博 士 論 文（要約）

The Neural Basis of Self-Efficacy in Relation to Motivation

(自己効力感の神経基盤と動機づけにおける役割)

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List of Abbreviation

3D-MPRAGE	3 dimensional magnetization prepared rapid gradient echo
3T	3 tesla
AC	anterior commissure
BDI	Beck depression inventory
BOLD	blood oxygenation level dependent
DARTEL	diffeomorphic anatomical registration using exponentiated lie algebra
CSF	cerebrospinal fluid
dmPFC	dorsomedial prefrontal cortex
EPI	echo planar imaging
ERN	error-related negativity
F	failure
fMRI	functional magnetic resonance imaging
FWE	familywise error
GLM	generalized linear model
GSE	general self-efficacy
HG	high group
L	left
LG	low group
M1	primary motor cortex
MAP	mean arterial pressure
MNI	Montreal Neurological Institute
MRI	magnetic resonance imaging
MSLQ	Motivated Strategies for Learning Questionnaire
PC	posterior commissure
preSMA	presupplementary motor area

R	right
S	success
SE	standard error
SD	standard deviation
SPM	Statistical Parametric Mapping
SW	stopwatch
VBM	voxel-based morphometry
vmPFC	ventromedial prefrontal cortex
WS	watch-stop

1. General Introduction

1.1. Studying motivation to understand behavior

We are constantly making decision on what actions to take. We receive stimuli from the environment and recognize the present state we are in. Depending on the state we are in and the goals we have, we decide our next action to execute so as to gain the most from the environment. How we interpret the environment, the reason why one makes that action within that environment, could be explained by the concept of motivation (Graham & Weiner, 1996; Weiner, 1980). The degree of motivation will determine how often we will generate that action, as shown in the law of effect (Thorndike, 1905).

The reasons why we are motivated will vary according to the gained reward after successfully executing the task. The incentive of reward varies based on the agents' state and how the agents subjectively assign values to the reward. Primary needs like hunger and thirst will motivate the agent to gain food or water (Hull, 1943). Explicit rewards like money (Knutson, Fong, Kaiser, Adams, & Hommer, 2000) and social reputation (Bénabou & Tirole, 2006; Izuma, Saito, & Sadato, 2008) will also motivate the agent to engage in behaviors that will result in gaining them.

Not only the accompanied reward to behavior, but the behavior itself could be a reward by experiencing the joy of engaging in that action (Ryan & Deci, 2000a). The incentive could arise by the realization of our goal, like achievement motivation (Atkinson, 1957; 1964) and self-actualization (Maslow, 1943). These factors could be labeled as the predicted outcome that an agent could receive by successfully executing the necessary actions.

1.2. Effects of subjective factor to motivation

The predicted outcomes that are externally determined are not the only factors that will determine our behavior. The relation between tasks and ourselves will also have influence, as an subjective factor. One example could be the effect of self-determination (Ryan & Deci, 2000b). This theory states that if an agent is able to freely choose a task from multiple choices based on their value or interest, performance improves compared to forced choices (Leotti, Iyengar, & Ochsner, 2010). Effect of self-determination choice has been shown to effect performance and preference (Patall, Cooper, & Robinson, 2008) in multiple situations, such as classrooms (Cordova & Lepper, 1996) and for kids and monkeys (Egan, Santos, & Bloom, 2007).

The fact that an agent could freely chose the task would also affect the processing of success and failure feedbacks. It has been shown that the not only self-determined choice resulted in the increase in performance, but self-determined choice resulted in no difference in the activation to success and failure feedbacks in ventromedial prefrontal cortex (vmPFC), while failure in forced choice caused a decrease in activation in vmPFC compared to success (Murayama et al., 2015). This discrimination of choice was not seen in the striatum. Since there was no difference in task difficulty, the fact that an agent chose that task on their own affected the processing of feedback and performance.

It is assumed that the subjective relation with the agent and the task will also have effect on the processing of given feedbacks and the motivation to that task. Of the subjective relation with tasks, I specifically focus on the concept of self-efficacy.

1.3. Concept of self-efficacy

Albert Bandura proposed the concept of self-efficacy within his social learning theory, which differentiated the effect of predicted outcome from our subjective belief about our own ability to succeed in a given task, and theorized that the agents' decision in engaging in that behavior will be varied by the belief of ability one has. This belief was defined as self-efficacy (Bandura, 1977; 1997). For example, the belief that a person has that s/he can pass a test is the self-efficacy specific to that test. On the other hand, social praise, resulting high grade at the end of term, and satisfaction that could be gained as a result of passing that test are included within the predicted outcome.

Bandura have denied the direct relation between the environment and behavior, and insisted that there is a cognitive factor that will be inserted between them that will affect behavior (Bandura, 1986). Although outcome expectancy will influence behavior, if an agent feels doubt in successfully performing that behavior, an agent may not engage in that behavior in spite of the reward that could be gained. For example, knowing the fact that studying for test is necessary for a good grade does not always motivate us to study.

