I want to get money, or win the game?’”
2. Interest: “How much were you interested in the game (or that of the other participant, computer-generated player PC1, or computer-generated player PC2)?”
3. Attention to self (or non-self) outcomes: “How much attention did you pay to the outcome of your choice (or to that of the other participant, computer-generated player PC1, or computer-generated player PC2)?”
4. Affect toward the gain (loss) of each player: “How good (bad) did you feel that your

choice (or that of the other participant, computer-generated player PC1, or computer-generated player PC2) resulted in a gain (loss)?”

5. Intimacy: “How much intimacy did you feel toward the other agents?” (rate for each of the three non-self players)
6. Personalization: “How did you feel or attribute intentionality toward the other agents?” (rate for each of the three non-self players)
7. Familiarity with the other human participant: “How much do you think you know about him/her?”
8. Period of acquaintance with the other participant: “How long ago did you first meet him/her?”

Regarding questions 2, 3, and 4, the participants rated each of the four players (self, human, PC1, and PC2). Regarding questions 5 and 6, they rated the three non-self players. Regarding questions 7 and 8, they rated the human player (the other participant).

Scores were rated on a 13-point scale (0 to 12). Scores 0 and 12 were labeled “not at all” and “very much,” respectively. For question 4 (“Affect”), 0 was labeled “very bad/sad” and 12 “very good/happy”. For each agent, the affect scores were rated for gain and loss independently, and were calculated as a difference score of gain minus loss. They rated the first half of the session during the half-time rest period, and the second half after the whole session ended.

Trait measurements

Two sets of trait questionnaires were administered: Japanese versions of Interpersonal Reactivity Index (IRI; Davis, 1983), Empathetic, Systemizing, and Autistic Quotient (EQ, SQ, and AQ, respectively; Baron-Cohen, Richler, Bisarya, Gurunathan, & Wheelwright, 2003; Baron-Cohen & Wheelwright, 2004; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). The IRI scale includes four subscales that measure “perspective taking,” which represents a cognitive aspect of empathy; “empathetic concern,” which reflects the capacity of the respondent for warm, concerned, compassionate feelings for others; “fantasy”, which measures a tendency to identify with fictional characters; and “personal distress”, which shows a tendency to make a self-oriented negative response to other’s negative

TABLE 2
Correlations between the MFN amplitudes and task-related state measurements

	Self	Non-self		
		Human	PC1	PC2
Total monetary outcome	-.03	-.02	.00	.00
Attention	-.09	-.14	.04	-.13
Affect	-.11	-.12	.17	-.08
Interest	-.16	.05	-.08	-.11
Personalization		-.39*	-.15	-.25
Intimacy		-.10	-.36*	-.06
Familiarity		.13		
Period of acquaintance		-.20		

Note: * $p < .05$.

experiences. The EQ was tested with its three subscales, as well as the total EQ score. EQ subscales measure “cognitive empathy,” “emotional reactivity,” and “social skills” (Muncer & Ling, 2006). SQ and AQ were additionally recorded to see if non-social (SQ) and autistic (AQ) traits were related to non-self performance and reward monitoring. Participants filled out the trait questionnaires during the period of EEG preparation, during the rest period mid-session, and after the EEG recording session had ended.

RESULTS

Behavioral and psychological data

The probability of gain/loss was made equal across all players to rule out potential confounding influences of the differential gain–loss probability. There was no association between the MFN amplitudes and monetary outcomes (Table 2).

Figure 3 represents the averaged scores of each task-related questionnaire (state measurement) for self and non-self agents. The scores for all items varied significantly among the non-self agents (human, PC1, and PC2), indicating that the participants observed the performances of those players with different mental states or attributions in several aspects.

ERP results

Grand-averaged ERPs for gain and loss and difference waves between the loss and gain of each agent are illustrated in Figure 4. For each agent, there was a visually discernible differentiation between loss and gain, indicating generation

of the MFN (see also Figure 5). This was confirmed as a main effect of Outcome (gain/loss), $F(1, 43) = 34.81$, $p < .0001$, by the ANOVA. Importantly, the ANOVA showed that the interactions of Outcome \times Agent, $F(2.1, 90.8) = 10.92$, $p < .0001$, which indicates the magnitude of the gain–loss differentiations (that is, the amplitudes of MFN), were not the same across agent types. The large effect of Agent, $F(1.9, 80.5) = 105.82$, $p < .0001$, reflects the fact that the general difference in P300 amplitudes among agent types was overlaid in the time window of the MFN (Yeung & Sanfey, 2004; Yeung et al., 2005).

