Consciousness and Cognition 119 (2024) 103654

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/yccog

Mapping the pre-reflective experience of "self" to the brain - An ERP study

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ARTICLE INFO

Keywords:
Electroencephalography
Pre-reflective self-experience
Ego
Evoked potentials
Healthy volunteers

ABSTRACT

The neural underpinnings of selfhood encompass pre-reflective and reflective self-experience. The former refers to a basic, immediate experience of being a self, while the latter involves cognition and introspection. Although neural correlates of reflective self-experience have been studied, the pre-reflective remains underinvestigated.

This research aims to bridge this gap by comparatively investigating ERP correlates of reading first- vs. third-person pronouns – approximating pre-reflective self-experience – and self- vs. other-related adjectives – approximating reflective self-experience – in 30 healthy participants.

We found differential neural engagement between pre-reflective and reflective self-experience at 254–310 ms post-stimulus onset. Source estimation suggested that our sensor-level results could be plausibly explained by the involvement of cortical midline structures and default mode network in the general sense of self but selective recruitment of anterior cingulate and top-down dorsal attention network in the pre-reflective self. These findings offer a deeper understanding of the experiential self, especially pre-reflective, providing a foundation for investigating self-disorders.

1. Introduction

During the last decades, it has been empirically demonstrated that a specific disorder of the self constitutes an important psychopathological feature of schizophrenia spectrum disorders and that this self-disorder is present before and after frank psychosis (Henriksen et al., 2021). It has been hypothesized that this self-disorder is at the very pathogenetic core of schizophrenia spectrum disorders (De Kock, 2020).

The contemporary concept of self-disorders refers to a disturbed structure of phenomenal consciousness, i.e., to a disturbed sense of the *experiential* or *minimal self*. Thus, the 'self' that is disordered in schizophrenia is a very basic, immediate experience of being a self. More specifically, it concerns the very first-personal articulation of experience that usually implicitly facilitates a sense of "mine-ness," "self-presence," or "ipseity" that transpires through the change of time and different modalities of consciousness (e.g., perception,

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https://doi.org/10.1016/j.concog.2024.103654
Received 25 September 2023; Received in revised form 31 January 2024; Accepted 1 February 2024
Available online 28 February 2024
1053-8100/

imagination, thinking) (Sass & Parnas, 2003). Typically, this pre-reflective experience of being a self saturates one's experiential life with a sense of self-familiarity in a taken-for-granted and unproblematic way (Henriksen & Nordgaard, 2014; Nordgaard Frederiksen & Henriksen, 2019; Nordgaard & Henriksen, 2016). Usually, I do not need to self-reflect to assure myself that I am, in fact, myself—I am always already pre-reflectively aware of being myself (Zahavi, 2014). This intimate, fundamental sense of self-presence is given before reflection; it arises from a structure of phenomenal consciousness that is operative in all experiential modalities; it is simply there, given and imbuing all my experiences with an elusive, yet absolutely vital feeling of "I-me-myself" (which we above also have described with the concepts of self-presence, experiential or minimal self, ipseity, and for-me-ness) (Hart, 2009; Parnas & Handest, 2003; Parnas & Henriksen, 2013). The neural substrates underlying the empirical observations have not yet been adequately investigated in healthy or clinical populations, when referring to the phenomenological definition of self-experience. Other domains and definitions of the self have been more thoroughly examined, being more accessible and less conceptual. Among the most relevant, the bodily self or the bodily embeddedness has been extensively studied in its two components, the feeling of agency or sense of ownership, more pre-reflective, and the sense or feeling of agency, more reflective (Gallagher, 2000; Synofzik et al., 2008). Even memory constructs and social self-consciousness have been used to indirectly investigate the self (Gallagher, 2000; Gallagher & Zahavi, 2008). However, these approaches not only have their limitations but also focus on particular subdomains of the self that are not central to our interest. Our concentration lies in the broader phenomenological definition of experiential self, and in this specific area, there is still much ground to cover (Gallagher & Zahavi, 2008). One primary reason for this knowledge gap is the technical challenges of designing a paradigm that effectively captures the distinct neural activations linked specifically to the experiential self. Knowledge of the neurophysiological correlates of the pre-reflective experiential self has the potential to lead to a breakthrough in pathogenetic and etiological schizophrenia research.

Imaging studies on self-referential processing have primarily focused on reflective processes, which entail self-assessment from a third-person perspective. The bulk of evidence points to the involvement of cortical midline structures (CMS) and default mode network (DMN) during self-referential processing (Hu et al., 2016; Knyazev, 2013; Northoff et al., 2006; Sperduti et al., 2011; van Veluw & Chance, 2014). The medial prefrontal cortex (mPFC) and other portions of the frontal lobe, the temporoparietal junction (TPJ), the insula, the cingulate cortex, and the hippocampal cortex are consistently more involved in self than in other-related thinking (Hu et al., 2016; Knyazev, 2013; Na et al., 2021; Northoff et al., 2006; Qin et al., 2020; Sperduti et al., 2011; van Veluw & Chance, 2014). Additionally, the right hemisphere tends to be more involved in self-processing than the left one (Hu et al., 2016; Na et al., 2021; van Veluw & Chance, 2014). However, there needs to be more comprehensive research conducted on pre-reflective processes from a first-person perspective, and currently, only hypotheses exist to explain these phenomena. In their work, Northoff et al. (2006) hypothesize that the same structures involved in reflective self-processing may also play a role in pre-reflective self-experience. Nevertheless, due to the absence of direct investigation into the pre-reflective experiential self in the mentioned studies, definitive conclusions regarding the participation and behavior of these structures during pre-reflective mentation cannot be drawn. Since self-disorders result from the affection of the pre-reflective experiential self, there is a pressing need for further investigation in this area.

