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Re-cognizing the new self: The neurocognitive plasticity of self-processing following facial transplantation

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The face is a defining feature of our individuality, crucial for our social interactions. But what happens when the face connected to the self is radically altered or replaced? We address the plasticity of self-face recognition in the context of facial transplantation. While the *acquisition* of a new face following facial transplantation is a medical fact, the *experience* of a new identity is an unexplored psychological outcome. We traced the changes in self-face recognition before and after facial transplantation to understand if and how the transplanted face gradually comes to be perceived and recognized as the recipient's own new face. Neurobehavioral evidence documents a strong representation of the pre-injury appearance pre-operatively, while following the transplantation, the recipient incorporates the new face into his self-identity. The acquisition of this new facial identity is supported by neural activity in medial frontal regions that are considered to integrate psychological and perceptual aspects of the self.

self-recognition | face | facial transplantation | self identity

Significance

Recognition of one's own face is a hallmark of self-awareness. Our face changes as we age, but these transformations do not necessarily alter our self-identity. But what happens when the face is altered or replaced through facial transplantation? We present the first longitudinal investigation of changes in self-face recognition throughout a patient's journey before a life-changing injury, during the injury, and after facial transplantation. Neurobehavioral measures show how he preserves a strong mental and neural representation of his pre-injury appearance and gradually incorporates the new post-transplant appearance into his self-identity. These changes and underlying neural processes highlight how the malleable representations of our face ensure the self's continuity over time.

The ability to recognize one's self in the mirror is a hallmark of ontogenetic development and self-awareness. As such, it has attracted considerable interest in psychological sciences and cognitive neuroscience. Human and some nonhuman primates display this unique ability to recognize their own appearance and build a mental representation, also called body-image (1). In infants, this ability that emerges around the 20th to 22nd mo of age coincides with the display of social emotions and scaffolds the sense of self (2–4). In the adult brain, multiple brain areas have been shown to underpin self-processing in general and self-face recognition more specifically (5). The right inferior frontal gyrus (IFG), the superior occipital cortex (Occ), and the right postcentral gyrus (rPoCG) are some of the regions that have been implicated in processing the physical features of one's own face (6–9), whereas midline cortical structures, such as the medial frontal cortex (MFC)/anterior cingulate cortex (ACC) and the precuneus are involved in processing psychological and self-referential aspects of the self, e.g., traits, autobiographical memories, and emotions (9–11). Although there has been considerable neuroimaging research investigating self-face recognition, one important question that has received far less attention relates to the continuity and plasticity of self-face representations as one's facial appearance changes over time (12). If the face is a key defining feature of our individuality, what happens when the face connected to the self is radically altered or replaced?

To answer this question, we investigated the self-face recognition abilities and the engagement of the underlying neural networks in an individual who underwent one of the most drastic changes to one's facial appearance, a partial facial transplantation. Across the history of human culture, and more recently with advances in plastic surgery, the possibility of changing one's own face for another has captured the imagination of writers, artists, and scientists. That possibility became reality in 2005 when the first partial face transplantation took place (13). As of April 2020, 47 face transplants have been performed on 46 patients to address severe facial disfigurements resulting from multiple etiologies (14–20).

Importantly, while the *acquisition* of a new face following such operations is a medical fact, the *experience* of recognizing this new face as one's own is an unexplored psychological outcome. The plasticity and cortical reorganization of somatosensory and motor cortices after hand transplantation (21) and sensorimotor recovery following facial transplantation (13, 22, 23) have been previously investigated. However, the plasticity and reorganization of self-recognition following alterations of the appearance of one's face have not been examined. With the present study, we focused on the very question of self-recognition of a new facial identity following partial facial transplantation.

In a longitudinal series of behavioral and neuroimaging investigations, we assessed whether and how a facial allograft comes to be perceived and experienced as the recipient's own face. This was achieved by tracing the neurocognitive processes related to changes in self-recognition as a result of changes in physical appearance following a severely disfiguring

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traumatic event and again following a partial face transplant. The primary aim of the study was to follow the gradual recognition of a new facial self-identity by investigating its underlying neurocognitive processes.

Our approach was theoretically motivated by the large body of research on self-face recognition conducted over the last thirty years. Within the prefrontal cortex, the ACC, the IFG, the medial, and middle frontal gyri are often implicated in self-face recognition, mostly on the right side; within the parietal cortex, there is involvement of the inferior parietal lobule, the supramarginal gyrus, and the precuneus, mainly in the right hemisphere. In addition, other regions such as the ACC (mainly on the right), and the bilateral insula, have also been shown to be involved during self-recognition (6). A recent meta-analysis (7) provides support for a right-dominated (8), but largely bilaterally distributed model for self-face processing, where four areas are consistently activated: the left fusiform gyrus, bilateral middle and inferior frontal gyri, and right precuneus. In an attempt to integrate these neural findings and conceptualize their relation to both physical and psychological aspects of self-recognition, a tripartite neural model for self-processing has been proposed by Northoff et al. (24). The lower level concerns face detection, the second level up the hierarchy concerns sensory information about the face for processing self-referential facial information (e.g., physical appearance of the self-face), and the third level concerns self-referential information involved in representing identity. When controlling for the familiarity of faces, past research has shown that self-recognition engages areas upstream of the lower level of face detection, such as the fusiform gyrus. Sensory information about the self is passed on from the fusiform face area (FFA) through to the precuneus for the processing of self-referential facial information. Third, self-referential information is passed onto higher cortical areas involved in making identity discriminations, and inferences about the mental states expressed in the stimuli, as well as utilizing that information to make accurate inferences about others' mental states. Accordingly, we predicted concurrent overlap across the perception of the different faces dependent on the change of the recipient's actual appearance with gradual emergence of self-recognition of the recipient's post-transplant face.

We therefore hypothesized that the progression of facial appearances over time will compete for the magnitude of cognitive processing and neural representation, especially in areas involved at the higher level of the tripartite mode, such as the medial frontal areas. We expected stronger engagement of these areas for the pre-injury face at the start of our investigation, with a gradual disengagement and engagement for the post-injury and post-transplant faces, respectively, toward the end of our investigation.

The patient was a 25-y-old male who sustained a ballistic facial injury in June of 2016 (Fig. 1). The initial injury involved the eyelids, nose, cheek, lips, maxilla, mandible, zygoma, and right orbital floor. After several reconstructive attempts, he presented with persistent lip incompetence, speech and feeding difficulties, visual alterations, and exposed hardware. Thorough evaluation was undertaken by the face transplant team, and the decision was made to proceed with partial facial transplantation since optimal functional and esthetic outcomes could not be achieved through autologous reconstruction. Understanding the associated risks, the patient consented to the procedure under the Institutional Review Board-approved (s14-00550) and registered clinical trial (clinicaltrials.gov; NCT02158793).

The patient had lived with extensive facial disfigurement* for 18 mo prior to facial transplantation on January 6th of 2018. The donor and recipient were ABO (i.e., blood group) compatible and met additional predetermined matching criteria based on age, sex, height, weight, dentition, craniofacial dimensions, and skin and hair color. A partial face, bilateral jaw, and teeth transplant was performed using customized surgical planning (25, 26). Pre-operative printing of customized skeletal cutting guides helped achieve accurate skeletal alignment for optimal fitting of the donor allograft to the recipient's facial defect. This was confirmed by post-operative computed tomography scan (26). The patient's post-operative course involved several revision procedures including repair of floor-of-mouth and palatal wound dehiscence on post-operative day (POD) 11, internal fixation of left mandibular nonunion, bilateral canthoplasty and complex tissue rearrangement of the lower eyelids and cheeks (POD 108), and left medial canthoplasty and complex tissue rearrangement of the left lower eyelid (POD 248). The patient has achieved facial motor and sensory recovery, in addition to improvements in speech and maintenance of oral nutrition. Sensory and motor recovery of the facial allograft were evaluated through multiple modalities including neurological examination, measurement of nerve conduction velocity/electromyography, monofilament sensory testing, speech and swallow evaluation, as well as achievement of functional end points such as tracheostomy decannulation and feeding by mouth. By one-year follow-up, sensory examination was intact to light touch and monofilament, speech was intelligible, and nutritional intake was by mouth. The tracheostomy was removed on POD 151 (15). Electromyography recorded the return of facial nerve function with noted improvement of nerve conduction and motor recruitment correlating with improved speech and facial function through a 2-y follow-up. The patient has since returned to his pre-injury daily activities.

