NEURAL CORRELATES OF INTERPERSONAL INFLUENCE: A NEAR-INFRARED SPECTROSCOPY STUDY

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Abstract

To examine the neural correlates underlying an individual's performance in a social context, this thesis discusses studies measuring brain activation changes in participants during a driving video game task using near-infrared spectroscopy (NIRS).

Classical literature in social psychology has categorized social influences into two types: "direct" interpersonal influence through social interaction between persons, and "indirect" interpersonal influence induced by the presence of others. This thesis presents three experiments, focusing on the "direct" (Exp. 1) and the "indirect" (Exp. 2 and Exp. 3) interpersonal influence, respectively.

In Exp. 1, to investigate the neural bases of intrinsic (deriving from intrapersonal processing centered on memory systems) and extrinsic (deriving from interpersonal processing dealing with "direct" social influence) cognitions in daily life, I repetitively measured bilateral prefrontal activation in three groups (one control and two experimental) using NIRS. The control group drove to a goal four times with distinct route-maps illustrating default turning points. In contrast, the memory group drove the memorized default route without a map (intrapersonal processing), and the emergency group drove with a map but was instructed to immediately change the default route following an extrinsically given verbal turning command (interpersonal processing).

I analyzed concentration changes of oxygenated hemoglobin (Coxy-Hb) in three critical periods (pre-turning, actual-turning, and post-turning). The emergency group showed a significant increasing pattern of Coxy-Hb throughout the three periods, and a significant reduction in Coxy-Hb throughout the repetitive trials, but the memory group did not, even though both experimental groups showed higher activation than the control group in the pre-turning period. These results suggest that the prefrontal cortex (PFC) differentiates the intrinsically (memory system) and the extrinsically ("direct" interpersonal influence) driven cognitive processing.

The objective of Exp. 2 was to examine the neural basis of "indirect" interpersonal influence deriving from the presence of others. Previous studies have reported that the presence of a stranger increases an individual's tension, whereas the presence of a friend decreases it. To address the contradictory effects of others' presence, I measured prefrontal activation in performers with or without an observer during a driving game task using NIRS. The participant's task was to drive from start to goal using a route-map either solely (single group) or with an acquainted partner (paired group). The paired participants alternated their driver-observer roles in a turn-taking style. The first driver (D1) took the role of observer (O2) in the subsequent task, and O1-D2 vice versa. The three groups (single, D1, and D2) were subdivided according to their game proficiency (high versus low).

The tension evaluation scores in single and D2 groups were higher than D1, while driving time and number of errors between the three groups did not show significant differences. NIRS data in low-proficiency performers demonstrated that single and D2 groups showed significantly higher activation than D1. These results suggest that the presence of an acquainted partner reduces a performer's tension (positive presence effect), and prior observation of another's performance negates the positive presence effect and leads to an increase of tension in the subsequent task.

Exp. 2 demonstrated that the presence of others may function positively to reduce a performer's tension. Exp. 3 was designed to verify whether this positive presence effect is induced by the performer's "subjective" appraisal of the co-present observer as supportive. That is, whether the performers who appraise the co-present observer as supportive show higher activation in the inferior parietal lobule (IPL: previously shown to be critical for positive emotional processing) than those who appraise the observer as non-supportive.

To address this issue, I measured the activations in the bilateral IPL of the driver-observer pairs of participants, when they performed a driving video game task using NIRS. The performer's task was to drive from start to goal using a default route-map, while their partner observed the performance. According to the performer's subjective appraisal of the co-present observer obtained after the driving task, the pairs were divided into three groups: supportive, non-supportive, and neutral.

The driving time, number of errors, and tension evaluation scores did not show significant differences between the three groups. However, NIRS data of performers in the supportive group showed significantly higher activation in the left IPL than those in the non-supportive group, but not in the right IPL. NIRS data of observers in the two groups concerned did not show any significant differences bilaterally in IPL. These results suggest that the left IPL responds distinctively according to the performer's "subjective" appraisal of a co-present observer.

In conclusion, the results of the present studies imply both practical and theoretical aspects. Exp. 1 using NIRS demonstrated that the PFC differentiates the intrinsically (memory systems) and the extrinsically ("direct" interpersonal influence) driven cognitive processing in daily activities. Exp. 2 and Exp. 3 showed that the presence of others as an observer may reduce a performer's tension, and this positive presence effect is induced by the performer's "subjective" appraisal of the co-present observer as supportive.

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Chapter 1.
Introduction

1.1. Cognition and performance

How do people control their behavior when interacting with the environment? This question has historically been central in the studies of cognition and performance (Thelen and Smith, 1994). Various cognitive theories have developed from several different perspectives emphasizing either side of a set of contradistinctive concepts on human nature. From the view point of human information processing, the cognitive theories diverge in aspects of human properties (passive versus active processing), dynamism of cognitive systems (static versus dynamic processing), and person-environment interaction (intrapersonal versus interpersonal processing).

For instance, in cognitive psychology, Neisser (1976) discussed "the perceptual cycle" describing the cognitive structures internal to the perceiver and the manner in which they change. Figure 1-1 illustrates the perceptual cycle. According to the perceptual cycle, the core component of the cognitive structures is the anticipatory schema. "Schemata are anticipations, they are the medium by which the past affects the future; information already acquired determines what will be picked up next. (This is the underlying mechanism of memory …)" (ibid, p. 22).

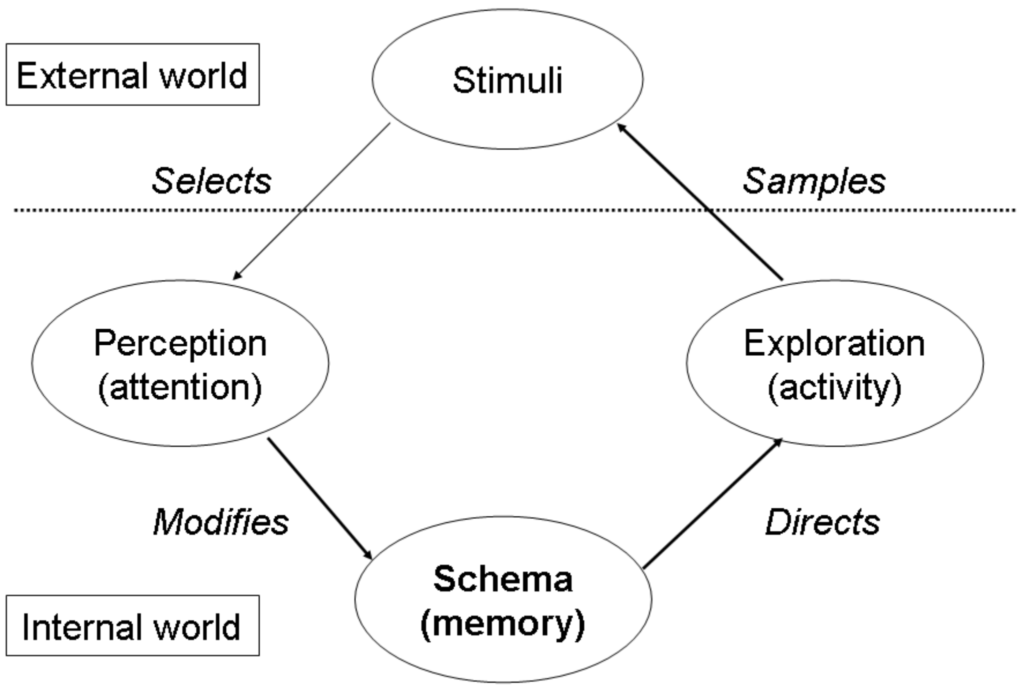

Figure 1-1. The perception cycle (modified from Neisser, 1976).

In cognitive science, Norman (1993), focusing on a perspective of the performer, suggests that “experiential cognition and reflective cognition” are both needed for the human cognitive system, and neither is superior to the other—they simply differ in requirements and functions. Specifically, “The experiential mode leads to a state in which we perceive and react to the events around us, efficiently and effortlessly. ... The reflective mode is that of comparison and contrast, of thought, of decision making. … leads to new ideas, novel responses. Both modes are essential for human performance ” (ibid, p. 16).

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In robotics, Pfeifer and Scheier (1999), shedding light on understanding intelligence, argue for the so-called embodied cognitive science in which they take the stance of placing importance on physical or body actions in the real world. As Pfeifer and Scheier emphasize (p. 77) “Real worlds differ significantly from virtual ones. Virtual worlds have states, there is complete information about them, the possible operations within them are given, and they are static. The real world is quite different. In particular, the real world has its own dynamics, which force the agents to act in real time.”

These historical developments of cognitive theories present a perspective shift on the cognitive system from passive perceiver to active performer interacting with the environment. However, the trends and vicissitudes in cognitive theories do not imply that either side of these perspectives is superior for understanding our cognitive system. If we appreciate that one of the salient features of human cognitive system is to integrate different functions in practical issues of everyday life, it is inevitable to examine both the intrapersonal processing as a perceiver and the interpersonal processing as a performer.

Although cognitive research has made many remarkable discoveries, the traditional cognitive theories have primarily sought to delineate the cognitive mechanisms of one individual’s behavioral processes (Levine et al., 1993). As a social species, we human beings live in a world where most of our daily behaviors are determined or affected by other persons in the vicinity (Hari and Kujala, 2009). If the social is ubiquitous, we face the problem of including almost all aspects of cognition as social (Van Overwalle, 2009). Therefore, it is important to investigate the cognitive mechanisms underlying an individual's performance in a social context, termed as social cognition.

1.2. Social cognition

Social cognition broadly consists of the cognitive processes "used to understand and store information about other persons including the self, and about interpersonal norms and scripts (or procedures) to navigate efficiently in the social world" (Van Overwalle, 2009). Social cognition has been studied from various theoretical perspectives, most notably social psychology.

To investigate the issue of how social contexts affect an individual's solitary behavior, classical social psychology literature has categorized the social influence into two types: "direct" and "indirect" interpersonal influences (F. H. Allport, 1920). Figure 1-2 illustrates these two types of interpersonal influences. "Direct" interpersonal influence is induced by the explicit verbal or non-verbal social stimuli from other persons. "Indirect" interpersonal influence derives from the presence of others (e.g., an observer) without any explicit communication and interaction. The later is the oldest but still contains unexplained perplexities in experimental social psychology (G. W. Allport, 1954), termed as social facilitation by F. H. Allport (1924).

Social facilitation represents the most rudimentary way in which social factors influence an individual's cognitive processes and performance (Levine et al., 1993). In the present study, I will mainly focus on the social facilitation effects, that is, the effects of the presence of others.

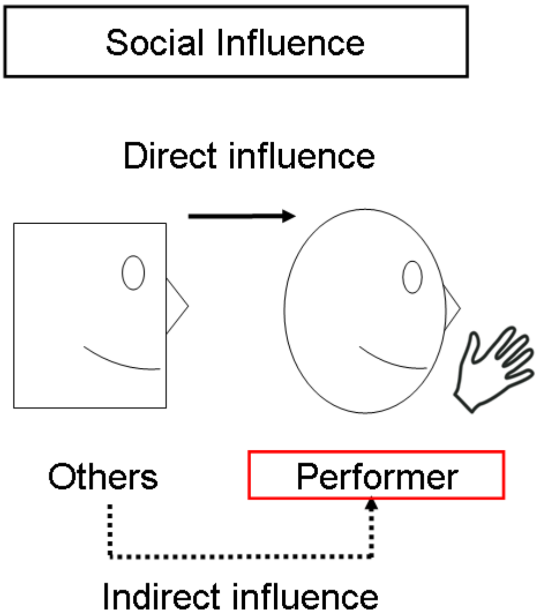

Figure 1-2. Illustration of two types of social influences. Standing on a perspective of the performer, social influence could be classified into two types: "direct" and "indirect" interpersonal influences.

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Early social facilitation literature has revealed conflicting effects from the presence of others on solitary performance. The presence of others improves an individual's performance with regard to task speed and accuracy (F. H. Allport, 1924), but also may impair it (Pessin, 1933). Although a large body of research has been generated until the late 1930's, "the basic question about social facilitation—its dynamics and its causes—which are in effect the basic questions of social psychology, were never solved" (Zajonc, 1965).

To explain these seemingly incompatible results in social facilitation research, Zajonc (1965) drew on Hull-Spence behavior theory (Spence, 1956) and proposed an "arousal" theory. Hull-Spence theory represents behavior as a function of habit strength and generalized drive: In the mathematical notation, $E = f(H \times D)$, where E, H, and D represent potential behavior, habit strength, and generalize drive, respectively. On the basis of Hull-Spence theory, Zajonc (1965) suggested that the presence of others increases an individual's arousal (drive), which in turn enhances emission of a habitual response from his/her behavioral repertoire. In a simple task, the habitual response is usually the correct one, leading to performance improvement, whereas in a complex task, it is usually the incorrect one, leading to performance impairment.

The assumption that social presence "increases" an individual's arousal, however, appears to go against reports in life science which show that presence of a supportive person "reduces" individual's nervous response, termed as social support (Cohen and

Wills, 1985; Lazarus and Folkman, 1984). As Zajonc (1980, p. 51) noted, “If we think of social facilitation as brought about by heightened levels of arousal, then a real or apparent contradiction arises with the empirical results and theories that deal with the effects of affiliation on reactions to stress”. For instance, Phillips et al. (2009) measured cardiovascular reactivity when participants performed a mental arithmetic task in the presence of a stranger or friend. They found that the presence of a friend may reduce blood pressure, whereas presence of a stranger was associated with an increase.

These two distinct streams of research—social facilitation and social support—suggest that the effects of the presence of others may rely on the social relationships between the performer and the other person present, as noted by Hutchins (1995, p. 224) “performance is embedded in real human relationships”. That is, according to the role of the co-present others (e.g., supportive or non-supportive), the brain and performance of the performer may change.

To clearly understand and explain the effects of the presence of others, it is necessary to properly appreciate how social presence affects a performer’s cognitive processes in the brain. As these processes are hidden, the traditional behavioral measurements are hard to resolve this problem, although the physiological measurements could offer some “indirect” hints.

Recently, the technological development of brain imaging methodologies provides a possibility to uncover the cognitive processes controlled by the brain in a social context (Frith and Frith, 2008).

1.3. Social cognitive neuroscience

Social cognitive neuroscience is a “burgeoning interdisciplinary field combining the tools of cognitive neuroscience with questions and theories from various social sciences including social psychology” (Lieberman, 2007). Research in social neuroscience can be classified into three main domains: facial recognition, theory of mind (or mentalizing), and social interactions (Frith and Frith, 2008). The first two classes are largely concerned with the effect of social situations on individuals as perceivers. The third domain directly investigates the social influences occurred between two or multi persons as performers.

Although the scope of social cognitive neuroscience research is vast and rich, the experimental paradigms used are primarily concerned with studying the neural mechanisms of one individual’s cognitive processes at the input end (Adolphs, 2003; Hasson et al., 2012). As Adolphs (2003) states that many studies have mainly focused on the visual modality by showing pictures or videos of social relevance to participants (often under passive viewing conditions). And the typical experiments isolate participants from their natural environments by placing them in a sealed room.

Hasson et al. (2012) has pointed out the vulnerability of cognitive neuroscience studies focusing on processes that occur with a single individual, and recommended promising strategies for a multi-brain from a single-brain frame of reference. The present study was partially motivated to embrace the frame of multi-brain in a social context, and aimed to investigate the neural mechanisms underlying performance in a “two-person” situation. That is, the present study moves a small step towards real-life “two-person neuroscience” (Hari and Kujala, 2009).

1.4. Brain imaging techniques

The earliest neuroimaging that focused on functional brain localization was positron emission tomography (PET). However, due to its poor temporal and spatial resolutions, PET was replaced later by the functional magnetic resonance imaging (fMRI) which becomes the dominant mode of functional neuroimaing (Lieberman, 2010).

fMRI is a non-invasive brain imaging technique to investigate the neural mechanisms underlying human perception and performance. Most fMRI studies use blood oxygen level-dependent (BOLD) signal to determine which brain regions are more or less active during any task. BOLD fMRI works on the principle that the blood flowing to an active region is more oxygenated than blood elsewhere, and oxygenated blood has different magnetic properties than deoxygenated blood: fMRI detects the spatial location of these different magnetic properties and reconstruct where blood was flowing to (Lieberman, 2010).

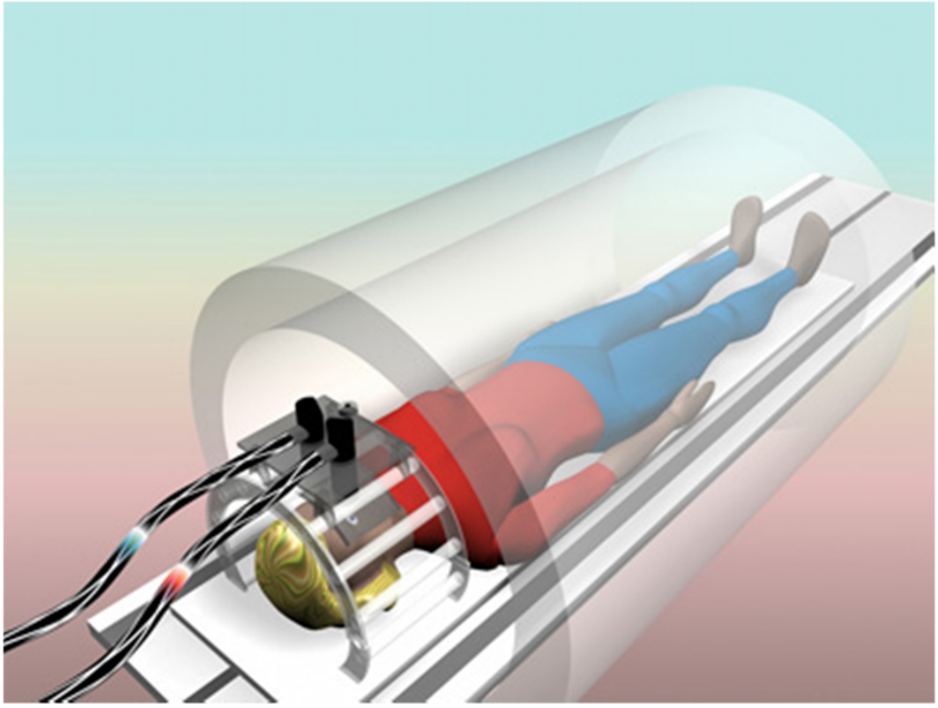

Figure 1-3. An example of classical experimental setting in fMRI studies (adopted from http://www.hitl.washington.edu/projects/magnet/).