In this study, we will adopt the methodology employed by Esslen et al. (2008), who aimed to explore the experiential self in healthy individuals via a lexical task conducted during EEG recording. More in detail, in their study on evoked potentials, they adopted a modified version of a known paradigm used to explore self-other differences, where participants were asked to judge the appropriateness of an adjective related to the self or another person with a yes/no response. The underlying theoretical basis of this experimental design stems from Wittgenstein's theories, which propose that pronouns function as placeholders for individuals, devoid of personal judgments. At the same time, adjectives carry evaluative characteristics that personal opinions can influence. Consequently, the characteristics of these two syntactic components align with those of pre-reflective and reflective self-experience, respectively. In particular, the first-person pronoun is expected to evoke an experience accessible to the subject of our investigation in a pre-reflective manner (Wittgenstein, 1958). In essence, the first-person pronoun functions as a placeholder, eliciting in subjects a sense of genuine pre-reflective self-experience—it serves as a reference to this experiential state. This feeling or experience represents, to the best of our understanding, the closest approximation of the genuine pre-reflective self-experience achievable through an experimental paradigm. Indeed, we acknowledge the methodological problem posed by the presentation and thus the perception of the first-person pronoun, as it inherently introduces reference (or representation) to pre-reflective experience. We will refer to the evoked sensation as "reference to the pre-reflective self-experience" or "approximate pre-reflective self-experience". The methodological approach pursued by Esslen et al. in their investigation of the experiential self exhibits marked dissimilarity from our own, leading to outcomes that do not coincide, which we further elaborate in the Discussion section. While their study imparts valuable insights toward understanding pre-reflective self-experience, the lack of a comparative analysis between the self-experience components limits the exploration of specific correlates of each component.

In our study, we implemented a novel analytical approach in which we performed an interaction analysis between the task factors to compare neural activation in the reference to the pre-reflective self-experience, hypothesized to occur at the level of pronouns, primarily first-person, and in the reflective self-experiences, hypothesized to occur at the level of adjectives. In this way, we could close in on the unique spatiotemporal patterns of brain activity believed to be associated with each mode of self-experience and isolate the correlates of the pre-reflective one more effectively than Esslen et al. (2008)'s method. In our study, we formulated four hypotheses. The first and primary hypothesis stated that pre-reflective and reflective self-experience would have unique spatiotemporal patterns of brain activity. These patterns could be approximated by combining our paradigm and analytical approach. The second hypothesis proposed that event-related potentials (ERPs) associated with the reference to the pre-reflective self-experience would appear shortly after the presentation of stimuli. This hypothesis draws from ERP studies that have demonstrated early occurrences of automatic processes, akin to the theorized nature of pre-reflective self-experience, soon after stimulus onset. In contrast, conscious and task-dependent processes tend to manifest in later processing stages, as indicated by the evidence collected from these ERP studies

(Lamy et al., 2009; Ruz et al., 2003; Shevrin, 2001; Wong et al., 1994). The third hypothesis suggested that the sources of brain activity associated with the approximate pre-reflective self-experience would be localized in the regions belonging to the CMS, particularly in the mPFC, with a right-lateralized tendency. Lastly, we wanted to assess the task specificity of our results by introducing a task in which participants assessed color concordance between pronouns and adjectives without reflecting on the semantic content. As a classic control condition to our primary task, we hypothesized that we could approximate the correlates of the reference to the pre-reflective self-experience through this approach while reducing the manifestation of reflective self-experience.

2. Materials and methods

2.1. Subjects

Thirty adult healthy volunteers (8 males, 22 females) (mean age 25.2 years ± 3.6) were included in the study. The age range was limited between 18 and 35 years to obtain a relatively homogeneous sample and avoid the effects of brain maturation or aging (Campbell & Feinberg, 2009). All participants spoke standard German or Swiss German; twenty-four were right-handed, and six were left-handed. We excluded subjects with a history of previous neurological or psychiatric illnesses, prior head trauma, current use of psychoactive substances, or uncorrected vision problems. The day before the investigation, participants were told not to consume alcohol or drugs. Informed consent was collected before the beginning of the experiment, according to the Declaration of Helsinki. Participants did not receive any form of payment. The study was approved by the Ethics Committee of the Canton of Bern (ID 2018–00562).

2.2. **Psychometric** evaluations

The socioeconomic status was collected from the participants using a general demographic questionnaire. The Edinburgh Handedness Inventory, Short Version (EHI-short form) (Veale, 2014), was used to determine the position of the answer keys on the keyboard employed to record the responses to the task. A set of questionnaires, including the Autism-Spectrum Quotient, Short version (AQ-K) (Freitag et al., 2007), the Social Phobia Inventory (SPIN, German version) (Connor et al., 2001), the Schizotypal Personality Questionnaire (SPQ-G, German version) (Raine, 1991), and the Interpersonal Reactivity Index (IRI) (Paulus, 2009) were used to exclude concomitant neuropsychiatric disorders. No subject scored above the thresholds; therefore, all were included in the analyses.

2.3. Cognitive tasks

Our experimental protocol, developed from the original version published by Esslen et al. (2008), included two different tasks, trait judgment, and color judgment. The main reason for modifying the paradigm was to assess the task type's specific role in the results. As the pre-reflective and reflective self-experience are the main focus of our study, the tasks aimed to isolate the ERP correlates of these domains. In the context of the pre-reflective self-experience, it is essential to note that we are working with an approximation or reference of it. This approximation is due to the inherent unfeasibility of isolating its true correlates using any currently-available paradigm, as mentioned in the introduction. Both tasks consisted of 3-word German sentences, displayed word by word at 0.5 s intervals on a screen and followed by a question mark lasting 1 sec, after which the participants had to make a yes/no decision, with a total inter-trial interval of 2 sec, for an overall duration of about 12 min each. Phrases in both tasks randomly began with either the personal pronoun in the first person (self-reference: n = 50) or the third person (other-reference: n = 50), followed by the corresponding auxiliary verb, and by one out of fifty trait adjectives adapted from the German multidimensional questionnaire "*Die Eigenschaftswörterliste*" (Janke, 1978). The adjectives were balanced according to their positive or negative valence, category, and length and were shown once in each condition. The first and the third word were randomly displayed in changing colors.

