

# Measuring the sense of self in brain-damaged patients

## A STROBE-compliant article

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### Abstract

Recently, researchers have focused on the embodied sense of self (ESS), which consists of the minimal and narrative selves. Although a study demonstrated that the ESS is related to brain dysfunction empirically, the subjective aspects of the ESS, and a systematic approach to it, have not yet been examined in brain-damaged patients. To examine this, we measured the ESS of patients with brain tumors before and after awake craniotomy.

A self-reported questionnaire called the Embodied Sense of Self Scale (ESSS) was used to measure the ESS in patients with brain tumors before and after surgery. For comparison, age-matched controls also completed the ESSS.

The ESSS scores of the patients with brain tumors before surgery were higher than those of the controls and improved after surgery. Before surgery, patients with left hemispheric lesions had a poorer ESSS than those with right hemispheric lesions. Episodic memory disturbance was highly correlated with malfunction of narrative self and ownership.

Brain lesions were associated with anomalous ESSS, associated with hemispheric laterality and cognitive dysfunction.

**Abbreviations:** ART = aligned rank transform, ESS = embodied sense of self, ESSS = Embodied Sense of Self Scale, GM = gray matter, MMT = manual muscle testing, PET = positron emission tomography, VBM = voxel-based morphometry.

**Keywords:** awake craniotomy, brain tumors, embodied sense of self, narrative self, sense of agency, sense of ownership

## 1. Introduction

The concept of self has interested researchers for centuries. However, no specific or consensual definition is yet available. Recently, philosophers, neuroscientists, and psychologists have proposed that the concept of the self can be divided into 2 components,

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the "minimal self" and the "narrative self."<sup>[1–4]</sup> The minimal self is the sensory level of the self devoid of temporal extension; it involves a sense of agency (i.e., the feeling of causing one's own actions)<sup>[1,5]</sup> and a sense of ownership (i.e., the feeling of owning one's own body and therefore experiencing sensations through it).<sup>[3]</sup> The narrative self is conceptualized as the self with temporal extension, including personality, identity, and continuity across time in the form of autobiographical memory.<sup>[4,6]</sup> The narrative self is dependent on the minimal self. The minimal self involves continuous embodied experience that is represented in the reflections about the body (sense of ownership) and its actions (sense of agency) that form the narrative self, its temporal extension.<sup>[7]</sup>

Studies have investigated disorders of self and their underlying mechanisms in patients with brain damage using empirical and objective measures (e.g., the rubber hand illusion).<sup>[6,8,9]</sup> Although these objective measures have clarified some aspects of the mechanisms underlying such disorders, other aspects remain unclear. One remaining mystery involves the mechanism by which the subjective aspect of the self is connected to the brain.<sup>[10]</sup> Until recently, there has been no validated systematic approach to elucidating the subjective aspects of the self. However, a recent study integrated the minimal and narrative selves into the notion of the embodied sense of self (ESS).<sup>[2]</sup> A self-administered questionnaire, the Embodied Sense of Self Scale (ESSS), was developed to measure the subjective aspects of the ESS and systematically assess each dimension of self. The results of this study confirmed that chronic psychiatric patients had anomalous ESSS.<sup>[2]</sup> More recently, a voxel-based morphometry (VBM) study reported that differences in the structural characteristics of the brains of healthy individuals were correlated with the subjective measurements of the ESSS.<sup>[11]</sup> These results imply that the ESS is associated with certain anomalous structural features of the

brain, including those related to brain damage, but no study has examined the ESS of patients with brain damage.

In the context of evidence that the subjective aspects of the ESS are related to brain structure,<sup>[11]</sup> it is important to examine how the ESS is associated with brain damage. Thus far, no specific evaluation tools have been developed to guide clinicians in the treatment of brain-damaged patients with an anomalous ESS.<sup>[12]</sup> However, information about the subjective features of the ESS of patients with brain damage may increase our understanding of disorders of the self and contribute to treatment.<sup>[2,13]</sup> This approach (i.e., the ESSS) is likely to attract researchers because it offers a way to measure the self, as the minimal and narrative selves are “the self” rather than a proxy.<sup>[2]</sup> Thus, we aimed to examine the subjective aspects of the self of patients with brain damage in terms of embodiment to clarify the relationship between the self and the brain. Specifically, we systematically measured aspects of the subjective ESS of patients with brain tumors before and after brain surgery.

