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Being Another Person To Be Future-minded: Common Neural Substrates of Perspective-taking, Prospective Memory, and Intertemporal Decision*

Hye-young Kim **Yeonsoon Shin** **Sanghoon Han**†

Department of Psychology, Yonsei University

Intertemporal choices are decisions between alternatives with outcomes that occur at different time points. An example would be smaller-but-sooner versus larger-but-later rewards. Recent evidence suggests an effect of future prospection on intertemporal choices. A number of neuroimaging studies have demonstrated the functional overlapping of perspective-taking and prospection. In the present study, a shared neural network involved in perspective-taking and future thinking was identified. Specifically, the lateral prefrontal cortex (LPFC), temporal pole, and parahippocampal regions were found to be those that reflect the interindividual variability in the delayed discounting rate (the *k* value). The perspective-taking capability was also significantly associated with the effectiveness of future thinking on regulating the discounting rate in the subsequent intertemporal choices. The emotional regulatory effect on intertemporal choice was also examined.

Key words : perspective-taking, prospective memory, intertemporal decision making, fMRI

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† Corresponding author: Sanghoon Han, PhD, (120-749) Department of Psychology, Yonsei University, Seoul, Korea
E-mail : sanghoon.han@yonsei.ac.kr

Almost all choices we encounter in our lives involve a tradeoff between costs and benefits at different points of time. That is, people normally assign different values to benefits that may arise now compared to those in the future, even when the magnitudes of the benefits are constrained to the same level. This phenomenon is well known as temporal discounting (Mischel, 1974; Liabson, 1997), which indicates that the subjective benefits or values of outcomes are continually discounted as time passes. From everyday decisions such as those related to spending and diet to life-changing decisions such as marriage and education, the imtertemporal trade-off is ubiquitous. Research on intertemporal decision-making has been an important topic in various fields, including economics, politics, and psychology (Berns, Laibson, & Loewenstein, 2007; Dasgupta, 2006; Foxall, 2010; Kable & Glimcher, 2007; Read, Frederick, Orsel, & Rahman, 2005; Van den Bergh, Dewitte, & Warlop, 2008). Interestingly, although the value being discounted as a function of the temporal distance is common, the degree of temporal discounting is indeed different from individual to individual. Thus, the various determining factors that affect an individual 's discounting rate have become of primary interest to researchers (Peters & Büchel, 2010; Read, Frederick, Orsel, & Rahman, 2005; Weber et al., 2007; Wittmann & Paulus, 2008).

Recent research has focused on prospective memory and how envisioning future episodes is related to reward-based decision-making factors such as delay discounting (Benoit, Gilbert, & Burgess, 2011; Boyer, 2008; Johnson et al., 2007 Kassam et al., 2008; Klineberg, 1968; Peters & Büchel, 2010). Specifically, thinking about a future event prior to making an intertemporal decision can reduce the incidence of a short-sighted choice (i.e., becoming more patient to wait for a larger future reward) (Benoit et al., 2011; Peters & Büchel, 2010). For example, during an intertemporal decision-making task, Peters and Büchel asked participants to make repeated choices between an immediate smaller reward (fixed, not presented on the screen) or a delayed larger reward (presented on the screen). In this experiment, the delay-discounting rate showed a significant difference between the *Episodic* condition, in which a subject-specific episodic tag was presented in conjunction with a combination of the reward amount and the waiting time, and the *Control* condition, in which only a delayed reward and a waiting time were presented without a personal episodic tag (Peters & Büchel, 2010). This finding is consistent with an earlier correlational study that investigated the relationship between prospective ability and intertemporal decisions, whose findings revealed that the individual delay-discounting rate is negatively correlated with a general ability to envision the future, measured by independent tasks and interviews (Klineberg, 1968). In the study, participants who were satisfied more with larger delayed rewards than they were with smaller immediate rewards showed greater everyday preoccupation with the future than with present events. Delaying subjects were also more coherent in their ordering of future events, representing a more organized future in a logical and predictable manner. Various functional neuroimaging studies investigating the relationship between future envisioning and time discounting suggest that a prospection network (hippocampus, mOFC, vmPFC, PCC) performs the role of mental representation for decision outcomes to support future-minded choices (Johnson et al., 2007; Peters & Buchel, 2011; Peters & Büchel, 2010; Schacter, Addis, & Buckner, 2007)

Along similar lines, researchers have suggested that delay discounting occurs due to the conflict between temporally different multiple selves (Ersner-Hershfield, Wimmer, & Knutson, 2009; Jamison & Wegener, 2010; Parfit, 1971; Pronin & Ross, 2006; Pronin, Olivola, & Kennedy, 2008). If one conceives his/her future self as a different being, not as oneself in a temporal continuum, delaying a possible immediate reward is unreasonable. Thus, the psychological connectedness to future selves, known as the "future-self continuity" hypothesis, may be an important factor in determining one's intertemporal decision-making pattern (Bartels & Rips, 2010; Ersner-Hershfield et al., 2009). Specifically, a previous neuroimaging study revealed that individuals perceive their current and future selves differently at the neural level, increasing the preference for immediate rewards for their current selves compared to future rewards for their future selves (Ersner-Hershfield et al., 2009). Beyond the different types of processing between current selves and future selves engaged in delayed reward gratification, Pronin et al. (2008) showed that people make rather more similar decisions for their future selves and others but different decisions for their future selves and present selves. Among the four experiments in their study, experiment 4 involved an intertemporal decision-making task which was to decide whether to defer a lottery prize for a delayed larger amount. Participants were far more likely to choose to delay the reward when they viewed the situation from the perspective of their future selves or another person, whereas they preferred the immediate reward in the present-self condition (Pronin et al., 2008).

The findings above build upon the contention of shared underlying mechanisms between episodic prospection and the construction of perspective representation. Indeed, recent neuroimaging studies have noted that a common brain network is involved in various cognitive processes, including autobiographical memory, future prospection, and perspective-taking (Buckner & Carroll, 2007; Hassabis et al., 2009; Schacter et al., 2007; Spreng & Grady, 2010; Spreng, Mar, & Kim, 2009). Especially according to the meta-analysis of Spreng et al. (2009), the functional overlap of prospection (which corresponds to "taking the future-self' perspective") and the theory-of-mind (which corresponds to "taking others' perspectives") was demonstrated in the hippocampus, medial parietal regions, the temporo-parietal junction, and in the lateral prefrontal cortex.