During the trait-judgment task, participants were asked to evaluate whether the presented adjective was descriptive to themselves, in the case of first-person pronouns, or to a well-known person, male or female, in the case of third-person pronouns. The other person was chosen at the beginning of the examination, excluding relationships involving strong emotions, and was maintained throughout the protocol. During the color-judgment task, participants had to focus on the colors without paying attention to the content and decide

Fig. 1. Visual representation of the experimental task. Examples of displayed sentences include: "Ich bin müde" (I am tired), "Sie ist glücklich" (She is happy), "Er ist aufmerksam" (He is attentive). min: minutes; ms: milliseconds; TOT: total.

whether pronouns and adjectives had the same color.

During the acquisition, the participants were seated at a distance of 100 cm from the screen, and their head was fixed in a chinrest to minimize head movements during the EEG recording. The task was implemented with the Psychopy (Peirce et al., 2019) program, and the responses were recorded by pressing a key on a pre-adjusted computer keyboard. The participants were informed that the investigator was blind to their answers and that their correctness was irrelevant. Participants were also instructed to respond after the disappearance of the question mark to avoid overlapping with the ERPs.

A visual representation of the task is available in Fig. 1.

2.4. EEG recording

EEG was measured with a 64-channel active-electrodes system and recorded with Brain Vision Recorder. Active electrode placement was aided by an application cap according to the international 10–10 system with Ag/AgCl gel, with the recording reference placed at FCz. The signal was recorded at a digital sampling rate of 500 Hz, with an analog band-pass filter from 0.1 to 200 Hz, and was amplified and digitized with two Brain Amps. The impedances were controlled to be below 20 kOhm. The recording room was dimmed and closed to provide an optimal test environment. Before the recording, participants were shown how body movements would influence the EEG recording to minimize artifacts.

Before performing the task, a resting EEG was recorded, lasting on average 5 min, both during eye movements, open eyes, and closed eyes. Due to a technical problem, the resting EEG data from one participant were corrupted.

2.5. Preprocessing

The EEG datasets were preprocessed in the Brain Vision Analyzer 2. First, the resting EEG data were used to create an individual filter for eye movements in the following way: an infinite pulse response (IIR) band-pass filter between 1 Hz and 20 Hz and a notch filter at 50 Hz were applied to the data, as well as an Independent Component Analysis (ICA) to visually isolate and remove muscle artifacts through an inverse method.

Afterward, each subject's ICA spatial correction filter was applied to the EEG recorded during task execution through spatial filtering, and manual identification of the remaining artifacts was performed to exclude residual confounding factors. The trials included in the periods marked in the manual identification of artifacts were excluded from the analysis. When needed, channels were topographically interpolated due to insufficient signal quality or to homogenize channel montages across the samplings, leading to 66 channels per individual. Eventually, the data were recalculated to an average reference and exported.

2.6. **Data** analysis

2.6.1. EEG data

2.6.1.1. Trait-judgment task. We averaged periods of 500 ms before and 1000 ms after introducing the stimulus separately for each condition and participant to obtain ERPs. We segmented the data with segments of interesting parts, which were time slots around the presentation of stimuli. We extracted four conditions of interest, namely "Self-Pronoun" (average number of trials: 44.6 ± 4.7), "Self-Adjective" (45.1 ± 4.3), "Other-Pronoun" (45.1 ± 4.7), and "Other-Adjective" (45.4 ± 6.2), which were then averaged within each subject across trials. The ERPs for the four conditions were time-locked to the presentation of the words, i.e., of pronouns and of adjectives, respectively.

The ERPs were exported to the MATLAB-based open-source toolbox Randomization Graphical User (RAGU) interface (Habermann et al., 2018). In RAGU, we first filtered our data with a band-pass filter from 0.5 Hz to 12 Hz, with a notch filter at 50 Hz. Subsequently, we established the experimental design as a within-subject two-factor design, with the first factor, "reference," encompassing self and other conditions, and the second, orthogonal factor labeled "word type," comprising pronouns and adjectives conditions.

We computed a Topographic Analysis of Variance (TANOVA) (Strik et al., 1998) from 0 to 500 ms on the normalized data, with 5000 randomization runs and a p-threshold of 0.05 (Habermann et al., 2018; Robinson, 2007). We obtained the pattern of dissimilarity between topographies across the selected period between self and other-reference, between pronouns and adjectives, and in an interaction between both factors. To account for multiple testing, we performed global duration statistics (GDS) on the results of the TANOVA, calculating the duration of periods with significant p-values to be exceeded to exclude those likely to occur under the null hypothesis (Koenig & Melie-García, 2010). To confirm our main hypothesis, we implemented an interaction analysis between word type and reference factors in which we compared the difference in self-other processing between pronouns and adjectives. We then performed post hoc analyses of the significant effect. We implemented post hoc TANOVAs with different factor combinations and plotted the average t-maps to visualize a representation of the factors' effect on the brain space. Specifically, we computed the interaction between reference and word type factors and the difference in self- and other-reference in pronouns and adjectives.

Lastly, we implemented a within-subject single-factor experimental design for the TANOVA analysis from 0 to 500 ms post-stimulus onset, including the self- and other-reference in pronouns.

2.6.1.2. Color-judgment task. Analogously as for the trait-judgment task, periods of 500 ms before and 1000 ms after the introduction of the stimulus were segmented in the four conditions of interest and averaged to obtain ERPs: "Self-Pronoun" (average number of trials: 46.2 ± 2.8), "Self-Adjective" (46.9 ± 2.7), "Other-Pronoun" (45.8 ± 3.3), "Other-Adjective" (46.6 ± 2.6). In RAGU, we first filtered the data and then defined a within-subject two-factor experimental design as a two-factorial within-subject design with "reference" and "word type" factors.

We computed a TANOVA (Strik et al., 1998) from 0 to 500 ms on the normalized data, with 5000 randomization runs and a p-threshold of 0.05 (Habermann et al., 2018; Robinson, 2007).