To further clarify the nature of the o-MFN, the ANOVA was reapplied to the data from observation trials (that is, human, PC1, and PC2). During observation of the non-self agents, the main effect of outcome was still strong, $F(1, 43) = 8.18$, $p = .0065$, indicating the significance of the o-MFN in this experiment. The main hypothesis of this

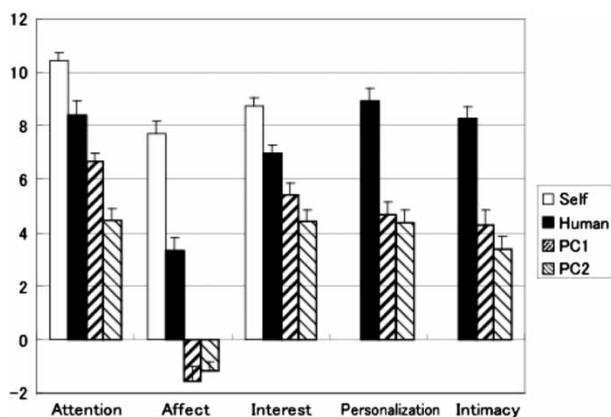


Figure 3. Scores on the state measurements averaged across all participants. Averaged scores of all participants' subjective ratings on attention, affect, interest, personalization, and intimacy felt toward each type of agent are shown. See the text for the details of each item. Error bars indicate *SE*.

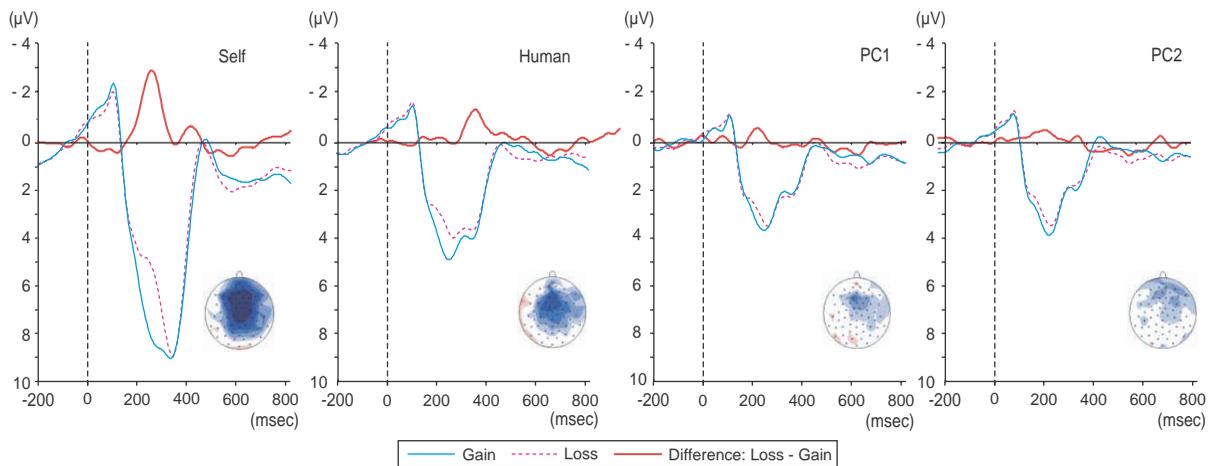


Figure 4. ERP responses to feedback for each agent. Grand-averaged waveforms and the difference waveforms at FCz are shown, time-locked to the feedback stimuli. The waveforms were bandpass-filtered at 1–12 Hz for illustration purposes. Scalp distributions of the difference wave (MFN) at peak latencies are shown viewed from the top with the nose pointing upward.

study was that the o-MFN changes in response to different targets. The interaction of Outcome \times Agent provides evidence for this hypothesis, although the statistics did not reach significance, $F(1.9, 80.6) = 2.42$, $p = .098$. Additionally, the significance of each MFN was individually tested. The MFNs evoked in self and human trials were significant, while the components evoked by the PC players were not (Table 1).

