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Like the back of my hand:

Visual ERPs reveal a specific change detection mechanism for the bodily self

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ABSTRACT

The ability to identify our own body is considered a pivotal marker of self-awareness. Previous research demonstrated that subjects are more efficient in the recognition of images representing self rather than others' body effectors (*self-advantage*). Here, we verified whether, at an electrophysiological level, bodily-self recognition modulates change detection responses. In a first EEG experiment (discovery sample), event-related potentials (ERPs) were elicited by a pair of sequentially presented visual stimuli (vS1; vS2), representing either the self-hand or other people's hands. In a second EEG experiment (replicating sample), together with the previously described visual stimuli, also a familiar hand was presented. Participants were asked to decide whether vS2 was identical or different from vS1. Accuracy and response times were collected. In both experiments, results confirmed the presence of the *self-advantage*: participants responded faster and more accurately when the self-hand was presented. ERP results paralleled behavioral findings. Anytime the self-hand was presented, we observed significant change detection responses, with a larger N270 component for vS2 different rather than identical to vS1. Conversely, when the self-hand was not included, and even in response to the familiar hand in Experiment 2, we did not find any significant modulation of the change detection responses. Overall our findings, showing behavioral self-advantage and the selective modulation of N270 for the self-hand, support the existence of a specific mechanism devoted to bodily-self recognition, likely relying on the multimodal (visual and sensorimotor) dimension of the bodily-self representation. We propose that such a multimodal self-representation may activate the salience network, boosting change detection effects specifically for the self-hand.

Keywords: Bodily-self recognition; self-advantage; change detection; EEG; N270

1. Introduction

The ability to recognize the own body visually (for example from a picture or when it is reflected in the mirror) has traditionally been considered as a pivotal marker of self-awareness (for a recent review see e.g. Apps & Tsakiris, 2014). However, while we usually distinguish other people's body by vision only, for bodily-self recognition we can rely on information coming from different sensory modalities (Tsakiris, 2010). To identify own body effectors, we usually resort to a wide network of sensorimotor (e.g. proprioceptive, somatosensory and motor) inputs, rather than to visual features *per se* (Ehrsson, Holmes, & Passingham, 2005; Frassinetti, Ferri, Maini, Benassi, & Gallese, 2011). Nonetheless, in a series of previous studies employing visual-matching tasks, Frassinetti and colleagues demonstrated that subjects are faster and more accurate in discriminating grey-scale pictures representing bodily-self effectors as compared to others' body effectors (the so-called *self-advantage*) (Frassinetti et al., 2011; Frassinetti et al., 2008; Frassinetti et al., 2009). The presence of such facilitation in participants' performance has been associated with the recourse to a sensorimotor network recruited when subjects had to recognize the bodily-self in "implicit" tasks (see e.g. Frassinetti et al. 2009; Conson, Volpicella, De Bellis, Orefice, & Trojano, 2017; in other words, the self-recognition is task-irrelevant, i.e. not explicitly required in task instructions). More specifically, the self-advantage was associated with the activation of a visual-sensorimotor network including, besides occipital areas, bilateral premotor cortex and right temporal cortex encompassing the extrastriate body area (Ferri, Frassinetti, Ardizzi, Costantini, & Gallese, 2012). However, even though the study by Ferri and colleagues revealed a direct involvement of the somatosensory cortices in self-hand recognition, since a motor task (i.e., hand-rotation) was performed, it cannot be excluded that the (motor) nature of the task might have contributed to the observed sensorimotor activation.

The idea that bodily-self recognition implies the interaction between visual and sensorimotor areas has been confirmed also by different lines of research that does not employ motor tasks, such as those studies investigating the neural correlates of a famous illusion of body ownership (i.e. the rubber hand illusion; see e.g., Botvinick & Cohen, 1998; Bucchioni et al., 2016; Burin et al., 2017; Della Gatta et al., 2016; Fossataro, Bruno, Giurgola, Bolognini, & Garbarini, 2018). During this illusion, participants, while watching a human-like rubber hand being touched synchronously with their own hand hidden from view, experience the feeling that the fake hand has become part of their own body. It has been demonstrated that, during this procedure, the functional connectivity between visual areas (e.g. lateral occipitotemporal cortex and extrastriate body area; EBA) and ventral premotor cortex is specifically modulated during the embodiment (i.e. when the fake hand is attributed to themselves) (Limanowski & Blankenburg, 2015; Zeller, Friston, & Classen, 2016), consistently with the fact that the illusion reduces the perceived objective (visual) dissimilarities between the own and the rubber hand (Longo, Schuur, Kammers, Tsakiris, & Haggard, 2009). Moreover, lesion studies of brain damaged patients exhibiting an impairment of self-other hands discrimination support the involvement of a visual-sensorimotor network in self-recognition. Indeed, the core lesion underpinning this deficit has been identified in the subcortical white matter connecting temporal areas, involved in the visual recognition of the body (i.e., the extrastriate body area, EBA), with anterior multisensory areas, such as the premotor cortex (Pia et al., 2020).

Furthermore, the recruitment of multimodal networks (including sensorimotor areas) in self-recognition is not only observed for limb discrimination, but it has been described for faces as well, without the involvement of a motor task (Cardini et al., 2011; Morita et al., 2018; Sugiura, 2015). For example, Cardini and colleagues found that ventral premotor cortex activity differed when viewing self-face as compared to another’s face, thus revealing a crucial role of sensorimotor areas in self-other face discrimination. Accordingly, the processing of the self-face has been associated to a specific sensorimotor pattern of activations, involving sensory (i.e., visual, somatosensory and interoceptive areas) and motor association cortices (i.e., premotor cortex and supplementary motor area – see Sugiura et al., 2015 for a review). Overall these findings suggest the presence of different mechanisms for self- *versus* other people's body recognition (De Bellis, Trojano, Errico, Grossi, & Conson, 2017; Ferri, Frassinetti, Costantini, & Gallese, 2011; Hu et al., 2016; Myers & Sowden, 2008), thus highlighting the specificity of self-recognition.

In the present study, we investigated whether implicit (task-irrelevant), bodily-self recognition has an observable electrophysiological correlate. To this aim, we exploited the repetition suppression phenomenon and we asked whether it could be modulated by implicit, bodily-self recognition. As widely described in the literature, event-related potential (ERP) amplitudes are strongly reduced when the same stimulus is repeated at short and constant time intervals (Iannetti, Hughes, Lee, & Mouraux, 2008; A. L. Wang, Mouraux, Liang, & Iannetti, 2010). Amplitude modulations induced by repetition have also been observed for abstract visual stimuli, such as different shapes (Y. Wang, Cui, Wang, Tian, & Zhang, 2004), and body-related pictures, mainly human faces (for a recent review see Schweinberger & Neumann, 2016). Importantly, the detection of a *change* within stimulus sequence is able to revert such amplitude reduction due to repetition. In other words, the sudden change of one or more stimulus basic features (e.g. modality, intensity, shape, or color) usually enhances the amplitude of the evoked responses (Valentini, Torta, Mouraux, & Iannetti, 2011; Y. Wang et al., 2004). However, this is not always the case. Through a paradigm exploiting intensity modulations of repeated painful stimuli, it has been shown that intensity increases but not decreases could revert repetition-related amplitude reduction (Ronga, Valentini, Mouraux, & Iannetti, 2013). The authors interpreted their findings suggesting that only *salient* changes were able to induce change detection-related responses.