To investigate the task-dependency of our results, we computed a post hoc TANOVA for the interaction between the reference and word type factors in the time period evidenced by the main TANOVAin the trait-judgment task. We also computed the interaction between factors in both tasks together.

Additionally, we implemented another within-subject single-factor experimental design for the TANOVA analysis, including only the self- and other-reference in pronouns from 0 to 500 ms post-stimulus onset. At last, we made a within-subject two-factor design including as factors "reference," self or other, and "task type," trait- or color-judgment, from 0 to 500 ms post-stimulus onset.

2.6.1.3. Source localization. We performed post hoc source visualization of the difference in ERPs of self and other-reference in the pronouns condition in the trait-judgment task to localize the sources of the effect we confirmed with the TANOVA. As the method of choice, we implemented the sLORETA Packet (Pascual-Marqui, 2002). Indeed, the topographic difference between maps of the conditions evidenced by the TANOVA implies the presence of different sources of brain activity. In this context, we used the sLORETA approach to explore this difference and visualize the sources of activity. The ERPs were averaged over the 254–310 ms window and voxelwise t-values were computed. Intracerebral current density was estimated using the sLORETA software (Pascual-Marqui, 2002) that used a boundary elements head model derived from the MNI152 template, and a total of 6239 voxels of 5 × 5 × 5 mm size that covered all cortical gray matter. The regularization parameter was set to a SNR of 100.

We were able to extract the coordinates of the regions involved in the contrast of interest, and, for each region, we considered the maxima and the minima of t-values with a threshold of 2.1, corresponding to a p-value of 0.05. As the source localization analysis was solely conducted to obtain the most plausible explanation in source space for an already statistically confirmed difference in sensor space, but not to accept or reject specific null hypotheses, we opted not to apply a correction for multiple comparisons, but to merely threshold the obtained t-values below a level we found less interesting.

3. Results

3.1. EEG data

3.1.1. Trait-judgment task

The TANOVA for the interaction effect between reference and word type factors yielded one window between 254 and 310 ms post-stimulus onset, in which the pre-reflective and reflective component are likely distinguishable and which survived the correction for multiple testing (Figs. 2 and 3). This implies that at some point during this period, the pre-reflective and reflective self-experience neural correlates differed (Sassenhagen & Draschkow, 2019). The post hoc TANOVA in the period 254–310 ms post-stimulus-onset confirmed the results of the interaction analysis, and the t-map provided an overview of the distribution of the sources contributing to the difference in the pre-reflective and reflective self-experience ($p = 0.0004$). Regarding the specific contributions of pronouns and adjectives, we found a significant difference between self- and other-reference in pronouns ($p = 0.0004$) but not in adjectives ($p = 0.8186$) (Fig. 4). Independently from the TANOVA analysis we also calculated the mean explained variance for the interaction analysis between 254 and 310 ms post-stimulus onset ($\eta^2 = 0.13$).

In the within-subject single-factor design, including reference factors in pronouns, we found a window at 212–308 ms post-

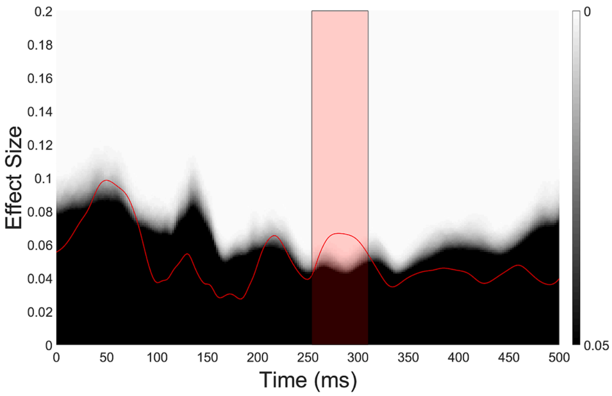

Fig. 2. Effect size of TANOVA for the interaction between reference and word type factors in the trait-judgment task over time. The red line represents the observed effect size and the shadow represents the density of the effect size in the 5000 TANOVA iterations over time. The window highlighted in red represents the window of significance between 254 and 310 ms. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