We tested the correlation between amplitude modulations of the MFN and P300 among different agent types to examine the possibility that the MFN modulation shown above was due to the variation of P300 among agent types. Following the analysis of Yeung et al. (2005), the difference in ERP amplitudes between agent types was calculated for both the MFN and the P300, and

the correlation of the differences between the two components was tested. We did this test on two kinds of pairing: self vs. PC1, which corresponded to the pair in the self-performance block; and human vs. PC2, which was the pair in the observational block. The test showed no significant correlation in either pair, indicating that modulation of the o-MFN amplitude across observational targets was somewhat independent of the P300 components.

Correlation between MFNs and psychological measurements

State scores

Table 2 depicts the Pearson's correlation coefficients between each MFN and the participants' subjective ratings in the post-task questionnaires. The amplitude of the MFN in the self trials had no significant association with the state scores. For the o-MFNs, two correlations were detected: in the human trials, the MFN amplitude correlated with "personalization" ($r = -.39$, $p = .02$). The amplitude in the PC1 trials correlated with "intimacy" ($r = -.36$, $p = .03$). No correlation was detected in the PC2 trials.

Trait scores

Correlation with the trait scores was tested for the MFNs of each target (Table 3 and Figure 6). Regarding the MFN for self, a marginally significant correlation was found with the "perspective taking" subscale of the IRI ($r = .29$, $p =$

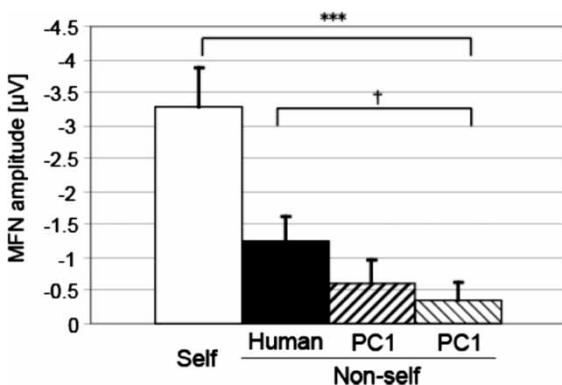


Figure 5. Mean amplitude (area mean with 40-ms window) of each MFN, averaged across participants. Error bars indicate SE. $\dagger p < .1$, $*** p < .001$.