Fig. 1. Pre-operative (pre-T1, 8 mo pre-transplant), and post-operative (11 mo post-transplant) clinical images. Printed with permission from and copyrights retained by Eduardo D. Rodriguez, MD, DDS. For the actual images used in the reported experiments, please see *SI Appendix*, Fig. S1.

Our study quantified self-recognition performance using both behavioral and neuroimaging measures, and contrasted the relative strength of the pre-injury, post-injury, and post facial transplantation self-face representations, with the ultimate aim of providing a comparison of these different self-representations before and after facial transplantation. The face transplant recipient took part in five experimental sessions, two before the operation (T1 to T2) and three after the operation (T3 to T5). By the time he was tested at T1, he had been living with his post-injury face for 10 mo.

*While the use of facial difference and other similar terms prioritise the perspective of the patient, the term "disfigurement" is favoured by some disability activists because it is enshrined in law in the Equality Act 2010. Disfigurement is also used in surgical and clinical contexts, and is therefore used in this paper.

Results

We first considered the competition and overlap between alternative facial identities present in the pre-transplant period. Candidates for facial transplantation have had at least two faces in their lifetime prior to transplantation: the face they had prior to onset of the disfiguring condition or traumatic event and the disfigured face. The relative competition between the pre-injury and post-injury faces for self-identity remains unknown and raises several questions. Is the face prior to the disfiguring event the one that underpins self-identity? How do these faces compete for self-identity and how is this conflict resolved? The first two sessions took place pre-operatively, at 8 mo (T1) and 2 mo (T2) before the transplantation, with the aim of establishing a baseline pattern of brain activity linked to the processing of the pre-injury and post-injury faces. In each session, the face transplant candidate saw a range of morphed faces containing varying percentages of "self-face" and familiar faces while performing a self-recognition task (Fig. 2*A*). We used both the pre-injury and post-injury face as self-stimuli and, on each trial, the patient was asked to indicate with a key press whether the depicted face looked more like "self" or "other". For each of the different facial appearances (pre-injury and post-injury), there were six different degrees of morphing (*Methods*).

Behavioral responses (i.e., self or other) were entered into logistic functions to estimate the point of subjective equality (PSE), defined as the degree of morphing with equal probability of being judged as self or other, for each of the two facial appearances. PSEs higher or lower than 50 suggest that morphed images must contain larger or smaller percentages of the self, respectively, to be recognized as "self". For functional magnetic resonance imaging (fMRI) analyses, brain areas showing increased activity during the perception of each self-face (vs. other's face) were estimated with parametric contrasts corresponding to the percentage of self in each photo.

The observed pattern of PSEs (Fig. 2*B*) suggested a liberal self-recognition bias toward the pre-injury face compared to the post-injury face. In other words, for the pre-injury face, a smaller percentage of self was needed to be present in the morphed image for the patient's face to be recognized as self (T1 = 43.7; T2 = 46.4), whereas for the post-injury face, the morphed image required approximately an additional 14% of the patient's disfigured face to be present for the morph to be recognized as self (T1 = 57.4; T2 = 59.2). This pattern suggests perseverance of the patient's pre-injury face in his mental representation of self-image. Moreover, as shown by the accuracy scores for self and other recognition (*SI Appendix*, Fig. S2), while the patient's performance for the recognition of his own face fluctuated both across time and across the different faces, performance for the recognition of the other's face was at the ceiling level independently of the time point and of the morphing identity. This pattern rules out a generalized deficit in face recognition and suggests a specific effect for recognition of his own facial identities. It is also worth noting that while the identification of the post-injury face was relatively diminished at some time points, accuracy at T1 was considerably high (>93%) showing already good recognition ability at this early time point. Together, this evidence suggests that the biases observed should be explained by psychological factors rather than the objective ability to recognize each facial appearance.

At the neural level, significant clusters of increased activity were observed for both the pre-injury and post-injury self-faces in several brain areas known to be involved in self-recognition

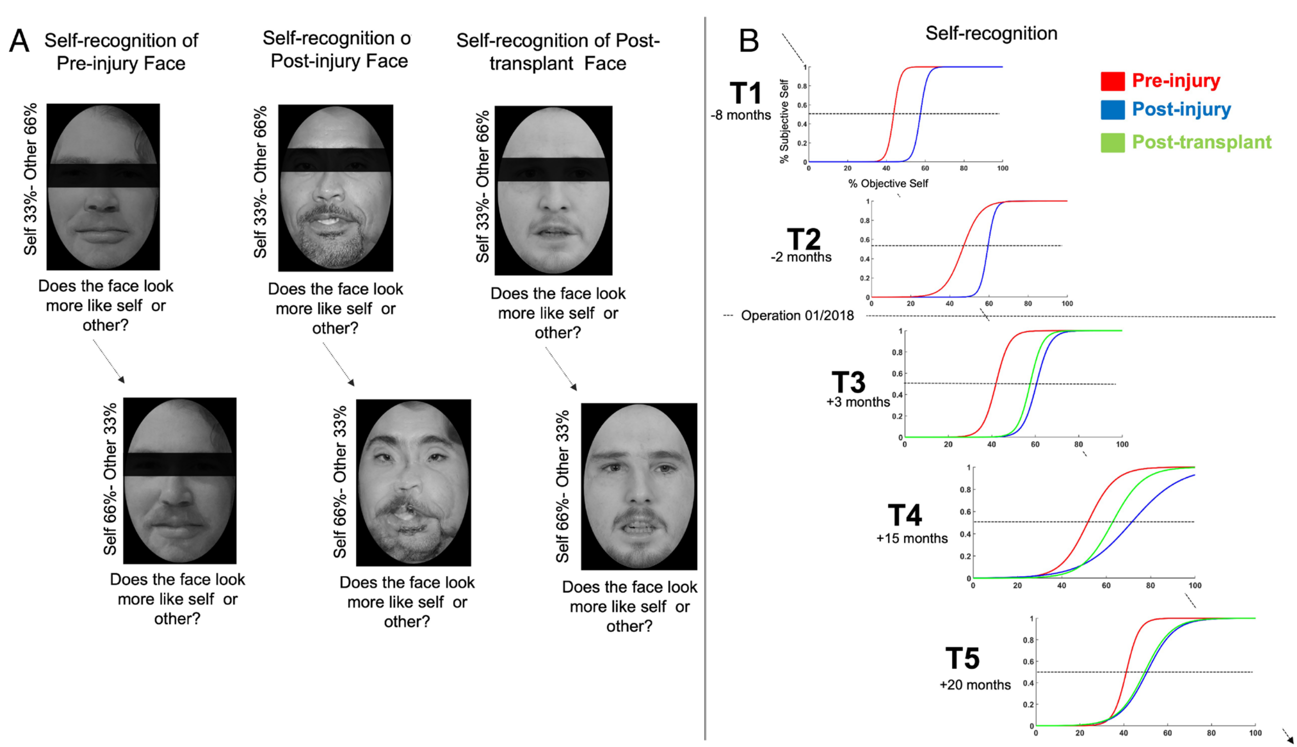

Fig. 2. (*A*) The behavioral self-recognition tasks used. On every trial, the patient was asked to indicate whether the depicted face looked more like himself or more like another familiar face. The area around the eyes is covered here for display purposes, but was visible to the patient throughout. At T1 and T2, self-recognition was performed in two settings. First, his pre-injury face was morphed with another familiar face, and next, his post-injury face was morphed with a second familiar face. For T3, T4, and T5, he performed the self-recognition in an additional third setting, where his transplanted face was morphed with a third familiar face. (*B*) Psychometric curves for the self-recognition of each face. The PSE for each curve is the x-value of the point where the curve intercepts the black horizontal line. Higher PSE values reflect the need for higher percentage of self-traits in the photo for self-recognition to take place. pre-injury T1 = 43.7; T2 = 46.4, T3 = 41.9; T4 = 51.6; T5 = 41.4; post-injury: T1 = 57.4; T2 = 59.2; T3 = 60.6; T4 = 71.3; T5 = 50.6; post-transplant: T3 = 57.6; T4 = 62.7; T5 = 49.5.