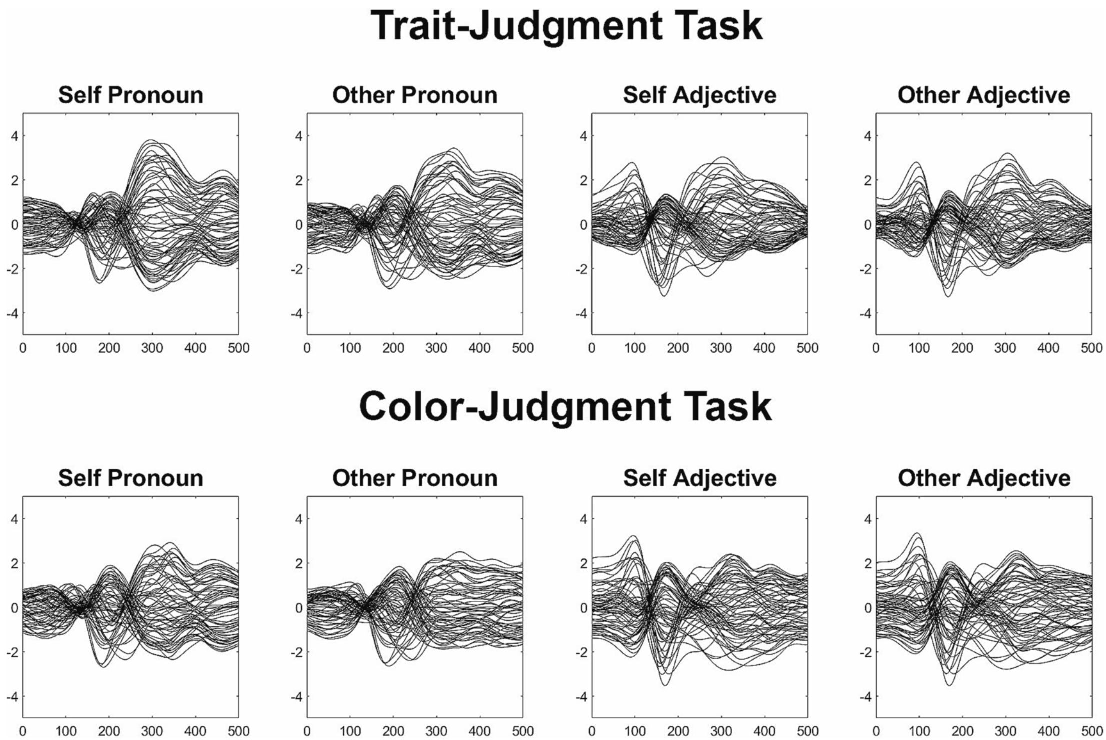

Fig. 3. Butterfly plot of the average ERPs per each subject in the four conditions in each task, from 0 to 500 ms post-stimulus onset. The effect observable at around 450 ms is an offset component depending on our experimental design. μV: microvolts; ms: milliseconds.

stimulus-onset, in which a difference in self- vs. other-reference occurs at some point ($p = 0.0002$). Additionally, we independently calculated the mean explained variance in the 212–308 ms time window ($\eta^2 = 0.13$).

3.1.1.1. Color-judgment task. The post hoc TANOVA for the reference × word type interaction in the time-period 254–310 ms post-stimulus-onset produced a non-significant result ($p = 0.3226$), not evidencing any difference in the pre-reflective and reflective self-experience, as did the post hoc TANOVA including both tasks ($p = 0.2142$) (Fig. 5).

In the within-subject single-factor design, including reference factors in pronouns, we found a window at 324–384 ms post-stimulus-onset, in which a difference in self- vs. other-reference occurs at some point ($p = 0.0152$). Additionally, we independently calculated the mean explained variance in the 324–384 ms time window ($\eta^2 = 0.08$).

To conclude, the design, including the reference factors in pronouns in both tasks, yielded no significant results throughout the time period.

3.2. Source localization

The sLORETA method (Fig. 6, Table 1) localized clusters in the right anterior superior and medial frontal gyrus, inferior parietal lobe, and temporal gyri, that expressed higher activity in self- than in other-processing in pronouns, i.e., higher activity in pre-reflective than in reflective self-experience.

Clusters in the left superior medial and middle frontal gyrus, left superior parietal lobe, right middle and superior temporal gyri, right posterior cingulate cortex, and bilateral anterior cingulate cortex expressed lower activity in self- than in other-processing in pronouns, i.e., in pre-reflective than in reflective self-experience.

4. Discussion

Our study used an innovative analytical approach to examine the ERP correlates of (approximate) pre-reflective and reflective modes of self-experience, employing a modified version of the lexical paradigm of Esslen et al. (2008). We found a discernible time window at 300 ms after the stimulus onset, during which the two modes of self-experience can be distinguished in correspondence with pronouns in the trait-judgment task. Additionally, our mapping of activity sources revealed clusters in the DMN and CMS, with the pre-reflective mode specifically involving the medial prefrontal cortex and inferior parietal lobe and the reflective mode involving the cingulate cortex and superior parietal lobe.

The finding that the reference to the pre-reflective mode is distinguishable from the reflective mode at the level of pronouns aligns

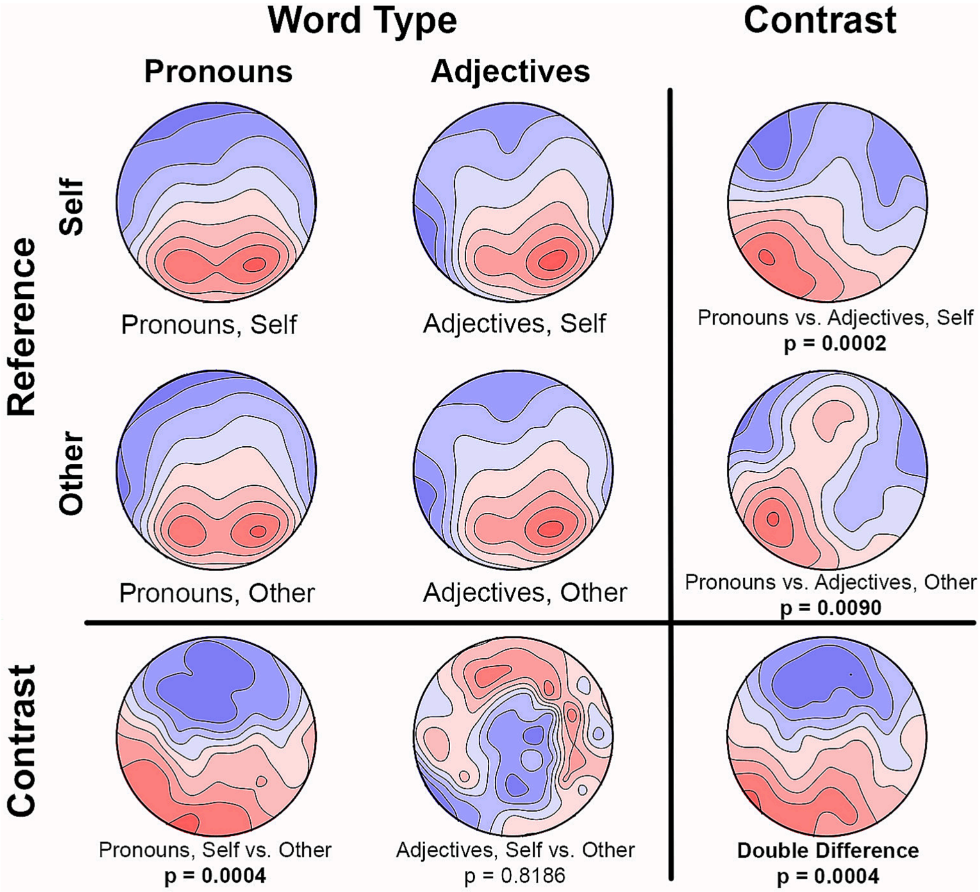

Fig. 4. Topographic mapping of mean ERPs in word type and reference factors and their interactions in the trait judgment task from 254 to 310 ms post-stimulus onset. Significant p-values are highlighted in bold. ERPs: event-related potentials; ms: milliseconds; p: p-value.