Based on the above evidence, changes involving the self-hand should be considered salient by the nervous system. Previous studies highlighted the specificity of self-hand recognition, which seems to rely on a peculiar sensorimotor mechanism. In other words, the difference between the self- *versus* other people's hand recognition, by resorting to distinct neural mechanisms, may represent a *kind* rather than a *degree* property. It seems therefore likely that stimulus changes involving the self-hand may elicit salience effect (i.e. the reversion of repetition suppression), which are similarly described as *kind* phenomena. Indeed, as demonstrated by previous studies (Ronga et al., 2013; Torta, Liang, Valentini, Mouraux, & Iannetti, 2012), the change detection effects induced by salient stimuli are expressed in an *all or nothing* fashion (i.e., the reversion of repetition suppression is not gradable but either present or absent). Analogously, since the self-hand could be more salient than the other's hands, we should expect that only the visual presentation of the self-hand may induce change detection-related responses. Conversely, changes between other people's hands, and even between familiar and not familiar hands, may not be salient enough to revert repetition suppression phenomena.

In our EEG paradigms, ERPs were recorded while participants were presented with grey-scale images depicting the right hands. Hand pictures were delivered in pairs (vS1 and vS2), at a constant 1-second interval, and might represent either the participant's self-hand or other people's hands. *Experiment 1* was directed to explore whether the presentation of the self-hand boosts the change detection mechanism, reversing the repetition suppression phenomenon. It was divided into two different conditions (*scenarios*): in the *With Self* scenario, the self-hand was included within the presented visual stimuli; in the *Without Self* scenario, the self-hand was never presented (see 2.1.2 for a rationale description). Subjects were asked to judge whether vS2 was identical or different from vS1 (*implicit recognition task*). ERPs to visual stimuli, as well as accuracy and response times (RTs) were collected. *Experiment 2* specifically aimed at replicating results of Experiment 1 also controlling for any familiarity bias in our behavioral and EEG results. In the design of Experiment 1, the self-hand is the only hand participants had some familiarity with. Therefore, in case we found any specific change detection response for the self-hand, we could not disentangle whether this result was driven by a mechanism specific for the body-self or by a general familiarity effect. To control for this aspect, in Experiment 2 we included a third scenario, namely the *With Familiar* scenario, where one of the two others' hands was familiar to the participants, by means of repeated presentation of such a hand in the immediately preceding scenario.

From a behavioral point of view, both in Experiments 1 and 2, we expected to confirm the presence of the self-advantage, i.e. higher accuracy and faster RTs any time when at least one self-hand was included in the pair of visual stimuli. From an electrophysiological point of view, if bodily-self recognition actually represents a unique and salient phenomenon, recruiting dedicated mechanisms and neural networks, then in both experiments we should observe a significant change detection effect (i.e. greater amplitude difference between responses to repeated *versus* non-repeated stimuli) only for images representing the self-hand. Crucially, in Experiment 2 we should observe a clear difference in the change detection responses between the With Self scenario and the With Familiar scenario, with significant change detection effect for the self-hand. We expect that this effect might specifically be observed on the N270 modulation, a component which has been systematically related to visual change detection (Bennett, Duke, & Fuggetta, 2014; Scannella et al., 2016; P. Wang et al., 2018; Zhang et al., 2008).

Alternative results, showing a similar change detection effect for self- and other people's hands, would instead challenge the idea of the presence of a specific mechanism for bodily-self recognition.

2. Materials and Methods

2.1 Experiment 1 (discovery sample)

2.1.1 Participants

Fifteen healthy right-handed subjects participated in the study (5 women) aged 22-26 years (mean±SD: 24.1 ±1.2; years of education: 17.9 ±1.0).

Sample size (N=15) was a priori determined to match the number of subjects involved in previous research investigating visual mismatch detection effects and exploiting the same EEG analyses employed in the present study (Wang et al. 2003, N=13; Wang et al. 2004, N=15; Bennet et al. 2014, N=16).

All participants gave their written informed consent to participate in the study, which conformed to the standards required by the Declaration of Helsinki and was approved by the Ethics Committee of the University of Torino (prot. n. 125055, 12/07/16).

2.1.2. Stimuli and Experimental Design

Visual stimuli consisted of grey-scale pictures (10x15 cm) of the dorsum of open right hands belonging either to the participants or to other people. Hand pictures were taken before the experiment, all in the same room, with controlled illumination conditions and were post-processed. As a first step, picture background was removed and replaced with a black uniform background, original color pictures were then converted in grey-scale images with the aim of standardizing different skin colors. Finally, hand images were resized in order to have all similar dimensions. The resulting visual stimuli were presented for 0.3s at the center of a 21-inch *Sony* CRT computer screen.

The experimental paradigm (presented in Fig. 1) partially replicated the methodology proposed by Frassinetti et al. (2009). However, stimulus presentation parameters (e.g. presentation mode, duration, interstimulus-interval, intertrial-interval) were modified in order to realize a paradigm suitable for EEG. The experiment consisted of a single session divided into two different scenarios (i.e. *With Self* and *Without Self*) and four 8-minute recording blocks (2 per scenario).

Each scenario was composed of 104 pairs of visual stimuli (vS1 and vS2), delivered at a constant 1 s inter-stimulus interval. The time interval between each pair was randomly jittered between 6 and 8 s, in a way that participants could not anticipate stimulus occurrence.

In both scenarios, vS1 and vS2 could be either identical or different. In the *With Self* scenario, visual stimuli included participants' self-hand. Four different types of pairs were presented: *Self-Self* (with both vS1 and vS2 depicting the self-hand); *Other1-Other1* (with vS1 and vS2 depicting the same hand belonging to a stranger – *Other1*); *Self-Other1* (with vS1 representing the self-hand and vS2 Other1's hand); *Other1-Self* (with vS1 representing Other1's hand and vS2 the self-hand).

In the *Without Self* scenario, the self-hand was never presented. Four different types of pairs were delivered: *Other2-Other2* (with vS1 and vS2 depicting the same hand belonging to a stranger – *Other2*, different from *Other1*); *Other3-Other3* (with both vS1 and vS2 depicting the same hand belonging to a stranger – *Other3,* different from *Other1* and *Other2*); *Other2-Other3* (with vS1 representing *Other2*'s hand and vS2 *Other3*'s hand); *Other3-Other2* (with vS1 representing *Other3*'s hand and vS2 *Other2*'s hand). Importantly, in both scenarios the others' hands were matched for the gender of participants.

The occurrence of each type of pair (probability of occurrence=0.25) was balanced and pseudo-randomized within each block so that the maximum number of consecutive pairs of the same type was two. Scenarios' presentation order was counterbalanced across subjects (i.e. With Self=A; Without Self=B; one half of the subjects follows the sequence ABBA and the other half BAAB).

With the present paradigm, it was possible to compare behavioral and electrophysiological responses to pairs of identical or different visual stimuli, either when the self-hand was present (*With Self* scenario) or not (*Without Self* scenario). Crucially, we decided not to intermix all stimulus types (Self, Other1, Other2, Other3) in a single scenario to avoid making self-hand stimuli rare as compared to the other stimuli, always representing strangers' hands.