Three limitations are evident in the early fMRI literature on human behavior in a social context. First, previous studies have mainly focused on the brain activation changes during the passive perception or the simple reaction to static stimuli; little is known about the neural response during more complex movements to be evaluated in real time. Second, most research on the effects of the presence of others has measured brain activity in single individuals with the virtual presence of others that does not directly assess activation changes in a real performer-observer situation. Third, numerous studies have used highly artificial experimental settings and do not examine the social influence during daily activities. Concerning the particular reasons, it is important to note that a technical limitation of fMRI constrains participants to lie in a motionless and solitary position and makes it difficult to assess cortical functions in naturalistic environments. Figure 1-3 shows an example of classical experimental setting in the fMRI studies.

Near-infrared spectroscopy (NIRS) provides a possibility to avoid these three limitations. Like fMRI, NIRS is also a non-invasive method for studying functional activation by measuring changes in the hemodynamic properties of the brain. Unlike fMRI, NIRS is portable, easy-to-use, and tolerant to motion artifact. That is, NIRS has relatively few physical constraints on participants, permitting serial assessments of tasks in less restricted and noisy conditions (Cui et al., 2012; Leff et al., 2011; Okamoto et al., 2004). Figure 1-4 shows an example of experimental setting in the NIRS studies.

Although NIRS has a relatively low spatial resolution of 20-30 mm and cannot measure deep brain structures (Hoshi and Tamura, 1993), several brain regions such as the prefrontal cortex (PFC), motor cortex, and parietal cortex are located in close proximity to scalp tissue, they are readily accessible using NIRS (Leff et al., 2011). On the other hand, it has been suggested that NIRS signals reflect not only cerebral hemodynamics but also scalp and facial blood flow (Ito et al., 2011). Concerning this issue, many studies have demonstrated strong correlations between NIRS signals and cerebral activation measured by fMRI (Hoshi et al., 2001; Huppert et al., 2006).

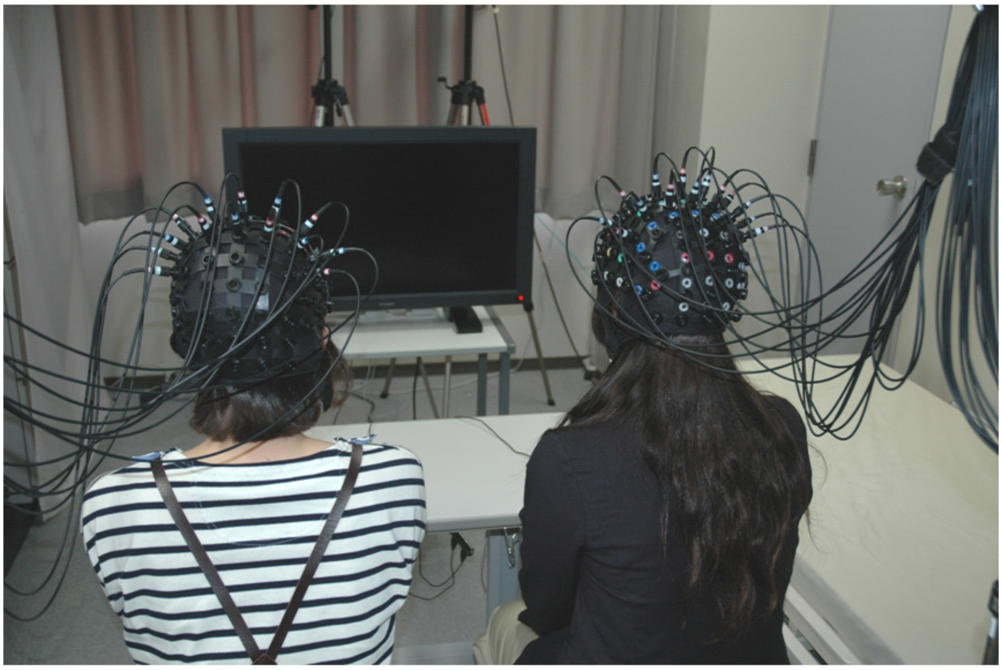

Figure 1-4. An example of experimental setting in NIRS studies.

Due to the advantages of high mobility and relatively few constraints on participants, NIRS is more suitable to investigate the neural correlates underlying performance in a "natural" social environment. Especially, a two-channel NIRS unit (PocketNIRS; DynaSense Inc., Japan) is highly portable because of its size (length: 100 mm; width: 61 mm; thickness: 18.5 mm) and weight (100 g including the batteries), and provides mobility for participants by transmitting the hemodynamic signals wirelessly via Bluetooth. Figure 1-5 shows the image of the PocketNIRS.

Figure 1-5. A two-channel NIRS unit (PocketNIRS; DynaSense Inc., Japan).

1.5. Research objectives and experimental structure

I start this section by introducing the structure of the present study. Then I describe the objectives, experimental tasks, and regions of interest in detail.

The present study aimed to examine the neural correlates of interpersonal influence between two persons in a real-life situation using NIRS. Interpersonal influence can be categorized into two types: “direct” and “indirect” influences. “Direct” influence is induced by the “explicit” verbal commands or actions of other persons, which is readily assessed. Therefore, the present study began with the exploration of the neural correlates of “direct” interpersonal influence. Then to investigate the neural substrates of "indirect" interpersonal influence, the present study examined two related questions in two experiments, respectively: how and why "indirect" influence affects an individual's brain and performance. Figure 1-6 illustrates the experimental structure of three experiments in the present study. Exp. 1 was conducted to test the neural basis of "direct" influence from other persons, and Exp. 2 and Exp. 3 were designed to examine "indirect" influence from the presence of others.

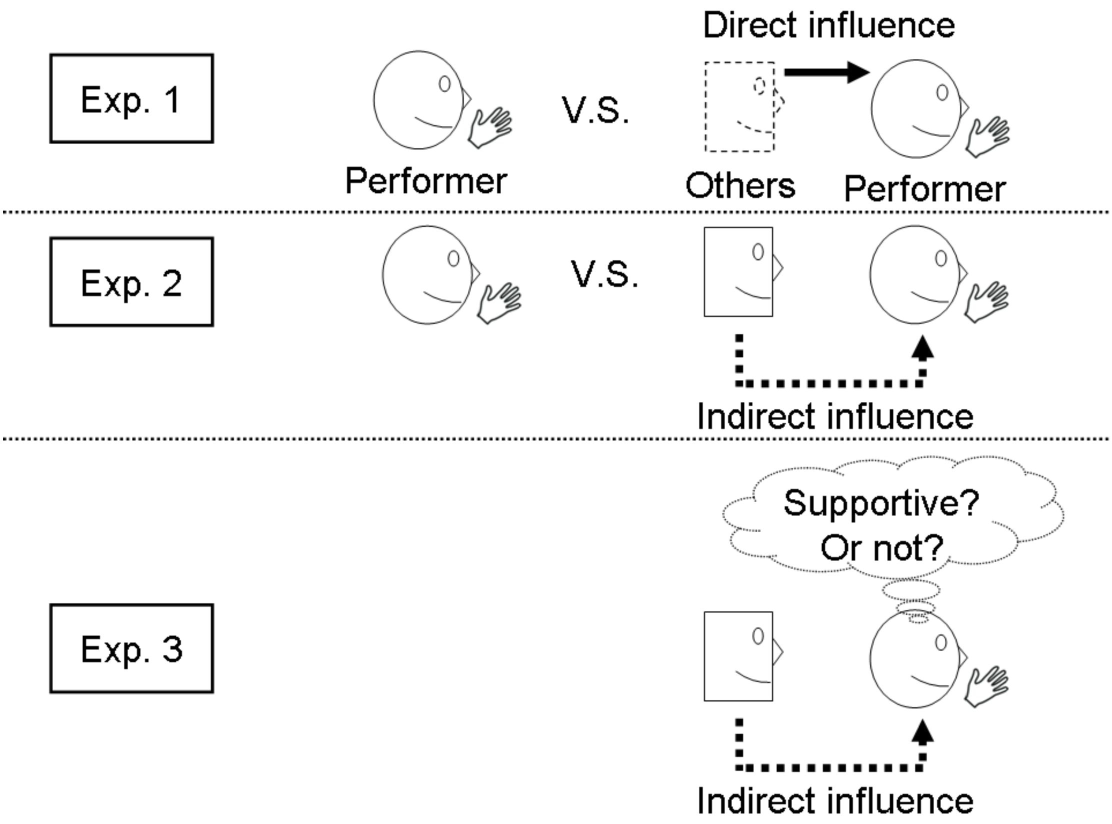

Figure 1-6. Experimental structure of the present study.

1.5.1. "Direct" influence from others (Exp. 1)

Exp. 1 aimed to examine the neural basis of "direct" interpersonal influence during daily activities. To address this issue, I manipulated two different cognitive loads during a driving video game task. One was an extrinsically-driven cognitive load induced by "direct" influence from others, such as an emergent demand for route changing ("turn left or right") given by a fellow passenger during driving. The other was an intrinsically-driven cognitive load that originated in the memory systems, for instance a vague memory for a driving route in the vicinity of a crossing street.

Specifically, I assigned the participants into three groups (one control and two experimental). The "control group" drove to a goal four times with distinct route-maps illustrating default turning points. In contrast, the "emergency group" drove with a map, but was instructed to immediately change the default route following an extrinsically verbal turning command given by an experimenter (extrinsically-driven cognitive load), and the "memory group" drove the memorized default route without a map (intrinsically-driven cognitive load).

Previous neuroimaging studies have suggested that the PFC constitutes the "highest level of the cortical hierarchy" dedicated to the representation and execution of actions (Koechlin and Summerfield, 2007). Figure 1-7 illustrates human brain mapping of PFC. In dynamic environments, an adaptive and flexible behavior is closely associated with three relevant cognitive processes—preparation before the events (action preparation), response to the events (action execution), and adaptation to the recurrent events (action adaptation).

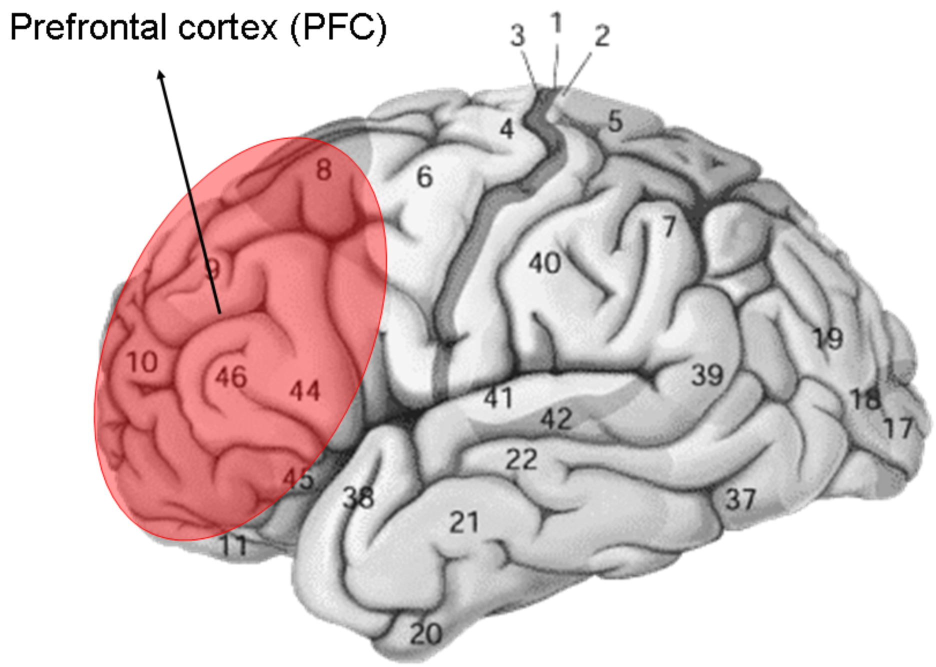

Figure 1-7. Human brain mapping of prefrontal cortex (PFC) (modified from http://thebrain.mcgill.ca/flash/capsules/outil_jaune05.html).

Using fMRI, prefrontal activation has been reported to be associated with action preparation (Sakai and Passingham, 2003). Concerning action execution, it has been suggested that the PFC plays an important role in both memory-guided behavior (intrinsically-driven action) (Fuster, 2001; Simó et al., 2005) and rapid response to the external stimuli (extrinsically-driven action) (Kenner et al., 2010). As for the action adaptation, growing evidence has shown that the PFC makes a vital contribution to effective organized behaviors. A fundamental principle of prefrontal function might be adaptation. That is, the PFC adjusts its function to match the requirements of the particular task undertaken (Duncan, 2001).

On the basis of these findings, the PFC is critical for both intrinsic and extrinsic cognitive processes. In Exp. 1, I measured prefrontal activation and focused on the activation changes in three critical periods associated with a turning maneuver (i.e., pre-turning, actual-turning, and post-turning periods). I hypothesized that the intrinsically- and the extrinsically-driven cognitive loads would show distinctive activation patterns in the PFC.

1.5.2. “Indirect” influence from others (Exp. 2 and Exp. 3)

1.5.2.1. How does the presence of others affect an individual’s brain and performance (Exp. 2)

The objective of Exp. 2 was to investigate the neural correlates of “indirect” interpersonal influence, that is, the effects of the presence of others in a real-life performer-observer situation. Previous studies have reported that the presence of others may increase an individual’s tension or may decrease it (Lazarus and Folkman, 1984; Zajonc, 1965, 1980). To examine whether the presence of an observer increases or decreases a performer’s tension, the participants were instructed to perform a driving video game task with or without an observer. The participant's task was to drive from start to goal using a route-map either solely (single group) or with an acquainted partner as an observer (paired group).

More recently, a growing effort has involved exploration of the neural basis of the anxious emotional state in a social context (Eisenberger et al., 2007; Hoffman et al., 2005; Karremans et al., 2011; Pontari, 2009). Specifically, the activity in the PFC may serve as an indicator of tension. Using Electroencephalography (EEG), Hoffman et al. (2005) investigated the psychophysiological correlates of tension (or "worrying") when participants performed an impromptu speech task in the virtual presence of others. The results revealed that the public speaking anxiety (tension) was positively correlated with left prefrontal activity.

In other brain imaging studies on the effects of the presence of others, it has been reported that prefrontal activation increases when an individual appraises co-present others as a threat or challenge, leading to an increase of tension, whereas both prefrontal activation and tension decrease when one appraises others as supportive (Ito et al., 2011; Karremans et al., 2011; Nawa et al., 2008).

For instance, using fMRI, Nawa et al. (2008) examined how social context affects an individual's motivated behavior when participants performed a monetary betting task in the presence (social condition) and in the absence (nonsocial condition) of an unfamiliar other. The fMRI data revealed that the participants showed significantly higher prefrontal activation in the social condition than the nonsocial condition. The results suggest that the presence of a stranger increases an individual's tension. In contrast, Karremans et al. (2011) demonstrated that the presence of an attachment partner reduced prefrontal activation due to decreasing of tension when participants were socially excluded.

It is noteworthy that the unfamiliar other and the attachment partner were not physically present in these two studies—the participants were asked to imagine such a situation.

Concerning the effects of the presence of others in a real social environment, using NIRS, Ito et al. (2011) measured prefrontal activation when participants performed a working memory task with or without observation by experimenters. The participant's task was to observe a sequence of stimuli, and to judge whether a currently presented stimulus was identical to the one presented *n* trials previously. The NIRS data revealed that the participants under observation by the experimenters yielded more errors and showed significantly higher prefrontal activation than those who performed without observation. These results suggest that the presence of unfamiliar others, for instance experimenters in their experiment, increases an individual's tension and influences the prefrontal activation.

Based on these findings, I measured participant's prefrontal activation in Exp. 2, and hypothesized that the presence of an acquainted partner would reduce a performer's prefrontal activation due to decreasing of tension.

1.5.2.2. Why does the presence of others affect an individual's brain and performance (Exp. 3)

Exp. 2 predicted that the presence of an acquainted partner may function positively to reduce a performer's tension. To verify whether the positive presence effect is induced by the performer's cognitive appraisal of their partner as supportive, Exp. 3 examined the neural correlates of the performer's cognitive appraisal of a co-present observer (supportive versus non-supportive). Exp. 3 used the same performer-observer paradigm as in Exp. 2. The performer's task was to drive to a goal under observation by a partner, and to appraise the role of their partner after the task. According to the performer's subjective appraisal of the co-present observer, the pairs of participants were divided into three groups: supportive, non-supportive, and neutral.

Previous neuroimaging studies have demonstrated that the frontoparietal network, including the inferior parietal lobule (IPL), may play an important role in social cognitive and emotional processing (Van Overwalle, 2009; Smallwood et al., 2012; Smith et al., 2004). Especially, the IPL is acknowledged to be crucially involved in the mirror neuron system (Newman-Norlund et al., 2009), self-other distinction (Lamm et al., 2007; Schulte-Rüther et al., 2007), and emotional memory retrieval (Mickley Steinmetz and Kensinger, 2009; Smith et al., 2004). Figure 1-8 shows human brain mapping of IPL.