with the phenomenological theories on the self (Zahavi, 2005, 2007; Metzinger, 2007). On the one hand, first-person pronouns, serving as approximations of the pre-reflective component, potentially encompass some of the qualities of *selfhood*, such as the first-person perspective and the sense of ownership. On the other hand, third-person pronouns lack these qualities and are perceived as distinct from the self, as objects of reflection. When considering processes at the level of adjectives, the absence of a difference between self- and other-reference may suggest that reflective processes occur similarly in both self- and other-reference and that self-other differentiation has already occurred as a distinction between pre-reflective and reflective self-experience at the pronoun level early after stimulus onset. In comparing our findings with those of Esslen et al. (2008), it is crucial to address some key points. Firstly, Esslen et al. adopted a priori hypothesis in their study, suggesting that pre-reflective self-experience would manifest at the pronoun level, while reflective self-experience would be evident at the adjective level. This choice significantly influenced their analytical approach, where the pre-reflective aspect was identified by comparing self- to other-reference at the pronoun level and the reflective aspect by comparing self- to other-reference at the adjective level, all without incorporating an interaction analysis between these factors, as we did. Our method allowed us to identify a temporal window where the distinct correlates of the two components could be disentangled. Furthermore, our results suggest that the critical difference occurs at the pronoun level, challenging the idea of considering adjectives as proxies for the reflective component. In summary, we can draw some comparisons between the pre-reflective correlates identified by Esslen et al. (self vs. other-reference in pronouns) and our findings. However, the reflective component, as per our results, should correspond to other vs. self-reference in pronouns, a contrast not reported in Esslen et al. (2008). Lastly, in their paradigm Esslen et al. also implemented a control condition for the pronouns, featuring meaningless letter combinations forming words (e.g., hcI, iSe, rE). The resulting activations linked to these letter combinations were subtracted from the activations associated with pronouns to allow for a comparison between self and other-reference, unbiased by the visual differences between words. In our study, the control task was not employed for this correction. Instead, it was utilized to assess result specificity and was treated identically to the main paradigm. With this context established, we can discuss the similarities and differences in results between our study and that of Esslen et al. (2008).

Concerning the time segments identified for self vs. other-reference in pronouns (indicating pre-reflective self-experience) in Esslen et al., some align closely with our findings, manifesting very early after stimulus onset (134–170 and 198–234 ms). However, we did not replicate later segments observed between 400 and 500 ms post-stimulus onset in our study. In terms of the TANOVA for self vs.

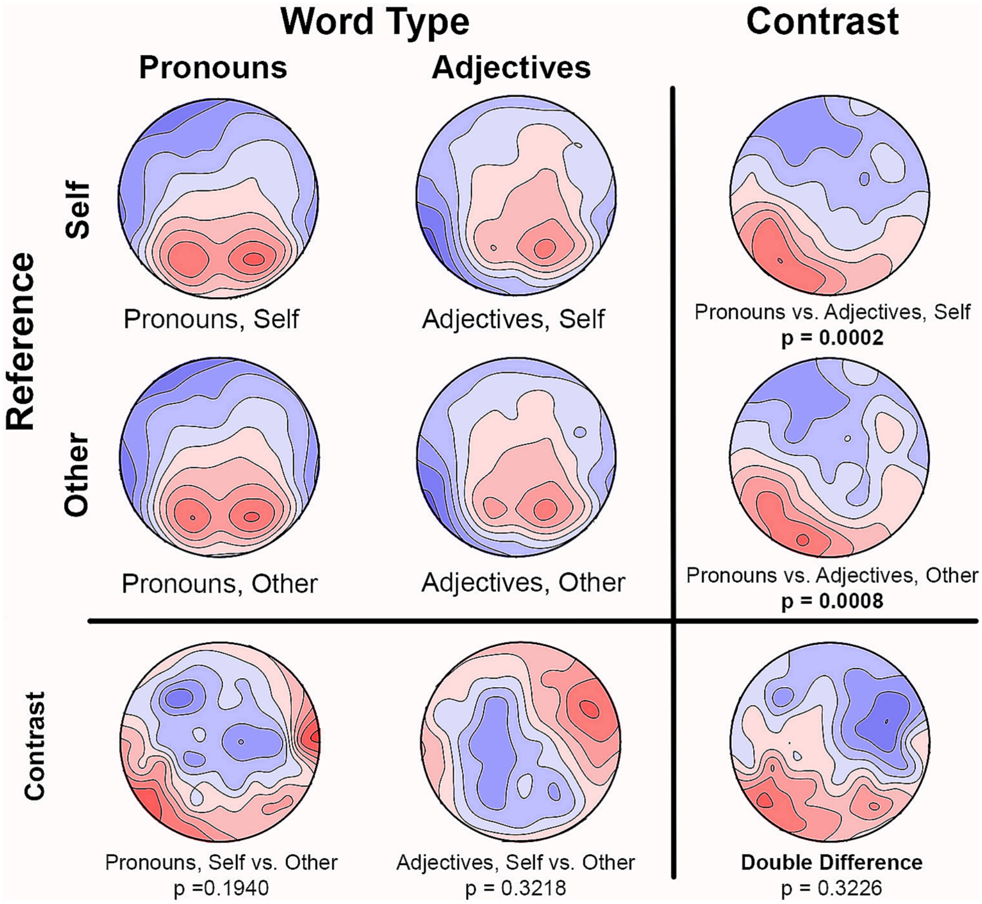

Fig. 5. Topographic mapping of mean ERPs in word type and reference factors and their interactions in the color judgment task from 254 to 310 ms post-stimulus onset. Significant p-values are highlighted in bold. ERPs: event-related potentials; ms: milliseconds; p: p-value.