Patients reported that surgery sometimes ameliorated and sometimes worsened their neurological or cognitive difficulties. At the same time, it is possible that brain surgery affected brain function related to the ESS. However, brain functions can be altered in many ways, including by mental illness, chronic pain, emotional distress, medication, radiation therapy, chemotherapy, and combinations thereof.<sup>[12,14,15]</sup> Based on the aforementioned association of the minimal and narrative selves with brain functioning, this study focused on physical and cognitive functions, and we hypothesized that physical and cognitive deficits would show an association with disruption of either the minimal or narrative self because the convergence of the minimal self contributes to the generation of the narrative self.<sup>[7]</sup> For example, sensorimotor deficits can disrupt the senses of agency and ownership because the inability to execute motor commands and use sensory feedback leads to a loss of limb control and sensation.<sup>[16]</sup> Moreover, cognitive deficits, such as episodic memory dysfunction, have also been reported to disrupt the narrative self.<sup>[17]</sup>

Although previous studies have discussed the relationship between hemispheric laterality and self, there is little consensus on the contribution of laterality to self because self does not seem to be unitary, but rather to be dependent on the specific self information domain.<sup>[18,19]</sup> Regarding the subjective aspect of the ESS, however, awareness of the anomalous sense of self may be related to deficits in right hemispheric function. Patients with unilateral spatial neglect due to right hemispheric injury were unable to respond to spatial stimuli on the left side, including their own body.<sup>[20,21]</sup> Patients with anosognosia (lack of awareness of one’s illness) following right hemispheric lesions do not notice their neurological disorders.<sup>[22]</sup> Therefore, hemispheric laterality may be associated with awareness of the anomalous sense of self.

To account for all relations between ESS and brain functions, we evaluated physical and cognitive functions, and the influence of hemispheric laterality and the ESS, before and after surgery.

## 2. Methods

### 2.1. Participants

The study enrolled 20 patients with brain tumors (10 women; mean age, 59.7 ± 13.5 years [range: 40–77 years]) (Table 1). The patients underwent awake craniotomy for brain tumor resection from 2016 to 2017 at the Tokyo Metropolitan Cancer and

**Table 1**

**Clinical characteristics of the brain tumor patients.**

	Mean	SD
Age, y	59.7	13.5
	n	%
Brain tumor location		
Frontal lobe		
Left	2	10.0
Right	4	20.0
Parietal lobe		
Left	4	20.0
Right	5	25.0
Temporal lobe		
Left	0	0.0
Right	1	5.0
Temporoparietal region		
Left	1	5.0
Right	0	0.0
Cerebellum		
Left	2	10.0
Right	1	5.0
Pathologic diagnosis		
Glioblastoma	4	20.0
Oligodendroglioma	1	5.0
Meningioma	6	30.0
Metastatic carcinoma	7	35.0
Radionecrosis	1	5.0
Neurilemmoma	1	5.0
Preoperative paresis	11	55.0
Postoperative paresis: worsened, 1; same, 2; improved, 8		
Preoperative sensory deficits	9	45.0
Postoperative sensory deficits: worsened, 1; same, 2; improved, 6		

Infectious Diseases Center Komagome Hospital. Awake craniotomy is safer than craniotomy under general anesthesia in terms of preserving neurological function.<sup>[23–25]</sup> General informed consent approved by ethics committee was obtained from all patients.