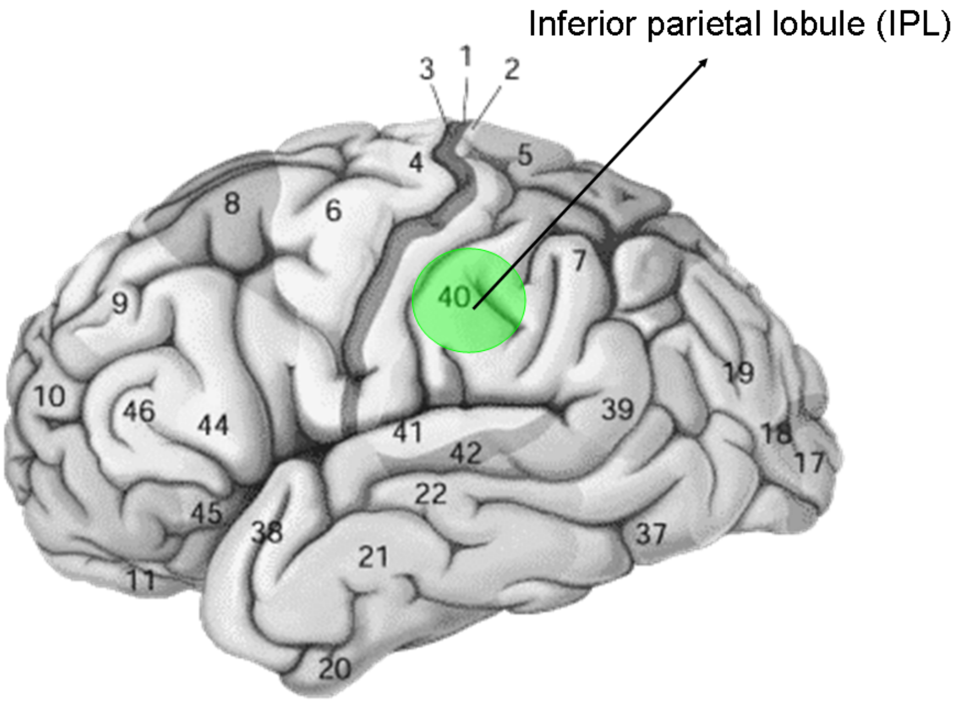

Figure 1-8. Human brain mapping of inferior parietal lobule (IPL) (modified from http://thebrain.mcgill.ca/flash/capsules/outil_jaune05.html).

Mirror neurons fire not only during action execution, but also during the observation of the same action (Rizzolatti and Craighero, 2004). The presence of mirror neurons has been confirmed in the ventral premotor cortex and the IPL in both macaques and humans (Chong et al., 2008; Fujii et al., 2008; Kilner et al., 2009).

In an fMRI study, Chong et al. (2008) first revealed mirror neurons in human IPL using fMRI adaptation. fMRI adaptation is based on the assumption that if two tasks A and B rely on the same neurons, performing A before B will reduce the response to B. Chong et al. (2008) demonstrated that the IPL showed reduced activity to the execution of an action that followed the observation of the same action, and vice versa. These results suggest that in the IPL, the observation and execution of an action recruits the same neurons. That is, the IPL contains mirror neurons.

It has been shown that the mirror neuron system is critical for social behavior and social attitude (Iacoboni et al., 2005; Kim et al., 2010). Using fMRI, Kim et al. (2010) examined the brain mechanisms involved in the attribution of a person’s attitude toward another person. Their experiment consisted of one attitude attribution task (experimental condition) and one gender matching task (control condition). In the attitude attribution task, the participants attributed other’s inner attitude (benevolent attitude or malevolent attitude) by observing facial affect in an emotional context. In the gender matching task, the participants were asked to judge whether the gender of people displayed in two pictures was matched or not. The results revealed activation in the left IPL during the attitude attribution task, compared to the gender matching task, suggesting that mirror neuron system and the left IPL play an important role in the attribution of a person’s inner attitude towards another person in an emotional situation.

Concerning the self-other distinction, in another fMRI study, Lamm et al. (2007) presented a series of video clips showing facial expression of pain resulting from medical treatment to their participants. Participants were instructed to imagine the feelings of the patient or to imagine themselves to be in the patient’s situation. The results showed that consideration of feelings and emotions of oneself elicited higher activation in the left IPL, whereas the right IPL was involved when thinking of the other. They suggested that the IPL may distinguish the processes of self and other.

Smith et al. (2004) examined the neural correlates of the retrieval of emotional memories using fMRI. Participants identified whether an object had been presented in a preceding study phase, in which the objects were displayed with positive, neutral, or negative emotional backgrounds. The fMRI data revealed higher activation in the left IPL (but not in the right IPL) when the participants identified the previously-studied objects associated with the emotional backgrounds than when they rejected unstudied objects. Furthermore, it was demonstrated that retrieving objects associated with positive emotional backgrounds elicited higher activation in the left IPL than that associated with negative emotional backgrounds, suggesting that the left IPL is associated with the retrieval of positive emotional memory.

On the basis of these findings, the left IPL should be one critical component involved in the performer's "subjective" appraisal of a co-present observer. In Exp. 3, I mainly focused on the bilateral IPL as regions of interest. I predicted that the performers who appraised their partner as supportive would show higher activation in the left IPL (but not in the right IPL) than those who appraised the observer as non-supportive.

Chapter 2.
Direct Influence from Others (Exp. 1)

2.1. Purpose

The purpose of Exp. 1 was to examine the neural basis of “direct” interpersonal influence during daily activities. To address this issue, I manipulated two different cognitive loads during a driving video game task. One was an extrinsically-driven cognitive load induced by “direct” influence from others. The other was an intrinsically-driven cognitive load that originated in memory systems.

It is a familiar enough phenomena that a driver’s cognitive loads increase in the vicinity of a crossing street due to a vague memory for a driving route and/or an emergent demand for route changing (such as “turn left or right”) given by a fellow passenger. That is, the self-memory-based turning maneuver originates in intrapersonal processing referred to as intrinsic cognition, and the others-command-based turning maneuver derives from interpersonal processing referred to as extrinsic cognition.

Previous neuroimaging studies have demonstrated that the PFC is critical for both intrinsic and extrinsic cognitive processes. Therefore, In Exp. 1 I measured activation changes in the PFC when participants performed a driving video game task under intrinsically- and extrinsically-driven cognitive loads using NIRS.

Recent brain imaging and EEG studies have investigated the neural correlates of the cognitive control of driving behavior, for instance, using high-end driving simulator (Calhoun et al., 2002; Jäncke et al., 2008). In contrast, I used a driving video game in this experiment as an experimental task to study cognitive loads stemming from the intrinsic cognition in one-person play, and the extrinsic cognition in two-person play. That is, I focused on two salient characteristics illuminated by driving video game: One is that it involves intrinsically-driven perception and performance such as action control of turning behavior. The other is that this one-person game likely becomes a pseudo two-person game when affected extrinsically by intervention of a game spectator—a condition where the "passenger" gives sudden commands.

Figure 2-1 illustrates the experimental design of Exp. 1. Participants were divided into one control group and two experimental groups according to the difference in the cognitive loads in each group. The control group was instructed to drive from start to goal using a route-map and was *not* ordered to change the default route at any point during the experiment. The two experimental groups were designed to receive relatively higher but different cognitive loads than the control group. The memory group was asked to memorize the default route before the driving game task, and then to drive without a route-map. The emergency group was permitted to drive with a route-map, but instructed to immediately change the default route when the participant received a verbal command (such as “turn left or right”) given by an experimenter. Figure 2-2 illustrates the experimental procedure in each group.

	Cognitive load	
	Extrinsically driven (rapid response)	Intrinsically driven (memory)
Control group	—	—
Memory group	—	○
Emergency group	○	—

Figure 2-1. Experimental design of Exp. 1.

The two experimental groups varied in different predictability of turning points, i.e., the emergency group did not know the timing of turning points determined by an experimenter, while the memory group had already known the turning points depending on a memorized route-map. Accordingly, the turning behavior in the emergency group had to be rapidly regulated due to the dictates of others, but the turning behavior in the memory group was controlled by oneself; participants needed to sustain their route-map memory and retrieve it.

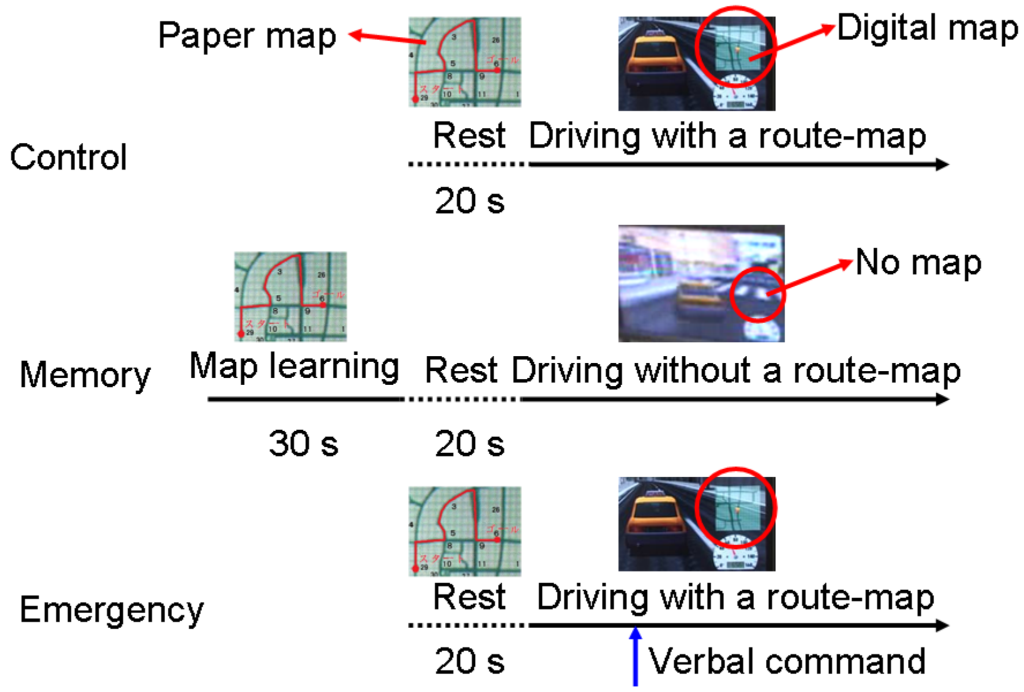

Figure 2-2. Experimental manipulation of Exp. 1.

I measured prefrontal activation changes in the three groups during three temporal periods—before and after a route changing (i.e., pre-turning, actual-turning, and post-turning periods). Furthermore, to examine the adaptation effect throughout the repetitive turning behaviors, I compared the prefrontal activation between the front half (the first and the second trials) and the rear half (the third and the fourth trials) of four experimental trials.

I hypothesized that the extrinsically- and the intrinsically-driven cognitive loads would show distinctive activation patterns in the PFC. According to the previous neuroimaging studies on action preparation, action execution, and action adaptation, I tested three predictions in Exp. 1.

First, during the pre-turning period, both the memory and the emergency groups would show higher activation than the control group due to preparation for the turning maneuver (the preparation effect). Second, in the actual-turning and the post-turning periods, the emergency group would show increasing activation from the pre- to the post-turning throughout the actual-turning period due to relatively lower predictability for turning points based on the dictations of others. In contrast, the memory group should not show increasing activation due to the relatively higher predictability for turning points based on their own memory (the predictability effect). Third, throughout repetitive trials, the emergency group would show lower activation in the rear half trials than that in the front half due to adaptation to the repetitive trials (the adaptation effect), while the memory group would not show the adaptation effect due to the sustained memory loads in the distinct trials.

2.2. Methods

2.2.1. Participants

Sixty-eight undergraduate students (62 males, 6 females, age: 19.7 ± 2.0 years) in Nagoya University participated individually for course credit. All participants were right-handed as measured by the Edinburgh Handedness Inventory (Oldfield, 1971), and had normal or corrected-to-normal vision. They were informed about the purpose and safety of the experiment, and the informed consent was obtained prior to participation in the experiment. This study was approved by the local ethics committee.

2.2.2. Apparatus

A two-channel NIRS unit (PocketNIRS; DynaSense Inc., Japan) operated at 735, 810, and 850 nm wavelengths was used to measure the concentration changes of oxygenated hemoglobin (Coxy-Hb), deoxygenated hemoglobin, and total hemoglobin of the participants.

Two probes were placed on the forehead using double-sided adhesive sheets and centered on the Fp1 and Fp2 positions, according to the international 10-20 system for EEG recording. Each probe consisted of one emitter optode and one detector optode located 3 cm apart. On the basis of 3-dimensional probabilistic anatomical cranio-cerebral correlation (Okamoto et al., 2004), Fp1 and Fp2 were projected onto the left and right prefrontal regions (see, Figure 2-3), and it has been shown that the NIRS detects hemodynamic changes in the brain with a depth of about 30 mm from the surface (Hoshi and Tamura, 1993; Leff et al., 2011). Therefore, I presumed that the PocketNIRS approximately measured the activation in lateral PFC located in close proximity to scalp tissues. The sampling rate for each channel was 10 Hz.

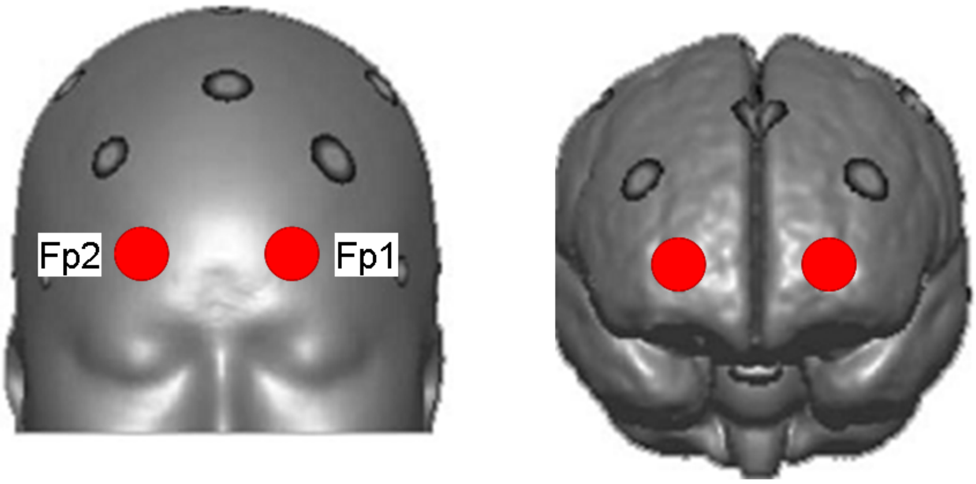

Figure 2-3. Location of Fp1 and Fp2 positions on the head and brain surfaces (modified from Okamoto et al., 2004).

2.2.3. Materials and design

A commercial driving video game ‘The Taxi 2’ (Simple 2000 series vol. 109) run on a Sony Playstation2 (Sony Computer Games Inc., Japan) was used. Figure 2-4 shows experimental setting in Exp. 1. During the experiment, a single participant sat in front of a table on which a 32-in. monitor (LDT32IV; Mitsubishi Elec., Japan) was placed. The driving game was displayed on the monitor without sound, and the participant controlled the game using a Sony game pad (DualShock 2; Sony Corp., Japan). Distance from participant to monitor was set to 120 cm.

Figure 2-4. Experimental setting in Exp. 1. Participant wore a PocketNIRS with a belt case.

The participants were divided into one control group and two experimental groups, according to the difference in cognitive loads manipulated by the combination of the route-stability (fixed or changing routes) and the memory-load (driving with or without a route-map). The participants' task in the control group was to drive from start to goal with a default route map. In contrast, in the emergency group, the participants were asked to immediately change the default route when a verbal command (such as left or right turn) was given very closely before a turning point in the default route by an experimenter. And in the memory group, they were instructed to memorize the default route in advance for 30 s, and then to drive without a route-map.

2.2.4. Procedure

Prior to the driving task, each participant practiced operating the game pad for 180 s. The driving task consisted of six trials with six distinct routes. The first two trials were training trials with a straight route. The subsequent four trials were experimental trials. Half of them had two turnings from start to goal (2T) in the default route, and the other half had four turnings (4T). The trial order was fixed as 2T-4T-4T-2T for all participants.

A single trial consisted of three phases, that is, a pre phase (20 s), a driving task phase, and a post phase (20 s). Before each trial, the participants were asked to follow an instruction presented on the monitor, and press a key of the keypad, which was placed in front of them, to start the trial. In the pre and post phases, a black monitor screen was displayed, and the participants were instructed to relax and sit comfortably. In the driving task phase, they were asked to drive to a goal, and press the same key when they reached the goal ending the trial. The performance of the participants was videotaped.

2.2.5. Data analysis

The NIRS data, which contained more than 10% non-near-infrared light signals, were defined as noise data. All noise data and the data obtained from the participants, who did not follow the instruction or who did not achieve the correct goal in more than 1 trial, were excluded from further analysis. Finally, data obtained from 15 participants for the control group, 14 participants for the emergency group, and 14 participants for the memory group were analyzed, respectively.

