Exploring the brain basis of the effects of self-talks on life satisfaction and changes in cognitive performance

Junhyung Kim

Department of Medicine

The Graduate School, Yonsei University

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Directed by Professor Jae-Jin Kim

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Junhyung Kim

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This certifies that the Doctoral Dissertation of Junhyung Kim is approved.

Thesis Supervisor : Jae-Jin Kim

Thesis Committee Member#1 : Seung-Koo Lee

Thesis Committee Member#2 : Jee-In Kang

Thesis Committee Member#3: Hae-Jeong Park

Thesis Committee Member#4: Sang-Hyuk Lee

The Graduate School
Yonsei University

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ABSTRACT

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Junhyung Kim

Department of Medicine
The Graduate School, Yonsei University

(Directed by Professor Jae-Jin Kim)

Background: Self-talk is the systematic use of cue words or phrases in a silent or vocalized dialog with one's self. This simple form of psychological interventions has been studied in a variety of fields. Positive self-talk is a practical way to promote life satisfaction through gratifying basic psychological needs, whereas negative self-talk is associated with life dissatisfaction. Both self-talks can also improve cognitive performance, but the underlying mechanism of such improvement has not been investigated. Thus, identifying the specific neural mechanism involved in the positive and negative self-talks is imperative. This study aimed to elucidate the effects of positive and negative self-talks on functional connectivity with respect to life satisfaction and cognitive performance.

Methods: In two experiments, 5-minute-long self-respect and self-criticism tasks were used as positive and negative self-talks. Forty-eight individuals with low life satisfaction (LLS, n=24) and with high life satisfaction (HLS, n=24) were scanned using functional magnetic resonance imaging at a baseline state and during and after self-respect or self-criticism tasks in Experiment 1. Experiment 2 included the short form of Progressive Matrices Test (sRPM) to measure differences in performance improvements between self-respect and self-criticism. Forty-six participants were scanned using functional magnetic resonance imaging in the following order: baseline, during-sRPM1, post-sRPM1, self-respect or self-criticism, during-sRPM2, and post-sRPM2.

Results: Experiment 1 showed that self-respect changed only the connection between the posterior cingulate cortex (PCC) and frontoparietal network, whereas self-criticism changed almost all of the connections examined. The group × condition interaction effect of self-respect was identified only in connection between the PCC and left ventrolateral prefrontal cortex, while that of self-criticism was observed in various connections based on the ventromedial prefrontal cortex and nucleus accumbens. In respect to basic psychological needs, functional connectivity after self-criticism was significant in predicting the needs of autonomy and relatedness only in the LLS group, whereas functional connectivity after self-respect could predict the needs of autonomy and competence only in the HLS group. In Experiment 2, increase in sRPM2 score compared to sRPM1 score was observed only after self-criticism. The self-talk-by-repetition interaction effect was not found for during-sRPM, but found for post-sRPM; decreased nucleus accumbens-based connectivity and increased within-posterior cingulate connectivity were shown after self-criticism compared with self-respect. However, the significant correlations between the connectivity change and performance change appeared only in the self-respect group.

Conclusion: The current study showed that positive and negative self-talks differently modulate brain states concerning life satisfaction and cognitive performance. Overall, self-criticism produces more noticeable negative changes in the brain than the positive changes of self-respect. Individuals with low life satisfaction may be more vulnerable to be negatively affected not only by self-criticism but also self-respect than individuals with high life satisfaction. The satisfaction of basic psychological needs can play a mediating role in the effects of self-talk tasks differently concerning life satisfaction. Concerning cognitive performance, self-respect may have both positive and negative effects due to enhanced executive functions and inaccurate confidence, respectively, whereas self-criticism may positively affect cognitive performance by inducing a less confident state that increases internal motivation and attention.

Key words : self-talk; self-respect; self-criticism; life satisfaction, cognitive performance; functional connectivity

ABBREVIATIONS

ACC (Anterior Cingulate Cortex)
ANCOVA (Analysis of Covariance)
ANOVA (Analysis of Variance)
BPNS (Basic Psychological needs Scale)
DLPFC (Dorsolateral Prefrontal Cortex)
DMN (Default mode network)
DMPFC (Dorsomedial Prefrontal Cortex)
FC (Functional Connectivity)
fMRI (Functional Magnetic Resonance Imaging)
HADS (Hospital Anxiety and Depression Scale)
HG (Heschl’s Gyrus)
HLS (High Life Satisfaction)
IPS (Intraparietal Sulcus)
ITG (Inferior Temporal Gyrus)
LLS (Low Life Satisfaction)
LOC (Lateral Occipital Cortex)
MNI (Montreal Neurological Institute)
MTG (Middle Temporal Gyrus)
NA (Nucleus Accumbens)
OFC (Orbitofrontal Cortex)
POC (Parietal Operculum Cortex)
PrCG (Precentral gyrus)
RMPFC (Rostromedial Prefrontal Cortex)
ROI (Regions of Interest)
RPM (Raven’s Progression Matrices)
RSES (Rosenberg Self-Esteem Scale)
VLPFC (Ventrolateral Prefrontal Cortex)
VMPFC (Ventromedial Prefrontal Cortex)
SMA (Supplementary Motor Area)
SPL (Superior Parietal Lobule)

SSFC (Summary Statistic of Functional Connectivity)
SWLS (Satisfaction with Life Scale)

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I. INTRODUCTION

1. Self-talk

Self-talk is defined as the systematic employment of cue words or phrases in a silent or vocalized discourse with oneself[1]. Two conceptual qualities characterize this process: verbalizations are necessary, and the sender of the message is also the receiver[2]. The structure in which this sort of mental intervention is employed is as a component of clinic-based training programs[3] or in a brief form immediately before the task for performance enhancement[4]. Self-talk is helpful in therapeutic and performance-enhancing interventions[5,6]. For example, self-talk is beneficial in regulating anxiety and depression in psychiatry[2,7] and performance enhancement in sport psychology[2]. Its favorable benefits have also been shown in terms of academic engagement and response[8]. Given the ease with which this short intervention may be used in various settings, studying how positive self-talk influences an individual's behavior may be valuable.

Previous studies on self-talk revealed that a variety of psychological elements contribute to the effects of self-talk. Concerning self-talk content, and even though purposeful or frequent use of negative self-talk seems counterintuitive[9], most research on self-talk has focused on self-talk with positive self-related content (positive self-talk). Positive self-talk has been shown to aid in the promotion of positive psychological states and cognitive regulation[10,11]. Additionally, mental activities involving positive self-talk, such as expressing appreciation, have been shown to boost and maintain good affect[12]. By contrast, negative self-talk relates to emotional distress[13]. Negative self-talk, on the other hand, has been shown in several studies to boost physical performance[14,15]. Numerous ideas have been advanced to explain how negative self-talk might be advantageous for performance development, including motivational interpretation[16], the reverse reflection of confidence[17], encouraging attempts to avoid a poor outcome[18], and perceiving negative self-talk as a challenge[15]. Although self-talk has been studied at the behavior level in various domains, the neurological mechanism behind its direct influence on the brain concerning performance has not been identified.

2. Life Satisfaction

Life satisfaction defines how people evaluate their lives not only in the moment but also overextended periods[19] and has been suggested to related to longer lives and better health[20,21]. Compared with those with high life satisfaction, people with low life satisfaction tend to be less flexible to negative feedback[22] and show negative self-cognition[23]. Life satisfaction is important in mediating the association between stress and depressive symptoms[24], and thus it has been widely accepted as a significant variable to measure mental health[25,26]. Therefore, developing a way to promote life satisfaction and the investigation of its mechanism is valuable for mental health in individuals with low life satisfaction. Positive self-talk is emphasized as a practical approach for enhancing life satisfaction through its beneficial effects on physical performance[9] and emotional intelligence[6,27].

Life satisfaction can be affected by numerous factors, including age, personality, outlook on life, experiences, career, and family. In particular, according to the self-determination theory, the satisfaction of basic psychological needs, such as autonomy, competence, and relatedness, is an important factor in life satisfaction[28]. People tend to be motivated by the satisfaction of optimally meeting their own psychological needs[29], and thus the satisfaction of these three basic needs represent essential nutrients for optimal functioning across the lifespan and across cultures[30]. Considering the contribution of satisfaction of the basic needs to life satisfaction, the effect of self-talk on enhancing life satisfaction can also be influenced by an individual's satisfaction of the basic needs. Positive self-talk can enhance positive emotion through satisfying the basic needs[9], whereas negative self-talk, such as self-criticism, drives people to a depressed or stressed state[31]. In addition, the association between self-control skills and subjective well-being is mediated by perceived satisfaction of the basic needs[32]. Taken together, basic psychological needs are likely to act as a potential mediator in the relationship between self-talk and life satisfaction.

Numerous variables influence life satisfaction, including age, personality, view on life, experiences, work, and family. According to the self-determination theory, life satisfaction is influenced by fulfilling basic psychological needs such as autonomy, competence, and relatedness[28]. Because people are often driven by the gratification of properly addressing their basic psychological needs[29], satisfying these three basic needs provides vital nutrients for good functioning throughout the lifetime and across cultures[30]. Given the importance of basic needs fulfillment to life satisfaction, the impact of self-talk on boosting life satisfaction may also be affected by an individual's basic needs satisfaction. Positive self-talk may increase positive feelings by meeting fundamental needs[9], while negative self-talk, such as self-criticism, can lead to depression or stress[31]. Additionally, the relationship between self-control abilities and subjective well-being is mediated by perceived basic requirements satisfaction[32]. Thus, when fundamental psychological demands are considered in aggregate, they are likely to mediate the link between self-talk and life satisfaction.

3. Candidate for Measuring Changes in Cognitive Performance, Fluid Intelligence

One of the variables measuring performance improvement is fluid intelligence which is the analytical intelligence associated with reasoning and novel problem-solving ability[33]. Fluid intelligence is minimally dependent on language and acquired knowledge[34]. Several studies have already used fluid intelligence performance to examine the effect of psychological factors on cognitive performance, such as depression[35], psychotic symptom[36], and pressure[37]. The previous study presented the beneficial effects of self-talk in academic engagement and academic responding[8], and improvement in the anagram-solving task related to fluid intelligence after self-talk was also reported[38]. Besides, the Raven's Progressive Matrices (RPM) test is one of tools for measuring fluid intellignece[39]. Therefore, it can be expected that changes in psychological states induced by self-talk could be related to performance, and the fluid intelligence test could be a suitable candidate for measuring the changes of performance related to self-talk.

One of the criteria used to assess performance progress is fluid intelligence, which is the analytical intelligence linked with thinking and the capacity to solve new problems[33]. Language and acquired knowledge have a negligible effect on fluid intelligence[34]. Numerous studies has previously employed fluid intelligence performance to investigate the influence of psychological variables such as depression[35], psychotic symptom[36], and pressure[37] on cognitive function. Recent research demonstrated the favorable benefits of self-talk on academic engagement and responding[8], as well as an improvement in the anagram-solving test associated with fluid intelligence after self-talk[38]. Additionally, the Raven's Progressive Matrices (RPM) test is one of the measures used to determine the intelligence of a fluid[39]. As a result, it is reasonable to assume that changes in psychological states caused by self-talk are connected to performance, and the fluid intelligence test may be a potential choice for assessing performance changes caused by self-talk.

4. Literature Review about Neural Mechanism concerning Self-talk, Life satisfaction, and Fluid Intelligence

While little is known about the brain mechanisms behind self-talk, earlier research has identified many areas related to psychological treatments. For example, psychological therapies encouraging mindfulness have been shown to improve life satisfaction through modulating functional connectivity between auditory areas and the default mode network (DMN), which includes the dorsomedial prefrontal cortex (DMPFC) and posterior cingulate cortex (PCC)[40,41]. Additionally, gratitude meditation alters functional connectivity between areas of the brain associated with motivation, such as the nucleus accumbens (NA) and prefrontal cortex, while resentment therapies significantly affect the link between the DMN and task-positive regions[42]. Additionally, previous behavioral research has demonstrated that the effect of self-talk may be moderated by other cognitive factors such as the salience of its content[43], selective attention[44], and fine motor coordination[45], and thus the salience, frontoparietal, frontostriatal, and cerebellar networks may be of interest when considering changes in brain connectivity associated with psychological interventions.

In earlier brain imaging investigations, persons with poor life satisfaction demonstrated a reduced amygdala and dorsolateral prefrontal cortex (DLPFC) reaction to pleasant emotional stimuli[46,47], and lower functional connectivity in the DMPFC in response to negative self-related words[48]. Although no systematic study has been conducted on the effects of self-talk on brain connectivity, their self-referential nature suggests that self-referential processing-related regions such as the ventromedial prefrontal cortex (VMPFC) or DMPFC[49,50], anterior cingulate cortex (ACC)[51], and PCC[52] may be involved.

Additionally, as intelligence research has advanced[53,54], conclusive findings concerning the biological foundations of intelligence have been established using evolved technologies such as brain imaging studies[55]. Bilateral frontal (i.e., DLPFC) and parietal (i.e., intraparietal sulcus, IPS) areas have been related with the RPM test-induced fluid cognitive processes[56,57]. The effects of cognitive load on functional connectivity have offered essential insights into active processes involving cognitive functions and subsequent processes occurring during the post-task resting state. For instance, research on post-task resting state connection has shown that alterations in connectivity reflect recent visual/cognitive experience[58] and predict later cognitive performance[59,60]. Additionally, connection in the post-task resting state is related to experience-induced plasticity[61]. Other examples include post-task changes related to cognitive functions, such as episodic memory[62] and visual perception[63].

5. Current Study Goals and Approaches

The main aim of this study is to investigate the neural mechanisms related to the effects of self-talk on life satisfaction and enhancing performance. By comparing the effects of different contents with functional connectivity, it will be important information that can be helpful in effectively using self-talk. Comparing responses to self-talk that differ according to life satisfaction provides insights about applying self-talk according to personal characteristics. In addition, comparing the effects of self-talk composed of contradictory contents on functional connectivity related to cognitive performance can provide insight into the utilization of self-talk by showing the mechanism of the effect of self-talk on performance. For this aim, two different tasks – called the self-respect and self-criticism tasks were designed for two different functional magnetic resonance imaging (fMRI) scanning experiments. Experiment 1 aimed to understand the effect of self-talks on the functional connectome with respect to life satisfaction and its relationships with the satisfaction of basic psychological needs, such as autonomy, competence, and relatedness, it aimed to identify the neurofunctional consequences during and after these tasks, analyze their differences between individuals with high life satisfaction (HLS) and those with low life satisfaction (LLS), and develop a model for predicting an individual's behavioral characteristics using resting-state functional connectivity. Experiment 2 aimed to understand the effect of self-talk on the functional connectome concerning self-talk types and whether the functional connectivity alterations explain variation in performance in the modified RPM test. To identify the difference in performance variations in repeated RPM tasks between individuals who underwent self-respect and self-criticism tasks, the neurofunctional consequences during and after RPM tasks, and correlations between individual variations of performance and functional connectivity alterations were examined.