(see Fig. 3 for T1 and T2 and *SI Appendix*, Table S1 for all significant clusters). Increased neural activity was present in the Occ for both the pre-injury and post-injury faces at both T1 and T2. Interestingly, clusters in cortical midline structures, such as the MFC, ACC, and precuneus, areas associated with self-referential processing (9, 10), showed a stronger engagement for the pre-injury face. This pattern accords with observations that activations of midline structures and portions of the ACC reflect self-processing as well as increased familiarity with self-related psychological and physical constructs, including information such as one's face (27–29). Conversely, the IFG shows a greater engagement for the post-injury face relative to the pre-injury face, and such involvement may reflect the processing of physical aspects of the post-injury self-face (30).

The pre-operative testing phase shows that the transplant candidate still maintained a strong representation of his pre-injury face while several brain areas were also engaged during the processing of his post-injury face. The pre-operative testing enabled us to establish a baseline self-recognition pattern to compare to post-transplant self-recognition (Fig. 3). Following successful facial transplantation, the three testing sessions focused specifically on the gradual emergence of self-identification for the new facial identity. To that end, we added the third face (post-transplant) in our experimental design, and assessed the transplant recipient's self-face recognition performance for his new facial identity.

The recipient's behavioral responses in the post-transplant testing sessions confirmed the same bias toward a more liberal recognition of the pre-injury face relative to the other two appearances. This suggested that despite the radical alterations to his appearance, first as a result of traumatic injury and later as a result of facial transplantation, the face transplant recipient still identified with his pre-injury face. However, the results also revealed a gradual enhancement in the recognition of the post-transplant face; there was gradual and consistent alignment of recognition of the patient's new face with his pre-injury face (see Fig. 2, time points 3 to 5). Therefore, the appearance of the newly acquired face slowly attained a comparable mental representation to that of the pre-injury face. To provide statistical support for this interpretation, we compared the PSEs of each face with Wilcoxon nonparametric pairwise comparisons. Results suggested a biased identification of the pre-injury face compared to the post-injury face ($z = -2.02$, $P = 0.043$) but no significant differences between pre-injury and post-transplant ($z = -1.60$, $P = 0.109$) nor between postsurgery and post-transplant ($z = -1.60$, $P = 0.109$) suggesting a reduced identification with the post-injury face. We note however that, due to the small and imbalanced number of observations across face conditions, statistical inferences should be made with caution**.**

Self-processing of the post-transplant face was also neurally supported by the observed patterns of brain activity, most notably increased activity in the medial frontal regions, ACC, Occ, and

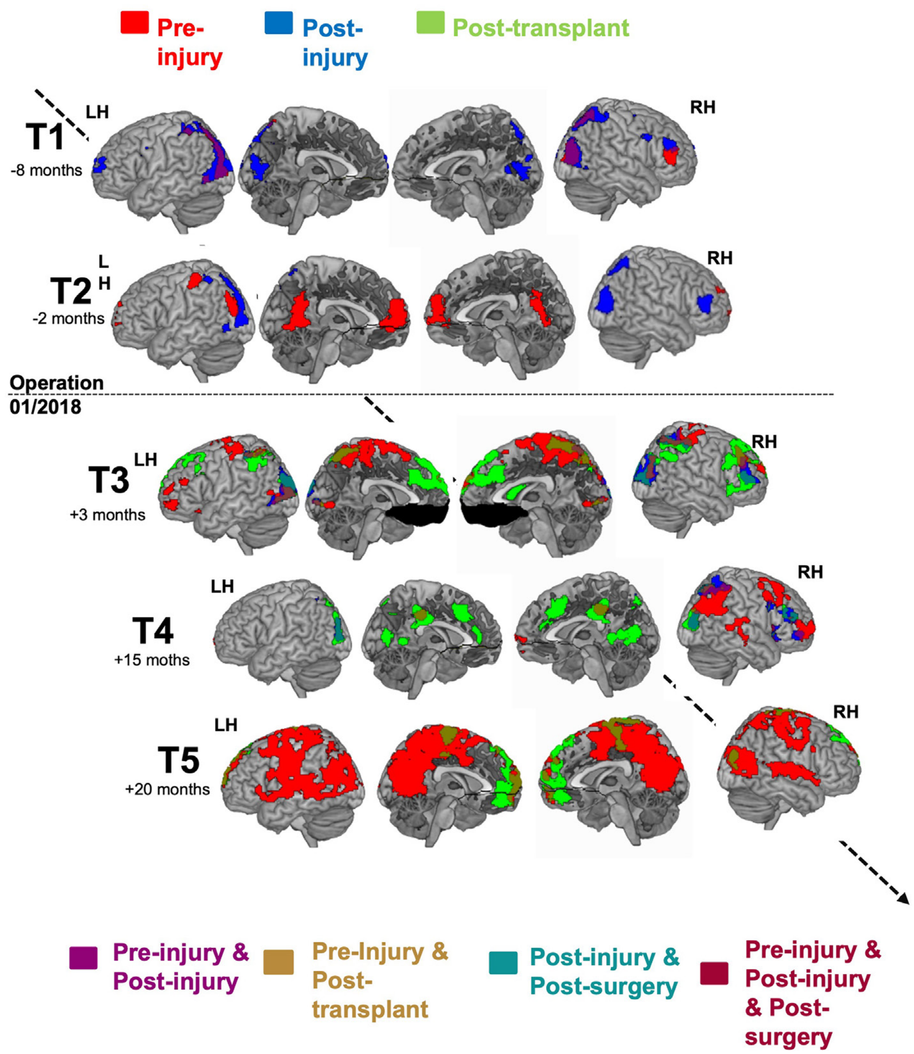

Fig. 3. BOLD response when looking at the three different faces (pre-injury, post-injury, post-transplant) (LH: left hemisphere; RH: right hemisphere).

right IFG across all three sessions (T3, T4, T5; Fig. 3). The right IFG, in particular, has been consistently implicated in facial self-recognition (6) and the existing neuroimaging data suggest that this area is involved in self-other differentiation (30) but also in multimodal representations of the self (31) and more diachronic self-representations (12) such as the self-recognition of both current and younger appearances of the self. The pattern we observed in the IFG during this longitudinal study is consistent with the hypothesis that post-transplant, the recipient comes to gradually recognize the post-transplant face as his own, while the post-injury face is no longer eliciting such neural responses at T5. The medial frontal regions such as the ACC have been shown to be activated in response to highly salient self-relevant information (32) and are thought to serve as a neural hub, integrating information about reflective aspects of the self with the processing and evaluation of perceptual self-face images (33). In addition to this gradually increasing enhancement of activation when seeing the post-transplant face, we observed a gradually decreasing engagement of the same brain areas when looking at the post-injury face and notably no evidence of engagement of these areas at T5 (*SI Appendix*, Fig. S4 and Table S4 for activation maps associated with increased and decreased activity for each self-face across time). Conversely, the perception of the pre-injury face remained associated with activity in areas related to self-processing across all sessions, including activity in medial prefrontal regions at T5 (Fig. 3). These patterns of whole-brain activity were largely mirrored by the patterns observed when plotting activity for each self-face in regions of interest (ROIs) previously identified in meta-analyses on self-face recognition (9) (Fig. 4). With regard to the pattern of activity in the ROIs, we note that activity in the rIns ROI was found to be, overall, increased for pre-injury and post-transplant self-face processing compared to the post-injury face. The insula is thought to be particularly important for the processing of internal bodily sensations and their integration with exteroceptive information. Strongly implicated in the generation of subjective and emotional feelings, it has been proposed that insula activity in self-face processing reflects affective and motivational states related to self-awareness (34) suggesting greater affective and bodily engagement with the pre-injury and post-transplant faces. We should also note that no significant activity in any of the self-face processing analyses was found in the amygdala (*SI Appendix*, Fig. S5), a region that is strongly involved in (mostly negative) emotional reactions to salient stimuli, including in the processing of the self-face by depressed individuals with recent suicidal attempts (35).