Because the oxygenated hemoglobin is the most sensitive parameter of regional cerebral blood flow (Hoshi et al., 2001), I focused on the Coxy-Hb during a route changing in each trial and in each group. Figure 2-5 shows an example of route changing periods. The route changing was defined by the following six seconds consisted of three periods—an actual-turning period (2 s), before and after the actual-turning period referred to as pre-turning period (2 s) and post-turning period (2 s), respectively. In the emergency group, the actual-turning period was determined by a verbal turning command that ordered the participants to turn in the opposite direction at the default turning point. That is, if a left turning was default at an intersection in a route-map, the verbal command “turn right” was given just before the default intersection. Three of four trials conformed to the rule above mentioned, and in one exceptional trial the same rule was applied to a crossing point prior to the default intersection due to the junction of three streets. The actual-turning period in the memory and the control groups was defined in terms of the same rule used in the emergency group.

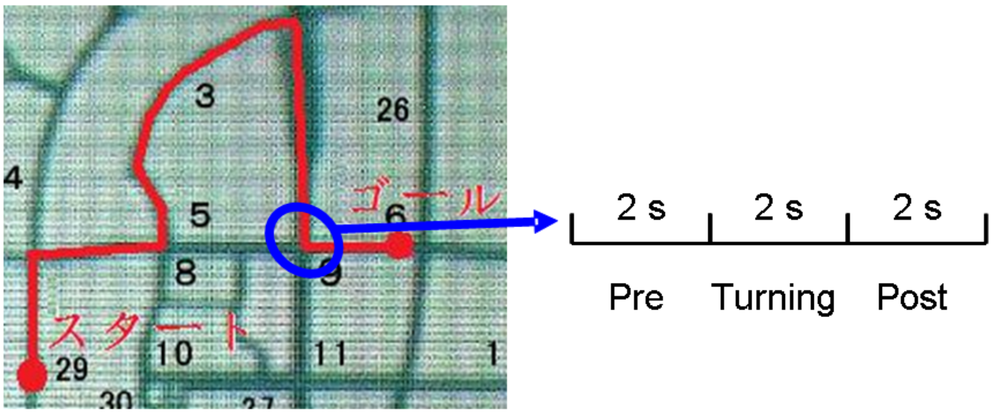

Figure 2-5. An example of route changing periods. The route changing consisted of three periods—an actual-turning period (2 s), before and after the actual-turning period referred as pre-turning period (2 s) and post-turning period (2 s), respectively.

A linear baseline correction was conducted on the NIRS raw data to remove any longitudinal signal drift using the mean value of Coxy-Hb during the last 5 s of the pre phase. The raw data from NIRS are all originally relative values and hence cannot be averaged directly across the participants or channels. To address this issue, raw data were converted to *z*-scores for analysis (Matsuda and Hiraki, 2006). *Z*-scores were calculated using the mean value and the standard deviation of Coxy-Hb during the baseline period in each trial and for each channel. A 4 s delay was set in order to reflect the time lag between hemodynamic response and the actual task. Then the z-scores were averaged during each turning period (pre-turning, actual-turning, and post-turning) over the front two trials as the front-half and the rear two trials as the rear-half, respectively. Finally, the group-averaged NIRS data were obtained for each group.

2.3. Results

2.3.1. Number of errors

In the present study, I defined an error as that which leads to collision or off-road driving, and calculated the mean number of errors during the urgent turning period in the emergency group and the planned turning period in the memory and the control groups as the performance index. Statistical analysis was conducted by means of Statistical Package for the Social Sciences (SPSS) and the significance level was set at $p < 0.05$.

Figure 2-6 shows mean number of errors in the three groups (control, memory, and emergency). To verify that the participants in each group yielded the equivalent number of errors, I conducted a two-way analysis of variance (ANOVA) [Group (control, memory, and emergency) × Front-rear section (front-half and rear-half)]. The results revealed a significant main effect of Front-rear section [$F(1, 40) = 27.32$, $p <$

0.001, $\eta_p^2 = 0.41$], but there were no significant main effect of Group and no significant interaction.

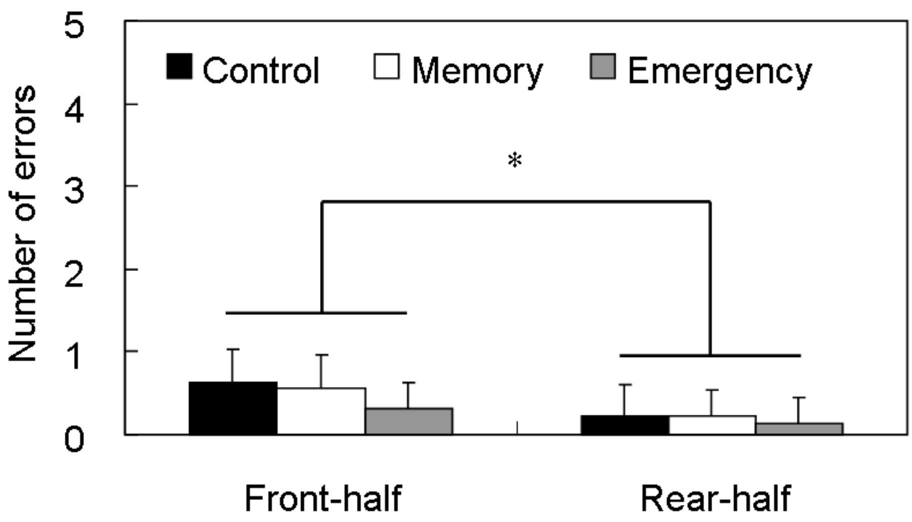

Figure 2-6. Mean number of errors during the urgent turning period in the emergency group and the planned turning period in the memory and the control groups. Front-half: first two experimental trials; Rear-half: latter two experimental trials. Error bars represent standard deviation. * indicates $p < 0.05$.

2.3.2. Brain activation changes in the prefrontal cortex

Figure 2-7 shows the average values of the z-score for Coxy-Hb during the three periods (i.e., pre-turning, actual-turning, and post-turning periods) in each group. To examine the prefrontal activation changes under intrinsically- and extrinsically-driven cognitive loads during these three periods and throughout the repetitive trials, I independently compared each of the two experimental groups versus the control group using a three-way ANOVA [Group (2) × Turning period (3) × Front-rear section (2)] in each hemisphere. For each ANOVA, Greenhouse–Geisser adjustment to the degrees of freedom was applied to correct for the violations of sphericity associated with repeated measures. Accordingly, for all F tests with more than one degree of freedom, the corrected p-value is reported. The post-hoc tests were carried out using Bonferroni's procedure.

The analyses of the memory group versus the control group revealed a significant main effect of Group [$F(1, 27) = 9.34$, $p < 0.01$, $\eta_p^2 = 0.26$] in the left PFC, but not in the right PFC. There were no significant main effects of Turning period or Front-rear section, and no significant interactions in either the left or the right PFC. To directly examine whether the memory group showed higher activation than the control group in the pre-turning period, I conducted a t test on the mean Coxy-Hb during the pre-turning period over the front and the rear half of trials, and it revealed a significant difference between these two groups [$t(27) = 2.58$, $p < 0.01$, $d = 0.57$].

Referring to the analyses of the emergency group versus the control group, in the left hemisphere, the results revealed the significant main effects of Group [$F(1, 27) = 6.82$, $p < 0.05$, $\eta_p^2 = 0.20$], Turning period [$F(2, 54) = 5.06$, $p < 0.05$, $\eta_p^2 = 0.16$], and significant first-order interactions between Group and Turning period [$F(2, 54) = 7.99$,

$p < 0.001$, $\eta_p^2 = 0.23$], between Front-rear section and Turning period [$F(2, 54) = 4.10$, $p < 0.05$, $\eta_p^2 = 0.13$], and a significant second-order interaction of all three factors [$F(2, 54) = 4.51$, $p < 0.05$, $\eta_p^2 = 0.14$].

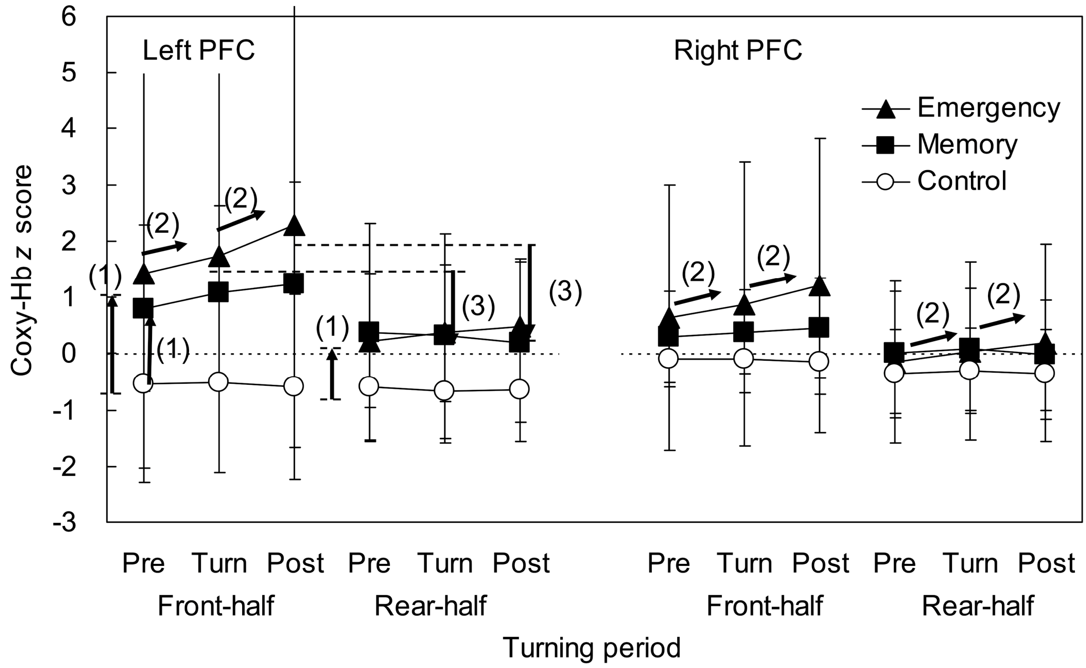

Figure 2-7. Average concentration changes in oxygenated hemoglobin (Coxy-Hb) during the urgent turning period in the emergency group and the default turning period in the memory and the control groups. PFC: prefrontal cortex; Pre: pre-turning; Turn: actual-turning; Post: post-turning; Front-half: first two experimental trials; Rear-half: latter two experimental trials. (1), (2), and (3) represent the significant differences ($p < 0.05$) corresponding to the three predictions (the preparation effect, the predictability effect, and the adaptation effect). Error bars represent standard deviation.

In the subsequent analyses, the emergency group showed significantly higher activation than the control group throughout all the three periods (pre-turning, actual-turning, and post-turning periods). In the emergency group, the prefrontal activation significantly increased from the pre- to the post-turning throughout the actual-turning period. Furthermore, the emergency group showed significantly lower activation in the rear-half than the front-half trials during the actual- and the post-turning periods.

In the right hemisphere, the results revealed a significant main effect of Turning period [$F(2, 54) = 7.87$, $p < 0.005$, $\eta_p^2 = 0.23$], and a significant first-order interaction between Group and Turning period [$F(2, 54) = 9.73$, $p < 0.001$, $\eta_p^2 = 0.27$]. The emergency group showed significantly higher activation during the post-turning period than the control group. And the prefrontal activation significantly increased from the pre- to the post-turning throughout the actual-turning period in the emergency group, regardless of the front-rear sections.

2.4. Discussion

This experiment was designed to create a new approach that provides mobility for participants in daily life environments to examining the previous cognitive theories presented independently from several different research fields and methods. To achieve this goal, I focused on prefrontal activation involving various cognitive functions and their integration. In particular, I predicted cerebral blood oxygenation changes in the PFC induced by the three task demands in a simulated driving game: the preparation for turning maneuver, the predictability for route changing, and adaption through repetitive trials.

First, the present data demonstrated higher prefrontal activations during the pre-turning period in both the memory and the emergency groups in the left hemisphere. The results indicate that the left PFC is involved in the preparation processing before the turning behavior regardless of different types of cognitive loads, i.e., intrinsically- and extrinsically-driven cognitive loads.

Second, the present data revealed an increasing pattern of prefrontal activation from the pre- to the post-turning throughout the actual-turning period in the emergency group, but not in the memory group. The results indicate that the intrinsically- and extrinsically-driven cognitive loads led to differential activation patterns in the bilateral PFC.

Third, the present data confirmed the adaptation effect, that is, the reduction of prefrontal activation throughout the repetitive trials in the left PFC in the emergency group. In contrast, the adaptation effect in the memory group was not significant, because the participants need to sustain a different route memory per trial and retrieve it throughout the repetitive trials.

These three effects were confirmed in the left PFC, but not in the right PFC except for the predictability effect in the emergency group. The evidence is consistent with the previous studies reporting that the left hemisphere is not only involved in the speech and memory, but also supports action in general, whereas the right hemisphere is indispensable for the attentional shifting and physical response to extrinsic events (Ramnani and Owen, 2004; Serrien et al., 2006).

Previous studies have reported that association-based information, such as knowledge of event sequence, takes an important role to reduce cognitive loads and produce higher performance in perception (Fan et al., 2007). The action-based plans in our daily life consist of knowledge of the occurrence probability of events (predictability) and preparation for motor action to the event (motor readiness). Thus, if the predictability has no association with the motor readiness, our cognitive system should be faced with a high cognitive load due to incomplete preparation and rapid reaction to the emergent event. It has been reported that healthy people enable the coordination of prediction and motor response using NIRS in comparison to the Alzheimer's disease patients (Tomioka et al., 2009).

It is noteworthy that the evidence for the adaptation effect found in this experiment was not a byproduct of simple repetitive effect but has been reported in other neuroimaging studies (Grill-Spector et al., 2005; Horner et al., 2008). Rather, it is closely related with the knowledge-based behavior derived from the "anticipatory schemata" by which the past affects the future (Neisser, 1976). It is also important that I focused on the emergency action that was envisioned, and the cognitive load was more than participants envisioned. That is, the emergency group showed higher prefrontal activation during the actual- and the post-turning periods, even though the participants were already instructed about the necessity of urgent turning, but did not know the exact timing of it. The results of this experiment, however, do not imply that ideal and sufficient processing in the intrinsic cognition as a perceiver is inferior to the extrinsic cognition as a performer. Rather this experiment invites our attention to that the extrinsically emergent events in our daily life produce higher cognitive loads and accordingly impact the intrinsic cognition. Therefore, both the intrinsic and the extrinsic cognitions are indispensable to support our adaptive and flexible behavior in the changing environment.

The theoretical implication of this experiment is the importance of cooperation between the intrinsic and the extrinsic cognitions, when we bring the intrinsic cognition into view of performance of interacting with others around us. Referring to the practical implication, this experiment suggests that the PocketNIRS provides a possibility to study the human interactive cognition, involving not only the perception in the laboratory environment, but also action in the everyday environment such as the outdoors and driving.

Chapter 3.
Indirect Influence from Others (Exp. 2)

In Chapter 2 (Exp. 1), I demonstrated that the extrinsically-driven cognitive load induced by “direct” interpersonal influence instantly activates the PFC, but the intrinsically-driven cognitive load does not. Focusing on the practical implication, the results of Exp. 1 suggest that PocketNIRS provides a possibility to investigate the social cognition in a more “natural” everyday environment. Using the same PocketNIRS as in Exp. 1, in this chapter (Exp. 2) I will examine the neural substrates of “indirect” interpersonal influence that is the effects of the presence of others in a real-life “performer-observer” situation.

3.1. Purpose

Concerning the effects of the presence of others, G. W. Allport (1954) asked “What change in an individual’s normal solitary performance occurs when other people are present?” (p. 46). In the same vein, his question inspires further inquires into the cognitive mechanisms and the neural correlates underlying performance in a social context (Wagstaff et al., 2008). The purpose of Exp. 2 was to investigate the issue of how the presence of others affects a performer’s brain using PocketNIRS.

In social facilitation literature, Zajonc (1965) suggested that the presence of others increases an individual's arousal. This assumption, however, appears to go against reports which show that the presence of a supportive person "reduces" individual's nervous response (Lazarus and Folkman, 1984; Pontari, 2009; Taylor, 2011). The ambivalence of the presence of others, both increasing and decreasing an individual's tension, urges me to examine the neural correlates underlying social facilitation effects.

Two predominant factors modulating one's tension in the presence of others are performer's prior social experience (Berger et al., 1981; Cottrell, 1972), and familiarity between performer and the co-present observer (Cohen and Wills, 1984; Guerin and Innes, 1982). Cottrell (1972) has claimed that in the presence of others an individual anticipates positive or negative evaluation from other person based on his/her prior social experience, which increases the individual's tension termed as evaluation apprehension. Concerning the familiarity between performer and co-present observer such as "strangers" and "friends", a considerable literature has demonstrated that the presence of a stranger increases an individual's tension (Bond and Titus, 1983; Guerin and Innes, 1982), whereas the presence of a friend decreases it (Cohen and Wills, 1985; Lazarus and Folkman, 1984).

More recently, a growing effort has involved exploration of the neural basis underlying the effects of the presence of others associated with anxious emotional state. (Eisenberger et al., 2007; Hoffman et al., 2005; Karremans et al., 2011; Pontari, 2009). Specifically, the activity in the PFC may serve as an indicator of tension. The prefrontal activation increases when an individual appraises co-present others as a threat or challenge, leading to an increase of tension (Nawa et al., 2008), but decreases when one appraises others as supportive, leading to a decrease of tension (Karremans et al., 2011).

Despite the effects made by both classical behavioral and current brain imaging studies to examine the effects of the presence of others, previous studies were not free from controversial aspects in the following three areas: difficulty of experimental task, familiarity between performer and co-present observer, and technical limitation of relevant apparatus used for neural study.

First, previous studies have pursued an ideally well-controlled experiment and adopted novel or unfamiliar tasks for participants. However, this refined method may not always coincide with more “natural” human social activities. Second, early research has mainly employed “strangers” or “friends” as co-present others. Few studies examine the effects of the presence of an acquaintance, who is neither stranger nor friend.