The belief of self-efficacy will affect both the initiation and persistence of behavior, since our decision is influenced by the expectation of our behavior. When an agent is about to choose what kind of actions to take, self-efficacy will affect this initial choice. If an agent is provided with choice options that differ in self-efficacy, they will avoid threatening situations that are surely for them to fail and choose behavior that they feel high in self-efficacy. Self-efficacy will also affect whether to continue engaging in the same behavior. The amount of effort and the amount of time spent in the face of obstacles will also be determined by self-efficacy (Gist & Mitchell, 1992).

1.4. Source of self-efficacy

The degree of self-efficacy to a certain task is affected by 4 factors: actual performance, vicarious experience, social persuasion, physiological and emotional states (Bandura, 1977; 1997). Agents use these factors as information about the task to determine self-efficacy to a certain task. These factors are also used to manipulate self-efficacy within lab experiments.

Actual performance has the most influence on self-efficacy, since this is the information that will be gained by direct experience of the task. Success will raise self-efficacy to a task, and failure will decrease it. The effect of failure will be stronger if it happens early in experiencing that task. Within lab experiments, making a task that a participant could never succeed is used to decrease self-efficacy by continuously experience failure (Smith, Kass, Rotunda, & Schneider, 2006) and the time spent or number of trials that a participants engage in that task is used as a index of tolerance to failure (I. Brown & Inouye, 1978; Lyman, Prentice-Dunn, Wilson, & Bonfilio, 1984).

Vicarious experience by watching others engage in tasks will also be the source of self-efficacy. Since we can learn about the task by watching others engaging in that task (Chang, Winecoff, & Platt, 2011; Hill, Boorman, & Fried, 2016; D. G. Perry & Perry, 1975), this information could also be used to determine self-efficacy. This will also work in both ways: viewing a model having difficulty in solving the task will decrease in self-efficacy, and easy solving will increase self-efficacy (Zimmerman & Ringle, 1981).

Social persuasion another source, which will be the result of verbal persuasion by others that will harbor self-doubts (Litt, 1988; Schunk, 1989). Although this is an easy method to influence human behavior, its effect is not strong and does not continue for a long time, which could be diminished in the face of failure or difficulty.

People will also use their physiological and emotional state to judge their self-efficacy. Being in a stressful situation will result in high arousal, which will effect our decisions of self-efficacy (Bandura, Taylor, Williams, Mefford, & Barchas, 1985), as well as our mood (Cervone, Kopp, Schaumann, & Scott, 1994; Kavanagh & Bower, 1985). How the intensity of physiological and emotional state will affect self-efficacy depends largely on how that state is interpreted by that person. If a person views their arousal to a situation as facilitator of performance, it may result in a higher self-efficacy, while if a person thinks that their arousal will result in failure, it sill contribute to a lower self-efficacy.

The 4 sources of information of self-efficacy will be integrated, which will be weighed differently, to determine an agent's sense of self-efficacy. Since actual experience has the most influence, the experience of actual mastery within a therapy greatly increased in self-efficacy compared to vicarious experience, though both treatments showed significant increase in self-efficacy (Bandura, Adams, & Beyer, 1977).

1.5. Past studies on self-efficacy

Self-efficacy was first introduced as a concept to explain the changes in behavior within therapy for phobias (Bandura, 1977), such as snake phobias (Bandura et al., 1977; Bandura, Reese, & Adams, 1982), spider phobias (Bandura et al., 1982; 1985), and height phobias (Williams & Watson, 1985; Williams, Turner, & Peer, 1985). Low self-efficacy increased fear arousal and higher self-efficacy increased performance attainments (Bandura et al., 1982). Treatment of guided mastery based on self-efficacy theory reduced anxiety and thought of danger and restored behavioral functioning, which was more effective than desensitization (Williams et al., 1985). The strength of self-efficacy accurately predicted phobic behaviors compared to perceived danger and anxiety arousal (Williams & Watson, 1985).

Later on, this concept has been shown to have relation with other clinical situations such as pain control (Bandura, Cioffi, Taylor, & Brouillard, 1988; Litt, 1988), smoking cessation (Cohn, Strong, Abrantes, & Brown, 2010; John, Meyer, Rumpf, & Hapke, 2004; O'Leary, 1985), and depression (Bandura, 1997; Maddux & Meier, 1995). Other situations include sea sickness (Eden & Zuk, 1995) and attempting a new form of back-dive (Feltz, 1982). More over, self-efficacy related to performance at work (Stajkovic & Luthans, 1998) and performance and motivation in academic settings (Lent, Brown, & Larkin, 1984; Multon, Brown, & Lent, 1991; Zimmerman, 2000), which were also seen for children challenging wire puzzles (Zimmerman & Ringle, 1981). Self-efficacy has been researched from multiple aspects within lab experiment to actual daily behaviors.

