The Neurological Asymmetry of Self-Face Recognition

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Abstract

While the desire to uncover the neural correlates of consciousness has taken numerous

directions, self-face recognition has been a constant in attempts to isolate aspects of

self-awareness. The neuroimaging revolution of the 1990's bought about systematic

attempts to isolate the underlying neural basis self-face recognition. These studies,

including some of the first fMRI (functional Magnetic Resonance Imaging) studies,

revealed a right hemisphere bias for self-face recognition in a diverse set of regions

including the insula, the Dorsal Frontal Lobe, the Temporal Parietal Junction and Medial

Temporal Cortex. Confirmation of these data (which are correlational) was provided by

TMS (Transcranial Magnetic Stimulation) and patients in which direct inhibition or

ablation of right hemisphere regions leads to a disruption or absence of self-face

recognition. These data are consistent with a number of theories including a right

hemisphere dominance for self-awareness and/or a right hemisphere specialization for

identifying significant social relationships including to oneself.

Keywords: Symmetry; Self-Face Recognition; Right Hemisphere; Self-Awareness

Introduction

It is most commonly thought that symmetry emerged in the metazoan nervous system in a radial manner and eventually bilateralism became a prominent feature in numerous major lineages. Allowing for redundancy and parallel processing, the nervous system of tetrapods (eventuating in avians, mammals, reptiles etc...) as well as arthropods have exploited the benefits of a bilaterally symmetrical nervous system for hundreds of millions of years. The majority of animals species routinely employed (and continue in extant species) independent mechanisms of neural processing allowed by symmetry, both radial and bilateral.

The human brain is no exception. The first impression of the human brain as noted as far back as the Greeks are the two distinct hemispheres. Except in rare cases of severe abnormal development, a human at any stage post-second trimester will anatomically have two distinctly visible hemispheres. These anatomical differences have given rise to functional differences, scientifically noted by Broca, Wernecke, and others in the late 1800's. While many claims are exaggerated such as females being more lateralized due to a more massive corpus callosum, many functional differences are real including language, motor function, sensoriperception, vision etc…
In terms of higher-order cognition, both verbal production and reception as well as non-verbal production and reception appear to largely lateralized with verbal predominantly in the left hemisphere and non-verbal in the right. While not an absolute, mental processing in humans appears to achieve parallel processing as the previous example demonstrates such that verbal an non-verbal stimuli can be processed simultaneously by the different hemispheres.

Research concerning left and right hemisphere differences in the brain appears to trend from 'too simplistic' to 'explains everything'. While Roger Sperry's Nobel Prize in 1981 seemed to cement the legitimacy of exploring hemispheric differences, the popular press has run with mythical notions such as people being 'right- or left-brained'. Here we present a brief, measured, scientific investigation of hemispheric differences in self-face recognition.

The History of Self-Face Recognition: Measuring Self-Awareness

Questions concerning self-awareness have been posed by almost all humans, including scientists, for millennia. From the ancient Greek scholars all the way through Gallup's mirror self-recognition tests in the 1970's, to today's modern brain imaging techniques, self-awareness has always been an intriguing topic to study and investigate.

Greek philosophers including Socrates (b. 470 B.C.E.) believed that introspection was necessary for humans to be truly cognizant and pure. Plato (b. ca. 428 B.C.E.) took this concept of self even further and stated that introspection was a human obligation and that knowledge of "good" and "self" were needed in order to be honorable and principled. Importantly, Aristotle (b. 384 B.C.E.) took a comparative approach to look at differences between self-awareness in humans and nonhuman animals through studying cognitive intelligence. He concluded that both humans and animals had basic functions, such as sight, smell, taste, etc., but *pure* intellect was only found in humans, which made a large distinction between humans and animals. Additionally, Aristotle was one of the first to attempt to create a relationship between the self, soul, and body.