Third, because of technical limitations of brain imaging such as fMRI constrains participants to lie in a motionless and solitary position, social presence studies have also suffered from two additional limitations. Most studies have measured brain activity in single individuals with the virtual presence of others that do not directly assess activation changes in a real performer-observer situation. Accordingly, numerous studies have used highly artificial experimental settings and do not examine the social presence effects during daily life tasks.

To avoid these three issues that obscure the effects of the presence of others, I provided solutions to the problems of the task novelty, the familiarity of a partner, and the technical limitation of measurement. First, I used a daily driving video game and the participants scored their proficiency in the driving game and their tension during the experiment using a questionnaire method. Second, to reduce the extreme polarization of familiarity, and to keep impartial appraisal of the co-present others, I intentionally recruited pairs of participants who were acquainted with one another. Third, using NIRS, I measured simultaneously prefrontal activation both in a player and in the acquainted partner as an observer.

In this experiment, I manipulated three experimental factors associated with social presence effects: The first was game playing style, whether the participants play without an observer in the single group or under observation by an acquainted partner in the paired group. The single group was expected to show higher tension than the paired group (referred to as positive presence effect).

The second factor was the participant's game proficiency whether they have extensive experience with driving video games. Based on previous studies on expertise and stress (VanLehn, 1996; Lazarus and Folkman, 1984), it was predicted that low-proficiency players, due to their higher tension than high-proficiency players in a social context or novel situation in experiment, are more susceptible even to simple stress, and conversely to the positive effect by the presence of an acquainted partner.

The third factor was the role taking order in the paired group, whether the participants take the role of the first player under observation by a partner or the second player under observation by the first player. It is noteworthy that the paired participants were instructed to alternate their player-observer roles in a turn-taking style, and to evaluate player's performance on the basis of observance of traffic rules as an observer. Accordingly, the first observer (O1) experienced how to evaluate the first player's driving performance, and O1 might have learned through the first experience of observation that he/she (D2 = O1) will be evaluated by the first player (D1 = O2) in the same manner in the second section. Based on Cottrell's (1972) theory of evaluation apprehension, I predicted that the second players (D2) would show higher tension than the first players (D1) due to increased evaluation apprehension, even though D2 played under observation by an acquainted partner just as D1 did. Figure 3-1 illustrates experimental manipulation of Exp. 2.

Therefore, I hypothesized that the first players (D1) in the paired group would show lower prefrontal activation than the single players due to decreasing of tension induced by the presence of an acquainted partner, while the second players (D2) would show higher activation than the first players (D1) due to increasing of tension resulted from prior experience of the observation of D1's performance. And I predicted to obtain these results in low-proficiency players rather than in high-proficiency players.

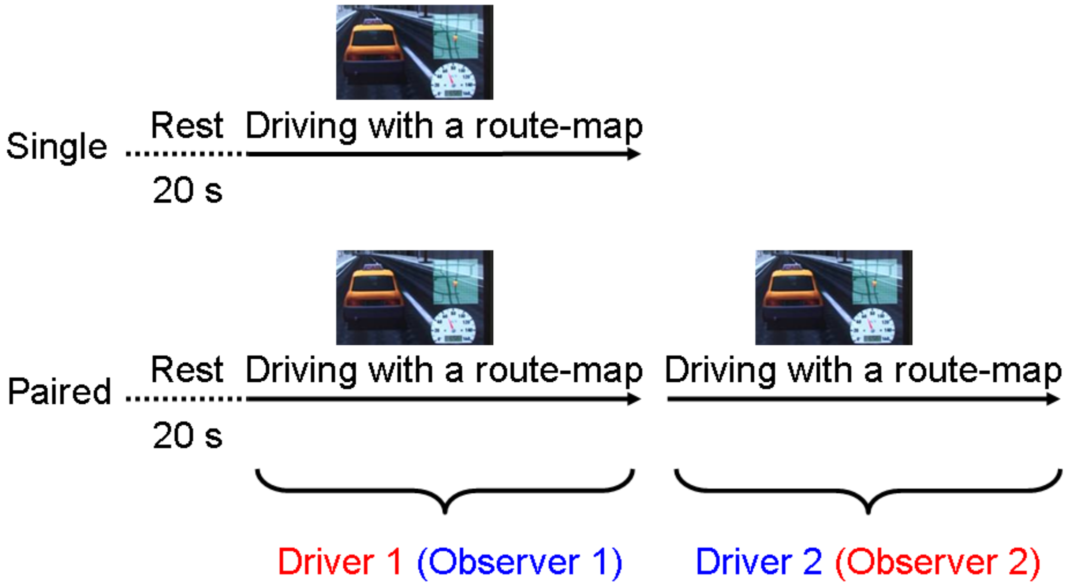

Figure 3-1. Experimental manipulation of Exp. 2. In the paired group, two participants alternated their player-observer roles in a turn-taking style. Accordingly, after D1's driving, D2 would drive the same routes in the subsequent task.

3.2. Methods

3.2.1. Participants

Sixty-two graduate and undergraduate students (53 males, 9 females, age: 21 ± 2.2 years) in Nagoya University participated for course credit. Participants were assigned to either single (n = 18) or paired (n = 44) groups, and then subdivided according to their game proficiency (high and low). Participant's game proficiency was evaluated by self-report on their game frequency (high: daily, weekly, and monthly; low: yearly and no experience) in the questionnaire after the experimental task. In the paired group, the same-gender pairs partnered with each other voluntarily, and their friendships were assessed by self-report on the duration of their acquaintance in the questionnaire (friendship: 1.7 ± 1.4 years). All participants were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971), and had normal or corrected-to-normal vision. They were informed about the purpose and safety of the experiment, and written informed consent was obtained prior to participation. This study was approved by the local ethics committee.

3.2.2. Apparatus

The PocketNIRS (DynaSense Inc., Japan) was used to measure the concentration changes of oxygenated hemoglobin (Coxy-Hb), deoxygenated hemoglobin and total hemoglobin. Two probes were attached to the forehead using double-sided adhesive sheets and centered on Fp1 and Fp2 positions, respectively, according to the international 10–20 system for EEG recording. Each probe consisted of one emitter optode and one detector optode located 3 cm apart. In the paired group, two sets of

PocketNIRS triggered by one signal were employed to measure the activation changes in paired player and observer simultaneously. The sampling rate was 10 Hz.

Single group Paired group

Figure 3-2. Experimental settings in the single and paired groups. Participant wore a PocketNIRS with a belt case.

3.2.3. Materials and design

The present study used the same driving video game (The Taxi 2) as in Exp. 1. Figure 3-2 shows the experimental settings in the single and paired groups. During the experiment, a player sat in front of a monitor (LDT32IV; Mitsubishi Elec., Japan) either solely in the single group or with an acquainted partner sitting beside him/her in the paired group. The driving game was displayed on the monitor without sound, and the player controlled the game using a Sony game pad (DualShock 2; Sony Corp., Japan). Distance from player to monitor was 120 cm.

3.2.4. Procedure

Prior to the experiment, participants were instructed to obey the traffic rules and drive to goal using a default route-map. Two further instructions were given orally to participants in the paired group: 1) the player's performance would be observed and evaluated by his/her partner who needed to report the player's performance after the driving task; and 2) they would be asked to alternate their player-observer roles when the first player accomplished his/her driving task. That is, the first player in the first section takes the role of observer in the second section, and the first observer in the first section takes the role of player in the second section (see, Figure 3-3). The two types of participants were described as "Driver first, Observer second" (D1-O2) and "Observer first, Driver second" (O1-D2). Accordingly, after D1's driving, D2 would drive the same routes in the subsequent task.

During the experiment, players practiced operating the game pad for 180 s, and then drove two training trials followed by four experimental trials with distinct routes. A single trial consisted of three phases, that is, a pre phase (20 s), a driving task phase, and a post phase (20 s each). In the pre and post phases, a black monitor screen was displayed, and the participants were asked to relax and sit comfortably without communication. In the driving task phase, players were instructed to drive from start to goal using a route-map, and press a key placed in front of them when they reached the goal ending the trial. The performance of the players was videotaped.

After all experimental trials, players were asked to rate their tension scores on a 5-point scale (1 = not at all and 5 = very much) for both their unsettled feeling and stress feeling.

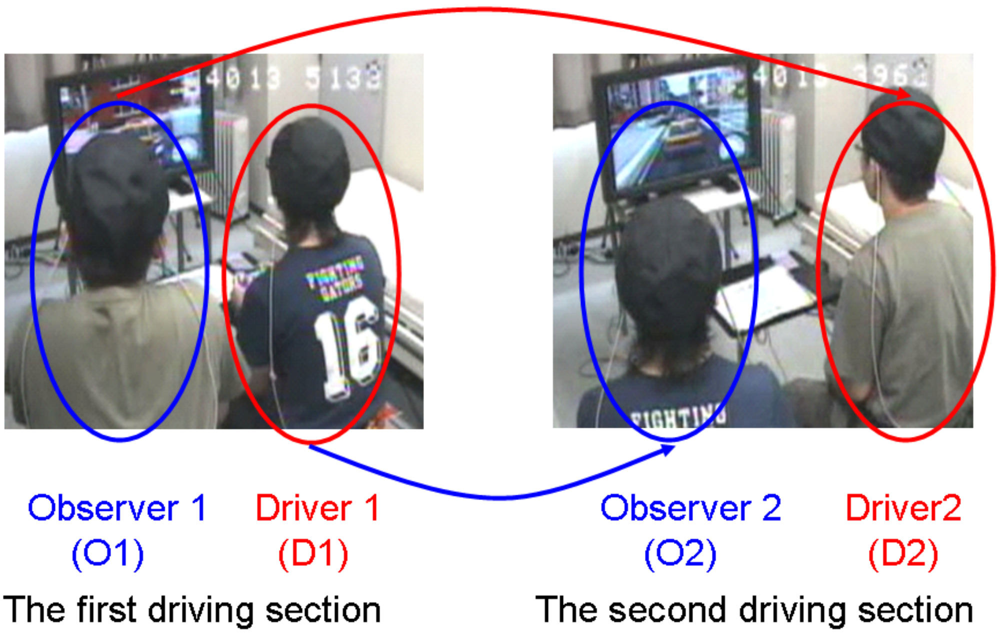

Figure 3-3. Illustration of player-observer (i.e., driver-observer) role changing in the paired group.

3.2.5. Data analysis

I obtained NIRS data of 62 participants (18 single and 22 pairs), but 11 who did not follow instructions (1 paired participant), and contained more than 10% non-near-infrared light signals (3 single and 3 paired participants) were excluded from further analysis. Finally, NIRS data collected from 51 participants, i.e., 15 participants in the single group and 18 pairs of participants in the paired group, were analyzed. Specifically, the single group consisted of 6 high- and 9 low-proficiency participants, the paired group was composed of 10 high- and 8 low-proficiency participants in D1, and 8 high- and 10 low-proficiency participants in D2.

I analyzed Coxy-Hb, and average change in Coxy-Hb during the driving task phase was calculated for each participant in each hemisphere. A linear baseline correction was conducted on NIRS raw data for each experimental trial, using the mean value of Coxy-Hb during the last 5 s of the pre phase. *Z*-scores were then calculated using the mean value and the standard deviation during the baseline period. NIRS data were averaged every 1 s and the driving error periods were excluded. The NIRS data without the error periods were averaged throughout the driving task phase across four experimental trials for each participant. Finally, the group-averaged data for each group was obtained.

3.3. Results

3.3.1. Driving time and number of errors

In this experiment, I defined an error as that which leads to collision or off-road driving, and driving time as the duration from start of a trial to arrival of the goal when participants pressed the key ending the trial. I calculated the mean driving time and the mean number of errors across four experimental trials as the performance indices. The significance level was set at $p < 0.05$.

Figure 3-4 shows the driving performance including the driving time and the number of errors in the single and paired groups. To examine the effects of the presence of an acquainted partner on player's solitary performance, I conducted a two-way analysis of variance (ANOVA) with Social presence (single, D1, and D2) and Game proficiency (high and low) as the between-participants factors. There were no significant main effects of Social presence [$F(2,45) = 2.94$, $p = 0.06$; $F(2,45) = 2.30$, *ns*] and Game proficiency [$F(1,45) = 1.96$, *ns*; $F(1,45) < 1$], and no significant interaction [$F(2,45) = 1.93$, *ns*; $F(2,45) < 1$] for either driving time or number of errors.

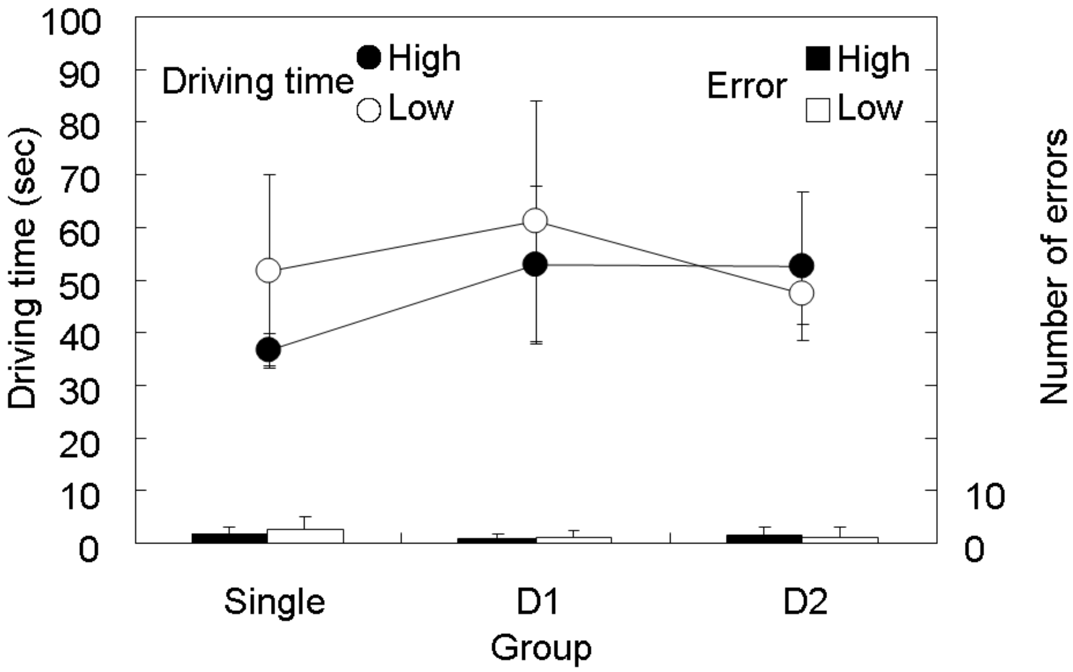

Figure 3-4. Mean driving time and number of errors during the driving task phase in the single and paired groups. D1 and D2 refer to the first and the second driver in the paired group, respectively. Error bars represent standard deviation.

3.3.2. Brain activation changes in the prefrontal cortex

3.3.2.1. Prefrontal activation of players in the single and paired groups

Figure 3-5 shows the mean Coxy-Hb during the driving task phase in the single and paired groups. To assess the neural correlates underlying the effects of the presence of others, I conducted a two-way ANOVA [Social presence (3) × Game proficiency (2)] on Coxy-Hb in each hemisphere. In the left PFC, there were no significant main effects of Social presence [$F(2,45) < 1$] and Game proficiency [$F(1,45) = 2.34$, *ns*], but there was a significant interaction [$F(2,45) = 7.15$, $p < 0.005$, $\eta_p^2 = 0.24$].

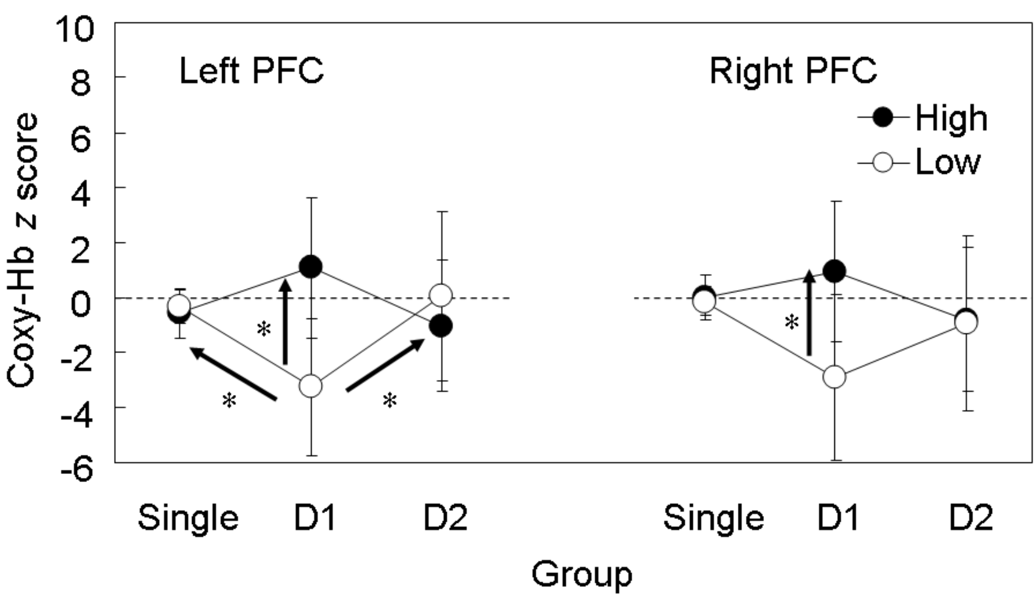

Figure 3-5. Average concentration changes of oxygenated hemoglobin (Coxy-Hb) during the driving task phase in the single and paired groups. D1 and D2 refer to the first and the second driver in the paired group, respectively. Error bars represent standard deviation. * indicates $p < 0.05$.