1.6. General self-efficacy

Self-efficacy had been theorized to be assigned to each tasks, but there is also evidence that the experience of mastery that will increase self-efficacy generalizes to other behaviors other than the actual accomplished behavior (Bandura et al., 1977). It was then predicted that not only do we possess a sense of self-efficacy to each tasks, but also our past experiences in variety of situations will result in a general expectation that an individual will have in new situations. The concept of self-efficacy was expanded to a more general concept, which could be called as general self-efficacy (GSE), an accumulation of numerous task-specific self-efficacy (Chen, Gully, Whiteman, & Kilcullen, 2000; Sherer et al., 1982).

Although GSE have been under debate of its relation to task-specific self-efficacy (Bandura, 1986), GSE have been shown to influence task-specific self-efficacy (Chen et al., 2000). Since GSE is a generalized concept and is not tied to specific tasks, it will not be affected by several experience of failure, like task-specific self-efficacy which will be decreased immediately by experience of failure (Smith et al., 2006). Moreover, it have been tested in 25 countries and suggested to be a uni-dimensional, universal concept (Scholz, Gutiérrez Doña, Sud, & Schwarzer, 2002).

1.7. Self-efficacy and motivation

Self-efficacy is an interesting concept to explain motivation and behavior. When we predict that an action will result in an incentive that has value to us, we generate that action so as to receive that incentive. Self-efficacy differentiates the expectation of outcome from the belief of successful execution that an agent has (Bandura, 1977). If this belief is low, it will result in an inhibition of behavior although the agent knows that s/he could receive incentive by executing that action. Inhibition of behavior may result in decrement of performance by not learning for tests in academic settings and resulting in not gaining that reward (Bandura, 1986).

Self-efficacy have been used to explain the motivational aspects of behaviors such as resilience to failure (Lyman et al., 1984), amount of time spent doing a task (I. Brown & Inouye, 1978; Cervone & Peake, 1986; Zimmerman & Ringle, 1981) and actual performance (Gist & Mitchell, 1992; Lee, 1982; Phillips & Gully, 1997; Stajkovic & Luthans, 1998). Since self-efficacy affects actual performance between individuals that have the same performance skill (Bandura, 1986; Lee, 1982; Phillips & Gully, 1997), the prediction of our skill will actually affect the actual outcome, as if we are controlled by the self-generated prediction about our skill.

1.8. Motivation in neuroscience

In my thesis, I will mainly focus on the neural basis of self-efficacy. Within the field of neuroscience, the ultimate goal for neuroscientists is to understand how the neurons and its electrical signals result in shaping our mind. Although there is still a large gap, understanding about behaviors, which is the outcome of our mind processing the given information, have made a significant progress. It has let to the understanding of how learning is implemented, how decision are made and how decisions are modified by the processing of information and neurotransmitters (Kandel, 2013).

Introducing the concept of motivation to the field of neuroscience have lead to a further understanding of behavior (Berridge, 2004), focusing on drive and incentives of stimuli. These factors are combined to result in the behavior of an agent (Minamimoto, La Camera, & Richmond, 2009; Schultz, 1998). Incentives, or rewards, that will motivate us to engage in behaviors vary, like food, money, and social rewards (Schultz, 2015). Although these incentive influence our behavior, the incentives that are investigated within neuroscience were mainly external with only few neuroscience research focusing on intrinsic (Murayama, Matsumoto, Izuma, & Matsumoto, 2010) or self-relevant information (Murayama et al., 2015) relating to motivation. By introducing the concept of self-efficacy to the field of neuroscience, it will give a further understanding of how our brain processes cognitive concept of motivation relating with the evaluation of self.

As self-efficacy is changed by the information gained from the environment, especially the direct experience of success and failure, it is assumed that the assigned self-efficacy to tasks could be related to the processing of given feedbacks while engaging in that task. I mainly focus on the neural correlates of self-efficacy especially from the perspective of feedback processing.

1.9. Feedback processing in neuroscience

Feedback exists when the resulting output of a system is used as an input signal, which forms a loop of information (Wiener, 1965). Received feedbacks are important factors in voluntary behavior, which is used to monitor performance and adjust behavior so as to reach the desired state. A simple example would be a thermostat. It will control the air conditioning system to keep the temperature at the desired set point, by turning off when it is too cold, and turn on when it is too hot. In order for the system to know when to turn on the conditioning on, it needs the information of the current temperature within that room. This will be compared to the set point temperature, and the necessary action is taken. Correcting of behavior by feedback is not only seen in engineering, but also an important factor in learning and controlling our behavior.

Given feedbacks are processed within the wide areas of the medial wall (Ullsperger, Danielmeier, & Jocham, 2014). Processing of feedback has been investigated by fMRI (e.g. Rushworth & Behrens, 2008), single-cell recording (e.g. M. Matsumoto, Matsumoto, Abe, & Tanaka, 2007), and event-related potentials (e.g. Bartholow et al., 2005). This feedback processing signal is not limited to error related activation (Holroyd & Coles, 2002; Mars et al., 2005; Ullsperger, Nittono, & Cramon, 2007), but also seen for unsigned prediction error (Walton, Croxson, Behrens, Kennerley, & Rushworth, 2007). The processed feedback will be used to monitor and adjust behavior (Hayden, Heilbronner, Pearson, & Platt, 2011; Rushworth & Behrens, 2008).