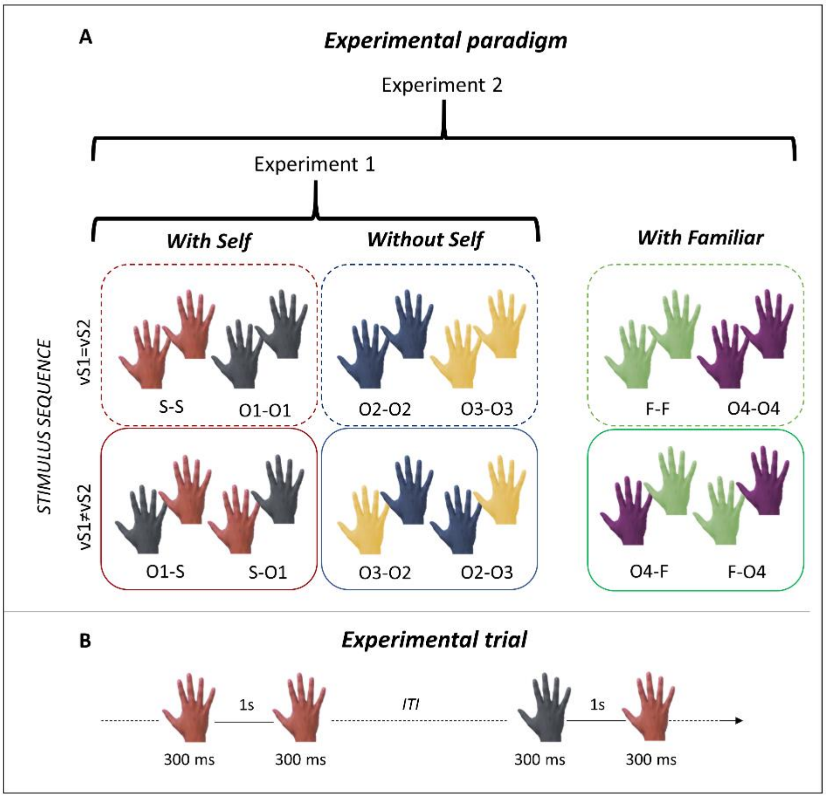

Figure 1 A. Experimental paradigm. Experiment 1 was divided into two different scenarios: *With Self* (where the self-hand was included), and *Without Self* (where the self-hand was never presented). Experiment 2 was divided into three different scenarios: *With Self, Without Self,* and *With Familiar* (where the familiarized hand was presented). **B. Experimental trial**. In both experiments, visual stimuli (vS1 and vS2) were displayed for 300 ms and were delivered at a constant 1 s inter-stimulus interval.

2.1.3 Behavioral task and EEG recording

During the experiment, participants were seated in a comfortable chair in a silent, dimly lit room, with their chest at a distance of 55 cm from the computer screen. They were asked to focus on the stimuli and look at a fixation cross, placed at the center of the screen. Subjects' task was to decide whether vS2 was identical or different from vS1 by pressing, as fast as possible with the right index finger, the “s” key for identical pairs and the “d” key for different ones on the keyboard. Accuracy and RTs were recorded by Eprime V2.0 software (Psychology Software Tools Inc., Pittsburgh, PA, USA).

The EEG was recorded using 32 Ag-AgCl electrodes placed on the scalp according to the International 10-20 system and referenced to the nose. Electrode impedances were kept below 5 kΩ. The electro-oculogram (EOG) was recorded from two surface electrodes, one placed over the right lower eyelid and the other placed lateral to the outer canthus of the right eye. Signals were amplified and digitized at a sampling rate of 1,024 Hz (*HandyEEG – SystemPlus Evolution*, Micromed, Treviso, Italy).

2.1.4 Data Analysis

Behavioral data. Subjects’ correct responses (i.e. *accuracy*) and *RTs* for each pair type were collected and averaged. Importantly, trials with individual RTs exceeding two standard deviations below or above the mean (of each specific experimental condition) as well as trials with missing or wrong response were discarded from RT analysis (Conson et al., 2015; Ronga et al., 2018; Sarasso et al., 2019). The average number of discarded responses per participant was around 5%. In order to explore the presence of the *self-advantage* effect in our matching task, we performed, on both accuracy and RTs as dependent variables, separate 2*4 repeated-measures ANOVAs with two within-subject factors: “Scenario” (two levels: *With Self* scenario; *Without Self* scenario) and “Condition” (four levels: the two pairs of identical and the two pairs of different stimuli in each scenario). The normal distribution of residuals was checked by using Shapiro-Wilk‘s test (p always > 0.05). To explore significant interactions, ad hoc planned comparisons were performed and corrected with Bonferroni’s test. Statistical analyses were performed using Statistica Software (StatSoft, release 8 RRID:SCR_014213).

Electrophysiological data. ERPs triggered by vS1 and vS2 were pre-processed and analyzed using Letswave v.6 (www.letswave.org) (Mouraux & Iannetti, 2008). Continuous EEG data were segmented into epochs using a time window ranging from 0.5 s before vS1 to 1 s after vS2 (total epoch duration: 3.1 s), and band-pass filtered (1-30 Hz) using a fast Fourier transform filter. Each epoch was baseline corrected using the interval from -0.5 to 0 s as reference. Filter and baseline correction were chosen according to previous studies investigating repetition suppression/change detection paradigms (Galigani et al., under review; Ronga et al., 2013; Torta et al., 2012; Y. Wang et al., 2004; Y. Wang et al., 2003). Artifacts due to eye blinks or eye movements were subtracted using a validated method based on an Independent Component Analysis (ICA – Jung et al. 2000). Finally, epochs belonging to the same pair kind (i.e. 26 epochs) were averaged time-locked to the onset of vS1. Thus, for each subject, eight average waveforms (Self-Self; Other1-Other1; Self-Other1; Other1-Self; Other2-Other2; Other3-Other3; Other2-Other3; Other3-Other2) were obtained.

Statistical analyses on ERPs. The analysis of electrophysiological data was performed on the second stimulus, focusing on the amplitude modulation of the N270 component, which is elicited around 270 ms after stimulus onset, in response to the detection of a mismatch in a pair of visual stimuli (see also § *Introduction*). Following the same methodology exploited by previous research investigating visual mismatch detection responses (Bennett et al., 2014; Scannella et al., 2016; P. Wang et al., 2018), ERP waveform amplitudes in the time window between 230 and 320 ms after the onset of vS2 were averaged and the resulting value was the object of further analyses. According to previous research (Bennett et al., 2014), mean amplitudes were extracted from four different clusters of electrodes (frontal: F3/Fz/F4; central: C3/Cz/C4; parietal: P3/Pz/P4; occipital: O1/Oz/O2). Importantly, despite the N270 is maximal at fronto-central electrodes (Li, Wang, Wang, Cui, & Tian, 2003; Scannella et al., 2016), we chose to analyse also central, parietal, and occipital clusters in order to have a broad picture of the scalp, as well as to verify that the source of the observed effects matched those described in previous studies. For each cluster, a single mean amplitude value was obtained by averaging each electrode mean amplitude.

With the aim of investigating change detection mechanisms for visual stimuli depicting self- versus other people's hands, the mean amplitudes of N270 extracted from frontal, central, parietal and occipital electrodes were used as dependent variables and entered in four identical statistical models (one for each cluster), i.e. a 2*4 repeated measures ANOVA with two within-subject factors: "Stimulus Sequence" (two levels: vS1=vS2, vS1≠vS2); and "Stimulus Identity" of vS2 (four levels: Self, Other1, Other2, Other3). The normal distribution of residuals was checked by using Shapiro-Wilk's test (p always > 0.06). Post hoc comparisons were performed by means of Bonferroni's test. Statistical analyses were performed using Statistica Software (StatSoft, release 8 RRID:SCR_014213).