Simple main effect tests revealed a significant main effect of Social presence in low-proficiency players [$F(2, 24) = 5.17$, $p < 0.05$, $\eta_p^2 = 0.30$], but not in high-proficiency players. The Bonferroni post-hoc tests demonstrated that D1 showed significantly lower prefrontal activation than D2 and single players. There was no significant difference between single players and D2. High-proficiency players in D1 showed significantly higher activation than low-proficiency players [$F(1, 16) = 13.02$, $p < 0.005$, $\eta_p^2 = 0.45$], but not in D2 and single players.

In the right PFC, the results revealed no significant main effects of Social presence [$F(2,45) = 0.63$, *ns*] and Game proficiency [$F(1,45) = 4.0$, $p = 0.05$], but a significant interaction [$F(2, 45) = 3.36$, $p < 0.05$, $\eta_p^2 = 0.13$]. Simple main effect tests did not reveal significant main effect of Social presence among the three groups. High-proficiency players in D1 showed significantly higher activation than low-proficiency players [$F(1, 16) = 8.72$, $p < 0.01$, $\eta_p^2 = 0.35$], but not in D2 and single players.

3.3.2.2. O1 versus O2

Figure 3-6 shows the mean Coxy-Hb during the driving task phase in O1 and O2. If the significantly higher prefrontal activation in D2 than in D1 reflects the D2's participant property, it is expected that O1 (= D2) should also show higher prefrontal activation than O2 (= D1).

To test whether the participants in D1 and D2 had the same quality, I conducted a two-way ANOVA [Observation order (O1 vs. O2) × Game proficiency (high vs. low)] on Coxy-Hb in each hemisphere. In both the left and the right PFC, the results revealed a significant main effect of Game proficiency [$F(1, 32) = 4.63$, $p < 0.05$, η_p^2

= 0.13; $F(1, 32) = 8.16$, $p < 0.01$, $\eta_p^2 = 0.20$], but no significant main effect of Observation order [$F(1, 32) < 1$; $F(1, 32) < 1$] and no significant interaction [$F(1, 32) < 1$; $F(1, 32) < 1$].

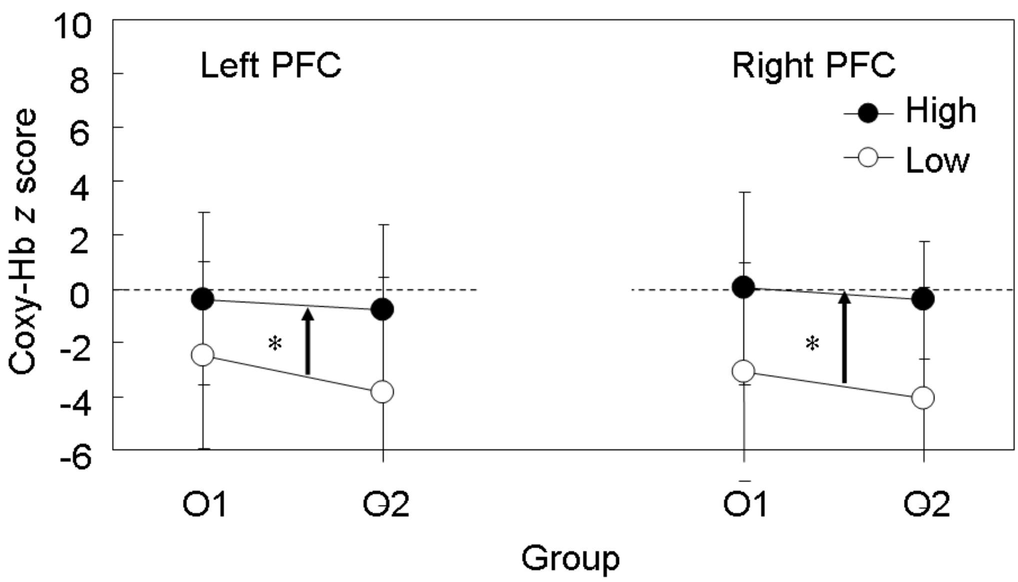

Figure 3-6. Average concentration changes of oxygenated hemoglobin (Coxy-Hb) during the driving task phase in O1 and O2. O1 and O2 refer to the first and the second observer in the paired group, respectively. Error bars represent standard deviation. * indicates p < 0.05.

3.3.3. Rating scores on participant's tension level

I evaluated participant's tension in the three groups (single, D1, and D2) by averaging their rating scores for the two questions. To assess whether D1 in the paired group reported lower scores than D2 and single players, a one-tailed *t* test was conducted between D1 and single players, and between D1 and D2, respectively.

Across game proficiency, the mean tension scores in the single, D1, and D2 groups were 1.5 (*SD* 0.6), 1.1 (*SD* 0.2), and 1.4 (*SD* 0.6), respectively. Paired *t* test analysis revealed significantly lower tension score in D1 than in D2 and single groups [$t(21) = 1.90$, $p < 0.05$; $t(17) = 2.06$, $p < 0.05$, respectively].

The same *t* test analysis was conducted for the tension scores between groups according to low- and high-proficiency players, independently. The tension scores of low-proficiency players in the single, D1, and D2 groups were 1.7 (*SD* 0.7), 1.1 (*SD* 0.2), and 1.5 (*SD* 0.8), respectively. The results revealed a significantly higher tension score in the single group than in D1 [$t(9) = 2.69$, $p < 0.05$], whereas there was no significant difference between D1 and D2 [$t(10) = 1.50$, $p = 0.08$]. In high-proficiency players, the tension score of each group was 1.1 (*SD* 0.2), 1.2 (*SD* 0.2), and 1.4 (*SD* 0.4), respectively. There were no significant differences either between D1 and single groups [$t(14) = 0.56$, *ns*] or between D1 and D2 [$t(10) = 1.29$, *ns*].

3.3.4. Correlation results

3.3.4.1. Correlation of errors between D1 and D2

Figure 3-7 shows the correlation of number of errors between D1 and D2 within the paired group. Focusing on the experimental treatment between D1 and D2 in the paired group, the distinctive feature of D2 (= O1) is prior observation of D1's performance. If O1 learned though the prior observation of D1's performance, we might expect improvement of D2's driving performance in the subsequent task. That is, if the prior observation in O1 was effective for the performance in D2, we might expect a negative correlation between the number of errors in D2 and D1.

I calculated the Pearson correlation coefficient (r) for the number of errors between D1 and D2. The result revealed a significantly positive correlation between D1 and D2 ($r = 0.51$, $p < 0.05$, two-tailed).

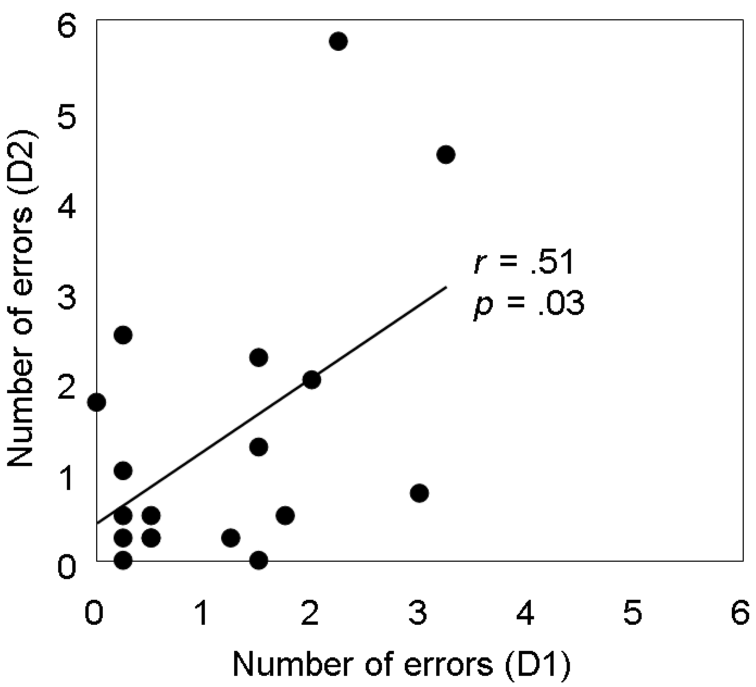

Figure 3-7. Correlation of number of errors between the first (D1) and the second (D2) players within the paired group.

3.3.4.2. Correlation between number of errors and own activation in D1 and D2

Figure 3-8 shows correlation between number of errors and one's own prefrontal activation in D1 and D2 within the paired group. If D2 was aware of error performance through the prior observation of D1's performance, we may expect a positive correlation between the number of errors and prefrontal activation in D2, but not in D1. I calculated the Pearson correlation coefficient (r) between the number of errors and one's own prefrontal activation in D1 and D2, respectively. The results in D2 revealed a significant positive correlation ($r = 0.50$, $p < 0.05$, two-tailed) in the left PFC, but not in the right ($r = 0.34$, *ns*, two-tailed). In contrast, the results in D1 showed a significant negative correlation in the right PFC ($r = -0.47$, $p < 0.05$, two-tailed), but not in the left ($r = -0.44$, $p = 0.07$, two-tailed).

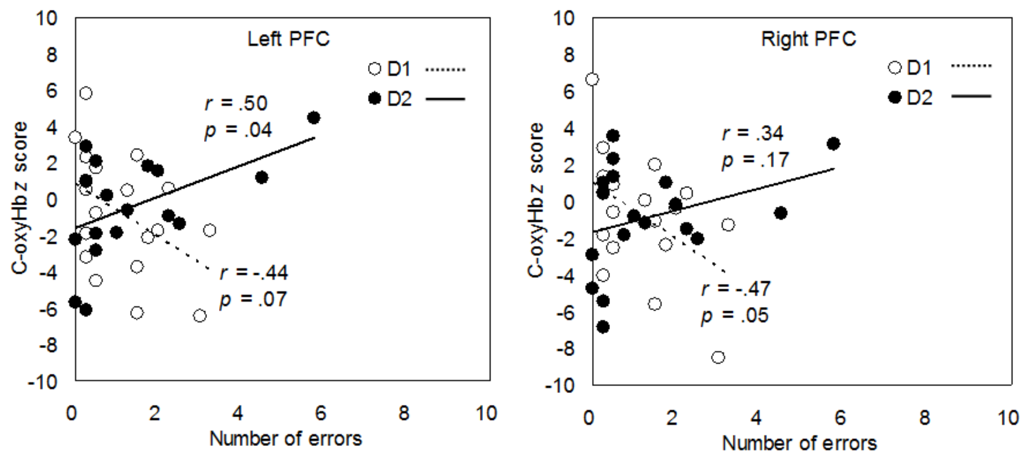

Figure 3-8. Correlation between number of errors and one's own prefrontal activation in the first (D1) and the second (D2) players within the paired group.

3.4. Discussion

I have noted that the effects of the presence of others might be obstructed by the task difficulty, the familiarity between performer and observer, and the limitation of apparatus effects in social neuroscience studies. This experiment was designed to avoid these three problems, and to examine the neural substrates of the effects of the presence of an acquainted partner in a real-life player-observer situation. To achieve this goal, I measured bilateral prefrontal activation in participants when they performed a driving video game task either solely without an observer in the single group or with an acquainted partner in the paired group using PocketNIRS.

The participants in the single group solely took the role of player (driver) in the driving game, whereas the participants in the paired group took both roles of player and observer in a turn-taking style. In the paired group, the participant who took the role of driver in the first session and the role of observer in the second session was represented as D1-O2, and vice versa the other partner was O1-D2. In this vein, the feature of D2 who took the role of observer in the first session is distinctive to D1 who had no experience of prior observation before their first driving in this experiment. I conducted the analysis of behavior data and NIRS data in these three groups (single, D1, and D2), who were separated into two subgroups based on their game proficiency.

The main purpose of this experiment was twofold. The first one was to confirm whether the prefrontal activation in D1 with an acquainted partner as an observer was lower than the single players without an observer. The second one was to test whether the first players (D1) and the second players (D2) in the paired group consistently showed lower prefrontal activation than the single players regardless of the player's prior experience of observation.

First, I confirmed that the tension evaluation scores in single and D2 players were significantly higher than D1, while the driving time and the number of errors in the single, D1, and D2 players showed no significant differences. These results suggest that the prefrontal activation in the three groups may reflect affective tension in each group, despite no significant differences for the behavioral data.

I obtained two main findings based on the NIRS data. Firstly, the first players (D1) in the paired group showed lower prefrontal activation than the single players when they were low-proficiency players. The result suggests that the presence of an acquainted partner functions as reducing a low-proficiency player's tension. Secondly, D2 showed higher prefrontal activation than D1 within the same experiment. If we accept a view of efficacy of prior observation in D2 (Chambon et al., 2011; Sanna, 1992), it is interesting that D2 revealed the increased activation.

Concerning what O1 (= D2) learned from the observation of D1's performance proceeding to D2's performance, two plausible explanations can be given to the increased activation in D2. One is that O1 learned the task difficulty from D1's error performance (Castellar et al., 2011; Sebanz et al., 2003). The alternative one is that O1 learned awareness of the role of observer. That is, as O1 observed and evaluated D1 in the first session, O1 learned that he/she will be evaluated by O2 (= D1) when O1 played as D2 in the second session. In other words, D2 learned to observe his/her own performance from other person's point of view, and presumably D2 was aware of O2's point of view (Wicklund and Duval, 1971). Accordingly, D2 might change the appraisal of O2 from supportive to non-supportive due to increased evaluation apprehension (Cottrell, 1972) and self-consciousness (Duval and Wicklund, 1972).

The correlation analyses conducted in this experiment support the latter interpretation. If D2 learned from D1's error performance, a negative correlation would be expected between the number of errors in D1 and D2, but a positive correlation was obtained. Furthermore, the correlation between a player's number of errors and his/her own activation showed positive in D2 (left PFC), but negative in D1 (right PFC). The conflicting correlation between number of errors and activation suggest that D2 was sensitive to his/her own error performance after prior observation of D1's performance, while D1 was not due to no prior experience of observation. According to Hoffman et al. (2005), the left PFC is associated with the anxious emotional state, such as tension (or "worrying" in their own words), while the right PFC is involved in anticipation of a stress situation, i.e., vigilance. Based on their report, presumably, D1's errors might be byproducts of tension reduction with an acquainted observer leading to low vigilance, whereas D2's errors might be reflected in increasing tension. Unfortunately, there were too few numbers of errors in this experiment to permit the verification of this speculation.

A unique aspect of this experiment is that I demonstrated contradictory aspects of social presence effects within one experiment. That is, the effects of the presence of others, leading to reduction of tension with co-present observer, may lose efficacy when the performer regards the co-present observer as non-supportive. It is also important that the present three experimental groups demonstrated distinctive prefrontal activation when the behavioral data in the three groups did not show any significant difference.

The results imply that the role of the co-present observer may be changed according to performer’s “subjective” appraisal, even though the “objective” social relationships with the co-present observer seem to be constant. Namely, the effects of the presence of others may rely on the performer’s cognitive appraisal of a co-present observer as supportive or non-supportive, which presumably derived from “self-motivated” processing.

Chapter 4.
Appraisal of Co-present Others (Exp. 3)

In Chapter 3 (Exp. 2), I examined the neural correlates of the effects of the presence of an acquaintance in a “performer-observer” situation. The results revealed that the presence of an acquainted partner reduced the performer’s prefrontal activation indicated by decreasing of tension, and prior observation of another’s performance negated the positive presence effect and led to an increasing of prefrontal activation indicated by increased tension. These results suggest that the effects of the presence of others may rely on the performer’s “subjective” appraisal of a co-present observer as supportive or non-supportive. However, to accept this conclusion, it is necessary to assess the neural basis of the performer’s “subjective” appraisal of a co-present others using the same “performer-observer” paradigm as in Exp. 2, and to confirm whether the responsible brain regions are activated when the performer appraises the co-present others as supportive.

4.1. Purpose

The purpose of Exp. 3 was to examine the neural correlates of the performer’s “subjective” appraisal of a co-present others. Previous neuroimaging studies have demonstrated that the left IPL should be one critical component involved in the player's "subjective" appraisal of a co-present observer (Kim et al., 2010; Lamm et al., 2007; Smith et al., 2004). In this experiment, I mainly focused on the bilateral IPL as regions of interest.

To examine neural substrates of the performer's subjective appraisal of a co-present observer, I measured activation in the bilateral IPL when player-observer pairs of participants performed a driving video game task used in Exp. 2. The player's task was to drive to a goal under observation by a partner, and to evaluate the role of their partner and their own tension levels in the driving task. Figure 4-1 illustrates experimental manipulation of Exp. 3. According to previous studies (Lamm et al., 2007; Smith et al., 2004), I postulated that the player's cognitive appraisal of a co-present observer would activate the left IPL underlying the player's self-motivated processing, but not processing of the influence of the observer.

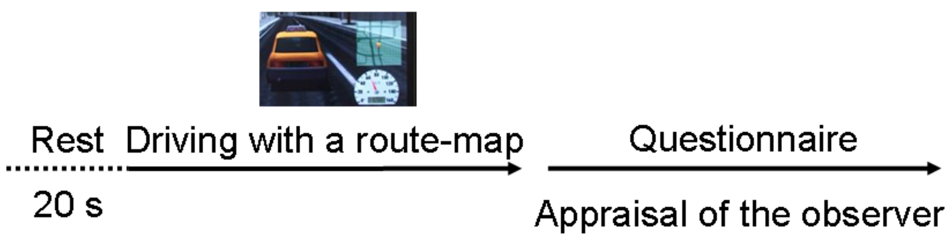

Figure 4-1. Experimental manipulation of Exp. 3.

Therefore, I predicted that the players would show higher activation in the left IPL when a player considers the paired observer as supportive than when a player considers the observer as non-supportive, but not in the right IPL.