1.10. Thesis overview

In my thesis, I focus on the neural basis of self-efficacy and its relation to motivation. In Experiment 1, I focus on the updating of self-efficacy to tasks. Since self-efficacy is mainly determined by the experience of success and failure, I controlled the success rate within a task to control self-efficacy to the task and investigated how self-efficacy is updated. As feedbacks are processed within the broad area of medial prefrontal cortex (medial PFC), I focused the analysis within this region. Also, how the difference in updating will effect the processing of feedbacks, resulting in the individual differences of self-efficacy was investigated. In Experiment 2, I investigate how the individual difference of general self-efficacy (GSE), which could be taken as the accumulation of self-efficacy to various tasks, will result in the individual difference of gray matter volume. In Experiment 3, I investigated the change of GSE. The change was induced by intervention of behavioral activation in participants who are categorized within subthreshold depression, and the change in gray matter volume and GSE was investigated. Since both experiments 2 and 3 are exploratory, the whole brain was investigated for the relation between GSE and the gray matter volume.

2. Experiment 1: Neural Basis of Updating of Self-Efficacy

(Deleted due to unpublished data)

3. Experiment 2: Neural Basis of General Self-Efficacy

3.1. Introduction

As Bandura stated, self-efficacy is largely affected by past experiences with the same task that the agent is about to do; experience of success will increase self-efficacy, and vice versa (Bandura, 1986). Not only are there difference in the self-efficacy that a person feels to tasks, but there are individual differences in the strength of one's belief in their ability to succeed in a variety of tasks, which is called general self-efficacy (GSE) (Sherer et al., 1982). GSE results from past outcomes of tasks and will affect our motivation to do them. We process outcome information of our actions, and our neural mechanisms change anatomically by this processing (Zatorre, Fields, & Johansen-Berg, 2012). Since GSE is a grand sum of these experiences, the brain regions that would be most relevant to GSE would likely be regions that process outcomes of tasks and expectation of future outcomes. Therefore I hypothesized that individual differences in GSE may also be reflected in the brain structure.

In the present study, I investigated the regional gray matter volume specific to GSE. GSE correlates with other factors related to motivation, such as subjective evaluation of self worth or self-esteem (Judge, Erez, Bono, & Thoresen, 2002), desire for accomplishment or achievement motivation (Bartels, 2007), and sensitivity to punishment or behavioral inhibition (Fennis, Andreassen, & Lervik-Olsen, 2015). Therefore, I used subjects' scores on questionnaires related to these factors in order to exclude them. Thus I found a significant correlation between gray matter volume in the posterior precuneus and GSE specifically.

3.2. Methods

3.2.1. Participants

Sixty-four healthy participants [mean age = 20.1, SD = 1.4, 29 males] recruited from Tamagawa University (Tokyo, Japan) took part in this study. All participants provided written informed consent and the experimental protocol was approved by the Ethics Committee of Tamagawa University.

3.2.2. Questionnaire

Self-reported GSE was measured using a questionnaire developed by Sherer *et al.* (1982), which was translated into Japanese and its reliability and validity was demonstrated in Japanese subjects (Narita et al., 1995). The GSE scale consists of 23 items, with responses made on a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). In order to find a gray matter region that specifically correlates with GSE score, I used other personality questionnaires that are related to motivation and hypothesized to correlate with the GSE scale as controls. These questionnaires included a self-esteem scale (Hoshino, 1970; Rosenberg, 1965), a behavioral inhibition system and behavioral activation system (BIS/BAS) scale (Carver & White, 1994; Takahashi et al., 2007) and an achievement motivation scale (Jackson, 1974). The internal reliabilities for each questionnaire measured by Cronbach's alpha were: GSE, $\alpha = 0.80$; self-esteem, $\alpha = 0.79$; BIS, $\alpha = 0.79$; BAS, $\alpha = 0.75$; achievement motivation, $\alpha = 0.72$.

3.2.3. Neural data acquisition & analysis

A structural image of the brain was acquired for each subject using a 3-tesla Siemens Trio A Tim MRI scanner (Siemens, Germany) with a 32-channel head coil. T1 weighted images were acquired using the three-dimensional magnetization prepared rapid gradient echo (3D-MPRAGE) sequence [TR = 2000 ms, TE = 1.98 ms, TI = 900 ms, Flip angle = 10 degrees, Echo space = 6.1 ms, FOV = 256 × 256 mm, 192 slices, voxel size = 1 × 1 × 1 mm] which took about 5 minutes. To correct for B1 inhomogeneities, images were reconstructed using pre-scan normalization. Image analysis was performed using Statistical Parametric Mapping software (SPM version 8; http://www.fil.ion.ucl.ac.uk). Preprocessing of the structural images was done by segmenting the brain tissues into six categories (Gray matter, White matter, CSF, Skull, Soft tissue, Air) based on the East Asian brain template. I used diffeomorphic anatomical registration using exponentiated lie algebra (DARTEL) to improve the realignment of small inner structures. Registered images were smoothed with a Gaussian kernel (full width at half maximum = 8 mm) and were transformed to MNI stereotactic space using affine and non-linear spatial normalization.