The study hypothesized that first, both tasks would induce modulations of functional connectivity and the pattern of these modulations would be different according to the level of life satisfaction. Based on the hypothesis that the modulations would occur particularly in the default mode, self-referential, and reward-motivation networks, the PCC, VMPFC, and NA as the regions of interest (ROIs) for seed-based functional connectivity analysis was defined. In addition, taking into account the existing reports related to the cognitive and emotional effects of self-talk, other brain networks was also focused on, including the frontoparietal network, frontostriatal network, visual network, salience network, and cerebellar network, as the targets for these modulations. Second, the part of resting-state functional connectivity related to these networks would be associated with the satisfaction of a component of basic psychological needs and resting-state functional connectivity before and after the self-respect or self-criticism tasks would predict an individual's satisfaction of basic psychological needs. Third, both self-talk tasks would differently affect performance variations of RPM task and functional connectivity, and these functional connectivity modulations would be differently correlated to variations of performance. To test this hypothesis, in Experiment 2, DLPFC, and IPS were added as ROIs in addition to the ROIs included in Experiment 1 to further investigate the effect on cognitive performance. Last, the functional connectivity modulations related to these networks would be associated with the performance variations.

II. MATERIALS AND METHODS

1. Experiment 1

A. Participants and Assignment

A total 276 healthy college students participated in the study, which was advertised on a bulletin board. All participants were examined first to establish cutoff values for two extreme groups in terms of life satisfaction, as measured by the Satisfaction with Life Scale (SWLS)[64]. This five-item, seven-point Likert scale (score range: 5–35; neutral, 20) assesses an individual's degree of life satisfaction. The cutoff scores for the highest 25% group (N = 110, mean = 21.7, standard deviation [SD] = 1.7) and the lowest 25% group (N = 78, mean = 14.0, SD = 2.1) were judged to be 20 in the highest 25% group (N = 110, mean = 21.7, SD = 1.7). Pregnancy and a history of significant neurological or mental diseases were excluded as exclusion criteria. Additionally, subjects were tested for handedness using the Annett Handedness Inventory[65] to rule out left-handed persons and those having contraindications to MRI scanning, such as dental plates. Finally, 24 volunteers from the highest group and 24 volunteers from the lowest group who were age- and sex-matched were chosen to participate in Experiment 1. The two groups of participants were dubbed the HLS and LLS groups.

B. Clinical Assessments

Participants completed two self-report questionnaires for this research. In addition to initial SWLS, participants performed a modified version of the Basic Psychological Requirements Scale (BPNS) to assess satisfaction with three fundamental psychological needs associated with intrinsic motivation: autonomy, competence, and relatedness[66]. Autonomy reflects the need for individual freedom to choose and accountability for one's actions; competence reflects the satisfaction of the need to be effective in the environment, such as exercising and expanding one's capabilities; and relatedness reflects the need to feel securely connected to others and a sense of belonging in one's social environment.

C. Audiovisual Stimuli

Before the fMRI scan, two 5-minute audiovisual stimuli produced by the individuals' own voices were generated to provide positive and negative self-talk stimuli. The positive and negative self-talk stimulus scripts included elements that may promote self-esteem or self-criticism, respectively. Additionally, the sender and recipient of the communication were made to coincide based on the conceptual features of self-talk. Table 1 contains the complete scripts for the tasks. The voices of the participants for the tasks were created by capturing the scripted reading at the pre-visit. The activities were then coupled with a visual stimulus that displayed the scripts in black letters on a gray background. (Figure 1). These materials aided participants in concentrating on their feelings of self-respect or self-criticism by telling themselves how much they respect or criticize themselves in their minds.

Table 1. Full scripts of the text for the self-respect and self-criticism tasks.

Scripts for self-respect
나에게는 여러가지 장점이 있다. 나는 나의 장점에 대해 잘 알고 있다. 나에게는 훌륭한 점이 많다. 나는 나의 훌륭한 점에 대해 잘 알고 있다. 나에게는 멋진 모습이 많다. 나는 나의 멋진 모습에 대해 잘 알고 있다. 생각해보면, 나는 할 줄 아는 것이 많다. 생각해보면, 나는 잘하는 것이 많다. 나는 나의 능력을 믿는다. 나에게는 잠재력이 있다. 나에게는 엄청난 잠재력이 있다. 나는 내가 무엇을 할 수 있는지 잘 안다. 나는 그것을 할 수 있다. 나는 잘 해낼 수 있다. 나는 마음만 먹으면 언젠가는 해내고야 만다. 나의 능력은 계속 성장한다. 나는 나 자신에 대해 자부심을 느낀다. 내 자신을 돌이켜보면 뿌듯하다. 나는 그동안 어려움을 잘 이겨냈다. 나는 앞으로도 어려움을 잘 극복할 수 있다. 나는 나를 믿는다. 나는 할 수 있다. 나는 내 자신이 자랑스럽고 뿌듯하다. 나는 나를 사랑한다. 나는 나 자신을 진심으로 존중한다. 나는 나 자신을 존중하고 사랑한다. 나는 내 주변사람들을 사랑하고 존중한다. 내 주변사람들은 나를 사랑하고 존중한다. 나는 내 인생의 주인다. 나의 인생은 내가 결정한다. 다른 누구도 아닌, 내가 나의 인생을 결정한다. 내 인생은 나의 결정에 달려 있다. 내 인생의 성공여부는 내가 결정한다. 나의 삶은 나의 것이다. 나는 내 인생의 주인이다. 나는 나자신을 존중한다. 나는 나를 진심으로 존중한다.
Scripts for self-criticism
나는 살면서 많은 실수를 저질렀다. 나는 내가 무엇을 잘못했는지 안다. 전부 다 내 탓이고, 다 내 잘못이다. 나에게는 단점이 많다. 나는 나의 단점을 잘 알고 있다. 나는 내가 무엇을 못하는지 안다. 나는 잘 할 수 있는 게 거의 없다. 나는 아무것도 할 수 없다. 제대로 할 수 있는 게 하나도 없다. 내 인생은 엉망진창이다. 나에게 잘난 점 이라고는 없다. 내 모습은 참으로 한심하다. 나는 내 자신이 부끄럽다. 남들이 내 진짜 모습을 안다면 실망할 것이다. 나는 내가 싫다. 나는 나 자신이 밉다. 나는 바보다. 나는 멍청하다. 나는 아무것도 못한다. 나는 그동안 잘한 게 하나도 없다. 나는 내가 밉다. 다른 사람들도 모두 다 나를 미워할 것이다. 모두 나에게 실망할 것이다. 모두 나를 싫어할 것이다. 나는 아무에게도 사랑받지 못할 것이다. 나는 남들에게 피해를 주는 사람이다. 나 때문에 다른 사람들이 불편해진다. 나는 계속 실패한다. 내가 못나서 실패하는 것이다. 중요한 일이 닥치면 나는 긴장한다. 나는 늘 실수를 반복한다. 나는 앞으로도 계속 실패할 것이다. 나는 내 인생을 망치고 있다. 나는 내 자신이 정말 싫다. 나는 이기적이다. 나는 욕심쟁이다. 나는 치사한 사람이다. 나 자신에게 화가 난다. 남들에게 부끄럽다. 사랑하는 사람들에게 미안하다. 나는 무언가 잘못되었다.

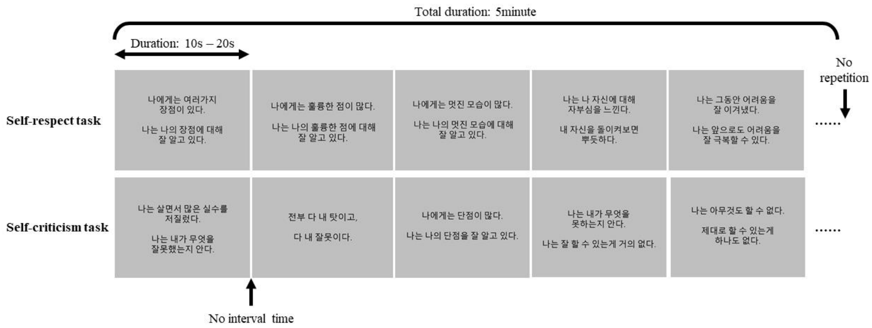

Figure 1. Illustration of audiovisual stimuli for self-respect and self-criticism tasks. Audiovisual stimuli consisted of the sequence of events without repetition. Each event comprised of two sentences that are related to each other. For each event, the recorded participant's voice of the presented sentences was presented for a period between 10 and 20 seconds, depending on the length of the sentence. There was no time interval between two consecutive events.

D. Experimental Procedures

Five 5-minute runs of fMRI scanning were performed on each participant in the following order: baseline resting state, the first task, the second resting state, the second task, and the third resting state. To enhance task effectiveness, a minute-long video tutorial explaining how to breathe was delivered during a brief break before each task, but there was no time delay between the task and the subsequent resting state (Fig. 2A). Participants were assigned the self-respect and self-criticism tasks in a counterbalanced sequence. The three resting-state sessions directed participants to gaze at a fixation cross provided on the screen, relax, and think about nothing in particular.

E. fMRI Acquisition

Images were acquired using a 3.0 Tesla MR scanner (Ingenia CX, Philips, Best, the Netherlands) with a 32-channel dS head coil. For each participant, fMRI scans were acquired using the multiband SENSitivity Encoding (SENSE) sequence (matrix size, 96 × 93; field of view, 216 mm; number of slices, 60; slice order, bottom-up and interleaved; slice thickness, 2.4 mm; echo time, 30 ms; repetition time, 800 ms; flip angle, 52°; MB factor, 6; and SENSE factor, 1). Additional fMRI scans of the same parameters with two opposite phases encoding directions (anterior to posterior and posterior to anterior) to correct geometric distortion of the multi-band fMRI data were acquired. Anatomical images were obtained in the coronal direction using a 3D T1-weighted fast gradient echo sequence (matrix size, 224 × 224; field of view, 224 mm; number of slices, 220; slice thickness, 1 mm; echo time, 4.6 ms; repetition time, 9.9 ms; and flip angle = 8°).

F. Pre-processing of fMRI data

All fMRI scans were corrected for susceptibility-induced geometric distortions using the FSL TOPUP tool[67,68] and followed by standard preprocessing steps using Statistical Parametric Mapping 12 (SPM12, http://www.fil.ion.ucl.ac.uk/spm). The first 10 scans were discarded for magnetic field stabilization. The remaining 375 scans for each run were realigned to the first image and corrected for acquisition time differences among the slices. Then, individual anatomical images were co-registered to the mean fMRI image. Subsequently, the fMRI data were spatially normalized to the Montreal Neurological Institute (MNI) template space and smoothed with a 6-mm full-width at the half-maximum Gaussian kernel. The time series at each voxel was further processed to remove the effects from nuisance parameters. Standard temporal preprocessing procedures including removal of the linear components associated with the six rigid-body head motion parameters plus their time derivatives, regression of the mean time series of the white matter and cerebrospinal fluid, removal of the linear trend, and band pass filtering (0.009-0.08 Hz) was applied.

G. Seed-based functional connectivity

Functional connectivity between the seed ROIs and the other brain grey matter were calculated using a correlation approach. The PCC was selected to investigate DMN resting-state functional connectivity[52]. The bilateral NA and VMPFC were selected to investigate the networks for reward-motivation[69] and self-referential processing[70], respectively. These ROIs would involve changes concerning self-talk tasks and life satisfaction based on our hypothesis. Three ROIs were determined by selecting all voxels within a sphere of 3-mm radius around selected MNI coordinates. Their MNI coordinates (x/y/z) were determined by referring to the results of previous studies that presented significant changes in an individual’s mental well-being induced by a kind of self-talk task (gratitude meditation)[42]: the NA, ±12/8/-8[69], the VMPFC, 9/51/16 and PCC, 1/-26/31[70].

The functional connection strengths between time series of each ROI and the entire brain area were determined at the first level using Pearson's correlation analysis, and the results were transformed to z-scores using Fisher's r-to-z transformation. A repeated-measures analysis of variance (ANOVA) was used to examine any significant variations in functional connectivity across groups, conditions, and tasks in the second-level random-effect analysis. The two second-level models (Figure 2B) were investigated to examine task-specific modulation of functional connectivity concerning life satisfaction. This experiment contained 2 (group: LLS and HLS) × 3 (condition: at the baseline, during the task, and after the task) ANOVA models for each task and seed ROI. Significant functional connectivity was detected using family-wise error (FWE) corrected P_{FWE} 0.05 from clusters identified at a $p < 0.001$ threshold for cluster formation. For the main effect of group and interaction effects of group × condition and group × condition × task, post-hoc analysis to identify the direction of the differences between groups was also conducted.

To identify the main effects of condition and task, however, the analysis was conducted only for brain networks that might be of interest in this study, because the difference in the amount of stimulation provided between the two resting states and one task state and between the two tasks was too large and thus the main effects in voxel-by-voxel comparisons appeared in the form of large clusters superimposed across the boundaries of brain regions. The functional connectivity values of 6 well-known functional modules for each seed ROI, which were the frontoparietal network, frontostriatal network, visual network, salience network, default mode network, and cerebellar network[71], were extracted to compare any significant differences among the three resting-states and between the two tasks. Significant main effects of condition and task were identified based on Bonferroni-corrected $p < 0.05$.