### 2.2. The Embodied Sense of Self Scale<sup>[2]</sup>

The ESSS is a self-reported questionnaire used to assess the experiences of the corresponding aspects of the sense of self on an everyday basis. Individuals rate each item by choosing a number ranging from 1 (*disagree*) to 5 (*agree*). A higher score indicates an anomalous ESS. The questionnaire consists of 3 subfactors: *agency*, which comprises 8 items related to the controllability and authorship of one’s own actions; *ownership*, which comprises 9 items related to bodily awareness and body perception; and *narrative*, which comprises 8 items related to the continuity and consistency of personality and identity. The ESSS is a reliable, valid, and statistically useful scale that clearly distinguishes healthy subjects from patients with ESS disorders, such as schizophrenia. The retest reliability of the ESSS in healthy controls at a 1-month intervals has been confirmed.<sup>[2]</sup>

### 2.3. Procedures

Each patient completed the ESSS questionnaire 3 or 5 days before the awake craniotomy and 9 or 11 days after the surgery. The interval from the pre- to postreport was 2 weeks for all patients. Pre- and postoperative paresis status was measured by

manual muscle testing (MMT). The MMT of each limb was assessed using an objective scale: 5 = normal, contraction against powerful resistance; 4 = good, contraction against gravity and some resistance; 3 = fair, contraction against gravity only; 2 = poor, movement only with gravity eliminated; 1 = trace, a flicker of contraction; 0 = zero, complete paralysis. We regarded diffuse motor strength or any detectable motor asymmetry (score <5 on the MMT) as paresis. Pre- and postoperative sensory deficits were measured by manually stimulating the skin; a neuropsychologist stimulated (i.e., lightly touched) homonymous parts on the left and right sides; that is, the shoulder, upper and lower arms, hand, upper and lower trunk, thigh, lower thigh, and foot. Patients were asked to close their eyes and report the strength of the touch on the contralesional side compared with the ipsilesional side using a scale ranging from 0 (*absent*) to 10 (*normal*) based on the “ten test.”<sup>[26,27]</sup> We regarded diffuse sensory strength (score <10) as a sensory deficit. Motor and sensory strength was measured for each limb, and the weakest of the 4 extremities served as the index. Based on these principles, we compared the pre- and postoperative data and applied the classification of worse, the same, or improved postoperatively (Table 1). To assess episodic memory function, we used the picture memory paradigm in the Randt Memory Test, a screening test of episodic memory.<sup>[28]</sup> The ESSS results of the brain tumor patients were compared with those of healthy age-matched controls (n = 189 [95 males, 94 females]; average age, 58.8 ± 5.0 years).

#### 2.4. Statistical analysis

The patient scores before and after surgery were standardized based on the control scores. Taking the standardized score of each item in each patient as  $z_i$ , the score of each item in each patient as  $x_i$ , the average score of each subfactor in the control group as  $\bar{x}$ , and the standard deviation of each subfactor in the control group as  $\varsigma$ , the standardized score  $z_i$  was determined using the formula:

$$z_i = \frac{x_i - \bar{x}}{\varsigma}$$

To explore the influence of laterality, paresis, and a sensory deficit on the ESSS score, we divided all patients into 2 groups in terms of laterality (patients with left [n = 9] and right [n = 11] hemispheric lesions) and the presence of either a motor or sensory deficit (with [n = 13] and without [n = 9] preoperative paresis or sensory deficits). As the data were not distributed normally (Shapiro–Wilk normality test,  $P < .05$ ), the aligned rank transform (ART) for nonparametric factorial data<sup>[29]</sup> was performed using *pre- and postoperative assessment* as within-subject variables, *subfactor* as a within-subject independent variable, *group* (laterality/the presence of motor or sensory deficits) as a between-subject independent variable, and *the average score per item* as the dependent variable. To explore the relationship between episodic memory function and the ESS, Spearman’s rank correlation was used to compare pre- and postoperative ESSS scores and scores on the episodic memory test. The statistical analyses were performed with R software (ver. 3.4.1; R Development Core Team, Vienna, Austria). Post hoc power analysis was performed using G\*Power 3 (<http://www.gpower.hhu.de>). Post hoc power was given by the formula  $1 - \beta$  in the “Results.” A  $P$  value <.05 was considered statistically significant.