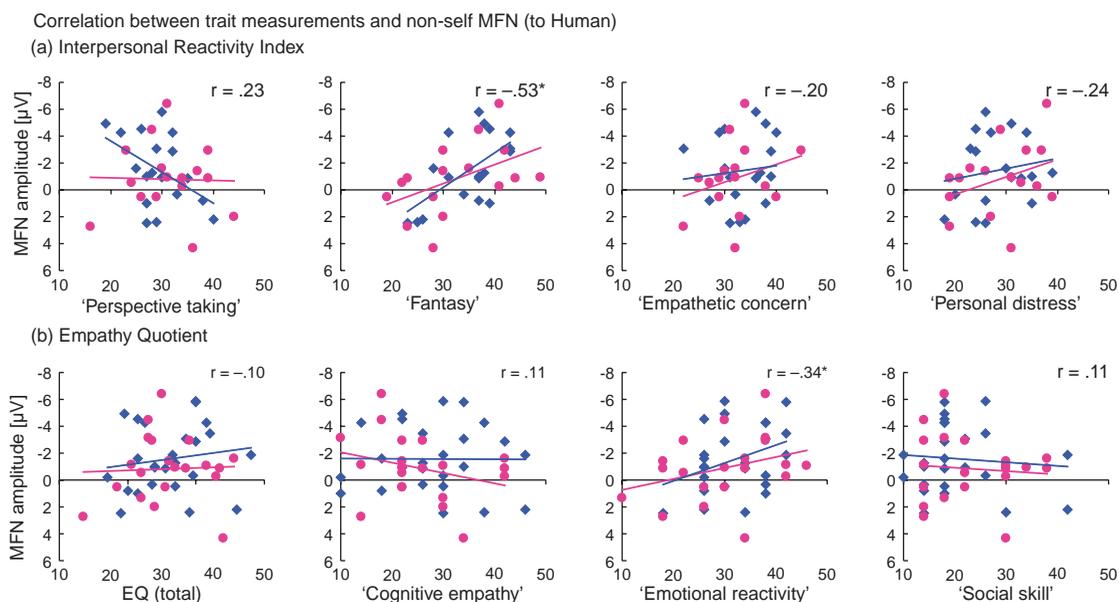


Figure 6. Scatter plot between the MFN amplitude (y-axis) in the human trials and the scores of empathetic measures (x-axis). Data from the male group is plotted in blue diamonds, while that from the female group is shown in red circles. The blue and red lines represent the best linear fit for each gender group, but correlation coefficients (r -values) in each panel were calculated from the total participant data. Note that the MFN is a negative potential, and thus, vertical axes indicating the MFN amplitude are increasingly negative going up. A negative correlation coefficient means a positive correlation between a psychological score and the magnitude of the related neural activity. $*p < .05$.

.094). In the human trials, two scales showed a significant correlation: One was the “fantasy” subscale of the IRI ($r = -.53$, $p = .0012$), and the other was the “emotional reactivity” subscale of the EQ ($r = -.34$, $p = .022$). During observation

of the decisions of computer-generated players, the MFNs showed no significant associations with trait scores.

DISCUSSION

The current experiment showed that an MFN-like pattern is elicited while observing the performances of non-self agents, consistent with the findings of previous reports. Importantly, this was true even though the observed outcomes were not related to the participants’ own benefit. For all agents (in response to the feedback for one’s own and the three non-self agents’ performances), the latencies of the MFNs were almost the same, at around 200–300 ms, with comparable morphologies and similar scalp distribution over the front-central sites. Among the three non-self agents, only the o-MFN to a human agent was statistically significant. Although the ERPs evoked when observing the computer-generated players displayed discernible MFN-like divergences along the same latency as the MFN in self performance, they did not reach statistical significance. The scores of participants’ subjective states during the task, such as attention, motivation, interest,

TABLE 3
Correlations between the MFN amplitudes and trait measurements

	Self	Non-self		
		Human	PCI	PC2
Davis’ IRI				
Perspective taking	.29†	.23	-.18	-.01
Fantasy	-.01	-.53*	-.27	-.10
Empathetic concern	-.03	-.20	-.04	.01
Personal distress	-.21	-.24	-.03	.22
EQ				
Total	-.07	-.10	-.04	-.08
Cognitive empathy	-.14	.11	.04	-.13
Emotional reactivity	-.13	-.34*	-.16	-.06
Social skill	.02	.11	.12	-.04
SQ	.08	.01	-.06	.07
AQ	.10	.00	-.03	.23

Notes: IRI = interpersonal reactivity index, EQ = empathy quotient, SQ = systemizing quotient, AQ = autistic quotient. † $p < .1$, $*p < .05$.

personalization and intimacy, differed significantly among the human and computer-generated players. Together with these psychological measurements, the ERP data suggested that the amplitude of the o-MFN reflected the participants' attitudes, which were manipulated by something other than the target of observation.

Furthermore, the correlation analysis between the amplitude of the MFN and psychological states and traits provided insight into the cause of the amplitude difference among different agents. Among the participants' state measurements, a rating for "personalization" on the observed performance was correlated with the o-MFN amplitude when observing a human agent. This aspect was scored to the extent that the participants attributed intentionality or mental states to the player while observing task performances in a display. Therefore, the correlation of o-MFN amplitude with this item suggested an effect of social processing to o-MFN amplitude. Empathy trait scores also showed significant correlations with the o-MFN amplitudes in the human trials. On the other hand, the o-MFN amplitudes when observing the computer-generated players did not show correlation with state or trait psychological scales, with the only exception between the o-MFN in the PC1 trials and the score of "intimacy". This lack of associations between the o-MFN and psychological measures in PC trials may be due to instability or a bad signal-to-noise ratio, because this component in the PC trials was so weak that it did not reach statistical significance. We interpreted the whole results on the o-MFN to mean the amplitude modulation of it reflected social and affective processing in the individual. In particular, the correlation found with the state and trait measurements suggests that the intensity of the o-MFN is associated with empathy to non-self performances.