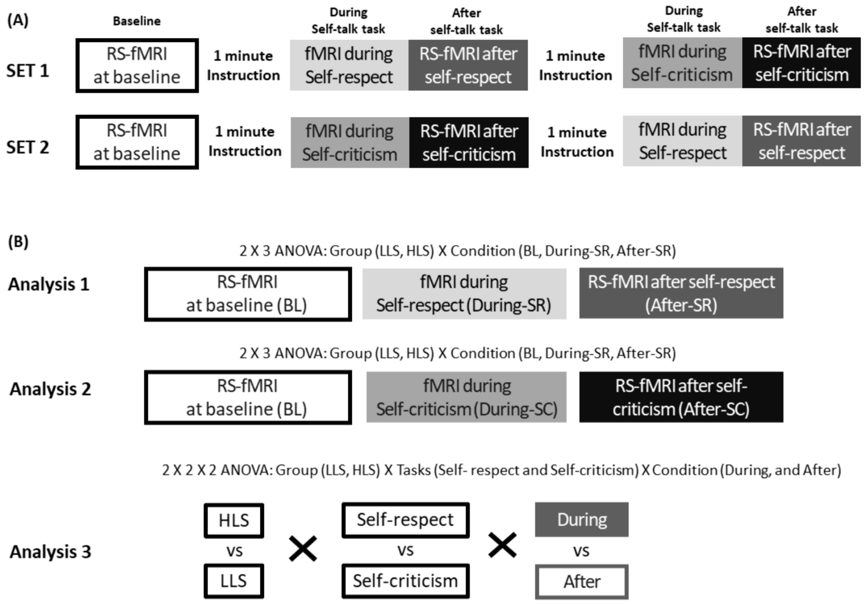

Figure 2. Illustration of experimental procedures and analysis method for Experiment 1. Functional magnetic resonance imaging (fMRI) experimental procedures (A), and the diagram for statistical method (B). The order of the self-respect and self-criticism tasks (SET 1 and SET 2) was counterbalanced across participants. Life satisfaction × condition analysis of covariance (ANCOVA) model was tested for self-respect in Analysis 1 and for self-criticism in Analysis 2.Abbreviation: LLS, low life satisfaction group; HLS, high life satisfaction group; RS-fMRI, resting-state fMRI; BL, baseline; SR, self-respect; SC, self-criticism.

H. Relationships between functional connectivity and basic psychological needs

To assess the capacity of resting-state functional connection before and after the two tasks for predicting an individual's basic psychological needs scores, a seed-based functional connectivity prediction model was constructed and applied to resting-state fMRI data and BPNS subscores[72]. As demonstrated in Figure 3, the process of developing this prediction model involved feature selection, model construction and prediction, and model significance testing.

To select input features, substantial relationships between functional connectivity and BPNS subscale scores were observed. The PCC, VMPFC, and NA-based resting-state functional connectivity maps were utilized to conduct linear regression analysis on the brain areas associated with autonomy, competence, and relatedness at baseline, after the self-respect test, and after the self-criticism task. Voxel-wise analyses were performed, and the significance was considered at $P_{FWE} < 0.05$ among clusters at a cluster-defining threshold of $p < 0.001$. The significant positive and negative associations were used as input features in subsequent analyses.

Based on the signs of the resulting significances, functional connections were separated into two parts: brain regions associated positively ($m^{(+)}$) and negatively ($m^{(-)}$) with the BPNS subscale scores. The new subject's BPNS subscale scores were then predicted using leave-one-subject cross-validation. Using n - 1 subjects (the training set), a predictive model was created iteratively and then evaluated on the remaining subject (the test set). Each was omitted once. Each iteration included model construction and prediction, as shown below. In addition, a summary statistic of functional connectivity (SSFC) was defined for each subject during the model building step by summing all functional connectivity values with significant correlations between BPNS subscale scores and each of the functional connectivity values in individual seed-based functional connectivity maps.

$$[SSFC]_i^{(+)} = \sum_v [FC]_v^{(i)} m_v^{(+)}$$

$$[SSFC]_i^{(-)} = \sum_v [FC]_v^{(i)} m_v^{(-)}$$

where $[FC]_{(i)}$ is a subject i’s feature vector of functional connectivity, and m(+) and m(-) are binary masks indicating the voxels showing significant positive or negative correlations with the BPNS subscale scores, respectively.

After obtaining SSFC for each subject in the training set, robust regression was used to model the association between SSFC (independent variable) and BPNS subscale scores (dependent variable).

$$[\text{Predicted BPNS subscore}]^{(+)} = A * [SSFC]^{(+)} + B$$

$$[\text{Predicted BPNS subscore}]^{(-)} = A * [SSFC]^{(-)} + B$$

$$[\text{Predicted BPNS subscore}]^{(+)\,\&\,(-)} = A^{(+)} * [SSFC]^{(+)} + A^{(-)} * [SSFC]^{(-)} + B$$

Finally, in the prediction step, positive SSFC and negative SSFC from the excluded subject were computed and inserted as an input to each of the two respective models to generate predicted BPNS subscale scores for that subject. These two steps were repeated iteratively so that each subject was excluded once. Finally, the predictive power of both models was assessed by correlating observed versus predicted BPNS subscale scores across all subjects.

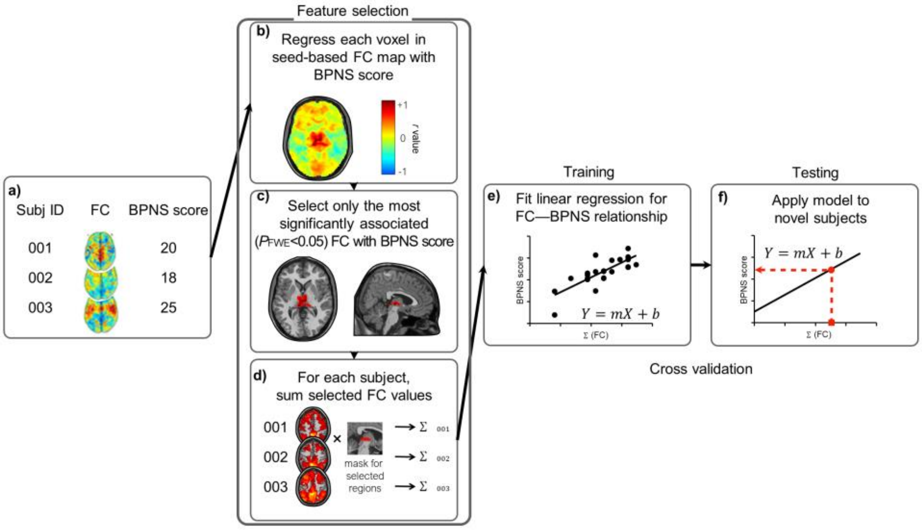

Figure 3. The process of generating the functional connectivity (FC)-based prediction model. For each participant, inputs to the prediction model were a seed-based FC map and the Basic Psychological Needs Scale (BPNS) subscale scores (a). Each voxel in seed-based FC maps was correlated with each of the BPNS subscale scores (b). The input data were divided into a training set and a testing set. Only the most significantly correlated FC was selected from the training data set (c). For each subject, the selected FC values was summed (d), fitted linear regression for FC-BPNS relationships (e), and applied the model to novel subject (f). Abbreviation: FWE, family-wise error

2. Experiment 2

A. Participants and Assignment

A total of 46 healthy college students participated in the study, which was advertised on a bulletin board. Pregnancy and a history of significant neurological or mental diseases were excluded as exclusion criteria. Additionally, subjects were tested for handedness using the Annett Handedness Inventory[65] to rule out left-handed persons and those having contraindications to MRI scanning, such as dental plates. Participants were randomly assigned to one of two groups: those who felt self-respect and those who felt self-criticism (self-respect group and self-criticism group, respectively). The participants were randomly assigned to the self-respect or self-criticism group using a computerized random number generator.

B. Clinical Assessments

Prior to performing fMRI tests, all subjects completed two self-report questionnaires. The first was the Rosenberg Self-Esteem Scale (RSES), which used a ten-item questionnaire and a four-point Likert scale to assess an individual's self-esteem[73]. The second was the Hospital Anxiety and Depression Scale (HADS), consisting of 14 questions (seven for anxiety and seven for depression) and a four-point Likert scale to assess an individual's degree of anxiety and depression[74].

C. Cognitive Tasks

Two sets of 5-minute cognitive tests (sRPM1 and sRPM2) were created to assess the effect of the self-talk task on cognitive performance before and after the task. The two activities were designed to be as close in complexity as feasible. From 60 questions in the RPM test[39,40] issues were randomly selected, and the response alternatives were reduced to four. The remaining 40 problems were randomly split into sRPM1 and sRPM2. Visual stimuli were displayed on the screen for 15 seconds in these activities, with a question in the middle and response possibilities at the bottom (Figure 4). In preliminary research, including ten persons not included in this fMRI trial, the average score for sRPM1 and sRPM2 was not statistically different (13.50 1.58 and 13.50 1.72, respectively; $t9 = 0.00$, $p = 1.00$).

D. Behavioral Data

The sRPM tasks were scored using the total number of correct responses, denoted by the sRPM1 and sRPM2 scores. The sRPM rise rate was determined using the formula [(sRPM2 score - sRPM1 score) / sRPM1 score] × 100 (%) to compare the modulation impact of two self-talk activities. In each group, paired t-tests were used to determine the sRPM1 and sRPM2 scores. The ANCOVA method was used to compare the increase rate of sRPM between two groups while adjusting for age since prior research has consistently shown age-related reductions in fluid intelligence in adults[34].

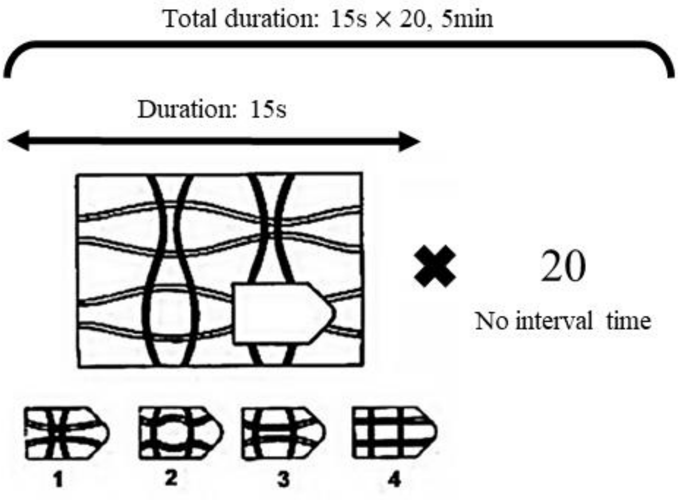

Figure 4. Illustration of cognitive tasks for sRPM1 and sRPM2. Each cognitive task consisted of 20 problems with four options from the RPM test without repetition. Each problem was presented for a period of 15 seconds. There was no time interval between two consecutive events.

E. Experimental procedures.

Experiment 2 used the identical audiovisual stimuli as Experiment 1, including the script, entire duration, presentation manner, and recording method. As seen in Figure 5A, the experimental approach included six 5-minute fMRI sessions in the following order: baseline resting state, first sRPM task (sRPM1), second resting state (post-sRPM1), self-talk task, second sRPM task (sRPM2), and third resting state (post-sRPM2). During the self-talk task sessions, participants were advised to maintain a respectful focus on mental imagery of self-respect or self-criticism, depending on their allocated group. The video coaching advised participants to concentrate on the narrated texts once and then mentally repeat them phrase by sentence. During the sRPM1 or sRPM2 session, participants selected their responses by hitting one of the four buttons on the screen with their index and middle fingers on both hands. The participants' sequence of performance on these two cognitive tests was counterbalanced. Throughout the three resting phases, participants maintained their focus on the crosshair in the center of the screen. For enhancing the effectiveness of the tasks, a minute-long following resting-state.

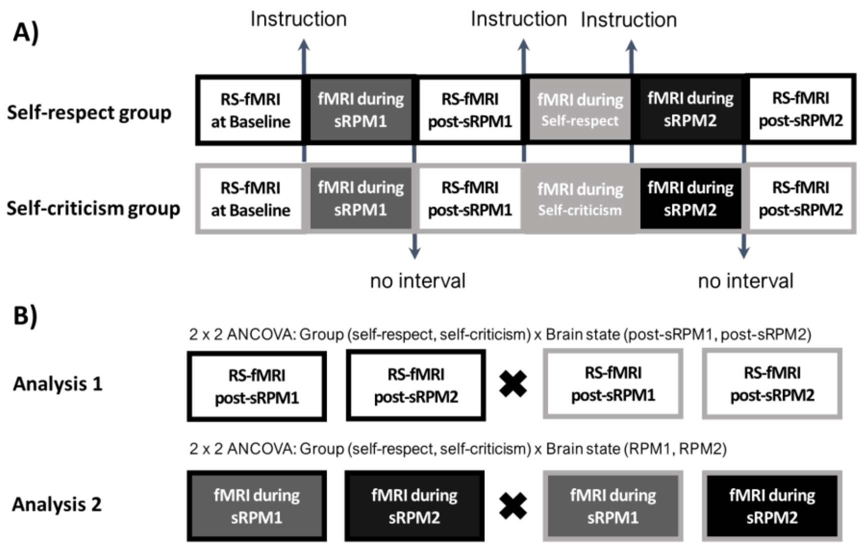

Figure 5. Illustration of experimental procedures and analysis method for Experiment 2. Experimental procedures of resting-state functional magnetic resonance imaging (rs-fMRI) and fMRI during the two short forms of Raven's Progressive Matrices (sRPM 1 and sRPM2) in the self-respect and self-criticism groups (a), and the diagrams for statistical analysis (b). The order of sRPM1 and sRPM2 was counterbalanced across participants in each group. Analysis of covariance (ANCOVA) was performed for self- talk (self-respect vs. self-criticism) × repetition (during-sRPM states in Analysis 1 and post-sRPM resting-states in Analysis 2).

F. fMRI Acquisition and Pre-processing of fMRI data

The acquisition of fMRI data followed the same protocol as in

Experiment 1. The FSL TOPUP tool[67,68] was used to compensate for susceptibility-induced geometric distortions in all fMRI images, and the first 10 scans were discarded for magnetic field stabilization. In MNI-space, functional data were preprocessed using the CONN functional connectivity toolkit (ver.19.c, http://www.nitrc.org/projects/conn) and SPM12. The remaining 375 functional images for each run were realigned to the first scan, and the slice-timing correction approach was used to adjust for temporal misalignment between various slices. Correcting motion was accomplished by regressing out both motion parameters and specific frames with motion outliers using the Artifact Rejection Toolbox (http://www.nitrc.org/projects/artifact_detect) implemented in CONN for outlier detection and scrubbing to generate confound regressors for motion parameters (global-signal Z value = 9; subject motion = 2 mm). Using the SPM12 unified segmentation and normalization procedure[75], functional and structural data were normalized to standard MNI space and segmented into grey matter, white matter, and cerebrospinal fluid tissue classes. To improve the signal-to-noise ratio and mitigate the effect of subject-to-subject variability in functional data and gyral architecture, functional smoothing was performed using spatial convolution with a Gaussian kernel of 6 mm full width at half maximum. Temporally band-pass filtered (0.009–0.08 Hz) functional data were then used to reduce low-frequency drift while limiting the effect of physiological, head-motion, and other noise sources[76].