Most famously, the French mathematician René Descartes (b. 1596) took the study of consciousness further as he is often considered the first neuroscientists that attempted to localize the self. Many of his ideas are still commonly bantered about today such as "*Cogito, ergo sum*" ("I think, therefore I am"), which speculated that the self can exist because it can think of its own existence. Outside of just defining the self, Descartes attempted to actually locate the self in the brain. Although his determination of self in the brain as being located in the pineal gland (due to its centralized position in the brain) was ultimately wrong, his comparative look at humans and animals had a lasting influence. Unlike Aristotle, Descartes believed that animals are intelligent, but did not have a soul or self. He found that animals do not use language, behave on impulses, and are not adaptable, so they cannot have a self.

The Ancient Greek philosophers and Descartes laid the groundwork for formalizing scientific investigations of the self under the umbrella of psychology. Most famously, Sigmund Freud explained the deep, buried unconscious mind by using the self while simultaneously explaining the self. Carl Jung believed that there were many common selves which people shared to some degrees. Jean Piaget believed that children refine their self through assimilation and childhood experiences, which in turn are a key role to growing into adulthood. Many philosophers (including Locke, Sartre, Hegel, and Hume) and psychologists (e.g., Seligman, Beck, and Kohler) examined relationships between self-awareness and cognition.

It is noted that many individuals were addressing self/other distinctions as other sciences came into their own. In the 18th century, Carolus Linnaeus, a Swedish botanist, created a binomial classification system for living organisms. While it is known

that many of his taxonomic names are still used today such as kingdom, order, species, etc. but we note here that one important classification was grouping humans along with other animals such as monkeys, apes, and bats as primates. Linnaeus remembered a Greek inscription, "*Nosce te ipsum*" ("Know thyself"), above the Temple of Apollo at Delphi, from which he assumed that the distinction between humans and other primates is the capability for self-recognition and self-knowledge. Therefore, he categorized humans into *Homo sapiens*, wise men, since he believed that self-awareness was the highest form of uniquely human intelligence.

Up until this time, the self was quite an abstract concept with little concrete evidence but that slowly changed when the mirror was seen as a tool to be used to measure cognitive abilities and self-awareness. In 1828, J. Grant was the first person to our knowledge to use a mirror for a self-recognition study. The study found that monkeys had a surprised reaction when looking at mirror glass, but orangutans had no emotional response to looking at the glass. The exact reaction of the orangutans was not recorded, just the lack of reaction, which was unfortunate, but enough of a reaction to record considering the monkey's strong reaction to the mirror (Grant, 1828). Soon after, Charles Darwin was one of the first to suggest using mirror recognition as a measure of higher cognitive abilities. His first recorded mirror test in 1840 examined the behavior of orangutans presented with a mirror, in which he recorded and later published in 1876, that the orangutans would look at the mirror as if they were seeing another animal (Darwin, 1876). This led to Darwin's conclusion that self-recognition was not an ability of non-human animals. Additionally, Darwin studied his 10 children as they

grew up, starting in 1839, and did mirror tests with them. His conclusions were that self-awareness and self-knowing were tied to the ability to self-recongize (Darwin, 1877).

In 1878 Maximillian Schmidt reported similar findings to Grant and Darwin (that orangutans did not have a self-reaction to a mirror but seemed to understand the reflective properties of the mirror). Schmidt noted that the orangutan was able to identify a human reflection in the mirror that was standing nearby (Schmidt, 1878). These findings were the norm in many studies performed around this time with non-human mirror tests. Another study done by J. von Fischer observed monkeys and baboons in front of a mirror and, once again, a negative mirror self-recognition result was reported.

Not too long after in 1889, Wilhelm Preyer, a German researcher, was able to define a definite sign of self through the use of mirrors. He studied how using only language would be an inadequate use to describe the self in children due to the lack of vocabulary, not the lack of understanding the "I," or ego. He created timelines using mirror recognition, language, and other time measures, such as shadow recognition, to pinpoint a child's timeline of self recognition. Through this, Preyer was able to confirm the use of mirrors for self-recognition tests due to his orderly, thorough reports. Although Preyer did not specifically work with apes, he did record nonhuman animal reactions compared to the human reactions (Preyer, 1889). Unfortunately, most mirror self-recognition researchers did not communicate together at the time so many went unnoticed causing a dip in the study of mirror tests for self-recognition.