One possible prediction based on this concept and on previous findings that have documented similar behavioral and neural activity patterns (Pronin et al., 2008; Spreng et al., 2009) would be that one's perspective simulation of others' mental states prior to self-projection into the future would enable one to enhance the envisioning of the future-self perhaps by easing the process of mentally recruiting and experiencing future events. Specifically, if the future-self continuity account is valid, actively forming another's mental state would further induce the distinct separation of the present self versus others while increasing the continuity between the future self and others (Pronin et al., 2008), which could then induce the delayed reward choice from the perspective of one's future self. In the current study, our primary research interest is to investigate whether perspective-taking can affect the decision-making pattern in the case of an intertemporal choice by modulating the future prospection effect on delayed economic choices (i.e., Peters & Büchel, 2010). For completeness and to investigate the effect of perspective-taking only on intertemporal decisions directly, we also included trials that do not require prospection during delayed discounting tasks (See the Methods section below for details).

While considering the influence of perspective-taking and episodic prospection on temporal discounting, our secondary objective was a determination of emotional perspective- taking, which has a potential regulatory effect on intertemporal decisions. Indeed, recent evidence suggests that emotional perspective- taking (sharing and understanding the emotional states of others) and cognitive perspective-taking (inferring others' mental states, such as their intentions and thoughts) engage discrete as well as common neural substrates. Neural networks revealed from a comparison of emotional versus cognitive perspective-taking include the inferior frontal gyrus and lateral prefrontal cortex, regions identified as those influencing the exertion of self-control (Figner et al., 2010; Hynes et al., 2006; McGuire & Botvinick, 2010;

Sakagami & Pan, 2007). These consistent results support the existing theoretical definition of emotional empathy, which posits the emotional regulatory mechanism as a primary component of it, separating self-feelings from other-feelings (Davis, 1983; Eisenberg, 2000; Jackson & Decety, 2004; Batson, Early, & Salvarani, 1997). To sum up, brain regions recruited for emotional perspective- taking have also been identified as key regions for self-control. This may be due to the regulatory mechanisms for self-other separation required to take the perspective of another person.

Furthermore, emotion is crucial for future prospection as well as episodic recall (Boyer, 2008; Damasio et al., 2000; Sharot, Delgado, & Phelps, 2004). Neuroimaging studies have shown that the recollection of a past event brings heightened activity not just in the parahippocampus but also in the amygdala, a region involved in more visceral emotional states (Sharot et al., 2004). Provided that imagining the future and remembering the past depend on the common neural machinery (Schacter et al., 2007, Spreng, Mar, & Kim, 2009), episodic future prospection would also trigger emotional circuitry, leading to the experience of immediate emotional rewards in a delay discounting task, thus effectively offsetting the effects of delay discounting (Benoit, Gilbert, & Burgess, 2011; Boyer, 2008; Peters & B üchel, 2010). Considering that subjective reward perception and attenuating one’s impulsivity are the key components of intertemporal choice, intertemporal decision-making could be a more emotional process rather than a cognitive process such as simple value computation. Based on the available evidence on the different neural involvement for emotional and cognitive perspective-taking, we divided perspective-taking tasks into two types (Emotional and Cognitive) and focused on the effect that the training of perspective-taking of others’ emotional states can have on subsequent intertemporal choices (Hynes, Baird, & Grafton, 2006).

In summary, the current experiment was aimed to investigate the role of perspective -taking in intertemporal choices. Specifically, we separated emotional and cognitive perspective -taking, and expected that emotional perspective -taking would impose superior influence on diminishing one's temporal discounting rate.

Materials & Method

Subjects Eleven healthy subjects were included in the study. Participants were 7 females and 4 males with a mean age of 23.6 years (ranging from 20 to 26 years). Informed written consent was obtained from the subjects after they were screened for magnetic resonance imaging risk factors. Participants were paid $20 per hour for their participation.

Experimental Procedure & Design Prior to scanning, each participant wrote down his/her future plans at 6 delay time points, which were to be used as personal future cues in the future-thinking conditions of the delay-discounting tasks. Only if it could be envisioned in detail was the valence of each future cue not controlled. The participants were instructed to fill in the blanks with regard to what, where and with whom when describing their future cues. After submitting their future cues, verbal instructions for the experimental tasks were given. The participants were also told that one of their choices during the scanning sessions would be randomly selected and enacted with the stated delay. After the verbal explanation, practice sessions were performed until the participants felt comfortable with the task and time limit.

All participants completed six sessions consisting of two tasks. These were two perspective-taking tasks and four delay-discounting tasks (see below for more details). A perspective-taking (PT) task (Emotional or Cognitive) was always conducted before a set of delay-discounting (DD) tasks (with and without the future-thinking cue condition), constructed in the order of PT1-DD1-DD2-PT2-DD1-DD2. Therefore, the participants were to make intertemporal choices under the following four conditions: DD with future cues after emotional PT (EF), DD without future cues after emotional PT (ENF), DD with future cues after cognitive PT (CF), and DD without future cues after cognitive PT (CNF) (See Figure 1). The order of the perspective-taking tasks was counterbalanced across participants. An instruction screen preceded each run to inform the participants of the task and condition that were about to begin.

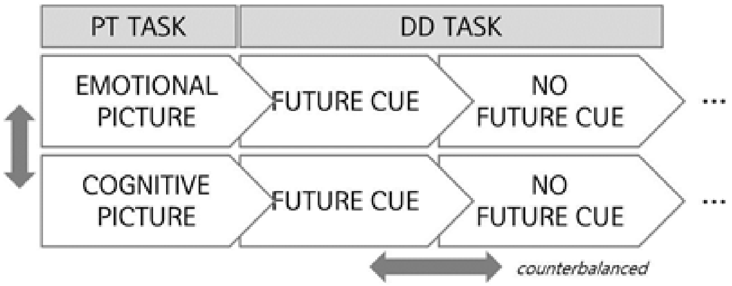

Figure 1. Behavioral Task During fMRI, participants performed six sessions, each consisting of two tasks; perspective-taking task and delay discounting task. A perspective-taking (PT) task was conducted before two delay discounting (DD) tasks (with future-cues and without future-cues). The order of PT and DD task was counterbalanced between subjects.

After the scanning process, outside the scanner the subjects completed questionnaires assessing their empathy abilities (Interpersonal Reactivity Index (IRI); Davis, 1983). The subjects also rated the easiness and vividness while imagining the event associated with each future cue during the scanning process (easiness: 1 - very difficult, 6 - very easy; vividness: 1 - not vivid at all, 6 - highly vivid).