G. Seed-based functional connectivity

Along with the three ROIs identified in Experiment 1 (NA, PCC, and VMPFC), the task-positive network, bilateral DLPFC and bilateral IPS, were selected. Because increasing the difficulty of RPM tests was known to be resulted in higher activation in IPS and DLPFC[56], the impact of task-related cognitive burden on functional connectivity associated with various modes of self-talk may give important insights. Their MNI coordinates (x/y/z) were established using data from earlier investigations[77]: the DLPFC, 42/24/24; and the IPS, 36/-54/39. Because we hypothesized that the NA in the reward-motivation network, the VMPFC in self-referential processing, the PCC in the DMN, and the DLPFC and IPS in the task-positive network would all undergo changes associated with the changes in performance of cognitive tasks in response to the two contrasting self-talk tasks, we used a seed-based whole-brain approach, selecting all voxels within a 3-mm radius of selected MNI coordinates as the ROIs.

In the first-level analysis, potential confounding factors for the estimated BOLD signal were estimated and removed separately for each voxel, subject, and functional run/session, using CONN's default denoising pipeline. These factors included noise components from cerebral white matter and cerebrospinal areas, estimated subject-motion parameters, identified outlier scans, or scrubbing, constant, and first-operator parameters. Functional connection between each ROI and each voxel in the brain was quantified using Fisher-transformed bivariate correlation coefficients between functional data time series. To determine whether there were any significant differences in functional connectivity associated with changes in cognitive performance during and after two self-talk tasks, two repeated-measures ANCOVAs were conducted with two distinct within-participant factors (during and after cognitive task: sRPM1 versus sRPM2, and post-sRPM1 versus post-sRPM1) and self-talk as a between-participant factor (Figure 5B).

Two self-talk tasks and two states during cognitive tasks were examined in ANCOVA model I: 2 (self-talk, self-respect versus self-criticism) × 2 (repetition, sRPM1 versus sRPM2). Two self-talk tasks and two resting states after cognitive tasks were evaluated in the ANCOVA model II: 2 (self-talk, self-respect versus self-criticism) × 2 (repetition, post-sRPM1 versus post-sRPM2). Age was included in the models to exclude any confounding effects since earlier research indicated that changes in functional connectivity78 cause age-related reductions in fluid intelligence. Statistical inferences for identifying brain areas with main and interaction effects were made using a cluster-level false-discovery-rate-corrected *p* (P_{FDR}) threshold of < 0.05 and a cluster-forming threshold of uncorrected $p < 0.001$ at the voxel level. Post-hoc two-sample t- or paired t-tests were used to compare the mean beta values of all voxels inside significant clusters, with significant findings defined as Bonferroni-corrected $p < 0.05$.

H. Relationships between changes in functional connectivity and increase of sRPM scores

To identify the brain regions with significant associations between changes in during-sRPM or post-sRPM resting-state functional connectivity and changes in cognitive task performance, functional connectivity difference maps of each ROI were calculated by subtracting during-sRPM1 from during-sRPM2 and subtracting post-sRPM1 from post-sRPM2 and used in linear regression analysis with the sRPM increase rates as a dummy variable. Voxel wise-analyses were performed, and the significance was considered at $P_{FDR} < 0.05$ among clusters at a cluster-defining threshold of uncorrected $p < 0.001$. Next, the Pearson correlation between the mean beta values of all significant clusters in functional connectivity difference maps and the sRPM rise rates was then calculated.

II. RESULTS

1. Experiment 1

A. Demographics and clinical characteristics

All 48 participants were included in the analysis for Experiment 1. Table 2 presents the demographic and clinical assessments of participants. There was no significant group difference in age ($t_{46} = 1.850$, $p = 0.707$), and sex (significant by *Chi-square*, p = 0.562). The SWLS scores were significantly higher in the HLS group (t_{46} = 12.8, p < 0.001). The HLS group showed significantly higher scores in all BPNS subscales than the LLS group: autonomy (t_{46} = 3.8, p < 0.001), competence (t_{46} = 4.9, p < 0.001), and relatedness (t_{46} = 3.4, p = 0.001).

Table2. Demographics and Clinical Characteristics for Experiment 1

Experiment 1 (n = 48)				
Variables	**HLS (n = 24)**		**LLS (n = 24)**	
	Mean	**SD**	**Mean**	**SD**
Age	22.0	2.0	23.3	2.5
Sex	12 males in both groups			
SWLS	21.4	1.6	14.7	2.1
BPNS				
autonomy	28.8	2.8	25.4	3.3
competence	29.2	3.5	24.5	3.3
relatedness	31.5	3.5	28.3	3.2

Note. HLS = high life satisfaction group; LLS = low life satisfaction group; SD = standard deviation; SWLS = Satisfaction with Life Scale; BPNS = Basic Psychological needs Scale.

B. Neuroimaging Results

(1) Analysis 1: Neural modulation associated with Self-respect task

The main effect of condition was conducted for brain networks that might be of interest in this study, which were the frontoparietal network, frontostriatal network, visual network, salience network, default mode network, and cerebellar network. In the case of Analysis 1 in Experiment 1, the significant regions were seen only in PCC-based functional connectivity with the frontoparietal network and in VMPFC-based functional connectivity with the salience network. Functional connectivity from PCC to frontoparietal network were increased during self-respect task and after self-respect task compared to baseline (Figure 4A). VMPRC-based functional connectivity with salience network was increased during self-talk task from baseline, then decreased after self-talk task (Figure 4B).

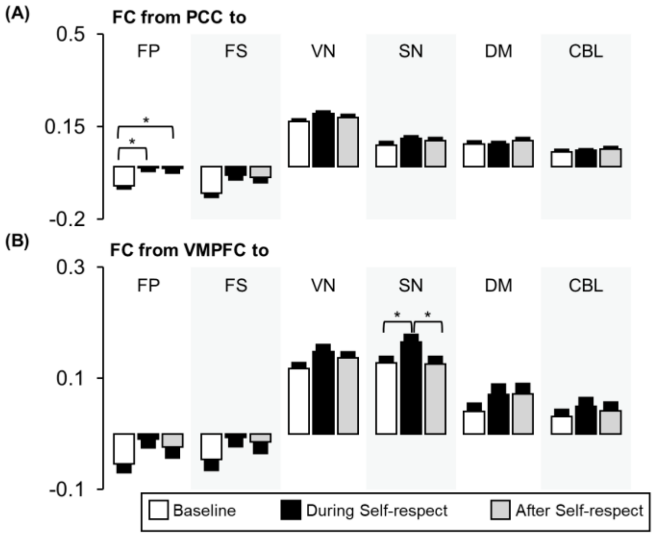

Figure 6. Illustration of the condition effect associated with self-respect obtained from Analysis 1 in Experiment 1. For each seed region, the average values of six functional modules are presented. The post-hoc comparison of the significant ANOVA results are also described within the plot. Asterisks denote statistical significance from the post-hoc comparisons with Bonferroni-correction at * $p < 0.05$. Abbreviation: FC, functional connectivity; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; FP, frontoparietal; FS, frontostriatal; VN, visual network; SN, salience network; DM, default mode; CBL, cerebellum.

A significant group × condition interaction effect from Analysis 1 in Experiment 1 was seen in the PCC – left ventrolateral prefrontal cortex (VLPFC) functional connectivity (Table 3). Post-hoc analysis of these significant Life satisfaction × condition interaction in the functional connectivity value presented that the functional connectivity values in the PCC – left VLPFC (x/y/z: -50/10/16) at the baseline did not significantly differ between the two groups, whereas those after the self-respect task were significantly higher in the LLS group than in the HLS group (t_{46} = 2.3, p =

0.025). The functional connectivity values in the PCC – left VLPFC (x/y/z: -44/38/-2) at the baseline and those after the self-respect task did not significantly differ between the two groups.

Table 3. Interaction effect of Life satisfaction and condition from Analysis 1 in Experiment 1

Analysis 1 in Experiment 1						
Source	**Target**	**MNI coordinate**			**Vox**	**Z**
		x	**y**	**z**		
PCC	L. VLPFC	-50	10	16	181	4.23
		-44	38	-2	136	4.05
VMPFC	No significant region					
NA	No significant region					

Significant clusters were obtained at voxel-level $P_{unc} < 0.001$ and cluster-level $P_{FWE} < 0.05$.
Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; L., Left; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; VLPFC, ventrolateral prefrontal cortex

The main effect of life satisfaction is presented in Table 4. First, regions significant to the effect of Life satisfaction (group: HLS and LLS) from Analysis 1 in Experiment 1 were the VMPFC-based functional connectivity with the right rostromedial prefrontal cortex (RMPFC) and the right DLPFC. The regions significant to the main effect of life satisfaction were carried to post-hoc analysis to observe the directionality. The right RMPFC was found to activate greater in the LLS group than HLS group, as well as right DLPFC.

Table 4. Main effect of Life satisfaction from Analysis 1 in Experiment 1

Analysis 1 in Experiment 1						
Source	**Target**	**MNI coordinate**			**Vox**	**Z**
		x	**y**	**z**		
PCC	No significant region					
VMPFC	R. RMPFC	8	56	6	859	5.78
	R. DLPFC	20	40	30	351	4.45
NA	No significant region					

Significant clusters were obtained at voxel-level $P_{unc} < 0.001$ and cluster-level $P_{FWE} < 0.05$.

Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; L., Left; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; RMPFC, rostromedial prefrontal cortex; DLPFC, dorsolateral prefrontal cortex.

(2) Analysis 2: Neural Modulation associated with Self-criticism task

The main effect of condition of Analysis 2 in Experiment 1was conducted for brain networks (frontoparietal network, frontostriatal network, visual network, salience network, default mode network, and cerebellar network) as in Analysis 1. The results from a post-hoc analysis on these functional connectivity values to characterize the pair-wise differences among the conditions are illustrated in Figure 7. The average value of functional connectivity from PCC to brain networks increased from baseline to during self-criticism task in frontoparietal network, frontostriatal network, visual network, salience network, default mode network, and cerebellar network . In the comparison between during self-criticism task and after self-criticism task, frontoparietal network, frontostriatal network, visual network, salience network, default mode network, and cerebellar network presented significant increase in after self-criticism task. From baseline to after self-criticism task, the average value of functional connectivity from PCC increased in several brain networks: frontoparietal network, frontostriatal network, visual network, salience network, and default mode network (Figure 7A).

The average value of functional connectivity from VMPFC to brain networks increased from baseline to during self-criticism task in frontoparietal network, frontostriatal network, visual network, default mode network, and cerebellar network. In the comparison between during self-criticism task and after self-criticism task, frontoparietal network, frontostriatal network, visual network, and cerebellar network presented significant increase in after self-criticism task. From baseline to after self-criticism task, the average value of functional connectivity from PCC increased in several brain networks: frontostriatal network, and visual network (Figure 7B).

The average value of functional connectivity from NA to brain networks increased from baseline to during self-criticism task in frontostriatal network, and cerebellar network. In the comparison between during self-criticism task and after self-criticism task, frontoparietal network, frontostriatal network, visual network, salience network, default mode network, and cerebellar network presented significant increase in after self-criticism task. From baseline to after self-criticism task, the average value of functional connectivity from PCC increased in several brain networks: frontoparietal network, frontostriatal network, visual network, and salience network (Figure 7C).

Except for functional connectivity between the VMPFC and salience network, the significant condition effect was seen in almost all connections, including PCC-based, VMPFC-based, and NA-based functional connectivity with brain networks. In particular, although the after-task condition was in the resting-state like the baseline, PCC-based, VMPFC-based, or NA-based functional connectivity showed a significant increase with two or four networks in the after-task condition than in the baseline.

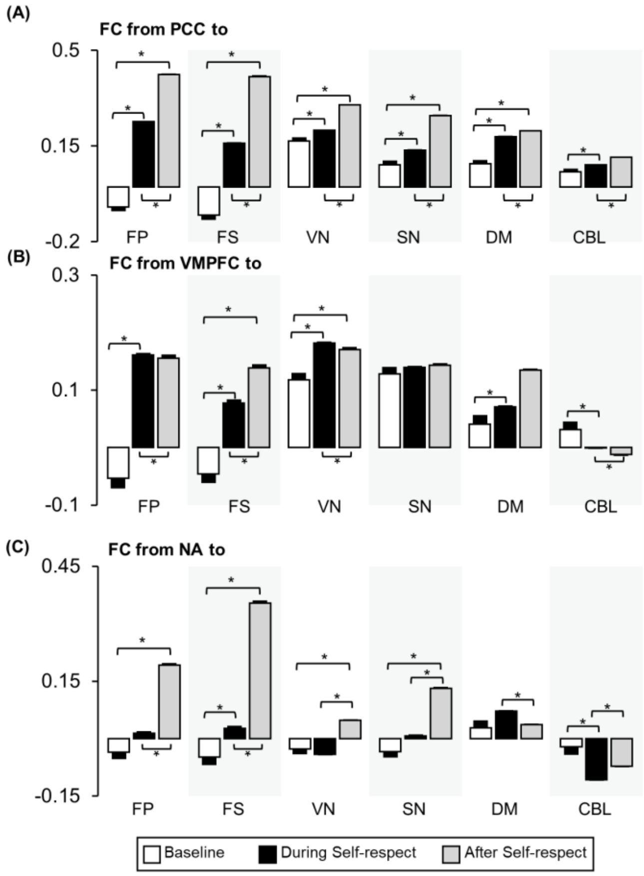

Figure 7. Illustration of the condition effect associated with self-criticism obtained from Analysis 2 in Experiment 1. For each seed region, the average values of six functional modules are presented. The post-hoc comparison of the significant ANOVA results are also described within the plot. Asterisks denote statistical significance from the post-hoc comparisons with Bonferroni-correction at * $p < 0.05$. Abbreviation: FC, functional connectivity; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; FP, frontoparietal; FS, frontostriatal; VN, visual network; SN, salience network; DM, default mode; CBL, cerebellum.