In order to limit the analysis to voxels that would include gray matter, I created a binary mask to include the voxels with a gray matter probability of over 30% in the gray matter template (grey.nii), and I excluded all of the other voxels from the multiple comparison (Fleming et al., 2010). In the whole-brain multiple regression analysis using a generalized linear model (GLM), I tested for a relationship between GSE score and regional gray matter volume. Age, sex, and total gray matter volume were included in the GLM as covariates of no interest, in order to regress out the effects correlating with these variables. This was also true for other personality scores related to motivation (i.e. self-esteem, BIS/BAS, and achievement motivation). The total gray matter volume was calculated for each participant as the total gray matter within the voxels that were included in the multiple comparison. The threshold was set to family-wise error (FWE)-corrected at a cluster-level of $p < 0.05$ after thresholding at $p < 0.001$ in the whole brain, in order to find a region specifically correlated with GSE, but not with other similar personality concepts.

3.3. Results

The correlation analysis showed a significant correlation between GSE score and other questionnaires as seen in previous studies (Table 3.1). The GSE score positively correlated with the gray matter volume in the right posterior precuneus ($x = 5$, $y = -72$, $z = 50$; $t = 4.85$) (Fig. 3.1). Within the same GLM, other questionnaires showed no significant relation with the

Table 3.1 Correlation between GSE scale and other questionnaires

Self-esteem	BIS	BAS	Achievement motivation
0.332 **	-0.355 **	0.296 *	0.533 ***

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$
GSE = general self-efficacy, BIS = behavioral inhibition system, BAS = behavioral activation system

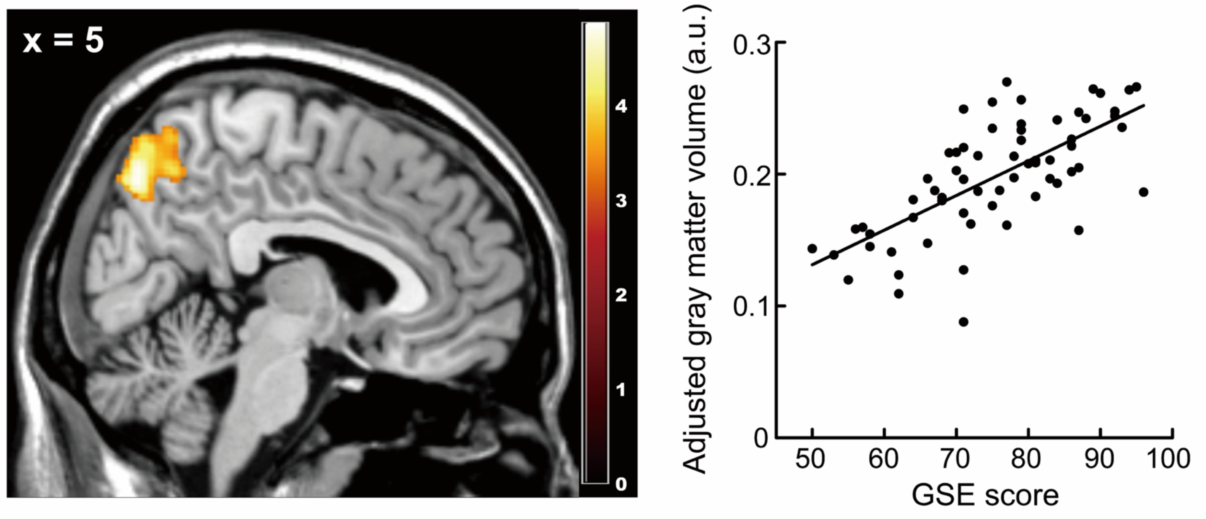

Fig. 3.1. Region where gray matter volume showed significant association with GSE score. Left: Gray matter volume in the right posterior precuneus (x=5, y=-72, z=50; t = 4.85) showed significant positive correlation with GSE scale. Right: A scatter plot of the adjusted gray matter volume taken from the peak voxel, as a function of GSE score. This plot is shown only for illustrative purpose and was not used for any statistical inference.

gray matter volume in any part of the brain (including the precuneus) that would exceed the threshold set for the multiple comparison.

3.4. Discussion

In the present study, I investigated the relationship between regional gray matter volume and individual differences in GSE. I found that the gray matter volume in the posterior precuneus showed a positive correlation with GSE across subjects. No significant relation was found between other questionnaires related to motivation (i.e., achievement motivation, self-esteem, and BIS/BAS) and gray matter volume (which exceeded the threshold for multiple comparison within the whole brain), even though these questionnaires showed significant correlation with GSE score. Thus, the GSE appears to be specifically correlated with the gray matter volume within the posterior precuneus.