For each perspective-taking task, 15 pictures with unpleasant emotional scenes and 15 other pictures with unpleasant moral scenes were used for the Emotional PT and Cognitive PT trials, respectively. The emotional pictures depicted persons or groups of people expressing negative emotional states (e.g., a person engaged in an argument; people crying at an accident scene), whereas the cognitive pictures depicted social scenes such as violations of moral codes (e.g., an abusive situation; a person threatening other people with a gun). The pictures used for the emotional PT tasks were mostly selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1995), except for two pictures obtained from popular media sources. The cognitive pictures were a subset of the moral pictures used in the study of Harenski, Antonenko, Shane & Kiehl (2008). The participants were instructed to answer two questions, both of which required them to focus on two different domains (emotional perspective-taking and cognitive reasoning) for each picture. (Emotional question: 'How would the person in the picture feel in this situation' Cognitive question: 'How appropriate would the person in the picture think his/her action in this situation is?') They were also told to take the perspective of the main subject in the picture instead of imagining themselves or the object of the situation. The participants rated each picture in line with the instructions on a three-point scale (Emotional scale: 1 = negative 2 = normal 3 = positive, Cognitive scale: 1 = inappropriate 2 = normal 3 = appropriate) with an option to choose "*irrelevant*" if they thought that the given picture was not related to the emotional state or the appropriateness of the action depicted in the picture (Figure 2, Panel A).

Each participant completed 4 delay-discounting runs, each of which consisted of 48 trials, and each trial had a CUE period and a DECISION period. A CUE period was always followed by a DECISION period. Under the *Future-Cue* conditions, one of the personal episodic future cues (e.g., watching a movie with friends downtown) reported by each participant before the MRI scanning process was displayed to remind them of the specific future events that they had planned on the respective day of reward delivery (Figure 2, Panel B). Meaningless character strings (i.e. '########'), instead of future cues, were presented under the

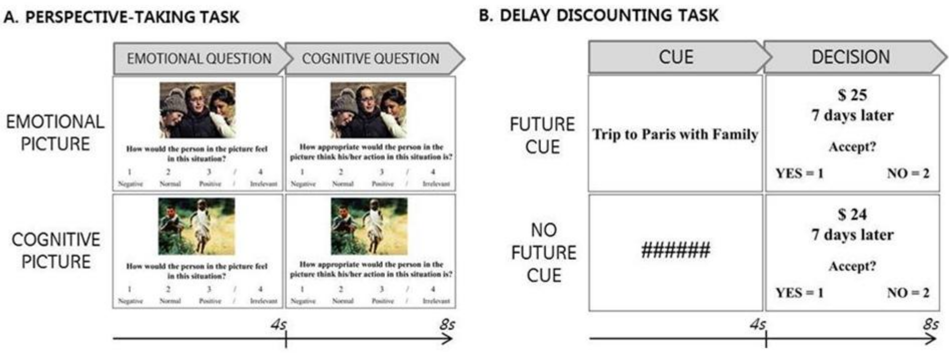

Figure 2. Perspective-taking Task and Delay discounting Task Overview

(A) Perspective-taking task had two conditions; Emotional PT and Cognitive PT, with unpleasant emotional pictures and cognitive pictures respectively. For each picture, two questions were to be answered (Emotional question and Cognitive question). Participants rated the pictures using 3-point scale with an option to choose “irrelevant”. (B) Each trial of the delay discounting task was comprised of CUE period and DECISION period. During CUE period, participants was instructed to remind the personal future events that they had reported before scanning when the future-cues are presented on the screen (Future-cue condition). During DECISION period, participants made repeated choices between given fixed reward and larger future reward option.

No-Future-Cue condition. During the decision period, only a delayed reward option was presented on the screen. During each trial, participants choose between a small immediate reward (e.g.,$20 today, not presented on the screen) and a large future reward (e.g., $48 after 180 days, presented on the screen). 48 different reward options were created with a combination of 6 different delays (1, 7, 30, 90, 180, 365 days) and 8 different reward amounts (ascending from $24 to $52 in a stepwise manner in $4 increments in the No-Future-Cue conditions. The magnitude of each reward was altered randomly by $1 either positively or negatively or remained the same in the Future-Cue conditions.).

On the basis of these repeated choices, the discounting rate (k) of each participant was calculated (Kable & Glimcher, 2007). The specific procedure to determine a typical value reflecting the discounting propensity of each participant followed the method used in Peters and B üchel (2009).

First, the indifference value for each delay was obtained by averaging the amount of two delayed options including the preference reversal point, that is, averaging the lowest delayed reward amount that a subject accepted and the next smallest amount. The indifference value indicates the amount at which a subject feels indifference between the immediate smaller option and the delayed larger option. By dividing the fixed immediate reward amount by the indifference value, the subjective value of the given fixed reward at each delayed time point was calculated. Then, a subject's condition-specific discounting rate (*k* parameter) was obtained by fitting this data into the equation below using the curve-fitting toolbox in MATLAB (The MathWorks, Natick, MA)

$$SV = \frac{1}{1+kD} \text{ -------------- Equation 1.}$$

Here, SV is the subjective value and D is delay in days (Laibson, 1997; Mazur, 1987). In this hyperbolic function, smaller *k* values indicate more patient behavior, i.e., accepting a longer delay for a larger reward compared to the immediate smaller reward option.

fMRI Data Acquisition Functional magnetic resonance imaging (fMRI) data was acquired using an ISOL 3.0 Tesla forte MRI scanner (ISOL Tech, Oxford OR63). After the acquisition of T1-weighted anatomical images, T2*-weighted EPI images were obtained (TR = 2000ms, TE = 31ms, 25 axial slices, no gap, interleaved collection). Before the functional data collection, five dummy volumes were discarded to allow for equilibration effects.

fMRI Data Analysis Data were processed using SPM8 (Wellcome Department of Cognitive Neurology, London). The slice acquisition timing was corrected by resampling all slices in time relative to the middle slice. This was followed by rigid body motion correction across all scans. Functional data were spatially normalized to a canonical echo-planar imaging (EPI) template using a 12-parameter affine and nonlinear cosine transformation, with volumes then resampled into 2 mm cubes and spatially smoothed with an 8-mm full-width-at-half-maximum isotropic Gaussian kernel. Each scanning session was rescaled such that the mean global signal was 100 across the volumes. For the analyses, the volumes were treated as a temporally correlated time series and modeled by convolving a canonical hemodynamic response function (HRF) and its temporal derivative with a delta function marking the onset of each trial. The resulting hemodynamic functions were used as covariates in a general linear model along with a basis set of cosine functions that were used to high-pass filter the data and a covariate representing session effects. Least-squares parameter estimates of the best-fitting synthetic HRF for each condition of interest (averaged across scans) were used in pair-wise contrasts and stored as a separate image for each subject. These different images were then tested against the null hypothesis of no difference between contrast conditions using one-tailed t tests. The data were statistically analyzed treating subjects as a random effect. Eleven subjects were recruited for this study and additional participant recruitment was not feasible because accessibility to the fMRI scanner was unavailable midway through the present study. For this reason, we used a slightly less stringent threshold, and unless stated otherwise, effects were considered significant if they exceeded an uncorrected threshold of $p < .005$ and consisted of five or more contiguous voxels. Application of these thresholds with eleven participants is reasonable, especially in emotion imaging literature (Bischoff-Grethe, Goedert, Willingham, & Grafton, 2004; Cloutier, Heatherton, Whalen, & Kelley, 2008; Phan et al., 2005; Phan et al., 2003; Rekkas & Constable, 2005) and were intended to strike a balance between type I and II error rates.