To directly compare brain responses between the different faces, we contrasted the activation maps for each face averaged separately across pre-transplant and post-transplant sessions in a pairwise fashion. Results (Fig. 5 and *SI Appendix*, Table S2) for the pre-transplant comparisons showed that the pre-injury face, compared to the post-injury face, was associated with increased activity in midline regions, specifically, in one cluster comprising the anterior cingulate cortex (ACC) and anterior portions of the medial prefrontal cortex (MPFC) and a cluster in the precuneus. Conversely, the perception of the post-injury (vs. pre-injury) face leads to increased activity in occipital regions and bilateral IFG. We also found a cluster in the dorsal MPFC, thus posterior to the regions typically associated with the processing of psychological aspects of the self. These results confirm pre-transplant engagement of self-processing brain regions to the perception of both faces, with the pre-injury face activating primarily midline regions involved in self-referential processing and the post-injury face brain areas associated with the processing of physical features of the self.

After facial transplantation, however, no brain region was found to be significantly more active for the post-injury face compared to the pre-injury or post-transplant face. In contrast, the pre-injury vs. post-injury comparison was now associated with widespread activations in lateral precentral/parietal cortices (including postcentral gyrus), superior temporal cortex, and posterior midline regions, such as the precuneus and posterior cingulate cortex, and to a less extent anterior MPFC (Fig. 5). Increased activity was also observed over precentral cortex/postcentral gyrus and superior temporal cortex in comparison to the post-transplant face. Notably, it was the perception of the post-transplant face that elicited greater activations in anterior midline regions, such as widespread activations over the ACC/MPFC and precuneus/PCC in the post-transplant vs. post-injury contrast and in the ACC only for the post-transplant vs. pre-injury comparison. The former contrast was also associated with increased activity in the IFG bilaterally and in the left insula. Together, this pattern of brain activity suggests increased psychological identification with the post-transplant face and decreased identification with the post-injury face.

The parametric analysis adopted here is consistent with the large body of neuroimaging research in self-face recognition (3) and provides a sensitive measure to identify brain regions that become more responsive as the percentage of self present in the photos increases. However, because this analysis is not necessarily aligned with the recipient's responses in the self-face recognition task, it does not inform on the patterns of brain activity associated specifically with the conscious identification of each face. Instead, it bypasses overt self-recognition and offers a more implicit measure of self-processing that is, partially, independent of any of the recipient's response bias.

To explore possible similarities and discrepancies between brain responses to automatic self-processing and overt self-recognition, we reanalyzed the data according to the patient's behavioral performance, that is, we contrasted trials where he responded as self or other to each face independent of the morphing level of the stimulus. The observed activations are largely consistent with those observed in the standard analyses (see Fig. 6 and *SI Appendix*, Table S3 for all significant clusters) suggesting an alignment between the neural areas involved in the processing of the three faces and in their overt recognition. One interesting exception is the activity in the medial prefrontal regions at T4 that was now present for the pre-injury and not for the post-transplant face. Tentatively, this may suggest a still rather implicit identification with the new appearance at this stage. However, and consistent with the main analysis on self-processing, at T5, there were no significant clusters for the post-injury face, while for both the pre-injury and post-transplant faces, we observe activations in medial frontal areas, and for the post-transplant face alone, we also observe activity in the IFG (Fig. 6).

Discussion

The face is our most distinguishable physical feature; it is central to our sense of self-identity and plays a fundamental role in social interactions as the primary vehicle for visual recognition of identity and nonverbal communication of emotions and intentions. Therefore, it is not surprising that individuals with acquired facial disfigurement tend to experience profound psychosocial challenges as they adjust to a new appearance with its associated functional and social considerations (14). Recent developments in the medical sciences have provided the opportunity for patients with severe facial disfigurement to undergo facial transplantation in order to restore most functional, social, and esthetic capacities. However,

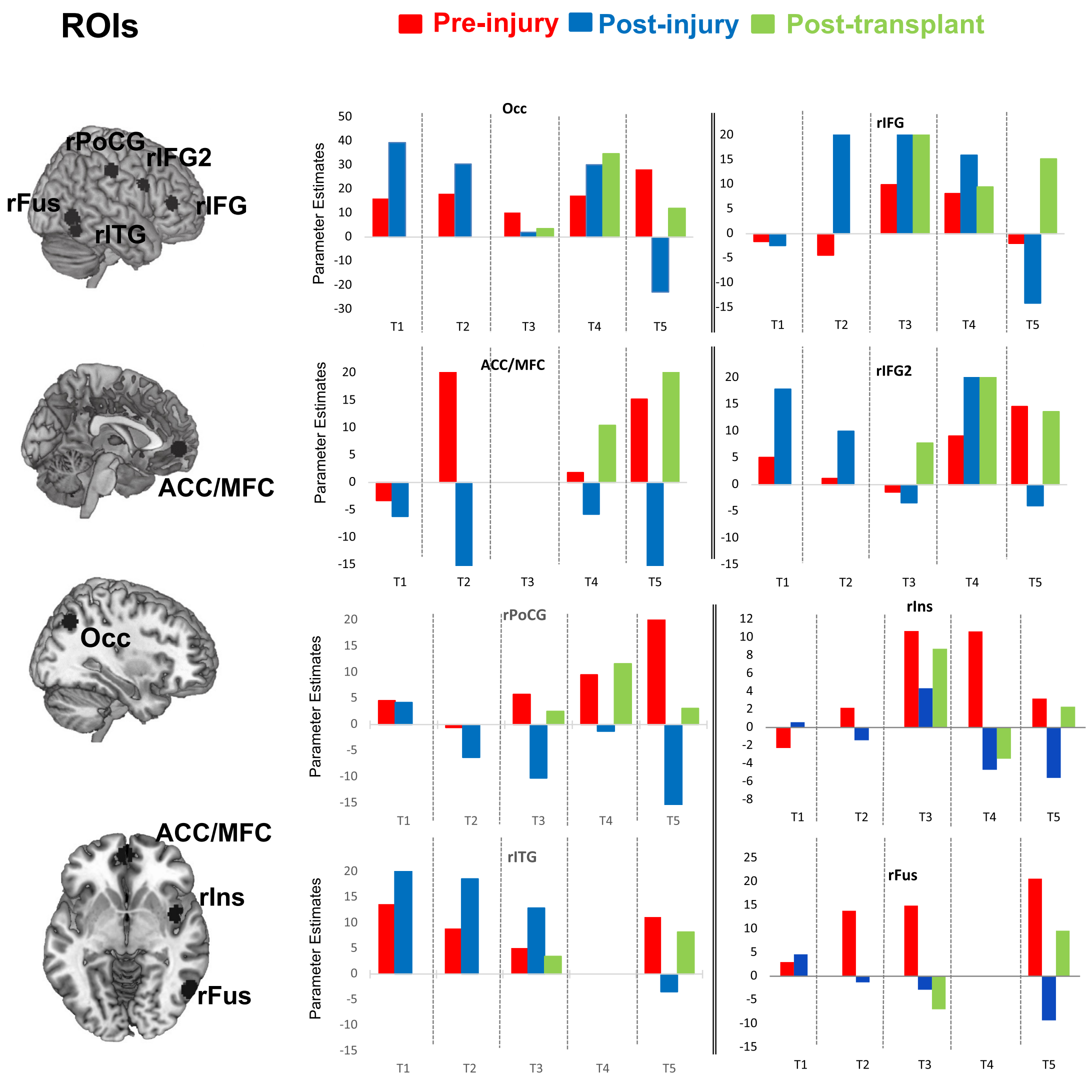

Fig. 4. Plots of parameter estimates for the observation of each self-face in the ROIs: superior Occ, right inferior frontal gyrus (rIFG and rIFG2), Anterior Cingulate Cortex/Medial Frontal Cortex (ACC/MFC), rITG, rFus, rIns, and rPoCG.

facial transplantation also comes with unique challenges as recipients need to integrate their new appearance into their self-identity. We present the first longitudinal investigation of changes in self-face recognition throughout a recipient's journey before and after facial transplantation. Behavioral indices and patterns of brain activity suggest that while the recipient shows overall good recognition of all three faces, he preserves a strong mental representation of his pre-injury appearance throughout the pre-transplant and post-transplant periods. Post-transplantation, he gradually incorporates this new appearance into his self-identity.