### 3. Results

#### 3.1. The effects of pre/postassessment, hemispheric laterality, and motor and sensory deficits

The ART test revealed a significant main effect of *pre/postassessment* [ $F(1, 80) = 24.03$ ,  $P < .001$ ,  $\eta_p^2 = 0.23$ ,  $1 - \beta = 0.99$ ], with higher scores being associated with the preoperative assessment, and a significant main effect of *subfactors* [ $F(2,80) = 3.32$ ,  $P = .04$ ,  $\eta_p^2 = 0.07$ ,  $1 - \beta = 0.81$ ]. The post hoc  $t$  test revealed a marginally significant difference between *agency* and *narrative* [mean *agency* score = 0.20; mean *narrative* score = -0.06,  $t(80) = 2.20$ ,  $P = .07$ , Cohen’s  $d = 0.24$ ,  $1 - \beta = 0.17$ ]. We found no significant main effect of *laterality* [ $F(1, 16) = 0.06$ ,  $P = .80$ ,  $\eta_p^2 = 0.004$ ,  $1 - \beta = 0.06$ ] or *sensory and motor deficits* [ $F(1, 16) = 1.93$ ,  $P = .18$ ,  $\eta_p^2 = 0.11$ ,  $1 - \beta = 0.47$ ]. We observed a significant interaction between *pre/postassessment* and *laterality* [ $F(1,80) = 6.35$ ,  $P = .013$ ,  $\eta_p^2 = 0.07$ ,  $1 - \beta = 0.64$ ]. The post hoc  $t$  test showed that, in patients with left hemispheric lesions, the average preoperative score was higher than the postoperative score [mean *left/preoperative* score = 0.54; mean *left/postoperative* score = -0.40,  $t(80) = -2.33$ ,  $P = .02$ , Cohen’s  $d = 0.92$ ,  $1 - \beta = 0.97$ ] (Fig. 1).

#### 3.2. Influence of memory deficit

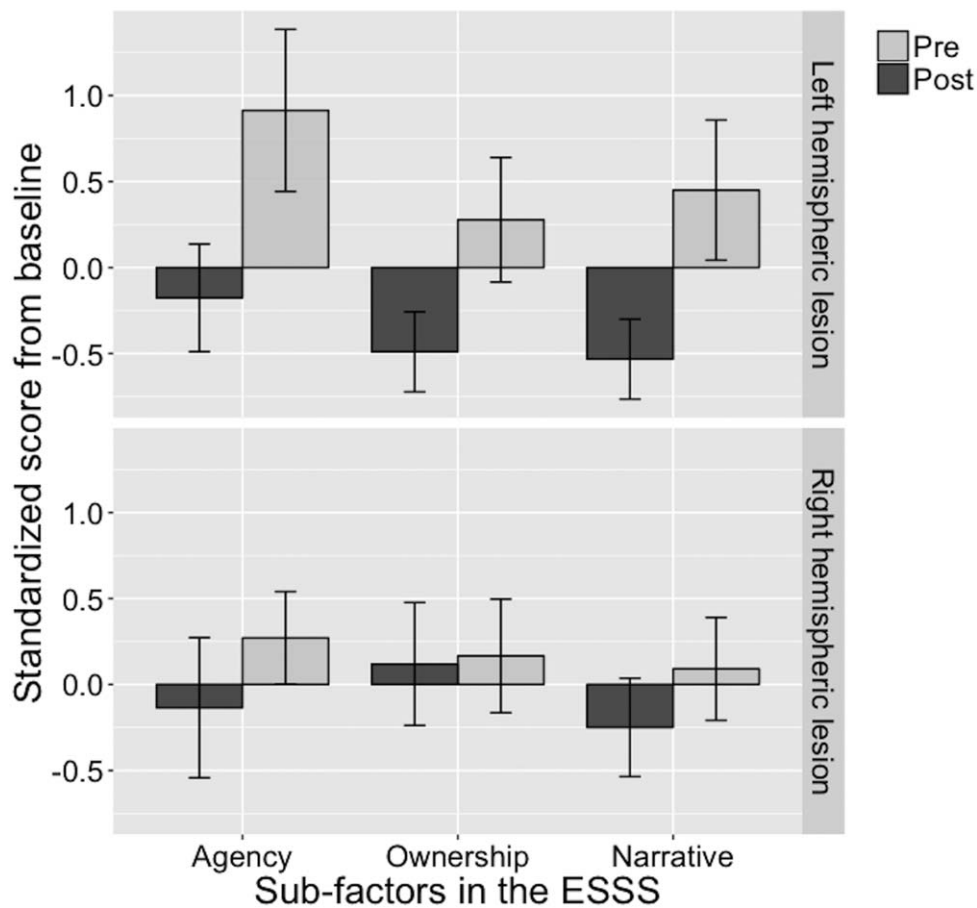
Significant correlations for preoperative *narrative* [ $r = -0.47$ ,  $P = .04$ ], *ownership* [ $r = -0.60$ ,  $P = .007$ ], and postoperative *ownership* [ $r = -0.54$ ,  $P = .02$ ] were observed and the remaining correlations were not significant (see Supplementary results, <http://links.lww.com/MD/C444>). We found no significant difference between the pre- and postoperative episodic memory scores [ $t(18) = -1.59$ ,  $P = .13$ ].