2.2 Experiment 2 (replicating sample and control for familiarity bias)

2.2.1 Participants

Fifteen healthy right-handed subjects participated in the study (10 women) aged 19-30 years (mean±SD: 24.88±3.1; years of education: 18.1±2.7). None of them participated to Experiment 1. Sample size (N=15) was a priori determined to match the sample of Experiment 1.

All participants gave their written informed consent to participate in the study, which conformed to the standards required by the Declaration of Helsinki and was approved by the Ethics Committee of the University of Torino (prot. n. 125055, 12/07/16).

2.2.2. Stimuli and Experimental Design

General procedures were identical to the Experiment 1, with the following exceptions. In the experimental paradigm (Fig. 1) we included a third scenario, i.e. the *With Familiar* scenario. In this scenario, we presented two others' hands. Importantly, one of these hands was familiar for the participant (i.e. the *Familiar hand*), since it had already been repeatedly presented in the immediately preceding scenario (which, depending on the specific sequence assigned to subject, might either be the *With Self* or the *Without Self* scenario). Four different pair types were presented: *Familiar-Familiar* (with both vS1 and vS2 depicting the familiarized hand); *Other4-Other4* (with vS1 and vS2 depicting the same hand belonging to a stranger – *Other4*); *Familiar-Other4* (with vS1 representing the familiarized hand and vS2 Other4's hand); *Other4-Familiar* (with vS1 representing Other4's hand and vS2 the familiarized hand). The occurrence of each pair type (p=.25) was matched across conditions and pseudo-randomized within each block, so that the maximum number of consecutive pairs of the same type was two. The presentation of the scenarios was counterbalanced, except for the *With Familiar* scenario that was always presented immediately following the scenario including the other's hand with which participants familiarized (i.e. With Self=A; Without Self=B; With Familiar=C; subjects may be administered with one of the following sequences: ACB; BAC; BCA; ABC).

Furthermore, in order to exclude that any possible negative results observed in Experiment 1 (such as the absence of a significant change detection effect in the *Without Self* scenario) were due to a signal to noise ratio problem rather than to a genuine absence of modulation, we doubled the number of trials in Experiment 2 (i.e. 52 trials per condition). Each scenario was therefore composed of 208 pairs of visual stimuli (vS1 and vS2), delivered at a constant 1 s inter-stimulus interval. The time interval between each pair was randomly jittered between 3 and 4 s, in a way that participants could not anticipate stimulus occurrence. The whole experiment was divided into six 8-minute recording blocks (2 per scenario).

2.1.3 Behavioral task and EEG recording

All procedures were identical to those of Experiment 1.

2.1.4 Data Analysis

<u>*Behavioral data*</u>. Subjects' correct responses (i.e. *accuracy*) and *RTs* for each pair type were collected and averaged. Importantly, trials with individual RTs exceeding two standard deviations below or above the mean (of each specific experimental condition) as well as trials with missing or wrong response were discarded (Bruno, Ronga, Fossataro, Capozzi, & Garbarini, 2019; Bruno et al., 2020; Conson et al., 2015; Fossataro, Bucchioni, et al., 2018; Ronga et al., 2018; Sarasso et al., 2018). The average number of discarded responses per participant was around 5%. In order to explore the presence of the *self-advantage* effect in our matching task, we performed, on both accuracy and RTs as dependent variables, two 3*4 repeated-measures ANOVA with two within-subject factors: "Scenario" (three levels: *With Self* scenario; *Without Self* scenario; *With Familiar* scenario) and "Condition" (four levels: the two pairs of identical and the two pairs of different stimuli in each scenario). The normal distribution of residuals was checked by using Shapiro-Wilk's test (p always > 0.05). To explore significant interactions, ad hoc planned comparisons were performed and corrected with Bonferron's test. Statistical analyses were performed using Statistica Software (StatSoft, release 8 RRID:SCR_014213).

<u>*Electrophysiological data.*</u> All the preprocessing of ERP data was identical to that of Experiment 1, except for the following. We obtained 52 epochs for each pair that were averaged time-locked to the onset of vS1. Thus, for each subject, twelve average waveforms (Self-Self; Other-Other; Self-Other; Other-Self; Other1-Other1; Other2-Other2; Other2-Other1; Other1-Other2; Familiar-Other3; Other3-Other3; Ohter3-Familiar; Familiar-Other3) were obtained. The normal distribution of residuals was checked by using Shapiro-Wilk's test (p always > 0.06). Post hoc comparisons were performed by means of Bonferroni's test. Statistical analyses were performed using Statistica Software (StatSoft, release 8 RRID:SCR_014213).

Statistical analyses on ERPs. The analysis of electrophysiological data replicated that of Experiment 1. The mean amplitudes of N270 extracted from frontal, central, parietal and occipital clusters were used as dependent variables and entered in four identical statistical models (one for each cluster), i.e. 2x6 repeated measures ANOVAs with two within-subject factors: “Stimulus Sequence” (two levels: vS1=vS2, vS1≠vS2); and “Stimulus Identity” of vS2 (six levels: Self, Other1, Other2, Other3, Other4, Familiar). The normal distribution of residuals was checked by using Shapiro-Wilk‘s test (p always > 0.07). Post hoc comparisons were performed by means of Bonferroni’s test. Statistical analyses were performed using Statistica Software (StatSoft, release 8 RRID:SCR_014213).

3. Results

3.1 Experiment 1 (discovering sample)

3.1.1 Behavioral results

Behavioral results are presented in Figure 2. Note that, overall are in line with our predictions, participants showed a more accurate and faster behavioral performance anytime the self-hand was included in the pair, thus indicating the presence of the *self-advantage* effect also in our sample.

Accuracy

The 2*4 repeated measures ANOVA performed on accuracy values revealed a significant Scenario*Condition Interaction ($F_{3,42=}$4.967; p=0.004; η^2=0.262), showing that the factor Condition was significantly modulated only in the *With Self* scenario. To further explore this interaction, four planned comparisons were run in the *With Self* scenario to compare identical pairs (*Self-Self vs Other1-Other1*), different pairs (*Other1-Self* and *Self-Other1*) and each identical pair with the corresponding different pair (*Self-Self* vs *Other1-Self*; *Other1-Other1* vs

Self-Other1). By applying Bonferroni's correction, alpha value was set at 0.012. Crucially, planned comparisons revealed that accuracy values of the *Self-Self* pair (mean±SEM= 93.71 ± 2.09 %) were higher, even though it did not reach the significance level after Bonferroni's correction (p=0.012), than those of *Other1-Other1* pair (mean±SEM= 83.64±3.81 %), whereas the accuracy rate of *Other1-Self* pair (mean ± SEM= 94.59±1.71 %) and *Self-Other1* pair (mean±SEM=89.64±2.79 %) were not significantly different (p=0.048). Moreover, the percentage of accuracy response were higher in *Self-Other1* pair as compared to *Other1-Other1* pair, even though the difference did not reach the significance level (p=0.014), but no significant differences emerged comparing *Self-Self* pairs to *Other1-Self* pair (p=0.683). This suggests the presence of a higher accuracy anytime the self-hand was included in the pair.