Since GSE correlates with the other questionnaires, it is assumed that there is an overlap between these traits. However, since I have identified that the precuneus has a specific relationship with GSE, I discuss below the distinct features of GSE that may relate to the function of the precuneus.

The precuneus, especially its posterior part, has been associated with episodic memory (Cavanna & Trimble, 2006). First, the precuneus shows activity during the retrieval of autobiographical events compared to general memories about the past (Addis, McIntosh, Moscovitch, Crawley, & McAndrews, 2004). Second, it has been shown that when we predict what will happen in the future, a neural network including the precuneus that is needed to recall past experiences is activated (Addis, Wong, & Schacter, 2007). Finally, the gray matter volume in a part of the precuneus correlates with the tendency for an individual to take first-person perspective when recalling autobiographical memories (Freton et al., 2014). Thus, the precuneus seems to accumulate past experiences and create a self-image in relation with the outside world. Since the GSE is not determined by one's experience of a single task, but rather the accumulated experiences that add up to a general expectation that an individual holds before executing a task (Bandura, 1977; Sherer et al., 1982), it seems reasonable that the precuneus is a key region involved in GSE.

Since the degree of self-efficacy one experiences in a task is related to past and present success or failure, it makes sense that the parts of the brain where feedback is processed would show a correlation with GSE score. In fact, Themanson *et al.* found that the amplitude of error-related negativity (ERN), which is generated in the medial prefrontal cortex after an error is made during a task, positively correlates with self-efficacy and post-error performance on that task (Themanson et al., 2011). The present results concerning GSE, however, point to a gray-matter region that stores episodic memories (posterior precuneus), rather than regions that are involved in feedback processing. One possibility is that the degree of self-efficacy one experiences in various tasks is gathered in the precuneus and sums up to determine a person's degree of GSE, which is represented by the gray matter volume in the posterior precuneus. This idea is supported by the fact that the precuneus is functionally and anatomically interconnected with regions including the medial prefrontal cortex (Cavanna & Trimble, 2006; Margulies et al., 2009; Zhang & Li, 2012).

This study is subjected to the limitations of the method of voxel-based morphometry (VBM). Since there is only the information about the volume of gray matter within the voxel, how the gray matter is structured within that voxel cannot be assumed from VBM. Differences in gray matter volume may result from folding within that voxel rather than from actual differences in thickness (Mechelli, Price, Friston, & Ashburner, 2005). The underlying biological structure of the differences between gray matter volume between individuals needs further investigation.

4. Experiment 3: Neural Basis of Changing in General Self-Efficacy

(Deleted due to unpublished data)

5. General Discussion

How we choose actions are affected by our motivation, and the reasons to be motivated varies according to incentives, needs, and cognition that an agent has (Weiner, 1980). Here I have investigated the neural correlates of self-efficacy, a cognitive factor of motivation, and it was shown to relate with plural areas of the brain, which are responsible for different steps in processing information.

5.1. Summary

In experiment 1, I investigated how the updating of self-efficacy will be related to feedback processing in the medial prefrontal cortex (medial PFC). Especially, the amount of activation within the ventromedial prefrontal cortex (vmPFC) showed the valance of the feedback received, and dorsomedial prefrontal cortex (dmPFC) showed a interaction between the difference of self-efficacy and feedback, which correlated with the participants' tolerance to failure, thus showing relation with participants' motivation in continuously committing in pursuing tasks that gives negative feedbacks.

Experiment 2 have shown that individual differences in GSE, which is an accumulation of self-efficacy to numerous tasks we experience everyday, significantly related with the individual differences of gray matter volume in the precuneus, which was present when similar concepts relating to motivation was excluded.

Experiment 3 have studied how the change in GSE will be seen in the change in gray matter volume, especially focusing on the population of subthreshold depression who have went through the intervention of behavioral activation. Since the intervention results in the participants to intentionally process the positive feedbacks, the amygdala, which is related with the processing of stimuli relevant to the motivation of the participant, showed a increase in gray matter volume after the intervention, which also showed significant relation with the individual difference of GSE.

5.2. Implication in understanding the neural correlates of self-efficacy

From the above three studies, the concept of self-efficacy was shown to relate to multiple areas within the brain, especially related in the processing feedbacks given from the environment and its accumulation within the brain so as to determine future behavior.

From experiments 1 and 2, the relation between task specific self-efficacy and GSE can be assumed as the following. By processing feedbacks gained in each tasks, self-efficacy to each task will be updated, and the processed experience will be accumulated to construct the index of GSE. Experiment 1 showed relation between self-efficacy and medial PFC, and experiment 2 showed relation between GSE and precuneus. Since there are functional and anatomical connectivity between these regions (Cavanna & Trimble, 2006; Margulies et al., 2009; Zhang & Li, 2012), it could be assumed that the processing of each given feedbacks within the medial PFC will also activated the precuneus, where it will accumulate the processes of feedbacks to numerous tasks, relating to the individual difference in gray matter volume that relates to GSE.