Three different general linear models (GLM) were created at the first level for perspective-taking, future-thinking and delay-discounting tasks, respectively. In the first model, brain responses were modeled to the onset of the question presentation in order to compare the brain activities during emotional and cognitive perspective-taking. The second and third models were designed to distinguish neural activities for future thinking and making decisions between two intertemporal alternatives using two factors: which perspective-taking task preceded (PT condition) and whether or not a personal future cue was presented (FT condition). Therefore, preprocessed images were modeled to four different conditions: a delay-discounting run with a future cue after emotional PT (EF), a run without a future cue after emotional PT (ENF), a run with a future cue after cognitive PT (CF), and a run without a future cue after cognitive PT (CNF). Additionally, two simple regression analyses were performed using the discounting rate *k* and the individual perspective-taking ability score, which is a subscore of the IRI (Davis, 1983) as a regressor at the second level. The first simple regression analysis was conducted to explore regions that reflect individual differences in intertemporal choice behavior, and second was done to identify regions where the correlational relationship between the general perspective-taking capability and the BOLD signal is expressed.

Results

Behavioral Results To examine the overall impact of emotional perspective-taking and cognitive perspective-taking on the intertemporal decision-making, a t-test was performed on the discounting rate *k*, representing an individual’s choice propensity (Equation 1), between the two overall PT conditions (Emotional vs. Cognitive) regardless of the future-thinking conditions. The discounting rate, the *k* parameter, significantly differed between the Emotional PT condition

Table 1. Differences in Discounting Rates Between Conditions

k parameter	F (FUTURE-CUE)		NF (NO FUTURE-CUE)	
	C (COG)	E (EMO)	C (COG)	E (EMO)
	.017* (.014)	.012* (.009)	.017 (.013)	.015 (.013)

* CF and EF comparison is significant at p < .05.
Values in parentheses indicate standard deviations.

(mean $k = 0.013$) and the Cognitive PT condition (mean $k = 0.017$) ($t(10) = -2.92$, $p < .05$), indicating a predominant regulatory effect of emotional perspective-taking on subsequent intertemporal choices. More importantly, this perspective-taking effect was statistically significant only when subjects were forced to imagine future episodes associated with their personal future cues presented on the screen ($t(10) = -2.28$, $p < .05$). There was no difference between these two conditions without future cues ($p = .55$) (Table 1).

These findings suggest that emotional perspective-taking (compared to cognitive perspective-taking) impose a greater effect on intertemporal choices, thus resulting in more patient behavior *when asked to envision personal future episodes*. It can be argued that Cognitive PT condition also could arouse emotion as well as Emotional PT condition due to the moral violation factors in pictures used in Cognitive PT. However, the proportion of reporting *irrelevant* to the Emotional question was significantly larger than the Cognitive question during Cognitive PT ($t(10) = -1.94$, $p < .05$). This shows that participants were relatively more oriented towards cognitive reasoning rather than emotional empathic process during Cognitive PT.

A correlational analysis was also conducted to investigate a possible general personality modulation effect on the intertemporal preferences. This revealed a significant positive correlational relationship between the perspective-taking capability, which is measured by a subscore of the IRI (Davis, 1983), and the k

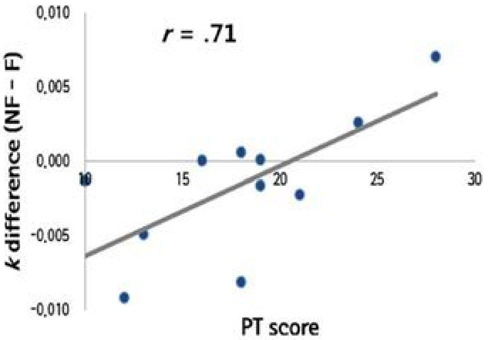

Figure 3. Correlation Between Individual Perspective-taking Capability Scores and Discounting Rate Differences of (NF - F)

value difference between the *No Future Cue* and the *Future-Cue* condition (r = .71, p < .05) (See Figure 3). This implies that a person with greater perspective-taking capability is more likely to be affected by future thinking, resulting in more patient intertemporal choices under the *Future-Cue* condition.

fMRI Results

Whole-Brain Amplitude Analysis. We first analyzed differences in the amplitudes of the BOLD responses between several contrast conditions of our main concern.

To identify the specific brain regions especially involving in processing others'emotional states, a contrast analysis between emotional perspective-taking questions versus cognitive perspective-taking questions was conducted. The Emotional Question > Cognitive Question comparison revealed greater activity in the dorsomedial prefrontal cortex (dmPFC; x, y, z = 8, -25, 53; -10, 53, 16), temporal parietal junction (TPJ; x, y, z = -57, -49, 21; 55, -54, 13), medial prefrontal cortex (MPFC; x, y, z = -10, 53, 16), parahippocampal (x, y, z = -28, -22, -6; 26, -35, -7), temporal pole (x, y, z = -36, 13, -17; -53, 13, -17), and lateral prefrontal cortex (LPFC; x, y, z = -50, 29, -8). The contrast analysis of the Emotional Picture versus the Cognitive Picture revealed activations in the temporal pole (x, y, z = 30, 10, -24), insula (x,y, z = 36, 9, -11), precuneus (x, y, z = 14, -74, 39), medial prefrontal cortex (x, y, z = -2, 56, -15), and orbitofrontal cortex (OFC; x, y, z = 8, 53, -21; -12, 51, -19), representing perspective-taking processing from emotional scenes. We next performed a contrast assessment between Future Thinking (with a future cue) and Control (no future cue) to find the effect of prospective memory. Significant activations were seen in the parahippocampal (x, y, z = -18, -7, -28), LPFC (x, y, z = -34, 56, -6; -46,45, -2)), STS (x, y, z = -61, -2, 0; 63, -2, 3)), caudate (x, y, z = 6, 10, 0), and insula (x, y, z = -46, -2, 2).

Finally, during the decision period of the delay-discounting task with future cues, significant activity was observed in several regions, including the parahippocampal (x, y, z = -18, 7, -17) and temporal pole (x, y, z = -53, 9, -16), ACC (x, y, z = -10, 36, 13). Compared to those after cognitive perspective-taking, the BOLD responses to the intertemporal choices with a future cue after emotional perspective-taking, a contrast which showed a significant difference in the k discounting rates, yielded greater activation in the left hippocampus (x, y, z = -34, -12, -13;), LPFC (x, y, z = -32, 27, 10), and temporal pole (x, y, z = -53, 7, -5). Talairach Daemon coordinates of these and all other activations reported in this paper are presented in Table 2.