Response Times (RTs)

The 2*4 repeated measures ANOVA performed on RTs revealed a significant Scenario*Condition Interaction ($F_{3,42}$=3.820; p=0.016; η^2=0.214). Crucially, as for the accuracy, the factor Condition was modulated only in the *With Self* scenario and it was further explored with four planned comparisons (see above). Faster RTs were found in *Self-Self* pair (mean±SEM= 675.42±52.50 ms) as compared to *Other1-Other1* pair (mean±SEM= 745.72 ±49.25 ms), even though the difference did not reach the significance level (p=0.017), whereas RTs of *Other1-Self* pair (mean±SEM= 727.64± 56.2 ms) and *Self-Other1* pair (mean±SEM= 680.16±52.78 ms) were not significantly different (p=0.057). Moreover, behavioral performance was significantly faster in *Self-Other1* pair as compared to *Other1-Other1* pair (p=0.0119), but no significant differences emerged comparing *Self-Self* pair to *Other1-Self* pair (p=0.102). Overall, the RT results parallel the accuracy results, showing the presence of a faster response anytime the self-hand was included in the pair.

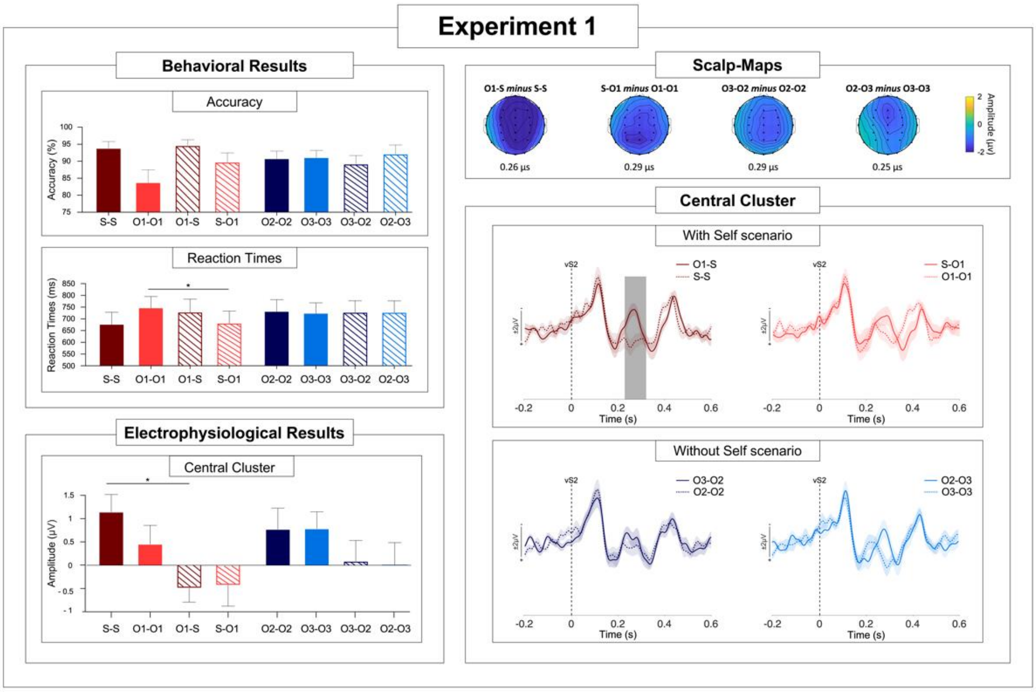

Figure 2. Experiment 1: behavioral and electrophysiological results. The top left panel represents the accuracy values (in percentages) and the subjects' RTs. Note that subjects' performance was more accurate and faster anytime the self-hand was presented. The bottom left panel represents the mean of ERP amplitudes in the range between 230 and 320 ms post vS2 onset (i.e. the window including N270 component). Y axis: the mean voltage amplitude (µV); X axis: experimental conditions. Note that the *With Self* scenario is represented in red, while the *Without Self* scenario is represented in blue. The top right panel represents the scalp map distribution of change response peaks (the latency corresponds to the peak of the subtractions waves). Maps are obtained by subtracting the response to vS2 of identical pairs from the response of vS2 of different pairs. The bottom right panel represents ERP waveforms in response to the vS2 at the central cluster (mean of the electrodes composing the cluster). Y axis: amplitude (µV); X Axis: time (s). Waveforms in dotted lines represent pairs of identical stimuli (vS1=vS2), waveforms in solid lines represent pairs of different stimuli (vS1≠vS2).

Shaded areas correspond to ERP sem (standard error of the mean). Significant differences are highlighted in grey. The top panel represents ERP waveforms in the *With Self* scenario. The bottom panel represents ERP waveforms in the *Without Self* scenario.

3.1.2 ERP results

Electrophysiological results for the central cluster are presented in Figure 2. Results for all the other clusters are presented in the Supplementary materials.

Note that, as expected, the contrast between pairs of identical stimuli (vS1=vS2) and pairs of different stimuli (vS1≠vS2) revealed a greater differential amplitude of the N270 in the *With Self* scenario when vS2 represented the self-hand (i.e. *Self-Self* vs. *Other1-Self*).

Frontal cluster

The 2*4 repeated measures ANOVA revealed a main effect of Sequence ($F_{1,14}$= 6.949; p=0.019; η^2=0.331), with overall larger ERP amplitudes for different as compared to identical vS2 (vS1=vS2: mean±SEM= 0.16±0.29 μV; vS1≠vS2: mean±SEM= -0.60±0.33 μV). A significant Sequence*Identity interaction ($F_{3,42}$= 2.974; p=0.042; η^2=0.175) was observed, suggesting that the difference between identical and different pairs was greater when vS2 represented the self-hand. Crucially, post-hoc analyses showed that only the *Self-Self* vs *Other1-Self* comparison was significantly different in the N270 time window, with a larger amplitude for the different as compared to the identical pair (p<0.001). All other comparisons were ≥0.60.

Central cluster

The 2*4 repeated measures ANOVA revealed a main effect of Sequence ($F_{1,14}$= 13.926; p=0.002; η^2=0.499), with overall larger ERP amplitudes for different as compared to identical vS2 (vS1=vS2: mean±SEM= 0.76±0.34 μV; vS1≠vS2: mean±SEM= -0.18±0.35 μV). A significant Sequence*Identity interaction ($F_{3,42}$= 3,067; p=0.038; η^2=0.180) was found. As for the frontal cluster, post-hoc comparisons showed that only *Self-Self* vs *Other1-Self* was significant, with a larger amplitude for the different as compared to the identical pair (p<0.001). All other comparisons were ≥0.08.

Parietal cluster

The 2*4 repeated measures ANOVA revealed a main effect of Sequence ($F_{1,14}$= 14.705; p=0.002; η^2=0.512), with overall larger ERP amplitudes for different as compared to identical vS2 (vS1=vS2: mean±SEM= 1.27±0.32 μV; vS1≠vS2: mean±SEM= 0.51±0.29 μV). Moreover, no significant Sequence*Identity interaction was found ($F_{3,42}$= 2,822; p=0.051; η^2=0.168).

Occipital cluster

The 2*4 repeated measures ANOVA revealed a main effect of Sequence ($F_{1,14}$= 5.106; p=0.040; η^2=0.267), with overall larger ERP amplitudes for different as compared to identical vS2 (vS1=vS2: mean±SEM= 1.60 ± 1.56 μV; vS1≠vS2: mean±SEM= 1.05±0.38 μV). Moreover, no significant Sequence*Identity interaction was found ($F_{3,42}$= 2.686; p=0.059; η^2=0.161).