4.2. Methods

4.2.1. Participants

Sixty-two undergraduate students (50 males, 12 females; age: 18.8 ± 1.1 years) in Nagoya University participated for course credit. Participants were paired in same-sex (player-observer) dyads. All participants were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971), and all had normal or corrected-to-normal vision. They were informed about the purpose and safety of the experiment, and written informed consent was obtained prior to participation. The present study was approved by the local ethics committee.

4.2.2. Apparatus

Figure 4-2 shows a multi-channel NIRS unit (FOIRE-3000/16; Shimadzu Co., Japan) and positions of NIRS channels. In Exp. 3, FOIRE-3000/16 was used to measure the player-observer pair's hemodynamic changes in oxygenated hemoglobin (Coxy-Hb), deoxygenated hemoglobin and total hemoglobin. Each participant had 14 optodes placed on their bilateral frontoparietal regions in a "2 × 7" lattice forming 19 channels. The middle channels in the lowest line were located at C5 and C6 positions (of the international 10–20 system for EEG recording). Each channel consisted of one emitter optode and one detector optode located 3 cm apart. The sampling rate for each channel was 8.7 Hz. Channel 2 and channel 17 covered the left and the right IPL (the regions of interest), respectively.

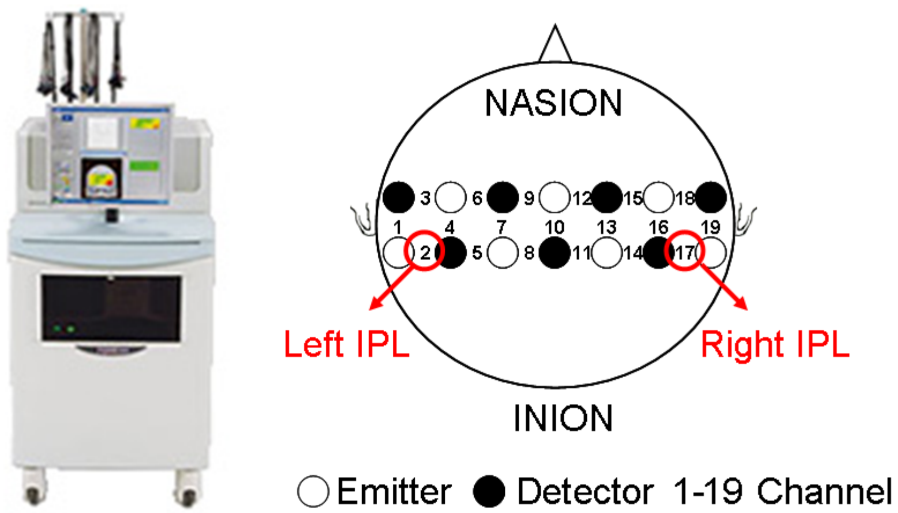

Figure 4-2. A multi-channel NIRS unit (FOIRE-3000/16; Shimadzu Co., Japan) and positions of the NIRS channels.

4.2.3. Materials and design

Exp. 3 used the same driving video game (The Taxi 2) as in Exp. 2. Figure 4-3 shows the experimental setting in the performer-observer situation. During the experiment, a player sat in front of a monitor (LDT32IV; Mitsubishi Elec., Japan) with a partner sitting beside him/her. The driving game was displayed on the monitor without sound, and the player controlled the game using a Sony game pad (DualShock 2; Sony Corp., Japan). Distance from player to monitor was 120 cm.

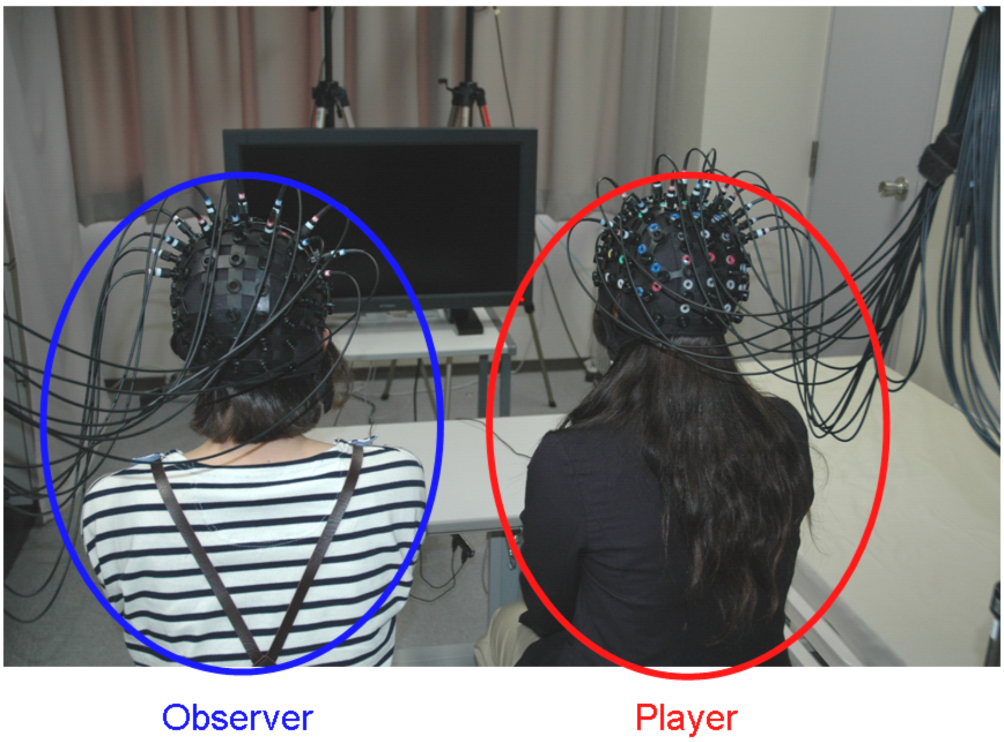

Figure 4-3. Experimental setting in the performer-observer situation.

4.2.4. Procedure

Prior to the experiment, two instructions were given orally to the participants: 1) the players were asked to obey traffic rules and drive to the goal using a default route-map; and 2) the player's performance would be observed and evaluated by his/her partner who needed to report the player's performance after the driving task.

During the experiment, the players practiced operating the game pad for 180 s, and then drove two training trials followed by four experimental trials with distinct routes. A single trial consisted of three phases, that is, a pre phase (20 s), a driving task phase, and a post phase (20 s). In the pre and post phases, a black monitor screen was displayed, and the participants were instructed to relax and sit comfortably without communication. In the driving task phase, players were instructed to drive from start to goal using a route-map, and press a key in front of them when they reached the goal ending the trial. The performance of the players was videotaped.

After the driving task, players were asked to give a written appraisal of the co-present partner in answer to the question "how did the presence of a partner influence your driving performance?", and to rate their tension scores on a five-point scale (1 = not at all, 5 = very much) for both their unsettled feeling and stress feeling.

4.2.5. Data analysis

Invalid NIRS data were excluded from further analysis, leaving 24 players and 18 observers for channel 2 (left IPL), and 23 players and 18 observers for channel 17 (right IPL). I analyzed Coxy-Hb, and average change in Coxy-Hb during the driving task phase was calculated for channel 2 and channel 17, respectively. A linear baseline correction was conducted on NIRS raw data from each trial using the mean value of Coxy-Hb during the last 5s of the pre phase. *Z*-scores were then calculated using the mean value and the standard deviation during the baseline period. NIRS data were averaged every 1 s, and the driving error periods were excluded. The NIRS data without the error periods were averaged throughout the driving task phase across four experimental trials for each participant.

4.3. Results

4.3.1. Driving time and number of errors

In Exp. 3, I calculated the mean driving time and the mean number of errors across four experimental trials as performance indices. The significance level was set at $p < 0.05$.

According to the player's appraisal of the co-present observer, participants were divided into three groups: supportive (n = 6), non-supportive (n = 7), and neutral (n = 11). Mean driving time (s) and number of errors were obtained for each of these three groups, respectively. Figure 4-4 shows the driving performance in the three groups. To examine the effects of the player's appraisal of a co-present observer on his/her own performance, I conducted a one-way analysis of variance (ANOVA) with Appraisal (supportive, non-supportive, and neutral) as the between-participants factor. There were no significant differences for either driving time or number of errors among these groups [$F(2, 21) = 2.18$, *ns*; $F(2, 21) = 1.73$, *ns*, respectively].

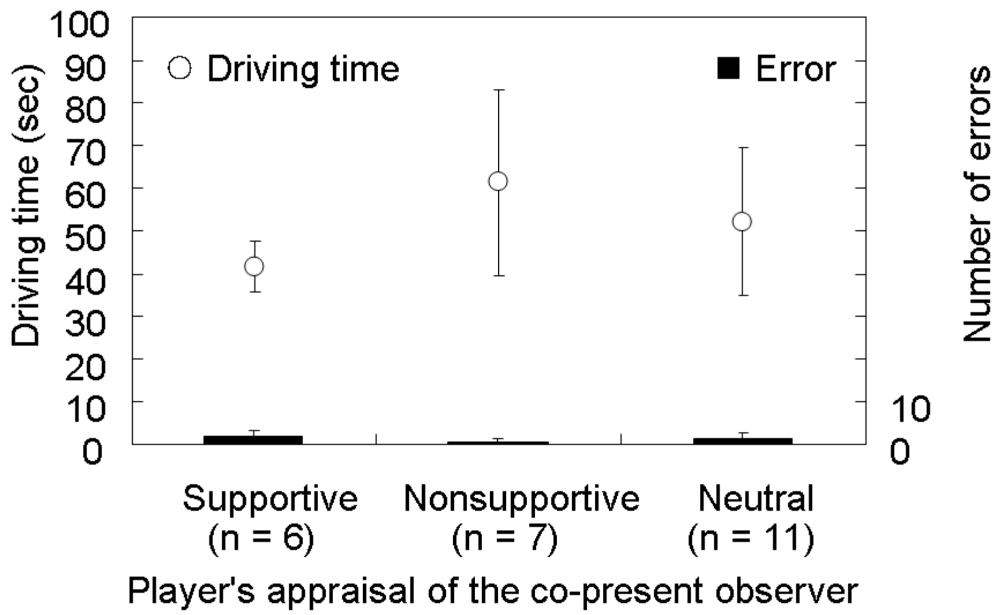

Figure 4-4. Mean driving time and number of errors in the supportive, non-supportive, and neutral groups. Error bars represent standard deviation.

4.3.2. Rating scores on participant's tension level

I evaluated participant's tension in the three groups (supportive, non-supportive, and neutral) by averaging their rating scores for the two questions. Figure 4-5 shows the tension evaluation scores in each group. To test the tension levels of the three groups, a one-way ANOVA [Appraisal (3)] was conducted on the player and the observer groups, respectively. There were no significant effect of Appraisal in either players [$F(2, 21) < 1$] or observers [$F(2, 15) = 1.06$, *ns*].

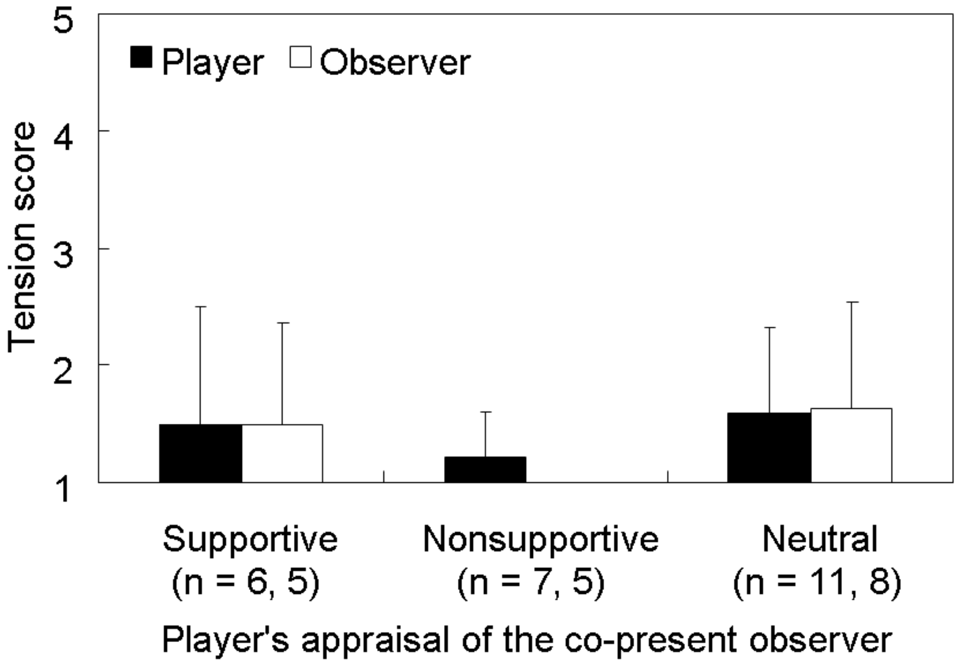

Figure 4-5. Mean tension evaluation scores in the supportive, non-supportive, and neutral groups. The numbers in the parentheses ($n = x$, y) represent the number of players (x) and observers (y) in each group. Error bars represent standard deviation.

4.3.3. Brain activation changes in the inferior parietal lobule

Figure 4-6 shows the mean Coxy-Hb in the supportive, non-supportive, and neutral groups. To assess the neural correlates of the player's appraisal of the co-present observer, I conducted a one-way ANOVA [Appraisal (3)] on the Coxy-Hb of players in the left IPL (channel 2) and the right IPL (channel 17), respectively.

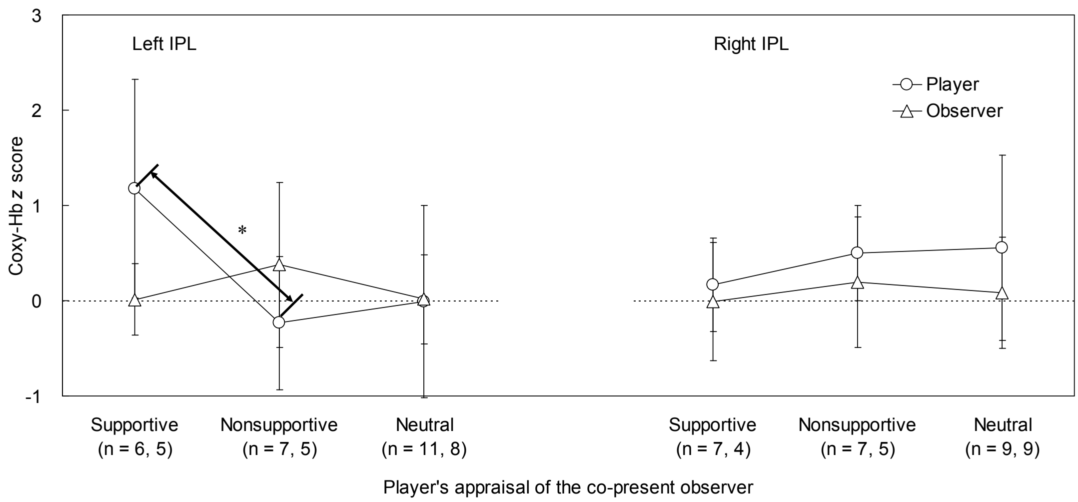

Figure 4-6. Average concentration changes of oxygenated hemoglobin (Coxy-Hb) in the bilateral inferior parietal lobule (IPL). The numbers in the parentheses ($n = x, y$) represent the number of players (x) and observers (y) in each group. Error bars represent standard deviation. * indicates $p < 0.05$.

In the left IPL, there was a significant main effect of Appraisal [$F(2, 21) = 3.97$, $p < 0.05$, $\eta_p^2 = 0.28$]. The Bonferroni post-hoc tests revealed that the players who appraised co-present observer as supportive showed higher activation than those who appraised others as non-supportive ($p < 0.05$). A non-significant trend was observed between supportive and neutral groups ($p = 0.08$). In contrast, the results did not reveal a significant main effect of Appraisal in the right IPL [$F(2, 20) < 1$].

To examine whether the observers who were appraised as supportive, non-supportive, and neutral showed equivalent activation, I conducted the same ANOVA [Appraisal (3)] in the bilateral IPL. There were no significant main effects of Appraisal in either hemispheres [$F(2, 15) < 1$; $F(2, 15) < 1$] .

4.4. Discussion

This experiment examined neural correlates related to the performer's cognitive appraisal of a co-present observer in a real-life performer-observer situation. To address this issue, I measured activation in the bilateral IPL when participants (players) performed a driving video game task under observation by partners (observers). According to the player's subjective appraisal of the co-present observer after the driving task, the pairs of participants were divided into three groups: supportive, non-supportive, and neutral.

The NIRS data demonstrated higher activation in the left IPL in the supportive group than in the non-supportive group, but not in the right IPL. The theoretical interpretations for the present results have two possible divergent paths depending on whether we attribute the effect of observer's support to observers or players.

One plausible explanation is based on the external influence from observer. That is, the non-supportive observers made the players self-conscious which made them less attentive. IPL is critical for spatial attention (Corbetta and Shulman, 2002), and presumably a more supportive observer may have allowed the player to concentrate on the task at hand, leading to greater parietal activity. Thus, the parietal activity may reflect greater concentration on a spatial task or greater arousal. However, in this experiment, the driving time and number of errors for players, and the tension evaluation scores both in players and observers did not show any significant differences between the supportive and non-supportive groups.

The alternative explanation is to attribute IPL activation to self (player) driven rather than other (observer) driven appraisal. Although they are not mutually exclusive, the unilateral activation in the left IPL in this experiment supports the self-driven interpretation. The left parietal activity is consistent with previous studies investigating emotional memory retrieval (Smith et al., 2004; Mickley Steinmetz and Kensinger, 2009) and the self-other distinction (Decety and Chaminade, 2003; Lamm et al., 2007; Schulte-Rüther et al., 2007).