The significant group × condition interaction effect was seen in the VMPFC – left DMPFC, VMPFC – right DLPFC, NA – right DMPFC, NA – bilateral DLPFC, NA – ACC, NA – right supramarginal gyrus, and NA – bilateral Heschl’s gyrus (Table 6). The results from a post-hoc analysis on these functional connectivity values to characterize the interactions are shown in Figure 8. The functional connectivity strengths of the VMPFC – left DMPFC at the baseline were significantly higher in the LLS group (t_{46} = 2.8, p = 0.008), whereas those after the self-criticism task were significantly lower in the LLS group compared to the HLS group (t_{46} = -2.9, p = 0.008). The functional connectivity strengths of the NA – left Heschl's gyrus at the baseline were significantly higher in the LLS group (t_{46} = 4.3, $p < 0.001$), whereas those after the self-criticism task did not differ between the two groups. The functional connectivity strengths of the NA – right supplementary motor area, NA – left DMPFC, NA – left DLPFC, NA – right DLPFC, and NA – bilateral ACC at the baseline did not differ between the two groups, whereas those after the self-criticism task were significantly lower in the LLS group compared to the HLS group (t_{46} = -2.3, p = 0.027; t_{46} = -2.2, p = 0.033; t_{46} = -2.0, p = 0.048; t_{46} = -2.3, p = 0.024; t_{46} = -2.3, p = 0.024, respectively).

Table 5. Interaction effect of Life satisfaction and condition from Analysis 2 in Experiment 1

Analysis 1 in Experiment 1						
Source	**Target**	**MNI coordinate**			**Vox**	**Z**
		x	**y**	**z**		
PCC	No significant region					
VMPFC	L. DMPFC	-16	42	32	109	4.12
	R. DMPFC	42	38	4	139	4.07
NA	R. DMPFC	18	52	40	128	4.50
	L. DLPFC	-26	22	44	167	4.05
	R. DLPFC	30	18	50	176	4.10
	B. ACC	0	4	18	146	3.64
	R. SMG	38	-36	60	316	4.81
	R. SMA	12	16	58	454	4.69
	L. HG	-48	-18	12	1859	6.37
	R. HG	50	-6	8	146	4.09

Significant clusters were obtained at voxel-level $P_{unc} < 0.001$ and cluster-level $P_{FWE} < 0.05$.
Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; L., Left; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; VLPFC, ventrolateral prefrontal cortex; DMPFC, dorsomedial prefrontal cortex; DLPFC, dorsolateral prefrontal cortex; ACC, anterior cingulate cortex; SMG, supramarginal gyrus; SMA, supplementary motor area; HG, Heschl's gyrus.

The main effect of life satisfaction is presented in Table 6. Target regions significant to the effect of Life satisfaction (group: HLS and LLS) from Analysis 2 in Experiment 1 were the PCC-based functional connectivity with the left VLPFC and right superior parietal lobule (SPL), VMPFC-based functional connectivity with right RMPFC and right DMPFC, and NA-based functional connectivity with left Heschl's gyrus (HG) and left precentral gyrus (PrCG). The regions significant to the main effect of life satisfaction were carried to post-hoc analysis to observe the directionality. Compared to the HLS group, functional connectivity in the LLS group was significantly higher in the VMPFC – right RMPFC, the VMPFC – right DMPFC, the NA – left HG, and the NA – left PrCG.

Table 6. Main effect of Life satisfaction from Analysis 2 in Experiment 1

Analysis 2 in Experiment 1						
Source	**Target**	**MNI coordinate**			**Vox**	**Z**
		x	**y**	**z**		
PCC	L. VLPFC	-56	28	18	118	4.56
	R. SPL	20	-56	72	126	4.25
VMPFC	R. RMPFC	8	56	6	120	4.45
	R. DMPFC	12	42	36	133	4.02
NA	L. HG	-48	-16	12	126	4.92
	L. PrCG	-36	-16	52	130	3.93

Significant clusters were obtained at voxel-level $P_{unc} < 0.001$ and cluster-level $P_{FWE} < 0.05$.

Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; L., Left; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; VLPFC, ventrolateral prefrontal cortex; SPL, superior parietal lobule; RPFC, rostromedial prefrontal cortex; DMPFC, dorsomedial prefrontal cortex; HG, Heschl's gyrus; PrCG, precentral gyrus.

(3) Relationships between resting-state functional connectivity and basic psychological needs

Table 7 presents the relationships between resting-state functional connectivity and BPNS subscale scores. At the baseline, significant positive correlations between NA-based functional connectivity and the autonomy scores were found in the left cerebellum in the LLS group and in the left postcentral gyrus in the HLS group. PCC- and VMPFC-based functional connectivity at the baseline showed no significant correlation with any BPNS subscale scores in both groups. After the self-respect task, PCC-based functional connectivity showed no significant correlations with any BPNS subscale scores in the LLS group, but the HLS group demonstrated positive correlations with the autonomy scores in the right thalamus and with the competence scores in the bilateral precentral gyri (facial motor areas), left precentral gyrus (hand motor areas), and right Heschl's gyrus. VMPFC- and NA-based functional connectivity after the self-respect task showed no significant correlations with any BPNS subscale scores in both groups. After the self-criticism task, the LLS group showed positive correlations of PCC-based functional connectivity in the left precuneus and left Heschl's gyrus with the autonomy scores; negative correlations of VMPFC-based functional connectivity in the left angular gyrus, right supramarginal gyrus, and left cerebellum with the autonomy scores; positive correlation of NA-based functional connectivity in the bilateral lingual gyrus and right middle temporal gyrus with the relatedness scores; and negative correlations of NA-based functional connectivity in the left caudate, left thalamus, and cerebellar vermis with the relatedness scores. However, no seed-based functional connectivity after the self- respect task showed any significant correlation with any BPNS subscale scores in the HLS group.

Table 7. Results of correlation analysis between resting-state functional connectivity and BPNS subscale scores.

Group	Functional connectivity		BPNS component	MNI coordinate, mm			Vox	Z
	Seed	Target region		x	y	z		
at baseline								
LLS	PCC	not significant						
	VMPFC	not significant						
	NA	L. Cerebellum	Autonomy	-22	-76	-30	122	4.07
HLS	PCC	not significant						
	VMPFC	not significant						
	NA	L. PoCG	Autonomy	-54	-28	58	125	4.21
after self-respect								
LLS	PCC	not significant						
	VMPFC	not significant						
	NA	not significant						
HLS	PCC	R. Thalamus	Autonomy	4	-18	2	389	5.13
		L. PrCG (face)	Competence	-48	-4	38	112	-4.2
		R. PrCG (face)	Competence	48	6	50	715	-5.21
		L. PrCG (hand)	Competence	-26	-28	56	148	-3.97
		R. Heschl's gyrus	Competence	54	-14	4	123	-4.06
	VMPFC	not significant						
	NA	not significant						
after self-criticism								
LLS	PCC	L. Precuneus	Autonomy	-12	-52	62	134	4.06
		L. Heschl's gyrus	Autonomy	-60	-60	16	106	4.06
	VMPFC	L. Angular gyrus	Autonomy	-36	-62	36	134	-3.97
		R. Supramarginal gyrus	Autonomy	48	-48	44	122	-3.94
		L. Cerebellum	Autonomy	-40	-74	-38	285	-4.14
	NA	L. Lingual gyrus	Relatedness	-22	-74	-4	223	3.97
		R. Lingual gyrus	Relatedness	26	-54	-6	308	3.62
		R. Middle temporal gyrus	Relatedness	54	-46	-2	185	3.79
		L. Caudate	Relatedness	-10	-8	16	122	-4.08
		L. Thalamus	Relatedness	-26	-22	18	163	-4.28
		M. Cerebellar vermis	Relatedness	0	-56	-28	117	-4.92
HLS	PCC	not significant						
	VMPFC	not significant						
	NA	not significant						

Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; L., left; R., right; B., bilateral; M., medial; NA, nucleus accumbens; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; PoCG, postcentral gyrus; PrCG, precentral gyrus.

These identified significant relationships were used as the input features of the prediction model, which was built based on different functional connections in each group and in each resting-state, including the baseline, after the self-respect task, and after the self-criticism task. As shown in Figure 9, the prediction model achieved significant correlations between the predicted and actual scores on the three BPNS subscale scores. Specifically, the observed autonomy scores showed significant correlations with the [predicted autonomy scores]$^{(+)}$ estimated by NA – left cerebellum functional connectivity at the baseline in the LLS group (r = 0.67, p = 0.0003) and NA – left postcentral gyrus functional connectivity at the baseline in the HLS group (r = 0.66, p = 0.0002).

After the self-respect or self-criticism task, the prediction model using PCC- and VMPFC-based functional connectivity achieved significant correlations between the predicted and actual scores on the autonomy scores. In the HLS group after the self-respect task, PCC – bilateral thalamus functional connectivity played a pivotal role in estimating the [predicted autonomy scores]$^{(+)}$ (r = 0.78, p < 0.0001). In the LLS group after the self-criticism task, PCC-based functional connectivity with the left Heschl’s gyrus and left precuneus (r = 0.72, p = 0.0001) and VMPFC-based functional connectivity with the right inferior parietal lobule, left angular gyrus, and left cerebellum (r = 0.68, p = 0.0003) showed an important role in estimating the [predicted autonomy scores]$^{(+)}$ and the [predicted autonomy scores]$^{(-)}$, respectively.

The competence and relatedness scores were predicted by functional connectivity only after the self-respect and self-criticism tasks, respectively. In the HLS group after the self-respect task, PCC-based functional connectivity with the bilateral precentral gyrus (facial motor area), left precentral gyrus (hand motor area), and right Heschl’s gyrus showed a crucial role in estimating the [predicted competence scores]$^{(-)}$ (r = 0.80, p < 0.0001). In the

LLS group after the self-criticism task, NA-based functional connectivity with the bilateral lingual gyrus, right middle temporal gyrus, the medial cerebellar vermis, left thalamus, and left putamen significantly estimated the [predicted relatedness scores]$^{(+)\,\&\,(-)}$ (r = 0.73, p = 0.0001) were found.

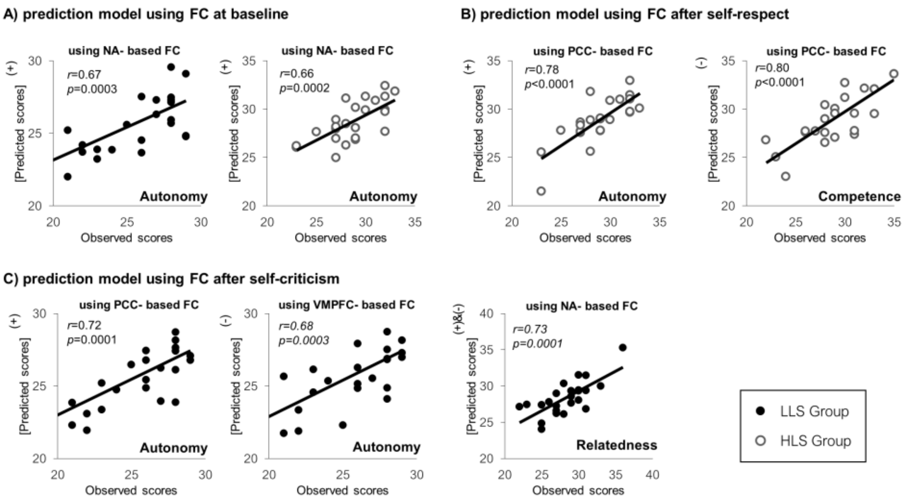

Figure 8. Scatter plot of the true values with respect to their predicted Basic Psychological Needs Scale (BPNS) subscale scores using the prediction model with the summary static of functional connectivity (FC). With the functional connectome-based prediction models, Pearson's correlations of r > 0.6 and p < 0.0005 were achieved for the autonomy scores using the functional connectome at baseline and after both tasks. Pearson's correlations of r = 0.73 (p = 0.0001) and r = 0.80 (p < 0.0001) were achieved for relatedness using the functional connectome after the self-criticism task and competence using the functional connectome after the self-respect task, respectively. The sign, which are (+)or(-), superscripted on the name of y-axis indicates that the only positive or negative relationships between functional connectivity and BPNS subscale scores were used to compute the predicted scores. The predicted relatedness scores were computed using both positive and negative relationships between functional connectivity and BPNS subscale scores. Abbreviation: NA, nucleus accumbens; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; LLS, low life satisfaction; HLS, high life satisfaction

2. Experiment 2

A. Demographics and Clinical Characteristics

Although a total of 46 participants were scanned, data from those with the sRPM1 score of seven (two standard deviations lower than mean) or less were excluded from the analysis because exceptionally low scores of the first cognitive task suggesting poor attention might have an excessive and inappropriate impact on the analysis. Three participants from the self-criticism group met this criterion and were excluded. The final analysis for Experiment 2 was conducted on the self-respect group of 23 participants and the self-criticism group of 20 participants. Table 8 presents the demographic and clinical assessments of participants. There was no significant group difference in age (t_{41} = 1.906 , p = 0.063), and sex (significant by *Chi-square*, p = 0.767). The RSES score, HADS – anxiety score, and HADS – depression score did not significantly differ between the two groups (t_{41} = 0.23, p = 0.819; t_{41} = -0.03, p = 0.976; and t_{41} = 0.13, p = 0.899, respectively).

Table 8. Demographics and Clinical Characteristics for Experiment 2

Experiment 2 (n = 43)				
Variables	**Self-respect (n = 23)**		**Self-criticism (n = 20)**	
	Mean	**SD**	**Mean**	**SD**
Age	22.5	2.1	23.9	2.7
Sex	12 males		13 males	
RSES	30.7	7.2	31.1	5.3
HADS				
Anxiety score	4.8	3.0	4.8	2.7
Depression score	5.1	3.4	5.3	2.7

Note. SD = standard deviation; RSES, Rosenberg Self-Esteem Scale; HADS, Hospital Anxiety and Depression Scale.

B. Behavioral data

Table 8 presents the behavioral summary of Experiment 2. Compared to sRPM1 score, a significant increase in sRPM2 score was observed in the self-criticism group (t_{19} = 2.80, p = 0.011, Figure 9A), but not in the self-respect group (t_{22} = 1.29, p = 0.212, Figure 9B). Accordingly, the self-criticism group showed significantly higher sRPM increase rate than the self-respect group ($F_{1,40}$ = 5.08, p = 0.030, Figure 9C).