3.2 Experiment 2 (replicating sample and control for familiarity)

3.2.1 Behavioral results

Behavioral results are presented in Figure 3. Note that behavioral results replicate the results of Experiment 1, showing a more accurate and faster performance anytime the self-hand was presented.

Accuracy

The 3*4 repeated measures ANOVA performed on accuracy values revealed a significant Scenario*Condition Interaction ($F_{6,84}$=5.130; p<0.001; η^2=0.268), showing that the factor Condition was modulated only in the *With Self* scenario. As for the Experiment 1, to further explore this interaction, four planned comparisons were run in the *With Self* scenario to compare identical pairs (*Self-Self vs Other1-Other1*), different pairs (*Other1-Self* and *Self-Other1*) and each identical pair with the corresponding different pair (*Self-Self* vs *Other1-Self*; *Other1-Other1* vs *Self-Other1*)-. By applying Bonferroni's correction, alpha value was set at 0.012. Planned comparisons revealed that accuracy values of the *Self-Self* pair (mean±SEM= 96.60±1.04 %) were significantly higher (p<0.001) than those of *Other1-Other1* pair (mean±SEM= 85.57±2.18 %), whereas the accuracy rate of *Other1-Self* pair (mean±SEM= 89.46±2.36 %) and *Self-Other1* pair (mean±SEM=92.09±2.34 %) were not significantly different (p=0.266). Moreover, the percentage of accuracy response were significantly higher in *Self-Other1* pair as compared to *Other1-Other1* pair (p<0.001) and in *Self-Self* pair as compared to *Other1-Self* pair, even if it did not reach the significance level (p=0.012), suggesting that the greater the accuracy the greater the presence of self-hand in the pair.

Response Times (RTs)

The 3*4 repeated measures ANOVA performed on accuracy values revealed a significant Scenario*Condition interaction ($F_{6,84}$=5.555; p<0.001; η^2=0.284), showing that, as for the accuracy, the factor Condition was modulated only in the *With Self* scenario. All planned comparisons performed in the *With Self* scenario were significant here, revealing that RTs of the *Self-Self* pair (mean±SEM= 623.81 ± 48.34 ms) were significantly faster (p=0.003) than those of *Other1-Other1* pair (mean±SEM= 732.31 ± 39.78 ms) and that RTs in *Self-Other1* pair (mean±SEM= 642.16±46.37 ms) were significantly faster (p<0.001) as compared to *Other1-Self* pair (mean± SEM=702.1742.74 ms). Moreover, RTs were significantly faster in *Self-Other1* pair as compared to *Other1-Other1* pair (p<0,001) and in *Self-Self* pair as compared to *Other1-Self* pair (p=0.010), suggesting that the behavioral performance was faster whenever the self-hand was present in the pair and it was depicted as the first stimulus.

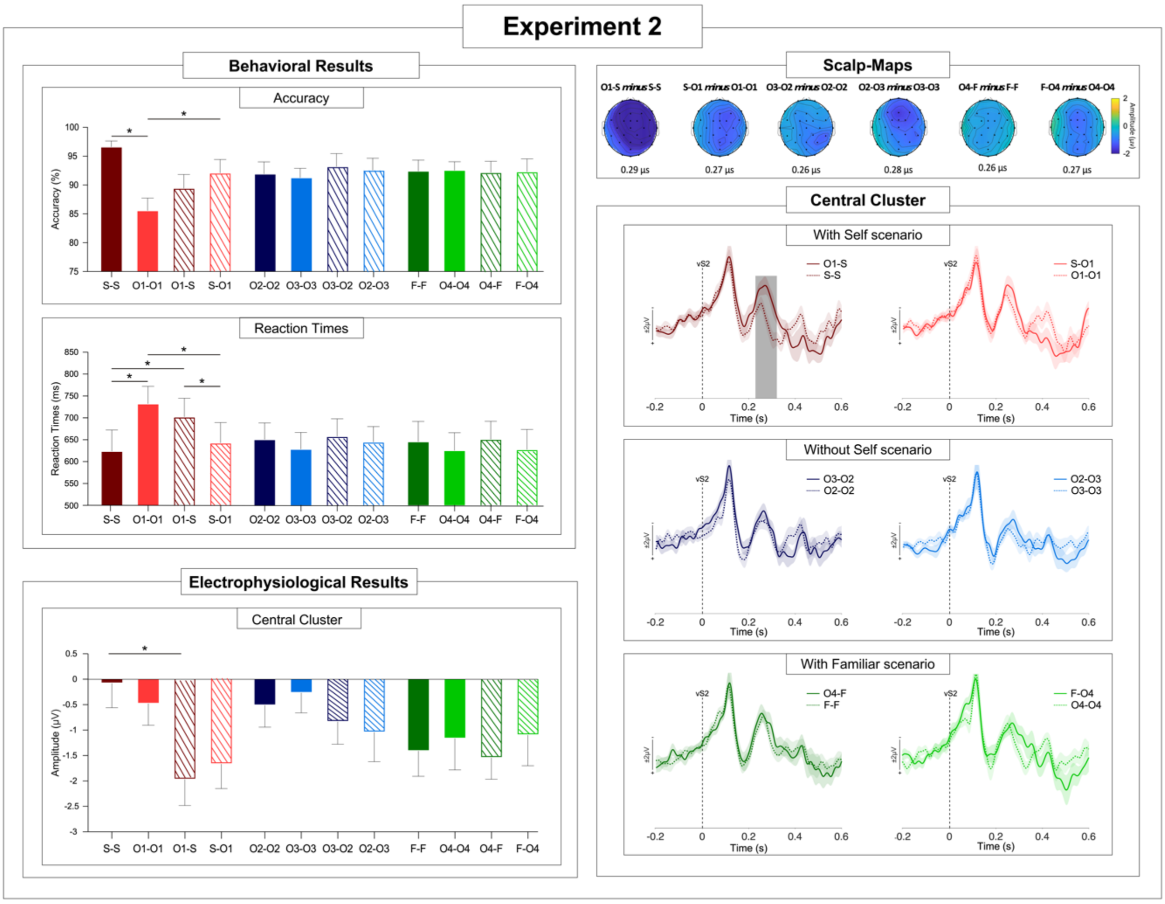

Figure 3. Experiment 2: behavioral and electrophysiological results. The top left panel represents the accuracy values (in percentages) and the subjects' RTs. Note that subjects' performance was more accurate and faster anytime the self-hand was presented. The bottom left panel represents the mean of ERP amplitudes in the range between 230 and 320 ms post vS2 onset (i.e. the window including N270 component). Y axis: the mean voltage amplitude (μV); X axis: experimental conditions. Note that the *With Self* scenario is represented in red,

while the *Without Self* scenario is represented in blue, and the *With Familiar* scenario in green. The top right panel represents the scalp map distribution of change response peaks (the latency corresponds to the peak of the subtractions waves). Maps are obtained by subtracting the response to vS2 of identical pairs from the response of vS2 of different pairs. The bottom right panel represents ERP waveforms in response to the vS2 at the central cluster (mean of the electrodes composing the cluster). Y axis: amplitude (μV); X Axis: time (s). Waveforms in dotted lines represent pairs of identical stimuli (vS1=vS2), waveforms in solid lines represent pairs of different stimuli (vS1≠vS2). Shaded areas correspond to ERP sem (standard error of the mean). Significant differences are highlighted in grey. The top panel represents ERP waveforms in the *With Self* scenario. The middle panel represents ERP waveforms in the *Without Self* scenario. The bottom panel represents ERP waveforms in the *With Familiar* scenario.