Table 2. Regions Demonstrating Greater Activation During Each Condition Contrast

Regions	Lat	BA	Talairach Coordinates			z-score
			x	y	z	
Emotional Question > Cognitive Question						
Middle Frontal Gyrus	L	6	-26	4	50	3.70
	L	11	-26	40	-20	3.35
Medial Frontal Gyrus	R	6	8	-25	53	2.55
	L	9/10	-10	53	16	3.09
Inferior Frontal Gyrus (LPFC)	L	47	-50	29	-8	3.35
	L	44/45	-42	20	14	3.75
Insula	L	47	-26	13	-14	4.57
Amygdala	L	34	-20	1	-10	2.87
Putamen	L		-24	7	-7	3.43
	L		-30	-10	-3	3.03
Parahippocampal Gyrus / Hippocampus	R	26/37	26	-35	-7	3.38
	L		-28	-22	-6	3.36
Superior Temporal Gyrus	L		-36	13	-17	3.85
	L	38	-53	13	-17	4.40
Middle Temporal Gyrus	L	21	-59	5	-15	4.04
	L	21/22	-57	-2	-8	3.79
Superior Temporal Gyrus	L	40	-57	-49	21	3.49
	R	22/39	55	-54	13	3.32
Inferior Temporal Gyrus	R	20/37	53	-51	-11	3.29
Postcentral Gyrus	R	3/43	61	-11	19	3.30
Paracentral Lobule	R	4/6	18	-32	55	3.59
Cuneus	L	18	-12	-76	27	2.85
Emotional Picture > Cognitive Picture						
Superior Frontal Gyrus	L	11	-12	51	-19	3.85
	R		20	54	-14	3.16
	R		20	-9	63	3.15
Orbital Gyrus	R	11	8	53	-21	3.81
	L	11	-12	45	-24	3.55
Medial Frontal Gyrus	L	11	-2	56	-15	4.08
Precentral Gyrus	R	6	16	-16	61	3.99
Insula	R	13	36	9	-11	3.35
Superior Temporal Gyrus	R	38	30	10	-24	4.12
	R		46	5	-10	2.99
Middle Temporal Gyrus	R	39	48	-71	24	4.65
Precuneus	R	7/19	14	-74	39	4.87
Cuneus		19	26	-76	31	4.85

Table 2. Regions Demonstrating Greater Activation During Each Condition Contrast (Continued)

Regions	Lat	BA	Talairach Coordinates			z-score
			x	y	z	
F > NF during CUE Period						
Superior Frontal Gyrus	L	8/9	-20	37	35	
Middle Frontal Gyrus	L	10	-34	56	-6	3.14
	L	10/46	-46	45	-2	3.43
Inferior Frontal Gyrus	L	45/47	-40	25	-1	2.88
Medial Frontal Gyrus	L	9	-8	41	33	3.43
	R	6/8	6	31	35	3.23
Precentral Gyrus	L	4/6	-55	-8	44	3.84
	L	44	-59	8	1	3.50
Anterior Cingulate	L		-12	29	-5	2.71
Cingulate Gyrus	L	32	-4	25	37	3.35
	R		8	18	39	3.02
Caudate	R		6	10	0	3.10
Insula	L	13	-46	-2	2	3.25
Parahippocampal Gyrus	L	35	-18	-7	-28	2.91
	R	36	38	-23	-24	3.30
Superior Temporal Gyrus	L	22	-61	-2	0	3.40
	L		-67	-40	7	3.62
	R		63	-2	3	2.88
F > NF during DECISION Period						
Superior Frontal Gyrus	R	9	14	58	31	2.96
Superior/Middle Frontal Gyrus	L	9/10	-24	45	13	2.90
Inferior Frontal Gyrus	L	45/46	-50	30	15	3.10
	L	46	-51	47	8	2.87
Precentral Gyrus	L	6/9	-46	-1	22	3.57
Anterior Cingulate	L	24/32	-10	36	13	3.07
Caudate	L		-16	9	20	2.72
Parahippocampal Gyrus	L	34	-18	7	-17	3.12
Superior Temporal Gyrus	L	21/38	-53	9	-16	3.08
Middle Temporal Gyrus	L	21	-61	-6	-13	3.30
Cuneus	L	17/18	-20	-89	9	3.68
EF > CF during DECISION Period						
Middlel/Inferior Frontal Gyrus	L	11/47	-32	27	-10	2.69
Medial Frontal Gyrus		25	0	11	-16	3.07
Parahippocampal Gyrus	L	19	-30	-53	-7	2.90
	L	35	-20	-7	-28	2.96
Hippocampus	L		-34	-12	-13	2.63
Superior Temporal Gyrus	L	22/38	-53	7	-5	2.70
Inferior Parietal Lobule	L	40	-51	-46	46	2.99

Lat. = laterality

BA = approximateBrodmann’s locations

Conjunction Analysis of Perspective-taking, Future thinking, and Delay discounting. Based on the above results of the whole-brain amplitude analysis, we found that several regions, including the LPFC, temporal pole, and parahippocampal, show somewhat common activation for the three different cognitive processing activities of the current study: perspective-taking, future thinking, and delay discounting. In addition, the current behavioral results also imply the possibility of functional connection between the three, showing a conditional effect of emotional PT on decreasing the delay-discounting rate only when there are future cues. Furthermore, substantial evidence to date demonstrates that autobiographical memory, future prospection and the theory of mind share common neural substrates (Addis et al., 2007; Buckner & Carroll, 2007; Hassabis et al., 2007; Schacter et al., 2007; Spreng et al., 2009; 2010). Therefore, we investigated the common neural substrates hired for perspective-taking and future thinking in the present study, as this is potentially also conjunct with the neural mechanisms of delay discounting. To do this, we initially instigated a formal conjunction between the above contrasts, perspective-taking (PT; Emotional versus Cognitive question) *and* future thinking (FT; Future-Cue versus No-Future-Cue condition). Consistent with previous studies, the posterior STS (x, y, z = -51, -19, 4), temporal pole (x, y, z = -59, 8, 1), caudate (x, y, z = -10, 8, 0), and insula (x, y, z = -40, 4, 1), which were commonly found as regions reflecting the shared network for theory of mind and prospection, were observed (Hassabis et al., 2007; Schacter et al., 2007; Spreng et al., 2009; 2010).