### 4. Discussion

This study examined the subjective aspects of the sense of self of patients who had sustained brain damage to clarify the relationship between the self and the brain from the perspective of embodiment. There were 3 main findings. First, before surgery, the ESSS scores of patients with brain tumors were higher than those of controls, and these scores improved after surgery. Second, before surgery, patients with left hemispheric lesions scored lower on the ESSS than did those with right hemispheric lesions. Third, episodic memory disturbances were strongly correlated with dysfunction in the narrative self and in the sense of ownership of the self.

Our analysis of changes in ESSS scores before and after surgery indicated that patients with brain tumors had elevated ESSS scores before surgery, regardless of their scores on the subfactors; after surgery, these scores either remained the same or improved compared with controls. This indicates that brain lesions disrupt the ESS and is consistent with studies indicating that brain lesions induce an alienation from one’s own body and disrupt the reorganization of identity.<sup>[12,13]</sup>

In terms of the relationship between each component of the ESSS and brain functions, one preoperative abnormality evident on the ESSS appeared to be associated with the hemispheric laterality of the brain tumor. According to the preoperative assessment, patients with brain tumors in the left hemisphere exhibited more extensive ESS deterioration than did those with brain tumors in the right hemisphere. Previous studies found a relationship between the concept of self and the functionality of the left hemisphere with regard to maintaining an ESS. An empirical study with apraxic patients found that the left parietal



**Figure 1.** The Embodied Sense of Self Scale (ESSS) scores for the brain-damaged patients before (pre) and after (post) the awake craniotomy for right and left hemispheric lesions. Error bars denote the SE.

cortex played a crucial role in generating self-initiated movement.<sup>[9]</sup> A positron emission tomography (PET) study found that activation during simulation of personal action was evident in the inferior parietal cortex and the somatosensory cortex of the left hemisphere.<sup>[30]</sup> Furthermore, a study evaluating the rubber hand illusion phenomenon revealed that left intraparietal sulcus status was related to limb ownership.<sup>[31]</sup> The left inferior prefrontal cortex was important for episodic regeneration of autobiographical memory.<sup>[32]</sup> Indeed, Kanayama et al (2017) found that the gray matter (GM) volume in the left hemisphere was correlated with subscale scores on the ESSS. It is possible that the association between the ESSS and left hemispheric lesions is attributable to the fact that patients with left hemispheric lesions are able to perceive the subjective aspects of self-disorders that are evaluated by the ESSS, whereas, similar to patients with anosognosia (lack of awareness of one's illness) secondary to brain lesions, patients with right hemispheric lesions do not notice these disorders.<sup>[22]</sup> Although none of our patients had been diagnosed with anosognosia, we suggest that patients with right hemispheric tumors have clinical conditions similar to anosognosia in terms of the subjective aspects of self-conception. Similarly, patients with unilateral spatial neglect due to right hemispheric injury were unable to respond to spatial stimuli on the left side, including their own body.<sup>[20,21]</sup> Although the influence of the neglect was not certain, the neglect-like symptom in the patients with right hemispheric tumors might lead to unawareness of the disrupted subjective aspects of self-conception. Therefore, the left hemi-

sphere may be associated with ESS disorders. Although many reports have described relationships between the domains of self and the left hemisphere, evidence of the relevance of the right hemisphere to selfness has also been reported.<sup>[33,34]</sup> In this context, small sample sizes have precluded robust statistical analyses of connections between specific brain lesions and selfness. Additional studies with larger patient samples are required to explore self-specific brain regions.