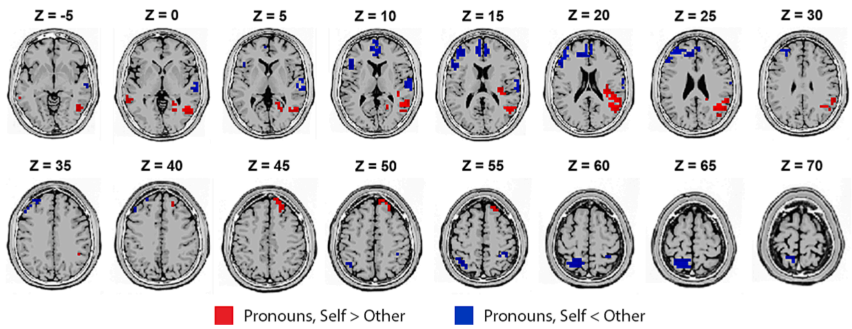

Fig. 6. sLORETA localization of sources of brain activity in self-reference compared to other-reference in pronouns in the trait-judgment task for the interval 254–310 ms post-stimulus onset. Regions exhibiting increased activity during self-reference, as compared to other-reference, are depicted in red, while regions showing higher activity during other-reference, as compared to self-reference, are indicated in blue. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

other-reference in adjectives (reflective self-experience in Esslen et al.), their reported brief period around 250 ms post-stimulus onset, in which only one brain region was identified as source, is comparable to our own lack of findings at the level of adjectives.

The findings from the source estimation analysis indicated that most of the clusters associated with both the modes of self-experience were in the DMN and the CMS. Although there was some overlap between the pre-reflective and reflective self-experience sources, distinct activations were observed. Furthermore, the study supported the existing literature on the right lateralization of structures involved in self-processing (Hu et al., 2016; Na et al., 2021; van Veluw & Chance, 2014). Our findings were also largely consistent with those of Esslen et al. (2008) in their LORETA high time resolution analysis they performed on segments from the

Table 1
Detailed results of source localization with sLORETA. The "self > other" values correspond to the maxima, and the "other > self" values correspond to the minima.

Condition	Structure	MNI coordinates			Uncorrected t
		x	y	z	
Self > other	Superior frontal, medial R	20	40	50	2.92
	Cingulate R	20	−45	25	2.18
	Parahippocampal R	25	−55	0	2.60
	Posterior cingulate R	20	−55	5	2.71
	Inferior Temporal R	50	−65	−5	2.40
	Lingual R	25	−65	0	2.42
	Middle occipital R	40	−65	0	2.70
	Middle temporal R	40	−60	15	3.12
	Angular R	50	−65	30	2.16
	Inferior parietal R	50	−50	25	3.04
	Supramarginal R	55	−50	30	2.56
	Insula R	40	−45	20	3.29
Other > self	Inferior frontal L	−50	30	20	3.40
	Medial frontal L	−5	50	15	3.51
	Middle frontal L	−45	40	20	3.57
	Precentral L	−45	15	10	2.37
	Anterior cingulate L	−5	45	15	3.59
	Uncus	15	0	−30	2.16
	Postcentral R	65	−20	15	3.22
	Precuneus L	−10	−60	65	2.76
	Superior parietal L	−20	−60	65	2.87
	Superior temporal R	65	−20	10	3.56
	Transverse temporal R	60	−20	10	3.43

L: left; R: right; t: t-value.

TANOVA lasting more than 10 s.

Concerning the reference to the pre-reflective mode, we evidenced clusters located in frontal structures and, in particular, the medial frontal cortex, which has been extensively documented in the literature on the "experiential self" and already hypothesized to be involved in the pre-reflective mode by Northoff et al. in 2006. Both the ventral and the dorsal parts are thought to be involved in self-referential processing and subtend to the pre-reflective self by differentiating between self- and non-self-referential stimuli, connecting with lateral structures devoted to higher-order processing. Moreover, even though both also are foci of the DMN and are thus involved in resting state activity, the medial frontal cortex appears to be particularly involved in self-related mentation and to have a regulatory activity on the other regions of the "core self" (Davey et al., 2016). We also found involvement of the right inferior parietal lobe, which is yet another component of the DMN (Alves et al., 2019; Andrews-Hanna, 2012). It is involved in self-referential activity and in agency (Igelström & Graziano, 2017; Knyazev, 2013; Northoff et al., 2006; Northoff & Bermpohl, 2004). Evidence also supports the relationship between this region and the ability to discriminate between self and others (Uddin et al., 2006). Despite the differences in the analytical approach we already thoroughly discussed, the regions evidenced by Esslen et al. also include medial structures, such as the medial frontal and the cingulate cortex. However, the activations evidenced were more widespread, including temporal structures in the left hemisphere.

In reflective self-experience, we evidenced clusters of activity in the anterior cingulate cortex, a region known for its involvement in processing self-related information (Northoff et al., 2006; Qin & Northoff, 2011), primarily related to physical self-representation (Hu et al., 2016). This finding aligns with previous evidence collected by Northoff et al. (2006), that suggests the anterior cingulate cortex, along with the medial prefrontal cortex, plays a crucial role in evaluating the degree of self-referentiality of stimuli, making it a key component of the "core self". Furthermore, we confirmed the involvement of the posterior cingulate cortex in self-processing as a midline structure within the DMN (Knyazev, 2013; Northoff et al., 2006; Northoff & Bermpohl, 2004; Qin et al., 2020; Qin & Northoff, 2011; Raichle, 2015; Uddin et al., 2009). It is also in line with the role of the posterior cingulate in integrating self-referential stimuli with personal autobiographical context and processing of other-referential reflection, consistent with findings by Vogeley et al. (2004) (Vogeley et al., 2004). Additionally, we observed activity in the superior frontal and middle frontal gyrus, which are highly positively correlated with the posterior cingulate cortex (Uddin et al., 2009) but did not find any activation in the medial frontal cortex. We also identified clusters in the superior parietal lobe, located adjacent to the posterior cingulate cortex, likely involved in memory processing and retrieval, linking new information to old memories (Lou et al., 2004).