In experiment 3, intervention of behavioral activation changed the gray matter volume within the amygdala, which showed relation to the individual difference of GSE. Since the individual difference of GSE did not show significant relation with the gray matter volume in the precuneus, the change is GSE will involve other regions than precuneus according to the characteristics of the intervention that caused the change in GSE, for example, the amygdala. It could also be assumed that the change in gray matter volume within amygdala will also affect the feedback processing within the medial PFC, due to its efferent connectivity to medial PFC (Nieuwenhuys et al., 2008).

By using neuroimaging methods, a further understanding could be accomplished by focusing on the processing of information, which could step into discussing how the concepts are represented by the processing of information within our brain.

5.3. Implication in understanding feedback processing and decision making

As our brain can learn about the environment to make prediction and select the appropriate or optimal behavior to increase what we could gain from the environment, it is possible that due to that fact that we *could* choose behavior according to the learned subjective values, there is a space left for our cognition to slip in. Self-efficacy will be one of the cognitive concepts that will affect how we select behavior since we have that cognitive function, and this prediction sometimes overwhelms the effect of explicit rewards (Bandura, 1986).

In the present study, especially in experiment 1, I focused on how given feedbacks will update self-efficacy, although given feedbacks are not only used to update self-efficacy. It is used to update the values of choices and actions that resulted in that feedback (Niv, Daw, & Dayan, 2006; Samejima, Ueda, Doya, & Kimura, 2007; Sutton & Barto, 1998). Given feedbacks are also used to monitor our performance and adjust our behavior to reach our goals (Ullsperger et al., 2014; Ullsperger & Cramon, 2004). Since processing of success and failure will also result in the change of self-efficacy, and this will affect our behavior, updating of self-efficacy will also need to be included within the model of our decision making in order for a further understanding of our behavior.

5.4. Implication in understanding the neural basis of concept of self

The concept of self have been an object of research from the time of William James (James, 1890), with following research from various fields such as philosophy, psychology, psychiatry and neuroscience (Kircher & David, 2003). How the concept of self is represented within the brain has been investigated mainly by comparing the neural activation to self-related and non-self-related stimuli (Legrand & Ruby, 2009). For example, picture of one’s own face (Kircher et al., 2000; Platek, Keenan, Gallup, & Mohamed, 2004), recalling of information about self, and assessing whether certain adjectives will match yourself (Kelley et al., 2002; Ochsner et al., 2005).

On the other hand, the concept of self have been proposed by many researchers (Kircher & David, 2003; Minsky, 1986; 2006; Nowak, Vallacher, Tesser, & Borkowski, 2000), and was also proposed that a method in investigating the neural correlates of processing the concept of self needs a paradigm shift (Legrand & Ruby, 2009). Especially, Legrand (2009) proposed that the concept of self could be characterized by a subjective perspective, defining self from the relation from other objects. Self-efficacy is an evaluation about the self that is relating to that task. By investigating the neural basis of self-efficacy, it may lead to the understanding of self, not limited to the direct representation but the representation of self that is constructed from relation with objects around us.

5.5. Limitation and future research directions

There are still many questions that need to be answered about the neural basis of self-efficacy. The limits of my thesis and future research directions concerning other studies are discussed.

5.3.1. Effects of feedback

In experiment 1, I have used a feedback of success and failure in order to control self-efficacy to the task, although the means of feedback is not limited to them. Instead of giving success and failure feedback trial by trial, it could be given as a total score at the end of the session (Shibata, Yamagishi, Ishii, & Kawato, 2009), or it could be given comparing to the other participant, telling them their rank within the participants (Nicholls, 1984). Feedbacks could also be given ambiguously since the feedbacks experienced in real life are not always easy to identify and what is received as feedbacks varies within individuals (Hackman & Lawler, 1971). The characteristics of the source of information will also effect the degree an person will consider feedbacks given from that source (Greller & Herold, 1975). Effect of different kinds of feedbacks to the change of self-efficacy, and how it will affect the processing of feedbacks within the medial PFC needs to be investigated.

Also, the effect of processing of feedback to other cognitive functions need to be considered. When viewed from learning theories, given feedbacks are signals for adjusting behavior, especially when negative or failure feedback is received (Sutton & Barto, 1998). In our daily life, negative feedbacks could indicate better performance in the future (Carver & Scheier, 1998). Although, when error feedbacks are received, it will also cause other effects. Error feedbacks are aversive to us and induces physiological responses such as startle response (Hajcak & Foti, 2008) and greater skin conductance response (Hajcak, McDonald, & Simons, 2004). How important a participant thinks the current task will change the response to feedbacks. Being told that the task is to measure intelligence, will increase the response to error (Bengtsson, Lau, & Passingham, 2009).Feedbacks of errors results in a raise in self-focus which continues longer within depressed individuals (Greenberg & Pyszczynski, 1986). Attention to self will also result in the decrease of the positive effect of feedbacks to performance (Kluger & DeNisi, 1996). The effects of feedbacks to self-efficacy may need to be considered carefully.