Table 9. Behavior summary of Experiment 2

Experiment 2 (n = 43)				
Variables	**Self-respect (n = 23)**		**Self-criticism (n = 20)**	
	Mean	**SD**	**Mean**	**SD**
sRPM1 score	12.7	1.8	12.5	2.3
sRPM2 score	13.3	2.4	14.2	1.7
sRPM increase rate (%)	5.6	18.8	17.1	24.8

Note. sRPM, short form of Raven's Progressive Matrices. sRPM increase rate = [(sRPM2 score – sRPM1 score) / sRPM1 score] × 100

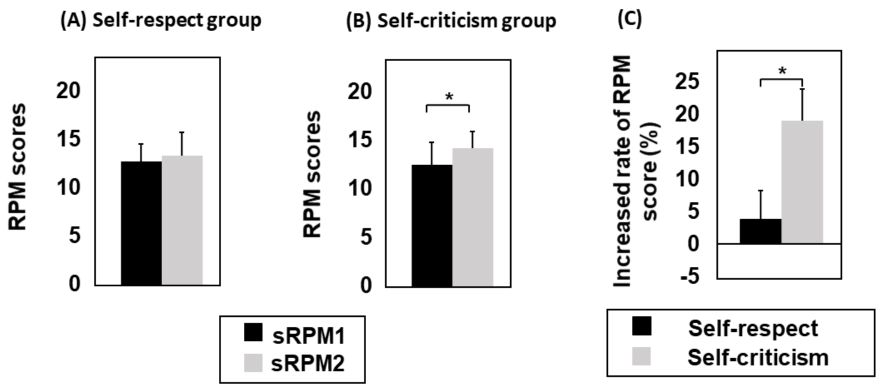

Figure 9. The sRPM scores and increased rate of RPM scores by the group (Self-respect and Self-criticism group). Comparisons of sRPM scores in Self-respect group (A) and Self-criticism group (B), and increased rate of RPM scores (%) (C). Abbreviation: RPM, Raven's Progressive Matrix.

C. Neuroimaging Results

(1) Analysis 1: Changes in functional connectivity during-sRPM

There was no inter-regional connectivity showing the self-talk × repetition interaction effect in Analysis 1. The main effect of self-talk is presented in Table 8. Target regions significant to the effect of self-talk (self-respect group and self-criticism group) from Analysis 1 in Experiment 2 were only in DLPFC-based connectivity with the right PrCG. The DLPFC – PrCG functional connectivity were carried to post-hoc analysis to observe the directionality, in which the connectivity strengths were significantly higher in the self-respect group than in the self-criticism group (t_{41} = 5.72, p < 0.001, Figure 11A).

Table 10. Main effect of self-talk from Analysis 1 in Experiment 2

Analysis 1 in Experiment 2						
Source	**Target**	**MNI coordinate**			**Vox**	**Z**
		x	**y**	**z**		
PCC	No significant region					
VMPFC	No significant region					
NA	No significant region					
DLPFC	R. PrCG	36	-26	54	298	5.14
IPS	No significant region					

Significant clusters were obtained at voxel-level P_{unc} < 0.001 and cluster-level P_{FWE} < 0.05.

Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; DLPFC, dorsolateral prefrontal cortex; IPS, intraparietal sulcus ; PrCG, precentral gyrus.

The main effect of self-talk is presented in Table 9. The main effect of repetition was seen in the connections of NA – right lateral occipital cortex (LOC), VMPFC – bilateral parietal operculum cortex (POC), PCC – left PrCG, and in the connection of DLPFC - right middle temporal gyrus (MTG). The results from a post-hoc analysis on these functional connectivity values to characterize the interactions are shown in Figure 11B. The functional connectivity strengths of NA – right LOC, VMPFC – bilateral POC, and PCC – left PrCG were all significantly increased during sRPM2 compared with sRPM1 (t_{41} = 6.10, p < 0.001; t_{41} = 6.00, p < 0.001; t_{41} = 5.23, p < 0.001; and t_{41} = 7.11, p < 0.001, respectively). The connectivity strengths of DLPFC - right MTG were significantly decreased during sRPM2 compared with sRPM1 (t_{41} = -6.40, p < 0.001).

Table 11. Main effect of repetition from Analysis 1 in Experiment 2

Analysis 2 in Experiment 2						
Source	**Target**	**MNI coordinate**			**Vox**	**Z**
		x	**y**	**z**		
PCC	L. PrCG	-56	04	16	452	7.36
VMPFC	L. POC	-54	-26	20	278	6.46
	R. POC	54	-28	26	119	4.24
NA	R. LOC	42	-78	-22	209	5.68
DLPFC	R. MTG	60	-32	-14	230	-7.05
IPS	No significant region					

Significant clusters were obtained at voxel-level P_{unc} < 0.001 and cluster-level P_{FWE} < 0.05.

Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; L, Left; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; DLPFC, dorsolateral prefrontal cortex; IPS, intraparietal sulcus ; PrCG, precentral gyrus; POC, parietal operculum cortex; LOC, lateral occipital cortex; MTG, middle temporal gyrus.

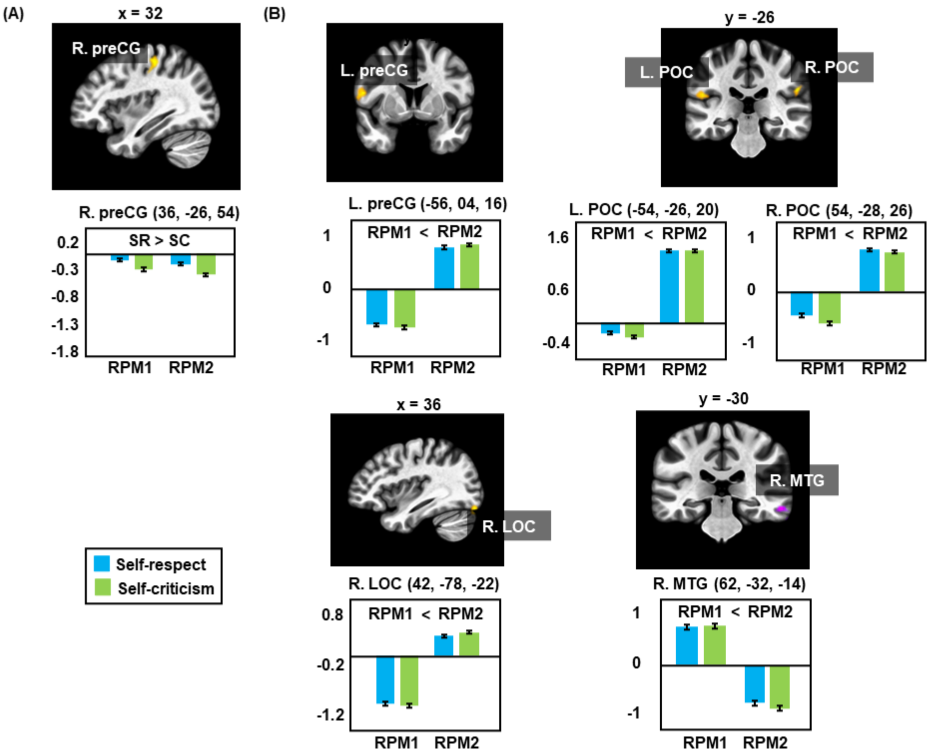

Figure 10. Main effect of self-talk and repetition in Analysis 1 of Experiment 2. Main effect of self-talk (A) and main effect of repetition (B). Abbreviations. L, Left; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; DLPFC, dorsolateral prefrontal cortex; IPS, intraparietal sulcus ; PrCG, precentral gyrus; POC, parietal operculum cortex; LOC, lateral occipital cortex; MTG, middle temporal gyrus.

(2) Analysis 2: Changes in functional connectivity post-sRPM

The interaction effect of self-talk and repetition is presented in Table 10. The self-talk × repetition interaction effect was observed in NA-based connectivity with the right inferior temporal gyrus (ITG). As shown in Figure 12, post-hoc tests showed that the NA-right ITG connectivity strengths in the post-sRPM1 resting-state did not differ between the two groups, whereas those in the post-sRPM2 resting-state were significantly higher in the self-respect group than in the self-criticism group (t_{41} = 5.27, p = 0.001).

Table 12. The interaction effect of self-talk × repetition from Analysis 2 in Experiment 2

Analysis 2 in Experiment 2						
Source	**Target**	**MNI coordinate**			**Vox**	**Z**
		x	**y**	**z**		
PCC	No significant region					
VMPFC	No significant region					
NA	R. ITG	52	-58	-10	113	5.04
DLPFC	No significant region					
IPS	No significant region					

Significant clusters were obtained at voxel-level $P_{unc} < 0.001$ and cluster-level $P_{FWE} < 0.05$.

Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; DLPFC, dorsolateral prefrontal cortex; IPS, intraparietal sulcus ; ITG, inferior temporal gyrus.

The main effect of self-talk is presented in Table 11.The main effect of self-talk was found only in NA-based connectivity with the left MTG and right LOC. Post-hoc tests showed that the connectivity strengths of these two were significantly higher in the self-respect group than in the self-criticism group (t_{41} = 5.20, $p < 0.001$; and t_{41} = 5.25, $p < 0.001$, respectively, Figure 12B). There was no inter-regional connectivity showing the main effect of repetition in Analysis 2

Table 13. The main effect of self-talk from Analysis 2 in Experiment 2

Analysis 2 in Experiment 2						
Source	**Target**	**MNI coordinate**			**Vox**	**Z**
		x	**y**	**z**		
PCC	No significant region					
VMPFC	No significant region					
NA	L. MTG	-66	-48	04	144	5.71
	R. LOC	54	-68	12	142	5.25
DLPFC	No significant region					
IPS	No significant region					

Significant clusters were obtained at voxel-level *Punc* < 0.001 and cluster-level P_{FWE} < 0.05.

Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; DLPFC, dorsolateral prefrontal cortex; IPS, intraparietal sulcus ; MTG, middle temporal gyrus; LOC, lateral occipital cortex.

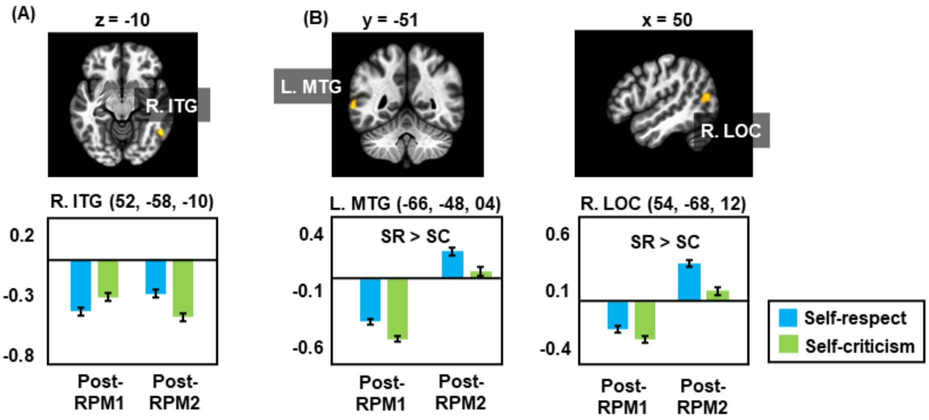

Figure 11. Interaction effect of self-talk and repetition and main effect of self-talk in Analysis 2 of Experiment 2. Interaction effect of self-talk and repetition (A) and main effect of self-talk (B).

(3) Association between changes in functional connectivity and increase of sRPM scores

To identify the effects of self-talk tasks on changes of cognitive performance associated with changes of functional connectivity, significant relationships between score increase rate of the short form of Raven's Progressive Matrices (sRPM) and changes of functional connectivity in during-sRPM states and in post-sRPM resting-states in each of the self-respect and self-criticism groups were investigated. Table 12 presents brain regions that showed the significant association between changes in inter-regional functional connectivity and sRPM increase rates. In the self-respect group, significant correlations between changes in during-sRPM state connectivity and sRPM increase rates were observed in IPS-based connectivity with the bilateral orbitofrontal cortex (OFC) (positive correlation), right temporal pole (positive correlation), right ITG, and right thalamus (negative correlation) (Figure 13A). The self-respect group also showed negative correlations between changes in post-sRPM resting-state connectivity and sRPM increase rates in NA-based connectivity with the left supplementary motor area (SMA) and left PrCG (Figure 13B). However, the self-criticism group showed no significant correlations for both during-sRPM state and post-sRPM resting-state connectivity.

Table 14. Results of correlation analysis between score increase rate of the short form of Raven's Progressive Matrices (sRPM) and changes of functional connectivity in during-sRPM states and in post-sRPM resting-states in each of the self-respect and self-criticism groups.

Group	Functional connectivity		MNI coordinate			Vox	Z
	Seed	Target region	x	y	z		
Changes in functional connectivity between during-sRPM1 and during-sRPM2							
	PCC	No significant region					
	VMPFC	No significant region					
	NA	No significant region					
	DLPFC	No significant region					
Self-respect	IPS	R. OFC	30	20	-28	247	7.96
		L. OFC	-32	24	-24	76	5.72
		R. temporal pole	48	04	-30	116	7.59
		R. ITG	62	-22	-20	61	5.41
		R. thalamus	20	-18	20	64	-7.34
	PCC	No significant region					
	VMPFC	No significant region					
Self-criticism	NA	No significant region					
	DLPFC	No significant region					
	IPS	No significant region					
Changes in functional connectivity between post-sRPM1 and post-sRPM2							
Self-respect	PCC						
	VMPFC						
	NA	B. SMA	±12	-36	60	1236	-8.07
		L. PrCG	-20	-22	62	93	-5.26
	DLPFC						
	IPS						
Self-criticism	PCC	No significant region					
	VMPFC	No significant region					
	NA	No significant region					
	DLPFC	No significant region					
	IPS	No significant region					

Significant clusters were obtained at voxel-level *Punc* < 0.001 and cluster-level P_{FWE} < 0.05.