In terms of the ESSS subscales, a sense of agency was not related to any physical or cognitive function. Kanayama et al (2017) found a positive correlation between *agency* scores and the GM volume of the cerebellum. The cerebellum is activated when there are discrepancies between the actual sensory consequences of an action and the predicted consequences that induced the sense of *agency*.<sup>[35,36]</sup> Accordingly, a cerebellar deficit was associated with *agency* deterioration. However, as we had only 3 patients with tumors in the cerebellum, we found no significant effect of such tumors on scores on the *agency* subscale.

We found that sense of ownership was related to episodic memory. Higher pre- and postoperative *ownership* scores, which indicated an anomalous sense of ownership, were strongly correlated with lower scores on the episodic memory test. This negative correlation suggested that patients who have difficulty with the retrieval of memories find it difficult to feel ownership of their own memories or thoughts. Furthermore, *ownership* alone showed a significant correlation with scores

on the episodic memory test after surgery, suggesting that postoperative impaired recall was associated with feeling a lack of ownership of one's inner world rather than with a loss of narrative coherence. However, although overall ESSS scores including ownership improved after surgery, the postoperative ownership score and the episodic memory index were significantly negatively correlated. This inconsistency might be considered to reflect weak improvement in the ownership score after surgery, as compared with the agency or narrative self-effect scores. In fact, statistical analysis did not indicate that subfactors exerted significant effects. However, it is possible that our small sample size (a limitation of the study) explains this inconsistency.

Narrative self was also related to episodic memory. An increasing preoperative *narrative* score was highly correlated with a worsening episodic memory test score. Narrative self was also related to episodic memory, and higher preoperative *narrative* scores were strongly correlated with lower scores on the episodic memory test. This showed that the preoperative narrative self had deteriorated in terms of episodic memory dysfunction. After surgery, we found no significant evidence indicating that improvement of the narrative self was attributable to episodic memory amelioration. This can be explained by the characteristics of narrative self, in which autobiographical episodic memory serves to sustain self-continuity<sup>[6,37]</sup> and episodic memory dysfunction inhibits the autobiographical memory accumulation as self-uniformity, resulting in disruption of the narrative self.<sup>[17]</sup> Theoretically, continuity and uniformity involve the concept of narrative self as a temporal extension of the minimal self, including agency and ownership. In this regard, the narrative self might be a higher, integrated function of the brain.

Accordingly, the neurological and cognitive dysfunctions were partially related to subfactors in the ESSS, suggesting that the neurological and cognitive dysfunctions reflect a malfunction of the ESS. However, based on a recent morphological study that found that the ESS was related to specific brain regions,<sup>[11]</sup> it is also possible that brain lesions are associated with abnormalities in the ESS. In this study, it was a partial reflection of the neurological and cognitive dysfunction on the ESS, and the sense of self in terms of embodiment as a function was affected by the brain lesions.

One limitation of the present study is that its sample size was too small to allow for the classification of tumor locations and sizes and the subsequent exploration of how such factors influence ESSS scores. Thus, our study is explanatory, and it may be important for future studies to analyze the relationship between the characteristics and types of brain lesions and ESSS scores. Moreover, dysfunction in one's ESS can be caused by mental illness, chronic pain, emotional distress, medication, radiation therapy, chemotherapy, or combinations thereof, but these factors were not examined herein.<sup>[12,14,15]</sup>

In a future work, we will explore the recovery of self-conception and the interaction between the neural basis thereof and various components by studying numerous patients with brain tumors, before and after surgery. If we can ascertain how each self-factor is represented in the brain (by studying patients with brain lesions), we may be able to predict disorders of specific aspects of self-subjectivity in terms of embodiment. Such research is valuable because the knowledge can be applied to clinical situations and guide both treatment and interventions, where the contributions of each component to the unified self would be clarified.

## Author contributions

KH and TA designed the study and analyzed the data. KH wrote the manuscript. TA and AM assisted in the preparation of the manuscript. All other authors performed data collection and reviewed the manuscript. All authors approved the final version of the manuscript.

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