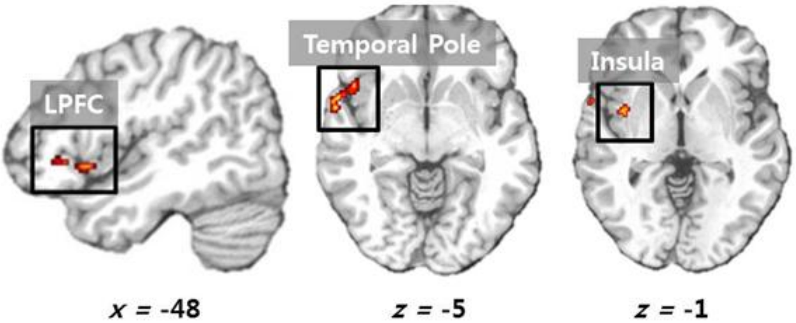

Figure 4. A Shared Neural Substrates for Perspective-taking, Future thinking, and Intertemporal choice

A triple-conjunction of emotional perspective-taking (compared to cognitive reasoning), future thinking, and delay discounting revealed a common activation in the left LPFC (left), left temporal pole (middle), and left insula (right). Each with uncorrected p-value threshold of .05, no extent voxels for each contrast; .05*.05*.05 = .000125.

Next, additional conjunction was originated for a more in-depth exploration of the shared neural circuit, including the delay-discounting (DD) choice (PT X FT X DD). Because the aim of the conjunction was to investigate whether the common neural substrates for perspective-taking and future thinking also influence intertemporal decision-making, a contrast map of EF versus CF, the condition that showed a significant *k* value difference, was used for the triple conjunction ($p < .05$, no extent voxels for each contrast; .05*.05*.05 = .000125). From this conjunction, activation was restricted to the lateral PFC (x, y, z = -49, 32, -4), temporal pole (x, y, z = -57, 9, -5), and insula (x, y, z = -39, 2, -1) (See Figure 4).

Simple Regression Analyses-Neural Correlates Reflecting the Individual Differences in the Discounting Rate. To identify the specific regions reflecting the individual differences in the discounting rate *k*, we performed a simple regression analysis on the basic amplitude contrast with the difference of the *k* value in each condition (F versus NF, EF versus CF). Because the *k* value represents the individual condition-specific discounting rate, the difference between the *k* values of two conditions demotes the superior behavioral effect of one condition compared to the other. The greater the difference in the *k* parameters between the two contrast conditions, the greater the activation that was observed in several regions traditionally associated with episodic memory and perspective-taking during both the Cue and Decision period (Addis & Schacter, 2008; Cavanna & Trimble, 2006). Specifically, during the prospection Cue period, significantly greater activation at the parahippocampal (x, y, z = 20, 1, -29), and temporal pole (61, 8, 1) in the F vs. NF contrast and at the hippocampus (x, y, z = 36, -26, -7), medial OFC (x, y, z = -10, 48, -21; 4, 53, -23), bilateral temporal pole (x, y, z = -44, 5, -12; 50, 7, -12), TPJ (x, y, z = 51, -43, 41), caudate (x, y, z = 8, 19, -3), and precuneus (x, y, z = 12, -56, 40) in the EF vs. CF contrast was observed as the difference in the *k* value of each contrast condition increased. These results suggest that the activation of these regions tracks the degree of individual sensitiveness to the future cue, consequently resulting in more patient behavior (which is indirectly reflected in the *k* value difference). During the Decision period, several areas, including the bilateral temporal pole (x, y, z = -46, 22, -18; 46, 15, -18), OFC (x, y, z = 14, 15, -19), and LPFC (x, y, z = -36, 56, -3) in the F vs. NF contrast and the MPFC (x, y, z = -4, 60, 4; -14, 57, 9), ACC (x, y, z = -2, 28, 12), pSTS (x, y, z = 55, -46, 19), and TPJ (x, y, z = -46, -65, 25; 44, -65, 28) in the EF vs. CF contrast were found as particular

Table 3. Neural Correlates Reflecting the Individual Differences in the Discounting Rate

Regions	Lat	BA	Talairach Coordinates			z-score
			x	y	z	
F > NF during CUE Period						
Superior Frontal Gyrus	L	8	-26	35	44	3.90
Middle Frontal Gyrus	R	10/46	51	47	13	3.92
	R	11/47	44	39	-7	2.80
	L	8	-44	25	41	3.53
Inferior Frontal Gyrus / Insula	R	45/47/13	34	19	-1	2.85
Parahippocampal Gyrus	R		20	1	-29	4.63
Superior Temporal Gyrus	R	22	61	8	1	2.99
Cuneus	R	19	12	-88	25	3.00
EF > CF during CUE Period						
Orbital Gyrus	L	11	-10	48	-21	3.30
	R		4	53	-23	3.40
Superior Frontal Gyrus	R	11	10	57	-18	2.95
Inferior Frontal Gyrus	L	47	-26	25	-6	2.92
	R		34	11	-16	3.54
Precentral Gyrus	R	3/4/6	57	-8	31	3.49
	R		44	-3	25	3.41
Caudate	R		8	19	-3	3.49
Parahippocampal Gyrus	R	28/35	28	-22	-16	2.94
Hippocampus	R		36	-26	-7	2.79
Superior Temporal Gyrus	R	38	50	7	-12	3.05
	L	38	-44	5	-12	2.96
Middle Temporal Gyrus	R	21	65	-8	-10	3.88
	R	21/38	59	5	-10	3.55
	R	37	51	-55	-2	3.31
Inferior Parietal Lobule	R	40	51	-43	41	2.95
	R		50	-35	35	2.99
Precuneus	R	7	12	-56	40	3.40
	R		10	-68	45	2.81
Cuneus	L	17/18	-12	-87	8	3.46
Fusiform Gyrus	L	37	-28	-51	-6	2.98

Table 3. Neural Correlates Reflecting the Individual Differences in the Discounting Rate (Continued)

Regions	Lat	BA	Talairach Coordinates			z-score
			x	y	z	
F > NF during DECISION Period						
Superior Frontal Gyrus	R	10	24	68	-3	3.90
Rectal Gyrus/Orbital Gyrus	R	11/25/47	8	24	-21	4.47
Middle Frontal Gyrus	L	10	-36	56	-3	4.37
Inferior Frontal Gyrus	R	11/25/47	14	15	-19	3.09
Superior Temporal Gyrus	R	38	46	15	-18	3.42
	L		-32	7	-21	3.12
	L		-46	22	-18	3.11
Inferior Occipital Gyrus	L	18/19	-30	-86	-6	3.00
EF > CF during DECISION Period						
Superior Frontal Gyrus	L	8	-14	41	45	3.00
	R	6/8	8	26	54	3.70
	R	10	22	61	7	2.91
Medial Frontal Gyrus	L	10	-4	60	4	3.62
	L	10	-14	57	9	2.55
	L	6	-6	-17	50	2.94
Anterior Cingulate	L	24	-2	28	12	2.66
Insula	R		38	-17	9	3.04
Middle Temporal Gyrus	R	20/21	48	1	-27	3.13
Superior Temporal Gyrus	R	13/41	44	-38	15	2.76
	R	13/40	55	-46	19	3.18
Middle/Superior Temporal Gyrus	R	39	44	-65	25	2.91
	L	39	-46	-65	28	2.78
	L	39	-42	-57	25	2.77
Posterior Cingulate	R	29	14	-46	17	2.92
Thalamus	R		16	-25	13	2.78
Precentral Gyrus	R	4/6	24	-18	63	2.94
Postcentral Gyrus	L	5	-32	-38	62	3.20

regions that were positively correlated with the *k* value difference of the contrasting conditions. That is, these brain areas responded more sensitively when processing various delayed reward options, especially among more patient participants. Table 3 shows all regions that reflect individual differences in the discounting rate.