5.3.2. Effects of self-efficacy to performance

The present study focused on the motivational aspect of self-efficacy and did not focus on its relation with performance. Although, self-efficacy has been shown to affect performance and the difference of self-efficacy will predict later performance (Bandura, 1986; Lee, 1982; Phillips & Gully, 1997). In fact, task performance have been known to be affected by factors such as free choice of that task (i.e. self-determination) (Leotti et al., 2010; Murayama et al., 2015; Patall et al., 2008), amount of reward that could be gained by successful execution of a task (Knutson et al., 2000; Minamimoto et al., 2009), and too much reward per trial resulting in the decrease in performance (i.e. choking under pressure) (Baumeister, 1984; Chib, De Martino, Shimojo, & O'Doherty, 2012; Chib, Shimojo, & O'Doherty, 2014; Mobbs et al., 2009). The characteristics of the tasks affect the processing of information about the task and the difference of performance is seen by the difference of conditions. How the sense of self-efficacy, a belief of succeeding in that task will affect performance, and how that will affect the information processing within the brain needs to be investigated.

5.3.3. Effects of other information to determine self-efficacy

In experiment 1, I have focused on the effect of direct experience of success and failure to self-efficacy. Although, self-efficacy is not solely determined by direct experience, but also determined by information such as vicarious experience, social persuasion and emotional arousal (Bandura, 1977). Also, in my study, I could not find a representation of the self-efficacy to the task itself, but this may be due to the fact that I only used the information of direct experience of success and failure for modifying self-efficacy. Since self-efficacy can be changed by other kinds of information, investigating how other information will change self-efficacy and investigating the related regions within the brain to find an overlap to the processing of information may lead to find a representation of the self-efficacy to each tasks.

5.3.4. Relation between gray matter volume and GSE

Experiments 2 and 3 have shown relation with the individual difference of gray matter volume and GSE. Since gray matter volume in precuneus and amygdala have been shown to relate to GSE, with amygdala especially relating to the intervention of behavioral activation, it is possible that GSE is not anatomically represented within one region, but according to how the change in GSE was induced, the effect will be seen in different regions. Although the relation could be explained by the functions of precuneus and amygdala, how the processing of feedbacks in our daily life will cause a change in gray mater volume needs investigation. The change in gray matter volume could be induced by changes such as sprouting of axons, synaptogenesis and neurogenesis (Zatorre et al., 2012). Also, within the amygdala, individual difference of gray matter volume has been reported to relate to difference in BOLD signals and difference in emotional arousal (Fastenrath et al., 2014). How the difference of gray matter volume will result in the difference of function in precuneus or amygdala and how it will affect GSE score still needs to be investigation.

5.3.5. Relation between task specific and general self-efficacy

Within the three studies, the relation between task-specific and general self-efficacy could not be investigated. Although, these two concepts are known to affect each other, GSE has been known to affect task specific self-efficacy especially in a situation where an agent is about to engage in new tasks, and the accumulation of task-specific self-efficacy will result in the general expectation of self-efficacy in numerous tasks (Sherer et al., 1982). Continuous observation of the processing of feedbacks and its effects to gray matter volume may lead to the understanding of the relation between task-specific and general self-efficacy.

6. Acknowledgements

First and foremost, I express my deep gratitude to my PhD advisor, Dr. Toshikazu Hasegawa, who has taught me from my undergraduate education, how science is done. I cannot show enough gratitude for his kind permission to do my dissertation work at Tamagawa University.

I would also like to acknowledge the other members of my PhD Committee – Dr. Yoshihiko Tanno, Dr. Yuko Yotsumoto, Dr. Isamu Motoyoshi and Dr. Dai Yanagihara for their time, patience, and thoughtful advice for my doctoral studies.

I owe my deep gratefulness to Dr. Kenji Matsumoto, who guided me through the world of neuroscience. I also thank acknowledge Dr. Yasumasa Okamoto for letting me in their project and analyze the data otherwise impossible within my field of research.

I greatly acknowledge the advices that were given during the seminars held in the department of cognitive and behavioral science. I especially show my gratitude to Dr. Kazuo Okanoya, Dr. Takuma Ishigaki, and also to Dr. Ikuya Murakami and Dr. Atsuko Saito, the former member of the department.

I will show my gratitude to the former and present lab members at Hasegawa lab, Matsumoto lab and Okamoto lab, especially to the co-authors of my study, Dr. Kou Murayama, Dr. Keise Izuma, Dr. Madoka Matsumoto, Dr. Yukihito Yomogida, Dr. Ryuta Aoki, Dr. Kazuki Iijima, and Dr. Tomoki Haji. Learning about their research and having discussion with all of them have given me insights for my research. I would also like to thank Nanae Fujiwara and Yuka Ueno, who have supported me to execute my research.

Last but not least, I express my sincere gratitude to my parents, Norio and Satomi Sugiura, who have always supported me with their warm encouragements.

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