Previous research on self-recognition has identified a network of brain regions that are consistently active when perceiving self-stimuli compared to familiar or highly meaningful stimuli (5, 6). In line with the literature, we observe consistent results in the face transplant recipient's self-recognition over time, such as the activity in the right IFG. The right IFG has previously been shown to be activated when distinguishing between self-face and other-face (30), as well as when participants engage with self-recognition of different appearances of one's self across different periods of life (12), a finding that speaks to the continuity and stability of self-face neural representations across the lifespan. For example, IFG was engaged when people recognize images of themselves from childhood as well as when recognizing their current appearance (12). In addition, the MFC was consistently activated during self-recognition of the post-transplant face (T3 to T5). This region has long been proposed to reflect the processing of abstract mental representations of the self, such as traits, autobiographical memories, attitudes, or emotional evaluations (typically positive) of the self (9, 11, 36–39). The engagement of this region was observed for both the pre-injury and post-transplant faces, a pattern that seems consistent with the hypothesis that the post-transplant face slowly but steadily acquires a comparably salient neural representation similar to the pre-injury face. The fact that MFC was consistently active during the perception of the post-transplant appearance suggests not only identification with this new appearance as a representative of the physical self but also as a higher-order and more reflective identification with the face, in line with the tripartite model of self-recognition (24). This area of the MFC was found to be active during the perception of the pre-injury face but not to respond to the patient's post-injury face, which seems to support the hypothesis of a preserved identification with the former appearance and weaker identification with the post-injury face, likely reflecting an adaptive modulation of an internal schema related to self-evaluation (39).

Cases of facial transplantation represent a dramatic change in one's facial identity with important psychological consequences. In

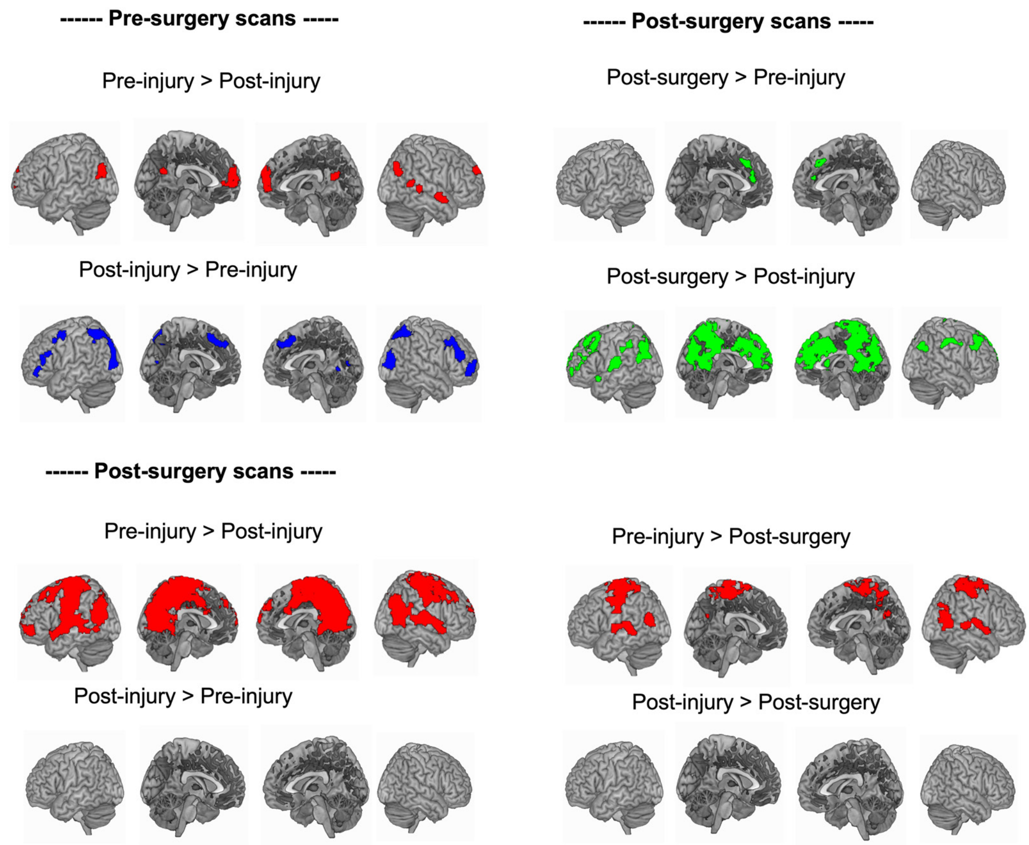

Fig. 5. Increased BOLD responses to the perception of each self-appearance relative to each other. For these comparisons, activation maps for the perception of each face were first averaged separately within pre-transplant and post-transplant scans.

line with the neural data, the emergence of self-recognition for the post-transplant face and the gradual disappearance of the mental representation for the post-injury face further document the plasticity of self-processing. The behavioral pattern observed here suggests that the face transplant recipient was able to recognize his post-transplant face more easily, compared to the post-injury face across almost all time points. At the time of facial transplantation, he had been living with his post-injury face for 18 mo, while the last time point he was tested at took place 20 mo following facial transplantation. In other words, he had spent roughly the same amount of time with each of these two faces; of course, the conditions of acquisition of the two faces were radically different. The post-injury face was the result of a highly traumatic event that resulted in severe disfigurement, and psychological adjustment to this severely injured face is often particularly difficult (40). On the other hand, the new face acquired through facial transplantation represents an elective decision with hope for substantial physical and psychosocial benefits. The apparent better adjustment to the post-transplant face and its superior self-recognition allude to the hypothesis that the changes observed in the neural network underpinning self-processing cannot be simply due to sensory processing and visual perception or familiarity with the face, as both the post-injury and post-transplant faces were present for comparable amounts of time and the self-face recognition accuracy for the post-injury face was highest for T1 (*SI Appendix*, Fig. S2). The observed pattern may reflect top–down modulations driven by affect and evaluative beliefs about the outcome of such a radical yet elective and medically successful intervention.

The present longitudinal study focused on one individual, raising concerns about the generalizability and replicability of our findings. To date, approximately 50 face transplants have been performed worldwide. To the best of our knowledge, this is the first study that investigates behavioral and neural changes in self-face recognition in such individuals. Testing individuals who undergo such life-changing experiences is especially challenging from scientific, ethical, logistical, and multidisciplinary perspectives. Our approach provides a proof-of-concept of a positive identification with a new facial identity and is important in advancing our understanding of the plasticity of self-recognition and for shaping future research approaches as such operations may become more frequent. Replicability is an ongoing process and one that may show a diversity in responses to self and identity. In preliminary studies that capture only post-transplant self-recognition, two additional patients that we tested exhibited unique patterns of self-recognition. One patient identified more with their "pre-injury" appearance but showed very accurate recognition and strong identification with their "post-injury" and "post-transplant" faces. This pattern was supported by neural engagement of key areas implicated in the self-face recognition network when asked to recognize post-injury and post-transplant faces. In contrast, the second individual retained a particularly strong mental representation of their pre-injury face and showed a lack of recognition as self of their post-injury and post-transplant faces, and the brain areas typically engaged during self-face recognition showed attenuated responses to their injured and post-transplant faces. These results indicate how differently these two recipients have adapted behaviorally, neurally, and presumably psychologically to their new appearance. This evidence of adaptive assimilation warrants further study of its functional underpinnings and long-term implications. In addition, and beyond quantitative measures of self-recognition, there is an increasing awareness of the need to develop better tools for assessing the quality of life in such cases that can