Personality Regulation on the Future Thinking and Delay Discounting. We also examined the correlation between neural activation during future thinking and individual perspective-taking ability as measured by the PT subscale of the IRI (Interpersonal Reactivity Index; Davis, 1983). As discussed above, a positive correlation was observed between the PT score and the *k* value difference of (No Future cue - Future cue). In addition to this behavioral finding, different neural activation was observed as the individual PT score differed. The results of a simple regression analysis of the PT score

Table 4. Neural Correlates Reflecting the Individual Differences in the Perspective-taking Capability

Regions	Lat	BA	Talairach Coordinates			z-score
			x	y	z	
F > NF during CUE Period						
Orbital Gyrus	L	11/47	-10	32	-23	2.82
Medial Frontal Gyrus	L	32	-16	14	40	2.75
Cingulate Gyrus	R	24/32	10	10	40	2.92
	L	32	-6	14	40	2.87
Superior Temporal Gyrus	R	38/47	34	13	-17	3.20
Parahippocampal Gyrus	L	34	-20	5	-17	2.83
Insula	L	13	-36	8	1	2.87
Superior Parietal Lobule		7	-34	-66	49	2.85
F > NF during DECISION Period						
Superior Frontal Gyrus	L	8	-18	43	43	2.92
Inferior Frontal Gyrus	R	47/45	55	16	1	3.20
Anterior Cingulate	L	33/24	-4	9	20	3.19
		33/24	0	16	18	2.77
Parahippocampal Gyrus	R	34/28	16	-9	-20	3.54
Inferior Temporal Gyrus	R	20-21	50	-3	-28	3.11
Precentral Gyrus	L	4/6	-55	-6	44	2.95

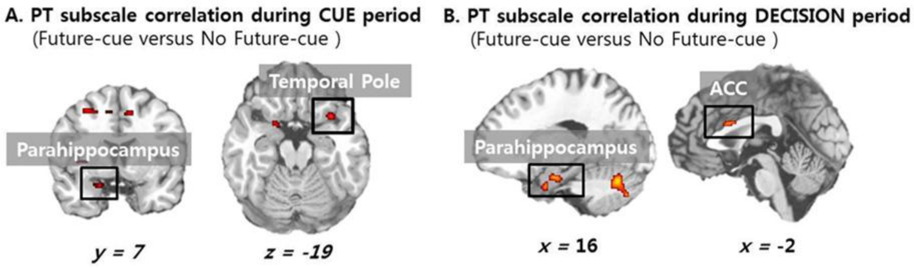

Figure 5. Neural Representation of Individual Perspective-taking Ability During Intertemporal Choice

(A) During the future prospection with personal future-cues, regions in which showed significant positive correlation with Perspective-taking subscale of IRI included parahippocampal and temporal pole. (B) During making intertemporal choices, regions in which showed significant positive correlation with Perspective-taking subscale of IRI included parahippocampal and anterior cingulate cortex (ACC). (A) and (B) are both thresholded at p < .005, uncorrected.

on the Future-cue versus No-Future-cue contrast were as follows. During the future-cue period, the prospective memory-related regions, including the parahippocampal (x, y, z = -20, 5, -17) and temporal pole (x, y, z = 34, 13, -17), showed greater activity with an increase in the PT score (Figure 5, Panel A). This implies that people with better perspective-taking ability are also good at prospection or imagination of their future plans. This result is also supporting evidence that prospective thinking and perspective-taking are correlated. Also, subjects with greater PT ability exhibited greater activation in the parahippocampal (x, y, z = -4, 9, 20) and ACC (x, y, z = -4, 9, 20; 0, 16, 18) during the choice period after future thinking (relative to the choice period without future thinking) (Figure 5, Panel B). Given the role of the ACC in cognitive control (Botvinick, 2007; Botvinick, Cohen, & Carter, 2004), these findings can be interpreted as suggesting that people with better perspective-taking ability perceive and control the intertemporal reward tradeoffs in a better way.

Discussion

This study is one of the first that attempts to investigate the influence of mental simulation activities such as perspective-taking and future prospection on economic decision-making, specifically on intertemporal choices that include temporal trade-offs. Behaviorally, future thinking after perspective-taking of another's emotional state successfully diminished the temporal discounting rate, consequently showing a more patient behavior pattern. At the neural level, we found that there are common neural bases concerning perspective-taking, prospective memory, and intertemporal choice. Specifically, a triple-conjunction analysis revealed that the lateral PFC, temporal pole, and insula were commonly recruited for the three different cognitive processing activities, especially when participants made more far-sighted decisions. Interestingly, the activation amplitude of the temporal pole and parahippocampal gyrus during the future-prospection tasks were positively correlated with the individual differences in the discounting rate as well as the perspective-taking ability. Given that the LPFC, temporal pole, and parahippocampal gyrus exhibited stronger activation patterns among those who showed more patient behavior, they may serve as a form of regulation that enables one to engage in the future-oriented decision-making.

LPFC and self-control in intertemporal choice Specifically, the LPFC, examined as a key region for emotional regulation (Kim & Hamann, 2007; McGuire & Botvinick, 2010; Ochsner, Bunge, Gross, & Gabrieli, 2002), may control impulsive behavior during the formation of an intertemporal choice.

Ochsner and his colleagues revealed that the ventral LPFC is employed when reappraising highly negative emotional scenes in less emotional terms, consequently reducing subjective negative affect (Ochsner et al., 2002). More recently, the regulatory role of the LPFC specifically on intertemporal choice was investigated using rTMS (repetitive transcranial magnetic stimulation).

According to Figner et al., (2010), the LPFC was revealed as a crucial neural substrate in the exertion of self-control in intertemporal choices. Disruption of the function of the LPFC with low-frequency rTMS increased impatient choices for sooner-but-smaller rewards compared to later-but-larger rewards.