Note. MNI, Montreal Neurological Institute; Vox, numbers of voxels; Z, maximum z-value within the cluster; R., Right; PCC, posterior cingulate cortex; VMPFC, ventromedial prefrontal cortex; NA, nucleus accumbens; DLPFC, dorsolateral prefrontal cortex; IPS, intraparietal sulcus ; OFC, orbitofrontal cortex; ITG, inferior temporal gyrus; SMA, supplementary motor area; PrCG, precentral gyrus

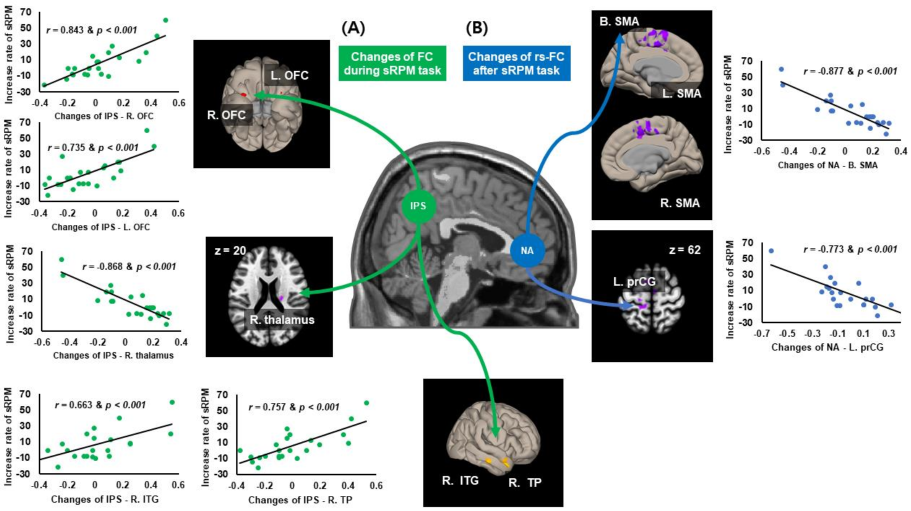

Figure 12. Association between changes in functional connectivity and increase of sRPM scores. Scatter plots showing the relationships between during-task and post-task changes in inter-regional functional connectivity (FC) and score increase rates of the short form of Raven's Progressive Matrices (sRPM) in the self-respect group. Abbreviations: rs-FC, resting-state functional connectivity; L. left, R. right, B. bilateral, NA nucleus accumbens, IPS intraparietal sulcus, SMA supplementary motor area, PrCG precentral gyrus, OFC orbitofrontal cortex, ITG inferior temporal gyrus, TP temporal pole

III. DISCUSSION

The present study examined the neural mechanism involved in the effects of self-talk through two experiments, whether self-respect and self-criticism cause different neural modulations concerning life satisfaction, and whether there is a different association between changes in cognitive performance and neural modulations induced by self-respect and self-criticism. The first experiment examined the effects of positive and negative self-talk interventions on the functional connectome concerning life satisfaction. The functional connectivity was evaluated at baseline and during and after the self-respect or self-criticism task in two groups consisting of individuals with high life satisfaction and low life satisfaction.

To identify the difference in the effects of positive and negative self-talks on functional connectivity concerning alterations in cognitive performance, changes in during-sRPM and post-sRPM connectivity before and after self-respect versus self-criticism were investigated. Behavior data showed that sRPM increase was significantly higher after self-criticism than after self-respect, suggesting that negative self-talk may be more beneficial in the improvement of cognitive performance than positive self-talk. The modulation effects on various networks and associations between connectivity alterations and performance changes also differed between the self-talk groups, suggesting that the modification of brain connectivity may play a mediating role in the effects of self-talks on the promotion of cognitive performance.

1. Demographic Data and Clinical Characteristics

There was no significant difference in age, the proportion of males, and education years in two experiments, indicating that demographical matching and randomization were appropriately performed in the Experiment 1 and Experiment, respectively. Because a score of 20 was suggested as the midpoint between satisfied and dissatisfied[64], our cutoffs may be appropriate to distinguishing participants into two groups (≥20 for HLS and ≤17 for LLS). In all subscales of BPNS, which is known to have a positive correlation with life satisfaction[30], results in which HLS was significantly higher than that of LLS also supported the appropriate grouping of participants. In Experiment 2, there was no difference between the two groups in RSES and HADS scores.

2. Behavioral Data

Increased sRPM score in the self-criticism group is consistent with previous findings for the beneficial effect of negative self-talk on enhancing performance[4,15]. Associated with the cognitive fatigue induced by the repetition of cognitive tasks, this result may be because negative self-talk has a significant influence on attention. Because negative stimuli increase attention to a subsequent stimulus compared with positive stimuli[79], negative self-talk, one kind of negative stimulus, can reduce inattention caused by task repetition. Alternatively, given that motivation is a critical factor in maintaining attention[80], self-criticism may reduce cognitive fatigue-related inattention by being interpreted more motivational. Previous study has suggested the motivational interpretation of negative self-talk as a reason for the beneficial effects of negative self-talk[5]. This motivational interpretation may be either because individuals try to avoid negative results on their own through negative self-talk[18] or accept it as a challenge[15]. Despite performance improvement after self-criticism, it was not correlated with connectivity change, maybe due to the ceiling effect as most participants showed an increase in performance.

3. Neural effects of the self-respect task

The condition effect of the self-respect task was detected exclusively in functional connectivity between the PCC and the frontoparietal network and between the VMPFC and the salience network. In particular, the significant difference between the baseline and after-task was only in the PCC-frontoparietal network connection. There was a negative correlation at the baseline between the two, which was changed after the self-respect task, but not a positive correlation. This minor change may be in the transient aftermath of self-respect as a task requiring attention-demanding. The reciprocal relationship of the negative correlation between the DMN and frontoparietal network may contribute to preparation for or adaptation to environmental events[81,82], and the reduced negative correlation between the two regions may be associated with increased variability of behavioral performances[83] and attentional lapses[84]. In our study, it is possible that the situation engulfed within the participants themselves would have caused a temporary attentional lapse.

The self-respect task had a significant group × condition interaction effect only on PCC-based functional connectivity with the left VLPFC; baseline connectivity strengths did not differ significantly between the LLS and HLS groups, but connectivity strengths after the task were significantly higher in the LLS group than in the HLS group. Given that the VLPFC is active when positive emotion is enhanced[85], this finding implies that self-respect was linked with a positive affect-related brain alteration solely in the LLS group. Alternatively, however, it needs to be considered that the VLPFC and sensitivity to negative life events are closely related to each other[86]. Recalling of mood-incongruent positive autobiographical memories in people with a sad mood causes activation in the VLPFC[87]. People with low life satisfaction can feel positive factors such as self-respect unfamiliar, fearful, and even threatening due to their pessimistic traits[88–90]. Therefore, it is possible that low life satisfaction made our participants have a negative perception of the self-respect stimuli and induced increased connectivity between the PCC and VLPFC. The PCC and VLPFC contribute to proactive interference, meaning that prior knowledge hinders the learning of new information[91,92]. Taken together, individuals with low life satisfaction may be susceptible to be negatively affected by positive self-talk with increasing spontaneous thoughts about themselves due to their pessimistic traits. For them to be positively affected by self-respect, one simple task is not enough, and further interventions and repetitions seem to be necessary.

4. Neural effects of the self-criticism task

The condition effect of the self-criticism task was observed in almost all connections examined, including changes in all PCC-based, VMPFC-based, and NA-based connections between baseline and after-task, in contrast to the self-respect task, which changed only the PCC-frontoparietal connection, implying that the self-criticism task induces more profound changes in the brain than the self-respect task. This finding is consistent with earlier findings that functional responses are more evident when negative stimuli are processed than when positive stimuli are processed[93,94]. Self-criticism elicits unpleasant feelings in the self as a type of self-punishment[95] and has been shown to enhance striatal activity linked with negative emotions such as anger, humiliation, and contempt[93]. Self-punishment during the self-criticism test has a comparable effect on depressed individuals as the rumination does. Previous research found activation in various brain areas, including the DLPFC, VMPFC, DMPFC, ACC, PCC, amygdala, and parahippocampus, during rumination in depressive patients[96], which is consistent with our findings of widespread connectivity alterations after the self-criticism task. The link between the PCC and subgenual-cingulate cortex was enhanced in depressive patients during rumination[97], and this connection was similarly elevated in our research during the self-criticism task.

Moreover, the self-criticism task shifted the functional connectivity between the DMN and frontoparietal network from a negative to a positive correlation. Given that reversing the reciprocal relationship between these two regions may be associated with decreased ability to deploy cognitive functions and increased sadness following repetitive negative thinking[98], the self-criticism task appeared to be extremely emotionally taxing, resulting in a significant attentional lapse, in contrast to the self-respect task. Alternatively, the performance of the self-criticism task may have been in a state of high external detail. The fact that activity within the DMN encodes information linked with current cognition or complex experiences during active task states supports this explanation[99]. Prioritizing off-task thinking is a function of the frontoparietal network, which includes the DLPFC[100]. Additionally, self-criticism strengthened the functional connection between all seeds and the frontostriatal network. The frontostriatal network is critical in the punishment-motivation system[101,102]. Functional connection between the NA and frontostriatal network has been considered to be critical in limiting the detrimental effects of pain[103]. Thus, brain reactions after self-criticism may reflect both sentiments of self-punishment and attempt to mitigate the generated detrimental consequences.

The self-criticism task also had a group × condition interaction effect in several VMPFC- and NA-based connections, in contrast to the self-respect task, which had only an impact in the PCC-left VLPFC. This shows that the more profound alterations in the brain after the self-criticism test may vary between those with low and high life satisfaction. The functional connection strengths of the VMPFC – left DMPFC, which were more significant in the LLS group than in the HLS group at baseline, were reduced after the self-criticism task. While both the VMPFC and DMPFC are engaged in self-referential processing, there is a functional dissociation between the two areas during the resting state, and emotional autobiographical recollection activates the DMPFC more strongly[104]. Given this, our findings on the VMPFC – left DMPFC to imply that the self-criticism task elicited a stronger recall of autobiographical experiences in the LLS group. Additionally, the

LLS group had decreased functional connectivity across several prefrontal areas based on NA after the self-criticism test. Individuals who are dissatisfied with their lives have a proclivity for incorrectly regulating negative emotion and cognition[105,106]. Previous research has shown that functional connection between the NA and PFC/ACC may be linked with initiating an appropriate response to decrease negative signals[107], and that functional connectivity between the NA and DLPFC may be associated with regulating an inhibitory control[108–110]. As a result, the LLS group's loss of these connections after the self-criticism exercise may be unable to manage unpleasant emotions. In other words, insufficient control of unpleasant emotions may be related to decreased NA-prefrontal connection in those with low life satisfaction.

5. Resting-state functional connectivity and basic psychological needs

At baseline, both the HLS and LLS groups demonstrated a positive correlation between NA-based functional connectivity and autonomy scores, and functional connections with high predictive power for predicting autonomy scores also corresponded to NA-based functional connectivity in both groups, implying that the motivation system may be intimately connected to the satisfaction of autonomy needs. The NA has long been considered a basic component engaged in motivation mediation[111], and aberrant resting-state connectivity of the NA has been seen in a variety of addiction illnesses, which are often associated with a problem of motivation[112–114]. Satisfaction with autonomy relates to the need for individual autonomy in making choices and feeling accountable for one's own[115] and is associated with life satisfaction[116–118]. Extrinsic motivation must be internalized and regulated to satisfy autonomy needs[29].

Meanwhile, the LLS group demonstrated significant associations between PCC- or VMPFC-based functional connectivity and autonomy scores after the self-criticism test, in contrast to the HLS group's results following the self-respect task. After self-criticism, PCC- and VMPFC-based functional connections played a critical role in predicting projected autonomy scores in the LLS group, as PCC-based functional connectivity after self-respect did in the HLS group. These findings show that in the LLS group, the desire for autonomy may be heightened after self-criticism, but in the HLS group, it may be heightened following self-respect. The DMN based on the PCC is implicated in mind-wandering[119] and autobiographical or perceptually dissociated thoughts[120]. Subjective well-being relates to autonomy support for goal progress[121], and self-criticism may occasionally impact extrinsic motivation by being viewed as an ego-dystonic supervisor[122]. Thus, depending on one's level of autonomy and life satisfaction, the degree of mind-wandering or internally directed thoughts caused by self-criticism may behave differently. The same may be true of those induced by self-respect.

In the HLS group, there were negative associations between PCC-based functional connection after self-respect and competence scores, and the competence scores were predicted by PCC-based functional connectivity after self-respect in the HLS group. Competence encompasses the requirements for environmental effectiveness, such as exercising and expanding one's capabilities[29,123]. Our results corroborate previous research suggesting that satisfaction of competence needs is a critical aspect in intrinsic motivation[28], and decreased activity in the PCC is known to be related to intrinsic motivation[124]. Individuals with high life satisfaction tend to have high self-efficacy[106], which can help to lessen the foreign feeling surrounding the content of the self-respect task where individuals speak positively about themselves. Therefore, our results can be interpreted as people with high life satisfaction can positively respond to self-respect, which may be important in satisfying their competence needs.

In the LLS group, there were significant relationships between NA-based functional connectivity and relatedness scores, and relatedness scores were predicted by NA-based functional connection after the self-criticism task. Relatedness includes the need to feel securely connected to others and belonging in his or her social environment[28,29]. Friendship intensity and quality are positively correlated with life satisfaction[125] and satisfying relatedness needs is critical for increasing life satisfaction via the thriving of intrinsic motivation[126]. Striatal activity, which includes the NA, has been implicated in the perception of intimate relationships[127,128]. Therefore, our findings suggest that individuals with low life satisfaction tend to react sensitively to self-criticism, activating issues of relatedness and their interpersonal desires as a reward.

6. Self-talks and Repetition of Cognitive Task

The repetition effect was shown for during-sRPM states, but not for post-sRPM resting-states. DLPFC-MTG connectivity was reduced in during-sRPM2 compared to during-sRPM1. The DLPFC-based network is required for important cognitive and executive functioning competencies[78], and MTG activity may result in increased task demand[129]. In the present investigation, task repetition over a short period of time might impair performance owing to cognitive fatigue[130,131]. Cognitive fatigue relates to a decrease in the amount of demand placed on cognitive activities of comparable difficulty[131]. Cognitive fatigue can be motivational fatigue related to a system that maintains motivation by monitoring internal states[132], resulting in reduced connectivity of the attention-related network[133]. Thus, reduced DLPFC-MTG connection may represent a reduction in cognitive load because of cognitive fatigue.