Clusters were identified in various regions of the temporal gyri, including the inferior, middle, and superior for the approximate pre-reflective mode and the middle and superior for the reflective mode. There is evidence supporting the involvement of these structures in self-related mentation. Specifically, the inferior temporal gyrus appears to be involved in spatial self-location and first-person perspective (Ionta et al., 2011), while the middle temporal gyrus is a component of both the CMS and the DMN and plays a crucial role in self-awareness (Chavoix & Insausti, 2017; Northoff et al., 2006; Qin et al., 2020; Qin & Northoff, 2011; van Veluw & Chance, 2014). The STG itself is associated with mental self-representation. It was also among those regions where self- and other-representation overlap and are in close communication with the PCC, a key node of both the CMS and the DMN. All these structures have a generating role in self-experience (Alves et al., 2019; Andrews-Hanna, 2012; Davey et al., 2016; Uddin et al., 2009).

Taking a different perspective on the interpretation of these results, it is notable that some of the clusters involved in reference to the pre-reflective self-experience are also components of the bottom-up ventral attention network, including the inferior parietal lobe and ventral frontal cortex (Corbetta & Shulman, 2002). This network, specifically its right lateralization, is crucial in attention reorienting. Conversely, some of the clusters involved in the reflective self-experience, particularly the superior parietal lobe, are components of the top-down dorsal attention network, responsible for attributing salience to the perceived stimuli (Corbetta & Shulman, 2002).

In relation to the work of Esslen et al., they looked at reflective activation as the areas more involved in self-reference at the level of adjectives. Therefore, while the comparison between our work was somehow possible for the pre-reflective condition, it does not make sense for the reflective condition.

In the color-judgment task, there were no differences in ERPs associated with the two modes of self-experiences throughout the time periods. This result is likely correlated with the design of the paradigm, in which the color-judgment task is built to reduce conscious reflection about the personal content of the sentence. However, when looking at the additional designs, including only pronouns in the two tasks, we could still find a difference in self- and other-processing, occurring earlier in the trait-judgment than in the color-judgment task. By looking at the additional study design, including the pronouns in both tasks, a lack of difference in self-other processing indicates that the mental processes involved are similar and, thus, that the modes of self-experiences are, as expected, partially task-independent.

The evidence gathered with our study lays the groundwork for further research in the experiential self and its associated pathological states, particularly self-disorders, which are a dimension of severe mental conditions like non-affective psychoses. By grasping the physiological engagement of distinct neural substrates linked to an approximate of the pre-reflective self-experience, we can shed light on potential alterations in individuals with self-disorders. This knowledge would contribute to our understanding of these conditions and present the opportunity to identify fresh therapeutic targets for addressing self-disorders, which conventional interventions have inadequately targeted (Henriksen & Nordgaard, 2014; Henriksen & Parnas, 2014).

5. Limitations

The current study is subject to some limitations. Firstly, one aspect that warrants consideration is the appropriateness of the task in effectively eliciting and differentiating between pre-reflective and reflective modes. Nevertheless, it is noteworthy to acknowledge the limited availability of evidence on this specific topic. Therefore, we have chosen to adopt and modify the sole paradigm that has previously demonstrated success. Additionally, we acknowledge a methodological challenge associated with presenting the self-pronoun, as it introduces a reference to the pre-reflective self-experience. Nevertheless, this approximation not only represents the closest achievable semblance to genuine pre-reflective self-experience within a language-related experimental paradigm, to the best of our knowledge, but it also serves as a necessary placeholder for conducting any analysis on the data. Secondly, while phenomenological theories about the experiential self propose an overlapping between pre-reflective, a basic and foundational aspect of consciousness, and reflective self-experience, a higher-order cognitive process, our chosen methodology does not provide further evidence in this aspect. As a result, the broader interpretations concerning the periods beyond the significance window in our results remain within speculation. Thirdly, an intrinsic limitation of the EEG modality is the low spatial resolution, which impacts the interpretation of the involved brain sources. Lastly, the question of whether sLORETA is sufficiently accurate to detect brain sources associated with pre-reflective and reflective thinking per se and whether this can be achieved with the placement of 64 electrodes remains a theoretical question that is open to speculation as long as no comparison has been made with the current ideal method for locating electrical sources, i.e., an fMRI examination. Follow-up studies should combine the two imaging techniques to achieve a high time resolution and the best possible spatial resolution.

6. Conclusions

Our study compared approximated pre-reflective and reflective self-experience in healthy individuals. Pre-reflective and reflective self-experience could be distinguished during a brief time window at approximately 300 ms after stimulus onset. The pre-reflective mode mainly involved the medial prefrontal cortex and the bottom-up ventral attention network. In contrast, the reflective mode implicated the cingulate cortex and top-down dorsal attention network. These findings contribute to our understanding of the neural mechanisms underlying pre-reflective self-experience and might have implications for clinical research and interventions targeting self-disorders. We see our methodology and the insights gained from its application as fundamental to integrating EEG and fMRI techniques, enabling resolution-optimized studies, particularly in individuals with schizophrenia spectrum disorders.

Declaration of Generative AI and AI-assisted technologies in the writing process.

During the preparation of this work, the authors used ChatGPT 3.5 in order to improve language and readability. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Piani Maria Chiara: Formal analysis, Investigation, Data curation, Writing - Original draft, Visualization, Project administration. **Gerber Bettina Salome:** Investigation, Formal analysis, Data curation, Writing – review & editing. **Koenig Thomas:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Supervision, Project administration. **Morishima Yosuke:**

Conceptualization, Writing – review & editing, Supervision. **Nordgaard Julie:** Writing – review & editing, Supervision. **Jandl Martin:** Conceptualization, Writing – review & editing, Supervision, Project administration.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Reference

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