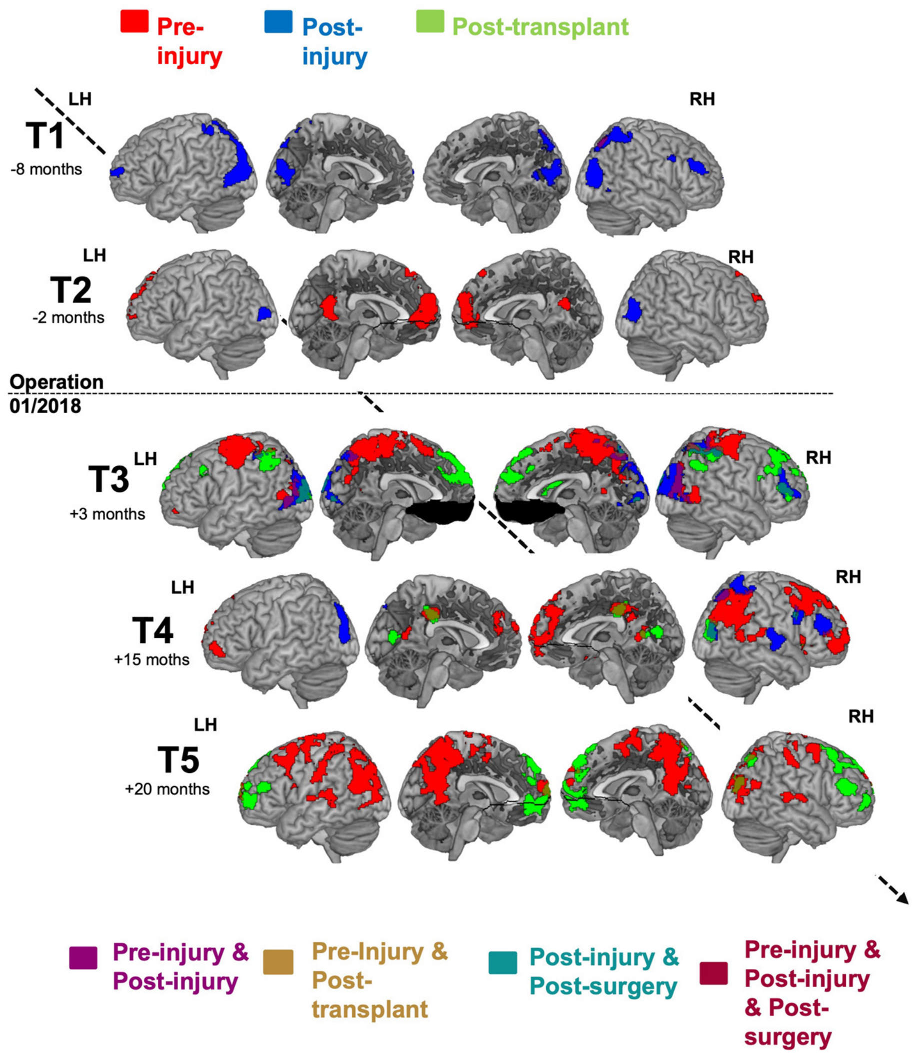

Fig. 6. Activations for the correct self-recognition for each face across each time point. Color pink indicates the overlapping activations when looking at the pre-injury and post-injury faces, color turquoise indicates the overlapping activations between when looking at the post-injury and post-transplant faces and color yellow indicates the overlapping activation when looking at the pre-injury and the post-transplant faces (*SI Appendix*, Table S3).

capture the actual life-enhancing impact of facial transplantation on the patient or their families (41).

This segues into a related issue of the extent to which there is stability of self-face representations over time in the absence of face transplantation. We have previously demonstrated this stability, where we looked at the same questions of plasticity of self-recognition in healthy individuals (12). There we found consistent results in terms of brain areas involved in recognizing different visual instances of one's own face (i.e., looking at one's self-photos taken at different ages), as the ones we observed in the patient reported here, with the involvement of the IFG. However, it must be noted that control subjects who haven't undergone such alterations in their facial appearance cannot be used as adequate control to a case of facial transplantation, given the very severe disfigurement and associated psychological trauma. For that reason, more appropriate experimental controls can be provided by the use of a longitudinal design, as we did here, and the inclusion of three different faces in the experimental tasks.

Finally, it is important to consider that affect and emotional responses may play a key role in how recipients of face transplants respond both to the post-injured face and their new facial appearance following transplantation. For example, profound negative affect potentially associated with the disfigured face may be on the basis of reduced identification with this face. Similarly, the gradual recovery of functionality and likely increased positive social feedback, among other factors, may have greatly contributed to an increase in positive associations and identification with the post-transplant face. The observed activity in brain areas such as the insula and the ACC might reflect greater affective engagement with the pre-injury and post-transplant appearances relative to the post-injury face. The importance of these brain regions in the emotional response during self-face processing has been shown in different studies associating reduced activity in these regions with negative affect, such as embarrassment (42) or in depressed individuals with suicidal ideation (43). Nevertheless, we need to note that our study focused on investigating the behavior and neural underpinnings of self-face recognition and was not designed to evaluate the recipients' emotional responses to each face. Ethical considerations in the present case meant that we were not able to support such interpretations with further examinations of these processes. When possible, future research may complete the present findings by exploring how affective dimensions relate to neural activity associated with the perception and recognition of different self-appearances.

This longitudinal study examined the neural plasticity of self-recognition in an individual who twice in his life underwent major alterations in his facial appearance. Facial transplantation raises fundamental ethical and psychological questions about personal identity and personal choices. Such interventions are pursued by individuals with severe facial disfigurement whose quality of life is greatly impacted. While the operation itself poses health risks such as lifelong immunosuppression and potential transplant rejection, there are also important functional, psychological, and esthetic benefits with considerable improvement in all aspects of quality of life (44), such as on independence, self-esteem, intimate relationships, social interactions, and potential return to employment. Our findings document how a surgically successful facial transplantation resulted in the gradual emergence of robust self-recognition capacity for a radically new facial appearance. These findings also highlight the extent to which the neural network that underpins self-recognition may process in parallel distinct representations of one's appearance. The self and its neural representation possess sufficient plasticity to ensure assimilation of changes while at the same time providing a sense of continuity over time. The plasticity and continuity of the self that we document here are particularly relevant for modern selves who, due to technological and medical advances, seem to be exposed to new, often radical, possibilities for change.

Methods

Ethical Approval. The patient provided written consent to participate in a clinical trial assessing self-face recognition in facial transplantation recipients requiring completion of a self-face recognition task during fMRI examination that was approved by the NYU Langone Health Institutional Review Board (Study # s16-01144; ClinicalTrials.gov, NCT03027141).

Stimuli. We presented to the patient photos of his own face in three settings (pre-injury; post-injury; and post-transplant) morphed with faces of same-sex people who were familiar to and chosen by him. The patient's pre-injury face was morphed with a photo of a same-gender relative of his, the post-injury face with a photo of a famous person of high familiarity to the patient (T1 to T5), and the post-transplant face with a photo of another famous person of high familiarity to the patient (T3 to T5). The patient's post-transplant photos were updated with recent photos before each scan (see the photos used in *SI Appendix*, Fig. S1). Due to practical constraints, only one photo of each face was used as stimuli. While this is a common approach in the field, it may induce bias as the patient might respond in particular ways to specific photos. However, we note that possible biases are less relevant as we compare activity maps across sessions. Each face used in T1 and T2 had six degrees of morphing (0%-self/100%-other; 20%-self/80%-other; 40%-self/60%-other; 60%-self/40%-other; 80%-self/20%-other; and 100%-self/0%-other) and those in T3 to T5 had four degrees of morphing (0%-self/100%-other; 33%-self/66%-other; 66%-self/33%-other; and 100%-self/0%-other) as there were three different conditions at T3 to T5 with the inclusion of the post-transplant face. Fewer levels of morphing had to be used in T3 to T5 to accommodate for the postsurgery stimuli and avoid overly long scanning sessions while maintaining statistical power. This can potentially induce biases in the power and sensitivity to estimate activity related to the perception of each face between pre-transplant and post-transplant sessions. However, because our analyses are mostly concerned with the comparisons between faces within sessions, such potential biases would not undermine the interpretations of our main results. The photos were desaturated (i.e., turned into black and white) and matched for mean luminance within face conditions, i.e., pre-injury, post-injury, and post-transplant. Moreover, a black oval-shaped template was imposed on them to remove non-facial attributes (e.g., background, hair, ears) that could interfere with facial recognition (45, 46). We also created one scrambled control image of each face by randomly rearranging the pixels. These images preserved some low-level visual properties (e.g., average luminance) but had no distinguishable shape, i.e., face. Including these pictures in the face-recognition protocol helped to control for brain activity related to low-level visual processing (e.g., luminance) not related to face recognition.