As mentioned in the introduction, the MFN is likely to reflect several types of processing ranging from the cognitive to the affective domain. The MFN is often considered to reflect the activity of the learning (RL) process. Consequently, although we consider the amplitude of the o-MFN to be modulated by empathy-related processes, it has been suggested that it also reflects learning processes, such as observational learning or classical conditioning (Miltner et al., 2004; van Schie et al., 2004; Yeung et al., 2005; Yu & Zhou, 2006). In the current experiment, the participants might have explicitly or implicitly

tried to find out and learn some task-related information, such as a pattern in the gain/loss sequence or a possible strategy employed by a non-self agent. Therefore one may assume that the o-MFN observed in the current experiment also reflected this learning process. However, it is difficult to explain the cause of the o-MFN amplitude modulation on the basis of learning or other cognitive theories. The RL theory to explain the MFN suggests that the amplitude modulation was affected by prediction error. Participants' predictions about the outcome can be manipulated by, for instance, the probability (Holroyd et al., 2003) or uncertainty (Pailing & Segalowitz, 2004; Yasuda et al., 2004) of outcomes. In the current experiment, however, the probability of gain/loss among all players was equal and the participants were told that every player performed the same tasks, and as such, outcome probability and uncertainty between players were not an issue. In fact, the results showed no association between the o-MFN and total amount of rewards each player received. Therefore, it is difficult to assume that a learning process was a factor in the modulation of the o-MFN amplitude.

A couple of previous studies have examined the MFNs in response to rewards given to participants not as a consequence of the participants' own decisions (Donkers et al., 2005; Hewig et al., 2008; Yeung et al., 2005). Yeung et al. (2005) reported that although being rewarded by the choice of a computer program in a gambling task significantly elicited the MFN, its amplitude was lower than that in self-choice trials. They also showed that the decrease in the MFN in non-self choices was correlated with decreased participant ratings of interest in the game. A recent study by Hewig et al. (2008) examined the o-MFN in a situation where participants "coached" another agent playing blackjack. Hewig and colleagues showed that the o-MFN in response to another's playing was largely affected by whether or not the player followed the participant's advice. Indeed, similar to our results obtained by defining the MFN as a loss-gain differentiation of ERPs, one of their results indicated that the o-MFN was shown only when the player rejected the participant's advice, but absent when the advice was taken by the player. As the authors noted, the nature of blackjack involves a possible confounding factor in the predictability of an outcome and a decision by a player whether to take another card. Thus, their finding was difficult to interpret,

since the MFN is sensitive to the predictability of the event (Holroyd & Coles, 2002; Nieuwenhuis et al., 2004a). It should also be noted that in their study, the outcomes of the players being coached were equally reflected in the benefits of the participants doing the coaching. One aspect that the results of Yeung et al. (2005) and Hewig et al. (2008) have in common is that the MFN in reward processing was sensitive to whether the reward was preceded or caused by self-decision. Although the respective authors both considered this aspect in relation to the learning process, in our view it is also related to a sense of self-relevance, that is, the degree to which an individual felt involved in the event being observed. Needless to say, a sense of self-relevance is important in social and affective processing. Our present study examined a situation where the events being observed were generated by another agent and did not benefit the observer. Therefore it strengthens the notion that the o-MFN can be an index of the degree of self-involvement in social cognition.

When discussing the “intensity” of a neurocognitive process, arousal is likely to be an important covariate. Thus, another question concerning the present results is whether the modulation of o-MFN observed here is explained by general arousal, rather than the specific affect of performance monitoring. In fact, subjective ratings about the tasks indicated that the participants consistently felt stronger attention, interest and affect when observing human gambling compared with computer-generated gambling, suggesting that general arousal increased more in human observation. However, it should be noted that the difference in the amplitudes of the o-MFNs among different non-self agents was not correlated with the difference in P300 amplitude, which is thought to be an index of arousal. This fact suggests that the intensity of empathetic processing is partly dissociated from general arousal, at least in the process reflected in performance monitoring.