Notably, overall present results confirmed the findings of Experiment 1.

3.2.2 ERP results

Electrophysiological results for the central cluster are presented in Figure 3. Results for all the other clusters are presented in the Supplementary materials.

Note that, as in Experiment 1, the contrast between pairs of identical (vS1=vS2) and different stimuli (vS1≠vS2) revealed a significant modulation of the N270 only in the *Whit Self* scenario when vS2 represented the self-hand.

Frontal cluster

The 2*6 repeated measures ANOVA revealed a main effect of Sequence ($F_{1,14}$=15,013; p=0.002; η^2=0.517), with overall larger ERP amplitudes for different as compared to identical vS2 (vS1=vS2: mean±SEM= -0.54±0.25 μV; vS1≠vS2: mean±SEM= -1.35±0.29 μV). A significant Sequence*Identity interaction was found ($F_{5,70}$= 4.895; $p<0.001$; $\eta^2=0.259$). Crucially, post-hoc comparisons showed that only vS2s belonging to *Self-Self* vs *Other1-Self* pairs were significantly different in the N270 time window, with a significantly larger amplitude for the different as compared to the identical pair ($p<0.001$). All other comparisons were ≥0.08.

Central cluster

The 2*6 repeated measures ANOVA revealed a main effect of Sequence ($F_{1,14}=12.186$; $p=0.004$; $\eta^2=0.465$), with overall larger ERP amplitudes for different as compared to identical vS2 (vS1=vS2: mean±SEM= -0.38±0.34 μV; vS1≠vS2: mean±SEM= -1.15±0.39 μV). A significant Sequence*Identity interaction was found ($F_{5,70}$= 3.621; $p=0.006$; $\eta^2=0.201$). Crucially, post-hoc comparisons showed that only S2s belonging to *Self-Self* vs *Other1-Self* pairs were significantly different in the N270 time window, with a significantly larger amplitude for the different as compared to the identical pair ($p<0.001$). All other comparisons were ≥0.71.

Parietal cluster

The 2*6 repeated measures ANOVA revealed a main effect of Sequence ($F_{1,14}=11.462$; $p=.004$; $\eta^2=0.450$), with overall larger ERP amplitudes for different as compared to identical vS2 (vS1=vS2: mean ± SEM= 0.26± 0.36 μV; vS1≠vS2: mean ± SEM= -0.38± 0.43 μV).). No significant Sequence*Identity interaction was found ($F_{5,70}$= 2.154; $p=0.069$; $\eta^2=0.133$).

Occipital cluster

The 2*6 repeated measures ANOVA revealed a main effect of Sequence ($F_{1,14}=9.257$; $p=0.009$; $\eta^2=0.398$), with overall larger ERP amplitudes for different as compared to identical vS2 (vS1=vS2: mean±SEM= -0.07±0.51 μV; vS1≠vS2: mean±SEM= -0.66±0.63 μV). No significant Sequence*Identity interaction was found ($F_{5,70}$= 0.677; p=0.642; η^2=0.046).

4. Discussion

The present paper, focused on bodily self-identification, explores whether the recognition of our physical identity has an observable electrophysiological correlate. More specifically, we exploited the amplitude modulation following different *vs* identical stimulation to verify whether implicit bodily-self recognition is able to modulate change detection responses, in a pair of sequentially presented visual stimuli. Importantly, previous literature investigating body-related change detection within the visual domain has mainly concentrated on face discrimination (Schweinberger & Neumann, 2016). Crucially, face visual features are extremely salient, since they are systematically employed for individual recognition. Still, self-face recognition seems to rely on sensorimotor representations, exploiting multisensory cues, such as speech processing (Cardini et al., 2011; Sugiura, 2015; Tsakiris, 2008). Not surprisingly, therefore, face changes induced change detection responses in visual evoked potentials. Conversely, the present study focuses on body effectors (right hands), whose visual features are not equally relevant for their discrimination. However, similarly to faces, the self-hand representation is supposed to recruit not only visual, but also sensorimotor brain networks (Apps & Tsakiris, 2014; Conson et al., 2017; Ferri et al., 2012; Limanowski & Blankenburg, 2015). Thus, thanks to this multimodal representation, we hypothesized that self-hand visual recognition should still entail a special change detection mechanism, inducing greater electrophysiological responses than those elicited by others' hands discrimination.

In the following paragraphs we (1) outline our behavioral findings as supporting evidence of the *self-advantage* effect and (2) discuss our ERPs results, which seem to confirm the salience of bodily-self stimuli, which are able to boost identity recognition and change detection both at behavioral and at electrophysiological levels. Importantly, the results highlighted in Experiment 1 (our discovering sample) were fully confirmed and extended in Experiment 2, which, besides controlling for a possible familiarity bias in our change detection effect, can be considered as a measure of internal replicability.

The self-advantage and visual ERPs

Our behavioral results highlighted the relevance of self-advantage (Frassinetti et al., 2009) in a repetition suppression paradigm, thus confirming the presence of such an effect for detection tasks, even though self-recognition is not explicitly required by experimental instructions.

In both experiments, participants' accuracy rate was modulated selectively in the *With Self* scenario (as indicated by the significant interaction between the factors Sequence and Identity in Experiments 1 and 2 - § *Results* 3.1.1; 3.2.1), where participants' performance was overall more accurate whenever the self-hand was included in the pair. The statistical analyses on RTs paralleled accuracy results, thus reveling a significant modulation only in the *With Self* scenario. In both experiments, we observed a comparable pattern of results, showing a complete replicability of our findings. Interestingly, in the RT analysis of Experiment 2, likely because of the increased number of trials included in this second experiment, all the planned comparisons were significant, thus showing RT facilitation anytime the self-hand was the first stimulus of the pair. To explain this result, we can hypothesize that the self-hand, when presented as the first stimulus, boosted subjects' working memory and thanks to its relevance for the system reduced the cognitive load and facilitated the active maintenance of the stimulus memory trace in order to solve the task (Scannella et al., 2016).

Taken together, both accuracy and RTs point out a clear self-advantage effect in our behavioral results, with overall faster and better performance when the self-hand was included in the pair.

From an electrophysiological point of view, as indicated by previous literature (Iannetti et al., 2008; Ronga et al., 2013), we hypothesized a significantly different ERP amplitude modulation between repeated and non-repeated conditions, highlighting, at least in the *With Self* scenario, a specific change detection mechanism. The present ERP data confirm our hypothesis (see below). Still, electrophysiological results in a way paralleled our behavioral findings, since in both experiments all significant modulations were selectively observed in the *With Self* scenario, thus pointing out the relevance of bodily-self recognition both from a behavioral and an electrophysiological point of view.

A specific change detection mechanism for self-hands is revealed by N270 amplitude modulation

From an electrophysiological point of view, in both experiments, we found a main effect of Stimulus Sequence, thus confirming also in the present samples the sensitivity of N270 component in revealing sudden mismatches in a stream of visual stimuli (Y. Wang et al., 2004; Y. Wang et al., 2003). Ferrari, Bradley, Codispoti, and Lang (2010), by employing an oddball task with picture sequences, showed that N270 amplitude dramatically decreased already after the first stimulus repetition and immediately increased for novel pictures, thus confirming results by Y. Wang et al. (2004) obtained with stimulus pairs. Furthermore, the presence of overall greater N270 amplitudes when vS2 was different rather than identical to vS1, is in line with earlier evidence, proposing the N270 as an electrophysiological biomarker of conflict detection in a sequence of incoming visual stimuli (Enriquez-Geppert, Konrad, Pantev, & Huster, 2010; Folstein & Van Petten, 2008).