There are two unique aspects of this experiment. First, the distinctive effects of the presence of others derive from the performer's cognitive appraisal of a co-present observer such as supportive or non-supportive, in agreement with the conclusion of Exp. 2. Second, the left IPL may be involved in the self-motivated positive appraisal. The theoretical implication here is that the performer's self-motivated positive appraisal toward a mere presence of others may function as an instigator of activity in the left IPL. From the perspective of influence of social context, it is interesting that NIRS may detect a player's self-motivated positive appraisal which the behavioral and self-tension ratings do not detect, at least in this experiment.

Chapter 5.
General Discussion and Conclusion

Chapter 5 consists of three sections: general discussion, remaining task for the future, and conclusion. I start the general discussion by summarizing the findings of the three experiments, emphasizing the “direct” and “indirect” interpersonal influences that occurred between two persons. I then discuss three main issues—behavioral data, NIRS data, and properties of the performer—that are closely associated with the results and the experimental manipulations in the present study.

5.1. General Discussion

5.1.1. Summary of the three experiments

The main purpose of the present study was two-fold. First, I aimed to examine the neural basis of “direct” interpersonal influence during daily activities. To address this issue, I manipulated two different cognitive loads during a driving video game task in Exp. 1. One was an extrinsically-driven cognitive load induced by “direct” influence from other persons. The other was an intrinsically-driven cognitive load that originated in memory systems. Specifically, I repetitively measured prefrontal activation in three groups (one control and two experimental). The control group drove to a goal four times with distinct route-maps illustrating default turning points. In contrast, the memory group drove the memorized default route without a map (intrinsically-driven cognitive load), and the emergency group drove with a map, but was instructed to immediately change the default route following an extrinsically given verbal turning command (extrinsically-driven cognitive load).

Second, I aimed at exploring the neural correlates underlying “indirect” interpersonal influence in a real-life performer-observer situation. To address whether the presence of others increases or decreases an individual’s tension, in Exp. 2 I measured prefrontal activation in performers with or without an observer during a driving video game task. The participant’s task was to drive from start to goal using a route-map either solely (single group) or with an acquainted partner as an observer (paired group). The paired participants alternated their driver-observer roles in a turn-taking style. The first driver (D1) took the role of observer (O2) in the subsequent task, and O1-D2 vice versa. The three groups (single, D1, and D2) were subdivided according to their game proficiency (high versus low). To explore why the presence of others increases or decreases an individual’s tension, in Exp. 3 I measured the activation in the bilateral IPL (previously shown to be critical for social cognitive and emotional processing) of the driver-observer pairs of participants, when they performed the same task in the same driver-observer situation used in Exp. 2. According to the performer’s subjective appraisal of the co-present observer obtained after the driving task, the pairs were divided into three groups: supportive, non-supportive, and neutral.

I obtained three main findings based on the NIRS data of three experiments. In Exp. 1, I analyzed concentration changes of oxygenated hemoglobin (Coxy-Hb) in three critical periods associated with a turning maneuver (i.e., pre-turning, actual turning, and post-turning periods). The emergency group showed a significant increasing pattern of Coxy-Hb throughout the three periods, and a significant reduction in Coxy-Hb throughout the repetitive trials, but the memory group did not. These results suggest that PFC differentiates the intrinsic (guiding actions via memory systems) and the extrinsic (modulating responses to external social stimulus, that is, “direct” interpersonal influence) cognitions.

In Exp. 2, the NIRS data in low-proficiency performers revealed that single and D2 groups showed significantly higher activation than D1, suggesting that the presence of an acquainted partner reduces an individual’s tension, and prior observation of another’s performance negates this positive presence effect and leads to increasing of tension.

In Exp. 3, NIRS data of performers in the supportive group showed significantly higher activation in the left IPL than that in the non-supportive group, but not in the right IPL. NIRS data of observers in the two groups concerned did not show any significant differences bilaterally in IPL. These results suggest that the left IPL responds distinctively according to the performer’s “subjective” appraisal of a co-present observer.

Taken together, the present study demonstrated that the extrinsically-driven cognitive load induced by "direct" interpersonal influence instantly activates the PFC, but the intrinsically-driven cognitive load does not (Exp. 1). Concerning "indirect" interpersonal influence, the effects of the presence of others (i.e., social facilitation effects) may rely on a performer's cognitive appraisal of the co-present observer as supportive or non-supportive (Exp. 2 and Exp. 3).

Classical social facilitation literature has mainly considered the task difficulty as a critical modulating variable (e.g., Zajonc, 1965). The results of the present study suggest that a better way to understand and explain the social facilitation effects is to focus on the mindset of the performer and investigate the factors moderating the cognitive processing of the performer's subjective appraisal of others.

In the present study, I measured both behavioral and NIRS data of performers in a two-person situation, emphasizing the role of the properties of performer in the interpersonal influence. I will discuss these three aspects: behavioral data, NIRS data, and properties of the performer, respectively, in the following three subsections.

5.1.2. Behavioral data

In the present study using a driving video game task, I mainly considered the mean number of errors and driving time as performance indices. The performance data did not show significant results in any of the three experiments. Concerning the task difficulty and the definition of error, two plausible explanations can be given for the nonsignificant results in the performance data. One is that the task difficulty of the driving video game task was not appropriate to detect individual differences on performance (Bond and Titus, 1983). The alternative explanation is that the error data in the present study may not reflect well-defined errors such as those in the true-false tasks. Although the participants were instructed to drive abiding by the traffic rules, the criterion of the traffic rules was not explained. That is, the definition of an error may be not clear for the participants in the present study. As a result, they may follow their own compliance behavior. To avoid the ambiguous definition of errors, in the future study clear error standards should be explained to the participants prior to the task.

5.1.3. NIRS data

To examine the effects of the presence of others, Exp. 2 and Exp. 3 measured the performer-observer pairs' activation in the PFC and IPL, respectively. Although the NIRS data demonstrated that the effects of the presence of others may rely on the performer's cognitive appraisal of a co-present observer, two limitations concerning the manipulation of the performer's cognitive appraisal and NIRS measurement in the concerned brain regions need to be considered.

5.1.3.1. Performer's cognitive appraisal of the co-present observer

In Exp. 4, the performer's subjective appraisal of their co-present partner was assessed through a questionnaire after the driving task. This post-questionnaire does not enable the assessment of the important temporal information concerning when the performer gave their appraisal: before the task, during the task, or only after the task during the questionnaire. As a result, it is hard to identify which processing period the NIRS data reflected, and whether the cognitive appraisal is a discrete or continuous processing as well. One plausible possibility is that the performers had already appraised their partner prior the experiment; in other words, they tended to consider others as supportive or non-supportive during daily life. That is, the NIRS data may reflect the performer's personality trait, and support the cognitive appraisal as a continuous processing. Further study is needed to clarify this issue, that is, when the performer appraises the co-present observer as supportive or non-supportive.

5.1.3.2. Simultaneous measurement of activation in PFC and IPL

In Exp. 2, D1 showed lower prefrontal activation than the single players. The decreased prefrontal activation in the presence of others may due to decreasing of tension in D1 as I interpreted, but there are also other possible explanations. For instance, the decreased prefrontal activation may reflect the passive hemodynamic changes called the "vascular steal" phenomenon. Decreases in signals are often observed around active areas. Their origin is sometimes interpreted as blood draining from neighboring areas to active areas and referred to as “vascular steal” (Matsuda and Hiraki, 2006). However, Exp. 2 did not permit the verification of whether some neighboring area of lateral PFC was activated or not, since Exp. 2 only measured the left and the right prefrontal regions using a two-channel NIRS unit.

Although Exp. 3 measured brain activation changes in the IPL using the same performer-observer paradigm, and confirmed the interpretation of Exp. 2, it is better to measure activation in the PFC and IPL simultaneously to assess both tension level and cognitive appraisal in one experimental framework in a future study.

5.1.4. Properties of the performer

The results of the present study suggest that the properties of a performer should be important variables modulating the effects of the presence of others. In the following two parts, I will discuss two related factors: relationship with the co-present observer and prior experience, respectively

5.1.4.1. Relationship between the performer and the co-present observer

It is noteworthy that I obtained the effects of the presence of others with acquainted pairs. However, in a real world we feel greatly encouraged by a diversity of people such as close family, friends, and even strangers. Since the human bonds of trust and friendship between two persons can be changed by both length of time and familiarity (Shah and Jehn, 1993; Sias and Cahil, 1998), the relationship of familiarity may ideally be a factor to be manipulated between two people as they progress from stranger to friend. That is, it is better to periodically measure the brain activation changes in the same pairs of participants from when they are strangers to when they become friends, even though the experimental manipulation may be challenging and the investigation time consuming.

5.1.4.2. Prior experience of the performer

The present results demonstrated that the prior experience of the performer affects the effects of the presence of others. There were two types of prior experience for the performer in the present study. One is prior experience in the relevant task; the other is prior social experience in the similar social situation.

Concerning the former, in the present study I focused on participants' game experience by their self-report. The alternative possibility is to manipulate a practical aspect of the experience in the experiment. One possible way is to manipulate participants' game skill with the amount of training sessions such as many versus few. Depending on the degree of game proficiency manipulated by experience immediately before the experimental task, we can directly test whether the accrued game skill affects the performer's cognitive appraisal of the co-present partner and how it influences the performer's tension level.

With respect to the social experience, there are two possible ways to obtain the social experience. One is through direct experience in social contexts. The alternative way is via observation of another's performance in social environments. Previous studies have demonstrated that prior success or failure experiences in the presence of others affect the performer's future performance in the similar situation (Geen, 1979; Seta and Seta, 1995). However, little is known about the role of the prior experience of observation in social facilitation effects. In this vein, the present study demonstrated that prior observation experience has a negative effect on performer's mental state in the subsequent task. I pointed out in Exp. 2 that O1 learned awareness of the role of observer from prior experience of observation of D1's performance, and rejected the possibility that O1 learned task difficulty from errors made by D1. If we compare two groups instructed differently, for instance half of the O1s are given a bias for error-performance observation of D1, and the remaining half of O1s are given a bias for correct-performance observation, it enables the examination of the role of prior observation of success or failure performance made by others, as well as the study of the neural correlates underlying the observational learning in the future work.

5.2. Remaining task for the future

The present study has demonstrated that the effects of the presence of others may rely on the performer's cognitive appraisal of a co-present observer as supportive or non-supportive. That is, the positive or negative appraisal of others by a performer may modulate his/her brain activation and correspondingly influence the behavior during daily activities. On the basis of this finding, an important remaining task in the future is to investigate the factors facilitating the positive cognitive appraisal of other person.

Previous studies have demonstrated that empathy has broad benefits for social interaction, in which it can be an effective tool for coping with misinterpreted behavior, thereby maintaining or improving the cooperation between persons (Rumble, 2010). To examine the factors facilitating the positive cognitive appraisal of others, one needs to focus on the empathy level of a performer in the further work.

Another important issue that deserves special consideration in future studies is the experimenter effect. In the present study, an experimenter was present with the participant in the experimental room to manipulate the experiment. That is, the single group was not an ideal alone situation in the present study, but in some sense a “two-person” situation—participants performed the task in the presence of an unfamiliar experimenter. Although the experimenter’s presence is common in most experimental settings (Sharma et al., 2010), further study is needed to examine the experimenter effect on the social interaction.

5.3. Conclusion

In conclusion, the results of the present study imply both practical and theoretical aspects. For the practical implication, the present results suggest that NIRS offers an easy-to-use, more ecologically valid, and robust approach to the study of social cognition in a more “natural” two-person or multi-person situation.

Concerning the theoretical implication, Exp. 1 demonstrated that the PFC differentiates the intrinsic and the extrinsic cognitive processes in daily activities. Exp. 2 revealed that the presence of an acquainted partner reduces an individual’s prefrontal activation due to decreasing of tension, and prior observation of another’s performance negates the positive presence effect and leads to increasing of activation in the PFC due to increased tension. Exp. 3 showed higher activation in the left IPL when the performers appraised the co-present observer as supportive than when they appraised others as non-supportive, suggesting that the left IPL distinctively responds according to a performer’s positive appraisal of a co-present others. Taken together, the results of Exp. 2 and Exp. 3 suggest that the effects of the presence of others may rely on a performer’s cognitive appraisal of the co-present others as supportive or non-supportive.

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List of major publications

Peer-Reviewed Journal Articles

1. **Liu, T.**, Saito, H., Oi, M., Pelowski, M. (2012). Appraisal of a copresent observer as supportive activates the left inferior parietal lobule: a near-infrared spectroscopy study using a driving video game. *NeuroReport*, 23(14), 835-839.
2. **Liu, T.**, Saito, H., Oi, M. (2012). Distinctive activation patterns under intrinsically versus extrinsically driven cognitive loads in prefrontal cortex: a near-infrared spectroscopy study using a driving video game. *Neuroscience Letters*, 506(2), 220-224.

Peer-Reviewed Proceedings

1. **Liu, T.**, Saito, H., Oi, M., Pelowski, M. (2012). Easing and rising of tension from presence of others in player-observer turn-taking in a driving video game: a near-infrared spectroscopy study. In: N. Miyake, D. Peebles, R.P. Cooper (Eds.), *Proceedings of 34th Annual Conference of the Cognitive Science Society* (pp. 1924-1929). Austin, TX: Cognitive Science Society.
2. **Liu, T.**, Saito, H., Oi, M. (2011). The effect of the presence of an observer on prefrontal cortex during a driving video game: a near-infrared spectroscopy study. *Proceedings of the 12th International Multisensory*

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Proceedings

1. **Liu, T.**, Saito, H. (2010). Brain response to unexpected events during simulated driving: a near-infrared spectroscopy study. *Proceedings of the 8th Congress of the Japanese Society for Cognitive Psychology* (p. 11). Fukuoka, Japan.

Appendix A. Edinburgh Handedness Inventory

どちらの手を使いますか？

	すべて左手	ほとんど左手	ほとんど右手	すべて右手
文字を書く				
ボールを投げる				
ハサミを使う				
歯ブラシを使う				
絵を描く				
マッチをする				
箒（ほうき）を持つときに上になる				
フォークを持たないときナイフを持つ				
箱の蓋（ふた）を開ける				
スプーンを持つ				

2 親等以内のご家族（祖父母，両親，兄弟姉妹，子，孫）に左手利きがいますか（いましたか）？

【はい・いいえ】，　誰に【　　　　　　　　　　】

氏名＿＿＿＿＿＿＿＿＿＿＿＿　　判定＿＿＿ E

Appendix B. Questionnaire on participant's game proficiency

テレビゲーム（プレイステーションなど）をしたことがありますか。

☐ したことがある
☐ したことがない

したことがあると答えた方に伺います。

何歳ごろ（何年前）からテレビゲームを始めましたか。

歳　　　年前

車を運転するゲーム（レーシングゲーム等）をしたことがありますか？

☐ 実験と同じゲームをしたことがある
☐ 実験とは別のゲームをしたことがある
☐ したことがない

車を運転するゲームをしたことがあると答えた方に伺います。

何歳ごろ（何年前）から車を運転するゲームを始めましたか。

歳　　　年前から

今でも車を運転するゲームをしていますか。

☐ している
☐ していない　（　　年　　ヶ月前まで）

どのくらいの頻度で，そのゲームをしていました（しています）か。

☐ ほぼ毎日
☐ 週に4～6回
☐ 週に1～3回
☐ 月に数回
☐ 年に数回

Appendix C. Questionnaire on friendship between paired participants

あなたは，今日の実験に一緒に参加した人と友達ですか？

☐ 友達　　☐ 友達ではない

「友達」と答えたヒトは，いつから友達になりましたか？ ( )内に書き入れてください。
例：去年の4月から友達　→　（　１　）年（　３　）ヶ月前から

（　　　）年（　　　）ヶ月前から

「友達」と答えたヒトは，親しさの程度を，該当する項目に☑を記入してください.
☐ 非常に親しい　　☐ ある程度親しい　　☐ 顔見知り

Appendix D. Questionnaire on tension scores (5-point scale)

	まったくあてはまらない	わずかにあてはまる	すこしあてはまる	かなりあてはまる	非常によくあてはまる
a. おちつかない気分だ	1	2	3	4	5
b. 不安な感じがする	1	2	3	4	5

Appendix E. Questionnaire on appraisal of co-present observer

車を操作した方にお聞きします。
あなたがゲームで運転する際に，あなたのお友達が見ていることは，
課題の遂行に役立ちましたか，妨げになりましたか？
どのように役だったか，あるいは妨げになったか具体的に記述してください。
（役だった・妨げになった）
（例. 友達が横にいて安心した、集中できなくて画面を良くみていなかった。）

ACKNOWLEDGMENTS

First of all, I would like to thank my advisor, Prof. Hirofumi Saito, and express my great gratitude for his guidance, warm support and concern. His scientific attitude, great intuition, and visionary mind have been stimulating and invaluable.

I am very grateful to Prof. Kazuhisa Miwa, Associate Prof. Nobuyuki Kawai, and Assistant Prof. Hidemichi Mitsumatsu for their constructive and valuable feedback throughout my Ph.D. project.

Furthermore, I would like to thank Dr. Misato Oi and Dr. Matthew Pelowski for their inspiring and supportive discussions and help.

I also would like to express my thanks to members of the Saito lab for their help in carrying out the experiments and preparing the manuscript. Especially, Alberto Lepe Garza offered great help for experimental programming at the very beginning of the project. Victor Palacios assisted with English usage in the manuscript.

Many warm hugs to my parents and my wife for their large help and support throughout school.

Finally, I would like to express my great gratitude to the China Scholarship Council (CSC). Without the financial support I would not have this opportunity to accomplish my Ph.D. project.

Tao LIU