Impaired self-control due to the dysfunction of the LPFC resulted in more choices for an immediate reward option despite the fact that the delayed reward option was subjectively valued higher. Importantly, the effect was significant only when the rTMS was applied on the left, but not on the right, which is consistent with our fMRI results (Significant activation in the left LPFC region was identified under the EF vs. CF contrast, which showed significantly different discounting rates). Taken together, these neuroimaging and rTMS results are evidences indicating that LPFC is greatly involved in self-control. It would seem that this region, which was activated commonly for emotional perspective-taking, future thinking, and intertemporal decision-making, played a key role in modulating impatience during the delay-discounting task in the current study.

Parahippocampus as a predictor of individual differences in the discounting rate Although we could not precisely replicate the 'episodic tag effect' observed in Peters and Büchel (2010), the regulatory effect of episodic future prospection on intertemporal choice can be inferred by the activation magnitude of the parahippocampal gyrus in this study. Peters and Büchel (2010) compared participants' discounting rate under two conditions, an Episodic tag condition in which an individual episodic cue representing the planned event on the respective delayed date is displayed on a screen, and a Control condition in which an individual episodic cue was absent. Participants showed significantly smaller discounting rates in the Episodic tag condition than in the Control condition, whereas in our study, there were no significant behavioral differences between the discounting rates under these two contrasting conditions (the discounting rate was numerically smaller in the Future-Cue condition, but it did not reach statistical significance; $p > .05$). However, the parahippocampal gyrus was revealed as a crucial region representing episodic future representation and furthermore predicting individual differences in discounting rates. The findings of Addis and Schacter (2008) suggest that the temporal distance and detail of the episodic events are positively correlated with the activity in the medial temporal lobe (MTL) including the hippocampus and parahippocampal gyrus. A similar pattern was evident in the present study. Imagery scores composed of self-reported easiness and vividness while imagining the future cues were positively correlated with the engagement of the left parahippocampal gyrus (x, y, z = -20, -15, -21). Moreover, the activation in the parahippocampal gyrus during future prospection was increased as a function of the individual perspective-taking capability, as measured by a subscore of the IRI (Davis, 1983). Thus, it can be inferred that one who is better at taking another's perspective can also envision future episodic events in a more detailed fashion. Moreover, the MTL responses during prospection were in line with the discounting rate differences between the two conditions with and without future cues, which also reflects a modulating effect of a future cue. Based on the positive correlation between the MTL activity and the future-cue effect (See Fig. 5, Panel A), it can be suggested that the degree of MTL commitment during future prospection would play a major role in modulating the subjective temporal distance of delay, consequently determining the behavioral patterns during delay discounting.

A dominant role of emotion in a prospection network Furthermore, it appears emotional perspective-taking helped increase the strength of episodic future representation in this study by easing the process of mentally recruiting and experiencing, in advance, the emotional component of the future event. From a series of neuroimaging studies examining the neural mechanisms underlying autobiographical memory, future prospection, and the theory of mind, a common brain network including the left-lateralized temporal pole, inferior frontal gyrus, and lateral temporal lobe were identified as crucial brain regions for common cognitive processing (Ruby & Decety, 2004; Spreng & Grady, 2010; Spreng et al., 2009). Among these, the left temporal pole and inferior frontal gyrus appear to be especially more involved in perspective-taking in an emotional context compared to cognitive reasoning (Ruby & Decety, 2004; Shamay-Tsoory, Aharon-Peretz, & Perry, 2009). Specifically, increased activity in the left temporal pole was observed when inferring the others ' feelings versus the others' opinions in Ruby and Decety's study (2004). Also from a lesion study by Shamay-Tsoory et al. (2009), subjects with lesions in the inferior frontal gyrus showed a significant deficit in emotional empathy but not in cognitive empathy. Thus, these results stand as a reasonable explanation for the result of our study, in which emotional perspective-taking had a superior impact on diminishing the individual discounting rate.

As there was no control group, the direction of the effect cannot be clearly distinguished as to whether emotional perspective-taking actually reduced the subjective temporal discounting rate or whether cognitive perspective-taking increased the subjective temporal discounting rate. Although our research objective here was to differentiate the subsequent effect of emotional perspective-taking process and cognitive reasoning, further studies are necessary to clarify the specific effect of each in more detail. Nonetheless, the current findings revealed that there exists some functional overlapping between perspective-taking, future thinking, and intertemporal decision-making. Emotional perspective-taking exerts a more influential role on regulating one 's impatience. Finally, the individual perspective-taking ability is closely related to the prospective decision-making, such as intertemporal choices.

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조망수용과 미래기억의 신경학적 유사성과 시점 간 선택에 미치는 영향

김혜영　　신연순　　한상훈
연세대학교 심리학과

선택을 결정하는 시점과 손익 결과가 나타나는 시점이 시간적으로 떨어져 있을 때의 의사결정을 ‘시점 간 선택 (intertemporal choice)’ 이라고 한다. 일반적으로 거의 모든 의사결정은 다른 시점 간의 선택이라 할 수 있는데, 눈앞의 작은 효용과 미래의 더 큰 효용 사이에서의 선택이 대표적인 예이다. 현재의 선택으로 인한 미래 결과에 대한 가치는 현재 가치로 할인하여 판단되는데, 이 때 적용되는 할인율은 개인마다 상이하다. 시점 간 선택에 관한 최근 연구들에 따르면 미래의 일화기억을 구성하는 활동은 시점 간 선택행동에 영향을 미치며, 기능성 자기공명 영상장치를 사용한 연구들은 이러한 미래전망 활동과 다른 사람의 관점에서 생각해보는 조망수용 활동에 공통적인 뇌 영역이 관여한다는 것을 발견하였다. 따라서 본 연구에서는 조망수용과 미래기억, 시점 간 선택에 공통적으로 관여하는 신경 네트워크를 살펴보고, 조망수용능력의 개인차에 따라 미래기억과 시점 간 선택 행동에서의 차이를 알아보고자 하였다. 외측전전두엽피질(lateral prefrontal cortex), 측두극(temporal pole), 해마방회(parahippocampal gyrus) 영역이 시간에 대한 할인율의 개인차를 반영하는 영역들로 관찰되었고, 조망수용능력이 좋을수록 효과적인 미래조망을 함으로써 시점 간 선택에서 보다 장기적인 관점의 의사결정을 할 수 있게 되는 것으로 나타났다. 타인의 ‘감정’에 대한 조망수용을 위해 일어나는 자신의 감정조절이 추후 시점 간 선택에 미치는 영향 또한 관찰되었다.

주제어 : 조망수용, 미래기억, 시점 간 선택, 기능성 자기공명 영상장치