NA-, PCC-, VMPFC-based connectivity increased in during-sRPM2 compared with during-sRPM1. The NA-related network is involved in motivation-related reward prediction[134,135]. Because the NA incorporates both external reward and novelty of stimulus[136], task repetition might result in reward system inactivation. Cognitive fatigue has a detrimental effect on motivation[132], but self-talks presented as self-related knowledge positively affect individual performance concerning motivation[5]. As a result, the shift in NA-based connectivity seems to support motivational interpretation of self-talks. Alternatively, it may represent inaccurate confidence linked with task familiarity. Inaccurate confidence refers to a high level of assurance that does not correspond to real accuracy[137]. In the right LOC, an increased NA-based connection was detected. Magnetic stimulation of the occipital brain impairs task accuracy but boosts inaccurate confidence[138]. The increase in confidence or lack of attention increases the variability of the internal signal for stimuli, thereby inducing inaccurate selection[139].

Given that the PCC and VMPFC are nodes of the self-referential network and DMN140, the enhanced connectivity between the PCC and PrCG or the VMPFC and POC is more likely to be caused by self-talk than task repetition. According to a recent investigation, the self-referential network and DMN connectivity are negatively connected associated with cognitive fatigue[131]. The DMN-PrCG connectivity is associated with associative learning or motivational assignments to ongoing motor task demands[141]. POC activity involves the retrieval of freshly acquired knowledge[142]. Thus, the self-referential network and DMN engaged by self-talks may contribute to performance improvement despite cognitive fatigue.

7. Neural Effects of Self-respect on Cognitive Performance

The main effect of self-talk was observed in DLPFC-PrCG connectivity for during-sRPM states and in NA-MTG and NA-LOC connectivity for post-sRPM resting-states. Self-respect results in stronger connectivity across all of these links than self-criticism does. Given the critical involvement in executive functions of DLPFC[78] and the responsibility for executing corrective strategies of PrCG[143], strong DLPFC-PrCG connectivity implies that self-respect may benefit executive functions more than self-criticism. The findings of NA-based connectivity are nearly unprecedented, making interpretation challenging. MTG activity is impacted by subjective confidence in one's accuracy of tasks[144,145], while LOC activity relates to a reward-related event sequence[146]. In the computational model of motivation[147,148], confidence is a contextual element. Thus, the NA-based connectivity for post-sRPM resting-states implies that individuals who have encountered self-respect are likely to be more confident than those who have encountered self-criticism. Alternatively, these findings may imply that motivated interpretations of positive self-talk are associated with an induced contextual component, such as more enhanced confidence. Given the relationship between external stimuli and increased incorrect confidence[138], robust NA-LOC connectivity in the self-respect group may include inaccurate confidence, impairing cognitive function associated with impulsiveness.

Only the self-respect group has shown significant relationships between connectivity and performance changes during and after sRPM. However, while self-respect group's sRPM scores remained constant, the connectivity changes were insufficient to manifest as behavioral changes. Alternatively, it might be that self- respect has a mixed influence on cognitive function. Changes in IPS-OFC connection during sRPM activities were shown to be positively linked with an increase in sRPM. The parietal network is critical for cognitive reasoning[130] and may be altered by psychological interventions[148]. The OFC is involved in visual and motor representation coordination and synthesis and performance on processing speed[149]. Therefore, our result may be associated with altered brain states that are beneficial for potential performance improvement induced by self-respect. In contrast, the increase in sRPM was inversely linked with changes in NA-based connection after cognitive tasks, indicating that greater NA-based connectivity induced by self-respect may have a detrimental effect on cognitive performance.

Concerning NA-based connection and confidence, self- respect may have a detrimental effect on cognitive performance by increasing impulsiveness, comparable to risk behaviors associated with inaccurate confidence detached from real results[54]. Taken together, the effects of self-respect on cognitive performance seem to be both negative effects due to impulsivity related to inaccurate confidence and positive effects related to enhanced executive functions. Since there are various methods other than self-respect for positive self-talk, additional studies using other self-talk tasks are needed to understand its effects on cognitive performance.

8. Neural Effects of Self-criticism on Cognitive Performance

Increased sRPM score in the self-criticism group is supported by the self-talk effects on DLPFC-PrCG connectivity for during-sRPM states and NA-MTG and NA-LOC connectivity for post-sRPM resting-states, which should be considered contrary to self-respect. Given that a less confident condition might generate motivation[150], these results show that self-criticism and subsequent motivational interpretation can improve performance when confidence is diminished by self-criticism task. This is further corroborated by NA-ITG connectivity in post-sRPM resting states, which did not vary across groups prior to self-talk but diminished after self-criticism. Because higher ITG activity is related to more confident states[137,151], and reduced ITG activity is associated with increased internal motivation[152], decreased NA-ITG connectivity may represent decreased confidence and increased motivation caused by self-criticism.

Although self-criticism was more effective than self-respect in increasing sRPM scores, it cannot be assumed that negative self-talk has a more significant impact on performance improvement than positive self-talk. The influence of self-talk diminishes with repetition[153], and prolonged exposure to negative self-talk is detrimental. As a result, our results on the effects of negative self-talk should be understood in the short term. Additional research is required to determine the long-term consequences of negative self-talk on the changes in brain connection that accompany changes in cognitive ability.

9. Limitations

The potential limitation of the study that could compromise the interpretations are discussed. First, although the significant neural mechanism of self-talk concerning life satisfaction and cognitive performance are illustrated, the current data of two experiments only consisted of young, healthy, college students who were likely of higher intellectual capacity than average. Thus, it is uncertain whether the results will be similar in the general population. It is necessary to extend these experiments in elders and individuals with lower education level in future investigation to increase the generalizability. Additionally, the nature of these samples may be the reason why their SWLS scores in Experiment 1 were not at the level of ‘extremely satisfied’ or ‘extremely dissatisfied’, though participants from the top 25% and bottom 25% of the scale score among volunteers were recruited. Second, there was no non-self-reflective neutral control task in our experiment, and thus analysis of the common elements of self-reflection was inevitably lacking. Third, sRPM scores represented mainly fluid intelligence, not overall cognitive performance, and the type and difficulty of cognitive tasks were not considered. Fourth, as the Experiment 2 compared two groups divided according to the type of self-talk tasks, there is a possibility that confounding factors may be involved. In fact, it might be desirable to see the effect of performing both self-respect and self-criticism in a single group. To do this, however, the experimental time given to one participant would be too long, and the sRPM sets would have to be doubled. These could lead to other confounding factors, and thus there is no choice but to choose the current two-group design. Fifth, Finally, the current study did not monitor physiological data, including heart rate, which can affect cognitive performance.

V. CONCLUSION

To investigate the neural mechanism of self-respect and self-criticism associated with life satisfaction and changes in cognitive performance, the present study addressed the neural effects on resting-state functional connectivity after self-respect and self-criticism with respect to life satisfaction and its relationships with basic psychological needs and compared the effects of positive and negative self-talks concerning both cognitive performance and functional connectivity.

The condition effect of each self-talk and the interaction effect of self-talk task × condition in Experiment 1 showed that the self-criticism task produces more powerful changes in the brain than the self-respect task. Our brain imaging results show that self-respect does not induce large changes in brain states quickly. Moreover, self-criticism stimulate negative emotions, but at the same time, the results based on the striatal network and nucleus accumbens based connectivity showed evidence supporting the hypothesis that self-criticism can be motivationally interpreted.

The significant increase in PCC-left VLPFC connectivity in LLS compared with that in HLS associated with self-respect and the group × condition interaction effect of self-criticism in various VMPFC- and NA-based connections support our hypothesis that people with different levels of life satisfaction differently respond to self-talk. Additionally, in the analysis of predicting the BPNS subscale score using functional connectivity, the results that were significant only by FC of after self-respect in HLS and FC of after self-criticism in LLS also supported the hypothesis that there are different responses to self-talk according to different levels of life satisfaction.

Based on our neural findings about the functional connectivity between PCC and left VLPFC, it can be inferred that individuals with low life satisfaction may be negatively affected by self-respect by inducing spontaneous thoughts about negative aspects of self. Self-criticism seems also inducing a greater recall of autobiographical memories in the LLS group and evoking inappropriate regulation of negative emotions.

Concerning improvement of cognitive performance, the beneficial effect was only presented in self-criticism group. Brain imaging results provided interpretations that aided understanding of these behavioral-level outcomes. In the case of self-respect, robust DLPFC-PrCG connectivity suggests that self-respect may reflect beneficial effects for executive functions. However, decreased DLPFC-MTG connectivity in during-sRPM2 suggested the effects of cognitive fatigue induced by the repetition of cognitive tasks. In addition, NA-based connectivity of post-sRPM resting-states in self-respect group showed possibility that enhanced confidence induced by self-respect can hinder the performance by impulsiveness. Both positive and negative effects of self-respect on cognitive performance is also supported by the brain imaging results showing a positive correlation for IPS-OFC connectivity and a negative correlation for NA-based connectivity with changes in cognitive performance in the correlation analysis. On the other hand, the self-criticism induces an increase in cognitive performance, maybe due to a less confident state that elevates internal motivation and attention contrary to self-respect. Decreased NA-ITG connectivity can reflect decreased confidence and increased motivation induced by self-criticism

These findings shed light on the effect of self-talks on mental health as a means of modulating the satisfaction of basic psychological needs related to life satisfaction and enhancing cognitive performance. Our study shows that by identifying brain responses to self-talk, interventions for improving positive self-talk and stopping negative self-talk can enhance mental health through brain changes. In addition, by identifying brain responses to self-talks, our study presented that both types of self-talks can enhance cognitive performance through different brain changes related to motivation. Additional studies are needed to elucidate the modulation of confidence and motivation concerning both self-talk and cognitive performance. Moreover, further studies need to address the long-term effect of positive and negative self-talks on changes in brain connectivity that underlie the modification of life satisfaction and cognitive performance changes. In addition, further studies also need to divide the elements of self-talk in more detail and use an analysis method that can suggest a causal relationship to increase a comprehensive understanding of the effects of self-talk on brain connectivity and behavioral changes.

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ABSTRACT(IN KOREAN)

자기대화가 삶의 만족도 및 인지과제 수행도 변화에 미치는 영향에 대한 뇌 기반 탐색

<지도교수 김재진>

연세대학교 대학원 의학과

김준형

배경: 자기대화는 자기 자신을 대상으로 문구를 체계적으로 음성을 통해 또는 침묵상태에서 사용하는 것이다. 이 간단한 형태의 심리적 기법은 다양한 분야에서 연구되었다. 긍정적인 자기대화는 기본적 심리적 욕구의 충족을 통해 삶의 만족도를 높일 수 있는 실용적인 방법인데 반해서, 부정적인 자기대화는 낮은 만족도에 영향을 준다. 또한, 두 가지 자기대화는 모두 인지 기능 발휘에 긍정적인 영향을 발휘한다. 하지만, 그러한 영향의 신경 메커니즘은 조사되지 않았다. 따라서 긍정적 그리고 부정적 자기대화와 관련된 특정 신경 메커니즘을 식별하는 것이 필수적이다. 이 연구는 삶의 만족도 및 인지 수행의 변화와 관련하여 뇌 기능적 연결성에 대한 긍정적인 자기대화와 부정적인 자기대화의 영향을 밝히는 것을 목적으로 하였다.

방법: 5분 길이의 자기존중 및 자기비판 과제를 긍정적인 자기대화와 부정적인 자기대화 과제로 2개의 실험에서 사용했다. 실험 1에서는 낮은 삶의 만족도 집단(24명)과 높은 삶의 만족도 집단(24명)의 48명의 대상자에게 자기존중 또는 자기비판 과제 전, 중, 그리고 후의 기능적 자기공명영상을 획득하였다. 실험 2에는

자기존중과 자기비판 간의 수행 향상 차이를 측정하기 위한 인지과제가 포함되었다. 46명의 대상자는 기능적 자기공명영상을 사용하였으며, 자기존중 집단과 자기비판 집단으로 무작위로 나누어져 각각에서 자기존중 과제 및 자기비판 과제 전 후로 인지과제를 수행하고 인지과제 전, 중 후에 기능적 자기공명영상을 획득하였다.

결과: 실험 1에서는 자기존중 과제가 후측대상피질과 이마마루엽 네트워크 사이의 뇌 연결성에만 영향을 준 반면 자기비판 과제는 조사된 거의 모든 뇌 연결성에 영향을 주었다. 기본적인 심리적 욕구와 관련하여 자기비판 과제 후의 기능적 연결성은 자율성 및 관계성의 욕구를 예측하는 데 낮은 삶의 만족도 집단에서만 유의미한 반면, 자기존중 후의 기능적 연결성은 높은 삶의 만족도 집단에서만 자율성과 유능성의 욕구를 예측할 수 있었다. 실험 2에서 자기대화 과제 전 점수에 비해 자기대화 과제 후 점수의 증가는 자기비판 과제에서만 관찰되었다. 인지과제 반복과 자기대화 과제의 상호작용 효과는 인지과제 중의 뇌 연결성에서는 발견되지 않았지만 인지과제 후의 뇌 연결성을 대상으로는 발견되었다. 그러나 연결성 변화와 성과변화 간의 유의한 상관관계는 자기존중 집단에서만 나타났다.

결론: 이 연구 결과는 긍정적인 자기대화와 부정적인 자기대화가 삶의 만족도와 인지 수행에 관한 뇌 상태를 다르게 조절한다는 것을 보여주었다. 전반적으로 자기비판은 자기존중의 긍정적인 변화보다 뇌에 더 눈에 띄는 부정적인 변화를 일으킨다. 삶의 만족도가 낮은 개인은 삶의 만족도가 높은 개인보다 자기비판 뿐만 아니라 자기존중에도 부정적인 영향을 받기 더 쉽다. 기본적인 심리적 욕구 만족은 삶의 만족도와 관련하여 자기대화 과제의 효과에서 미치는

역할이 다르다. 인지 수행과 관련하여 자기존중은 각각 향상된 실행 기능과 부정확한 자신감으로 인해 긍정적인 영향과 부정적인 영향을 모두 미칠 수 있는 반면, 자기비판은 내적 동기와 주의를 증가시키는 덜 자신감 있는 상태를 유도하여 인지 수행에 긍정적인 영향을 미칠 수 있다.

핵심되는 말 :자기대화; 자기존중; 자기비판; 삶의 만족; 인지 수행; 뇌 연결성

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