More crucially for the present study, we also found a significant interaction between the factors Sequence and Identity, thus indicating that N270 amplitude was selectively modulated in the *With Self* scenario. Post-hoc comparisons revealed that the amplitude modulation between identical *vs* different pairs (i.e. *change detection*) was significant only for stimuli representing the self-hand. Notably, this effect was found mainly over frontal and central electrodes, where in both experiments it was fully significant. For the parietal and occipital clusters, we found no significant modulations in both Experiment 1 and 2. These results are fully consistent with source localization studies, showing a fronto-central distribution of the N270 component (Li et al., 2003; Scannella et al., 2016).

The confinement of significant change detection effects to the *With Self* scenario is a crucial finding since, as expected, it demonstrates that a reversion of repetition suppression mechanism within the N270 time window are not automatically elicited by the system anytime a change in the stimulation pattern occurs. Instead, mismatch detection responses emerge only when stimulation changes are valued as salient (Ronga et al., 2013). Importantly, our results confirm that the salience of the self-hand, as demonstrated by its ability to revert repetition suppression effectively, represents a *kind* rather than a *degree* property expressed by *all or nothing* effects. Interestingly, such salience of self-recognition turns up even when entailing the (task-irrelevant) identification of body effectors, selectively through their visual appearances. Apparently, recognizing our own body seems to represent an *aprioristic* relevant matter for the individual, independently from specific task instructions.

A similar line of research, focused on investigating the electrophysiological signatures of self and other’s face recognition, reported that the amplitude of an occipito-temporal negative component, peaking around 250 ms post stimulus onset, appeared larger in response to familiar, rather than unfamiliar faces (Schweinberger & Neumann, 2016; Tanaka & Pierce, 2009). Even though such a component was emerging from different neural sources as compared to our fronto-central N270 (see e.g., Caharel, d’Arripe, Ramon, Jacques, & Rossion, 2009), results of Experiment 1 cannot exclude that the familiarity of the self-hand could somehow contribute to N270 modulation in the With Self scenario. To explore this possible familiarity-related effect and confirm the results of Experiment 1, we run Experiment 2, where a scenario with a familiar hand was added in the experimental paradigm. Importantly, and as supporting evidence of the specificity of our effect for the self-hand, we found that presenting a familiarized hand did not boost change detection responses (as demonstrated by the absence of any behavioral and electrophysiological modulations in the *With Familiar* scenario – see 3.2.1 and 3.2.2). This finding seems to indicate that the enhancement of change detection mechanisms is driven by a self-specific effect and not by a mere familiarity effect, even though we cannot rule out that the special familiarity acquired by the self-hand somehow contributed to the observed effect. Overall, it may be challenging to distinguish specific self-recognition driven effects from familiarity-driven effects and previous studies present controversial evidence. Butler and colleagues (Butler, Mattingley, Cunnington, & Suddendorf, 2013) found similar electrophysiological signatures of self-face and highly familiar faces (i.e., those of dizygotic twins), suggesting that self-bodies, when compared to other bodies with a similar exposure, do not involve unique featural encoding. On the other hand, Alzueta, Melcon, Poch, and Capilla (2019) recorded EEG activity while participants performed a facial recognition task, where they had to discriminate between their own face, a friend's face, and an unknown face. Crucially, authors pinpointed a specific modulation (within the time window of P200), distinctive of the processing of self-face, suggesting that self-body parts have dedicated processing mechanisms, clearly distinguishable from the detection of others' familiar bodies. We believe that our results, revealing a selective modulation of N270 component only when the self-hand was presented, may be considered as a supporting evidence of the tenet that self and other body parts have different neural representations (see below).

Overall the present findings suggest that, in a visual detection task, self- and only self-hand changes are salient enough to reverse repetition suppression mechanism. In other words, self-hand recognition, similarly to other sensory stimulation valued as relevant by the system, might trigger the activity of the "salience network" (mainly including multimodal, associative cortices, such as the anterior cingulate cortex and the insula) (Legrain, Iannetti, Plaghki, & Mouraux, 2011; Mouraux, Diukova, Lee, Wise, & Iannetti, 2011), thus boosting the mismatch detection effect. However, this possible mechanism does not explain how the system recognizes the self-hand. Previous studies showed that the nervous system may employ a number of different strategies to recognize the bodily self, entailing the identification of visual features and/or the sensorimotor information (Ferri et al., 2012; Frassinetti et al., 2011; Tsakiris, 2010).

The specificity observed for self-hand recognition in our data suggests that the self has a systematic processing advantage, likely related to its inherent multimodal dimension. Differently from images depicting others' bodies, which cannot be felt, visual stimuli representing the bodily-self have immediate access also to sensorimotor information, thus enriching their representation and salience. The present results, therefore, are compatible with the idea of an integrated, multisensory network devoted to the recognition of the bodily-self (Limanowski & Blankenburg, 2015, 2016; Zeller et al., 2016). The visual representation of body effectors, besides primary visual cortices, may activate a circuit of sensorimotor areas (including the ventral-premotor cortex) and of extrastriate, associative visual cortices (such as the extrastriate body area – EBA – in the temporal lobe) (Ferri et al., 2012; Frassinetti et al., 2011; Limanowski, Sarasso, & Blankenburg, 2018). However, how can this multimodal activity be observed? Recently, a novel EEG paradigm has been specifically designed to highlight the sensorimotor activity in response to visual body recognition (Galvez-Pol, Calvo-Merino, & Forster, 2020). EEG responses to bodily-self visual information should be recorded either in isolation (*visual-only condition*) or in combination with task-irrelevant motor and somatosensory events (*multimodal condition*). Then, the activation recorded in visual-only condition should be subtracted from the multimodal condition. This subtraction should highlight the supposed contribution of sensorimotor activity in response to bodily-self images. In the present study, we demonstrate that the implicit self-body recognition boosts the change detection and we postulate that this enhanced mechanism is related to the activation of a multimodal sensorimotor network devoted to the recognition of the bodily-self. If our hypothesis is correct, future studies should exploit such a multimodal EEG paradigm in the context of visual mismatch detection protocols, thus uncovering the neural mechanisms underlying the enhancement of change detection effects for the bodily-self.

Author contribution

Mattia Galigani: conceptualization, methodology, software, formal analysis, investigation, writing and original draft, visualization.

Irene Ronga: conceptualization, methodology, software, formal analysis, investigation, writing and original draft, visualization.

Carlotta Fossataro: software, formal analysis, writing and review and editing.

Valentina Bruno: software, formal analysis, writing and review and editing.

Nicolò Castellani: investigation, writing and review and editing.

Alice Rossi Sebastiano: investigation, writing and review and editing.

Bettina Forster: conceptualization, methodology, writing and review and editing.

Francesca Garbarini: conceptualization, methodology, writing and review and editing, supervision, project administration, funding acquisition.

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Open practices

The datasets generated during this study, the experiment code, and the experimental stimuli are available at Mendeley https://data.mendeley.com/datasets/rz6gcc29dj/draft?a=e8a769c7-

c293-4839-bc95-75a86e427156. The present experiments and analyses were not pre-registered. In our methodological section, we report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study.

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