Procedure. The patient was positioned in the fMRI scanner in a dimly lit environment. The visual stimuli were back-projected on a screen behind the magnet and visible to the patient via a mirror mounted on the MRI head coil. The entire session consisted of four blocks of fMRI during which the patient performed the self-recognition task (approximately 11 min) and one structural MRI sequence (approximately 5 min), carried out between the 2nd and 3rd fMRI blocks. Each block of the self-recognition task consisted of 90 trials: six of each condition (Face × Morphing level) and 18 scrambled images. Thus, the entire task comprised a total of 24 trials per condition presented in a fully randomized fashion. Data from the fourth (and last) block of T5 were discarded due to excessive head movements (movement spikes > 3 mm).

In each trial, a photo was presented for 2 s in the center of a black screen. The photo then disappeared from the screen, and immediately two labels (Self and Other or "Scramble" and Self) were shown for 2 s on either the left or right side of the screen, randomized and equally distributed on the left or the right across the whole experiment. During this period, the patient was required to indicate, with a left or right key press, whether the depicted face looked more like self or other. No feedback on performance was given and a fixation cross "+" was present between trials. The intertrial interval varied randomly between 4 and 10 s.

MRI Acquisition Parameters and Data Analyses. Whole-brain imaging data were acquired with a three Tesla Siemens Magnetom Skyra (Siemens Medical Systems, Erlangen, Germany). Thirty-four slices of functional magnetic resonance (MR) images were acquired using multiband echo-planar imaging (EPI) with the following parameters: acceleration factor = 2, TR = 1,000 ms, TE = 30 ms, slice thickness = 3.0mm, flip angle = 62°. Additionally, an anatomical T1-weighted magnetization-prepared rapid gradient-echo (MPRAGE) sequence was acquired as reference (TR = 2.3 s, TE = 2.98 ms, voxel size 1 × 1 × 1 mm, Field of View (FOV) = 256 × 256 × 160 mm, 160 axial slices).

SPM12 (www.fil.ion.ucl.ac.uk) implemented in MATLAB (v 2018a, The MathWorks, Natick, MA) was used for data preprocessing and statistical analyses. The first four image volumes of each run were used for stabilizing longitudinal magnetization and were discarded from the analysis. Standard preprocessing methods were adopted. To correct for head movements, rigid body transformation (realignment) was applied and six estimated motion parameters for each subject were added as regressors of no interest in the statistical multiple regression model. Functional images were coregistered to the patient's deskulled structural image and normalized to the standard SPM12 EPI template, resampled to 2-mm isotropic voxel size, and spatially smoothed using an isotropic Gaussian kernel of 8-mm FWHM.

To maximize the comparability of activation patterns across sessions, data from all sessions were analyzed in a single general linear model. Data were best fitted at every voxel by convolving the event onset delta functions with the canonical hemodynamic response function (HRF) for each event type: 12 experimental conditions (i.e., T1 to T2: 2 faces × 6 morphing levels; T3 to T5: 3 faces × 4 morphing levels), the scrambled faces, key presses, and the six motion regressors. HRF analyses were time-locked to the photo onset (duration = 0 s). To identify voxels whose activity covaried parametrically with the percentage of self in the photo, we created parametric contrasts for each face. That is, the parametric modulators scaled the HRF amplitude to correspond to the percentage of self in each photo and identify brain activity related to the processing of self-features for each face. The activation maps are presented in Fig. 3 and *SI Appendix*, Table S1. In a separate analysis, to directly compare patterns of brain activity in response to the different faces, first, we averaged the brain activity for each self-face separately for pre-transplant and post-transplant scans. Then, we created *t* test contrasts comparing these averaged activations maps to look for brain areas showing increased brain activity for each self-face relative to the other self-faces in a pairwise fashion (activation maps reported in Fig. 5 and *SI Appendix*, Table S2 of activations). An additional set of analysis was carried out by contrasting brain responses to photos the participant identified as self with those identified as other. Thus, the design comprised four experimental conditions in T1 to T2 (2 faces × 2 response types) and 6 (3 faces × 2 response types) in T3 to T5 (activation maps reported in Fig. 6 and *SI Appendix*, Table S3 of activations). For all whole-brain analyses, initial voxel-level statistical maps were set to a threshold at $P < 0.005$ (uncorrected) and corrected for multiple comparisons at cluster level $P < 0.05$ (false discovery rate).

For descriptive purposes (Fig. 4), ROI analyses were carried out by computing an F-contrast reflecting the parametric increase of brain activity in response to the increased percentage of self present in each morphed image shown. That is, this contrast provides the average activity (contrast estimates) for the perception of each self-face (vs. other faces) in the six ROIs identified by a meta-analysis (9) as involved in self-face recognition and self-referential processing (Fig. 4): ACC (MNI coordinates: x = −1, y = 53, z = −1); two regions within the right inferior frontal gyrus (MNI coordinates: x = 46, y = 38, z = 10; and: x = 51 y = 9, z = 27); superior Occ (MNI coordinates: x = 27, y = −67, z = 43); right inferior temporal gyrus (rITG) (MNI coordinates: x = 50, y = −56, z = −14); and rPoCG (MNI coordinates: x = 54, y = −22, z = 41). We note that while this metaanalysis (9) did not identify any region in the fusiform gyrus and insular cortex, others have argued for the importance of these regions in the processing of perceptual and affective-motivational aspects of self-processing, respectively (34). Therefore, we included in our analyses two additional ROIs identified in another recent meta-analysis as more active for self vs. familiar stimuli (34) (Fig. 4): right fusiform gyrus (rFus) (MNI coordinates: x = 55, y = −61, z = −3); right insula (rIns) (MNI coordinates: x = 43, y = 3, z = −1). Finally, we also investigated the possible activation of the amygdala in self-face processing, which would likely reflect affective responses (35) and report these results in the *SI Appendix*.

It is important to note that MRI-safe maxillomandibular hardware and orthodontic appliances utilized post-transplantation-induced image artifacts over the rostral areas of the anterior prefrontal cortex, particularly at T3. Such artifacts were greatly mitigated at T4 and T5 with the removal of orthodontic brackets and by changes in image acquisition parameters (see further details in *SI Appendix*). To account for this and investigate activity in the anterior prefrontal regions we reran all analyses in a separate generalized linear model without the data acquired at T3. Results from this model are reported only for anterior prefrontal regions and sessions T1, T2, T4, and T5. This region can be identified in Figs. 3, 5, and 6 by a delimitating black contour, and detailed activation maps can be found in *SI Appendix*.

Data, Materials, and Software Availability. Raw behavioural data data have been deposited in OSF (https://osf.io/gy8fx/?view_only=69a7b59426b54aa3bd860468eb727cb8) (47). Some study data available raw imaging data will not be made publicly available for privacy protection. Making the raw neuroimaging data of one identifiable individual fully available to the wider community is unethical and violates medical confidentiality and their privacy as anyone could explore this person's brain (responses) in ways that could fall outside the direct remit of the study.