It has been claimed by studies on empathy in several fields that empathy consists of several components (see for example, Davis, 1983; Preston & De Waal, 2002; Decety & Lamm, 2006). One principal axis of the concept of empathy is “emotional or cognitive” dichotomy. Although the terminology largely depends on the researcher, emotional empathy often implies automatic sharing of and emotional reactivity to another’s emotional state, while cognitive empathy often implies

intellectual and reflective understanding (Baron-Cohen & Wheelwright, 2004; Preston et al., 2007). Correspondingly, the empathy questionnaires used in this study consisted of subscales that can be categorized into cognitive and emotional processing. In the Davis IRI scales “perspective taking” is cognitive, while others, including “fantasy,” are considered emotional (Davis, 1983). In the Baron-Cohen EQ scores, “cognitive empathy” represents a cognitive trait while “emotional reactivity” is an emotional trait (Lawrence et al., 2004, Muncer & Ling, 2006).

This study showed that two subscales, “fantasy empathy” in the IRI and “emotional reactivity” in the EQ, were correlated with the human non-self MFN. The fantasy scale in the IRI measures the tendency to transpose oneself into the feelings and actions of fictitious characters (for example, in books and movies). A sample from this scale is “I really get involved with the feelings of the characters in a novel.” Higher scores on this scale seem to further reflect the susceptibility of one’s thoughts to intrusion of counterfactual mentalizing. In other words, it may reflect an automatic aspect to empathy, which occurs easily even with no target. As for the “emotional reactivity” in EQ, an example is “Seeing people cry doesn’t really upset me” (a reverse item). Higher scores on this scale reflect the tendency to have an emotional reaction in response to others’ emotional states (Lawrence et al., 2004). As described above, these scores reflect emotional aspects of empathy. Together with the finding that cognitive empathy (that is, “perspective taking” in the IRI and “cognitive empathy” in the EQ) did not show an association with the o-MFN, these results suggest that an association between the o-MFN and empathy traits may be explained in terms of emotional and automatic reactivity to the affective states of others.

Recent research in social neuroscience has shown that psychological questionnaires on social behavior are correlated with neural activity variation between individuals (see for example Fukushima & Hiraki, 2006; Gazzola et al., 2006; Singer et al., 2004, 2006). Among studies that utilized Davis’ IRI as a measurement of empathy, neural activity correlations were found between motion perception and “perspective taking” (Gazzola et al., 2006), pain and “empathetic concern” (Singer et al., 2004, 2006), and loss and “fantasy” (current report). These tasks required relatively low-level perception, rather than “highly cognitive” tasks (but for another view see

Lawrence et al., 2006). This implies that individual differences in social traits are at least partly based on a low-level perception of others. Further, although a study of pain-observation failed to find any association between empathetic neural activity and IRI scores (Jackson et al., 2005), the examples above indicate that the subscales showing a correlation with neural activities in social cognition are not consistent. This point of discrepancy may be at least partially due to whether the affective process was involved in a task. The measure of “perspective taking”, which represents cognitive empathy, was associated only with motion perception (Gazzola et al., 2006), which presumably involved almost no emotion. On the other hand, the other tasks, which involved the affective experiences of others, were associated with the affective empathy scales. However, because this is still a tentative and rather coarse explanation, further investigation is required to further elucidate what aspect of empathy is associated with which part of neural processing in social cognition.

Along with the observed inter-individual difference, our data also demonstrated systematic intra-individual differences in neural activity. Thus, one future research direction is to examine the possible effects on non-self performance monitoring, such as familiarity with or gender of an observational target. Further, recent studies as well as the current report have shown how the empathetic neural response varies depending on several factors, such as personal preference (Singer et al., 2006) and interpretation of an event (Lamm, Batson, & Decety, 2007). We believe these examples of intra-individual modulation in social neural activities can be considered a kind of emotion regulation (Decety & Lamm, 2006; Ochsner & Gross, 2005). The neural dynamics of modulation and how it correlates with interpersonal attitudes should be further elucidated.

CONCLUSION

This study found that the MFN was elicited in response to the monetary rewards of other agents. This was the case when the outcomes were not linked to the observer's own reward. The amplitude of the o-MFN varied depending on who performed the observed performance. Amplitude was correlated with the participants' subjective intensity of self-attribution to their partner as well

as with their empathy scores. We conclude that the amplitude of the o-MFN reflects empathetic states toward external agents. Further research is required to examine how the recognition and knowledge about the other person modulates the neural activity of non-self performance monitoring. The present data suggests that the neural activity of non-self performance monitoring can be a neurophysiological index of interpersonal attitude and social personality.

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