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1. G. G. Gallup Jr., Self-recognition in primates: A comparative approach to the bidirectional properties of consciousness. *Am. Psychol.* **32**, 329–338 (1977).
2. B. Amsterdam, Mirror self-image reactions before age two. *Dev. Psychobiol.* **5**, 297–305 (1972).
3. M. Lewis, M. W. Sullivan, C. Stanger, M. Weiss, Self-development and self-conscious emotions. *Child Dev.* **60**, 146–156 (1989).
4. P. Rochat, Five levels of self-awareness as they unfold early in life. *Conscious. Cogn.* **12**, 717–731 (2003).
5. J. Gillihan, M. J. Farah, Is self special? A critical review of evidence from experimental psychology and cognitive neuroscience. *Psychol. Bull.* **131**, 76–97 (2005).
6. C. Devue, S. Brédart, The neural correlates of visual self-recognition. *Conscious. Cogn.* **20**, 40–51 (2011).
7. S. M. Platek, K. Wathne, N. G. Tierney, J. W. Thomson, Neural correlates of self-face recognition: An effect-location meta-analysis. *Brain Res.* **1232**,173–184 (2008).
8. J. P. Keenan *et al.*, Self-recognition and the right prefrontal cortex. *Trends Cogn. Sci.* **4**, 338–344 (2000).
9. C. Hu *et al.*, Distinct and common aspects of physical and psychological self-representation in the brain: A meta-analysis of self-bias in facial and self-referential judgements. *Neurosci. Biobehav. Rev.* **61**, 197–207 (2016).
10. R. J. Murray, M. Debbané, P. T. Fox, D. Bzdok, S. B. Eickhoff, Functional connectivity mapping of regions associated with self- and other-processing. *Hum. Brain Mapp.* **36**, 1304–1324 (2015).
11. L. Q. Uddin, The self in autism: An emerging view from neuroimaging self in autism. *Neurocase* **17**, 201–208 (2011).
12. M. A. J. Apps, A. Tajadura-Jiménez, G. Turley, M. Tsakiris, The different faces of one's self: An fMRI study into the recognition of current and past self-facial appearances. *Neuroimage* **63** (2012).
13. J.-M. Dubernard *et al.*, Outcomes 18 Months after the First Human Partial Face Transplantation. *N. Engl. J. Med.* **357**, 2451–2460 (2007).
14. W. J. Rifkin *et al.*, Achievements and challenges in facial transplantation. *Ann. Surg.* **268**, 260–270 (2018).
15. R. S. Kantar *et al.*, Facial transplantation for an irreparable central and lower face injury: A modernized approach to a classic challenge. *Plast. Reconstr. Surg.* **144**, 264E–283E (2019).
16. A. J. Lindford *et al.*, The Helsinki approach to face transplantation. *J. Plast. Reconstr. Aesthetic Surg.* **72**, 173–180 (2019).
17. T. Garrel-Jaffrelot, *Frenchman is first in World to get 2 full face transplants*. (The New York Times, 2018).
18. S. Kirkey, *Canada's first face transplant*. (National Post, 2018).
19. M. De Bac, Transplanted face rejected: "Now we need a new donor". *UpToDate* (2018). https://www.corriere.it/english/18_settembre_25/transplanted-face-rejected-now-we-need-new-donor-0916a0ea-c0d2-11e8-8c2f-234b69fe8a3d.shtml. Accessed 1 March 2020.
20. J. Ducharme, Meet the first African-American face transplant recipient. *UpTodate* (2019). https://time.com/5709294/first-african-american-face-transplant/. Accessed 1 March 2020.
21. P. Giraux, A. Sirigu, F. Schneider, J. M. Dubernard, Cortical reorganization in motor cortex after graft of both hands. *Nat. Neurosci.* **4**, 691–692 (2001).
22. T. S. Westvik, A. Dermietzel, B. Pomahac, Facial restoration by transplantation: The Brigham and Women's face transplant experience. *Ann. Plast. Surg.* **74**, S2–S8 (2015).
23. H. Uysal *et al.*, Referred facial sensation on the hand after full face transplantation. *Neurology* **86**, 836–839 (2016).
24. G. Northoff *et al.*, Self-referential processing in our brain–a meta-analysis of imaging studies on the self. *Neuroimage* **31**, 440–57 (2006).
25. R. S. Kantar *et al.*, Facial transplantation for an irreparable central and lower face injury: A modernized approach to a classic challenge. *Plast. Reconstr. Surg.* **144**, 264e–283e (2019), 10.1097/PRS.0000000000005885.
26. E. P. Ramly, R. S. Kantar, J. R. Diaz-Siso, A. R. Alfonso, E. D. Rodriguez, Computerized approach to facial transplantation: Evolution and application in 3 consecutive face transplants. *Plast. Reconstr. Surg. Glob. Open* **7**, e2379 (2019).
27. D. Legrand, P. Ruby, What is self-specific? Theoretical investigation and critical review of neuroimaging results. *Psychol. Rev.* **116**, 252–282 (2009).
28. P. Qin, G. Northoff, How is our self related to midline regions and the default-mode network? *NeuroImage* **57**, 1221–1233 (2011).
29. P. Qin *et al.*, Dissociation between anterior and posterior cortical regions during self-specificity and familiarity: A combined fMRI-meta-analytic study. *Hum. Brain Mapp.* **33**, 154–164 (2012).
30. L. Q. Uddin, J. T. Kaplan, I. Molnar-szakacs, E. Zaidel, M. Iacoboni, Self-face recognition activates a frontoparietal bmirrorQ network in the right hemisphere: An event-related fMRI study. *Neuroimage.* **25**, 926–935 (2005).
31. J. T. Kaplan, L. Aziz-zadeh, L. Q. Uddin, M. Iacoboni, The self across the senses: An fMRI study of self-face and self-voice recognition. *Soc. Cogn. Affect. Neurosci.* **3**, 218–223 (2008), 10.1093/scan/nsn014.
32. I. Perini *et al.*, The salience of self, not social pain, is encoded by dorsal anterior cingulate and insula. *Sci. Rep.* **8**, 1–9 (2018).
33. Morita *et al.*, The anterior insular and anterior cingulate cortices in emotional processing for self-face recognition. *Soc. Cogn. Affect. Neurosci.* **9**, 570–579 (2014).
34. P. Qin, M. Wang, G. Northoff, Linking bodily, environmental and mental states in the self–A three-level model based on a meta-analysis. *Neurosci. Biobehav. Rev.* **115**, 77–95 (2020).
35. G. Alarcón, J. Y. Teoh, M. Sauder, E. E. Forbes, K. Quevedo, Amygdala functional connectivity during self-face processing in depressed adolescents with recent suicide attempt. *J. Am. Acad. Child Adolesc. Psychiatry* **58**, 221–231 (2019).
36. C. Feng, X. Yan, W. Huang, S. Han, Y. Ma, Neural representations of the multidimensional self in the cortical midline structures. *Neuroimage* **183**, 291–299 (2018).
37. P. Tacikowski, C. C. Berger, H. H. Ehrsson, Dissociating the neural basis of conceptual self-awareness from perceptual awareness and unaware self-processing. *Cereb. Cortex.* **27**, 3768–3781 (2017), 10.1093/cercor/bhx004.
38. L. A. Watson, B. Dritschel, M. C. Obonsawin, I. Jentzsch, Seeing yourself in a positive light: Brain correlates of the self-positivity bias. *Brain Res.* **1152**, 106–110 (2007).
39. M. Sugiura, Three faces of self-face recognition: Potential for a multi-dimensional diagnostic tool. *Neurosci. Res.* **90**, 56–64 (2015).
40. S. Pearl, *Face/On: Face Transplants and the Ethics of the Other* (The University of Chicago, Press Books, 2017).
41. F. Bound Alberti, M. Ridley, E. Herrington, J. L. Benedict, S. Hall, What we still don't know about vascularized composite allotransplantation (VCA) outcomes and quality of life measurements. *Transplant. Rev. (Orlando).* **36**, 100708 (2022).
42. T. Morita *et al.*, The anterior insular and anterior cingulate cortices in emotional processing for self-face recognition. *Soc. Cogn. Affect. Neurosci.* **9**, 570–579 (2014).
43. K. Quevedo *et al.*, The neurobiology of self-face recognition in depressed adolescents with low or high suicidality. *J. Abnorm. Psychol.* **125**, 1185–1200 (2016).
44. M. A. Aycart *et al.*, Quality of life after face transplantation: outcomes, assessment tools, and future directions. *Plast. Reconstr. Surg.* **139**, 194–203 (2017).
45. M. A. J. Apps, A. Tajadura-Jiménez, G. Turley, M. Tsakiris, The different faces of one's self: An fMRI study into the recognition of current and past self-facial appearances. *Neuroimage* **63**, 1720–1729 (2012).
46. A. Sel, R. T. Azevedo, M. Tsakiris, Heartfelt self: Cardio-visual integration affects self-face recognition and interoceptive cortical processing. *Cereb. Cortex* **27**, 5144–5155 (2016), 10.1093/cercor/bhw296.
47. R. Azevedo, M. Tsakiris, Data for PNAS paper Re-cognizing the new self: the neurocognitive plasticity of self-processing following facial transplantation. OSF. https://osf.io/gy8fx/?view_only=69a7b59426b54aa3bd860468eb727cb8. Deposited 6 December 2022.