Outside the occasional mirror test on monkeys, orangutans, and chimpanzees, most mirror self-recognition slowed down, until 1929 when Robert and Ada Yerkes who found strong results suggesting no self interest in mirrors by the nonhuman primates,

once again seeing a reaction as if the animal were seeing another animal in the mirror and not itself (Yerkes & Yerkes, 1930). Following this, mirror tests were done rarely and without any true lineage of experiments to follow. In 1940, C. W. Huntley also performed a little known experiment, which recorded human participants having a large emotional reaction to the realization that the recorded voice played back, hand pictures, and handwriting were indeed their own (Huntley 1940). Arnold Gesell, a Yale child developmentalist, studied similar theories in the early to mid 20th century as Piaget and Preyer and studied many self indicators of how a child's timeline develops these indicators (Gesell & Ilg 1943). Unfortunately lack of expansion on these previous theories with mirror tests led Gesell's reports to fall through the cracks.In the 1940s, Jacques Lacan suggested that the formation of the self and mirror recognition were correlated. But due to lack of mirror experimentation, his research was overlooked. In 1954, in a paper for the journal *Human Biology,* a photograph of a chimpanzee named Vicki using a mirror to guide pliers over her teeth was taken, but the authors, Keith and Catherine Hayes, did not discuss this relevance (that there was evidence that a *non-human had self-recognition*)and it went unrecognized (Hayes & Hayes, 1954).

Gallup's Mirror Self-Recognition Test

The lull of interest in mirror tests finally changed abruptly in 1970 (Gallup) when Gallup published research of a nonhuman animal positive mirror self-recognition test. Gallup's mirror and mark test combined many previous ideas about self-recognition and in the article he commented that there is likely a connection between self-recognition and self-knowing. By creating a test that measured a real physical trait along with a well

thought out process that eliminated random chance, Gallup made a solid argument for

self-recognition in chimpanzees. However, he and others immediately picked up the

notion that self-recognition in a mirror may in fact be evidence that humans are not the

only self-aware organism on this planet.

The first test consisted of a ten day period of a mirror placed in the testing site

with the chimpanzees to allow them to acclimate with the mirror. This created a baseline

behavior of the chimpanzees which was typical mirror behavior, as seen with previous

tests where there was no significant reaction to the mirror. Then the chimpanzees were

placed under anesthesia and a small mark that was dry and odorless was placed above

the eyebrow where the chimpanzees could not see directly. After waking up from

anesthesia, the chimpanzees' behavior was observed without a mirror. It was found that

the chimpanzees did not react to their new mark (in the absence of a mirror), no

smelling or touching occured, and therefore it was concluded that they were unaware of

the mark. After this short baseline period, mirrors were placed in the chimpanzee test

site again and their reactions were observed. When seeing their reflections in the mirror,

the chimpanzees would touch and smell the mark and investigate their hands after

touching the mark. This indicated that the animals recognized that the mark had not

been there previously and that they had to use a mirror to find the mark. This test itself

was a breakthrough but Gallup conducted two more tests to confirm this conclusion.

The second test was almost identical to the first, with the exception of the initial

10 day pre-mark mirror exposure. Gallup hypothesized that without the previous mirror

exposure, the chimpanzees would not react to the mark as being odd on their face,

which proved to be true. The chimpanzees were given the mark and indeed did not

react to it in any significant manner, leading Gallup to conclude that the first group did mirror self-recognition (MSR). The third test Gallup conducted was identical to the first, but instead of chimpanzees, he used a non-ape control-monkeys. He observed their reactions pre-mark and post-mark with a mirror and the monkeys gave no sign of MSR (Gallup, 1970).

The three tests put together create a clear, concise result that chimpanzees are able to recognize themselves in the mirror. Gallup published his findings in 1970 not only discussing the test and the breakthrough results he found, but also contemplating the higher consciousness of non-human animals. Before, it was assumed humans have the highest form of intelligence and cognition and that animals have some intelligence but not necessarily a soul or self. With these findings, Gallup opened up the discussion of nonhuman animals possibly having a higher order cognitive process and internal world. With this mirror and mark test, Gallup also sparked a new way of research with the ability to test consciousness hypotheses.

Since Gallup's initial findings, the literature has swayed from conservative (only humans, chimpanzees, orangutans have self-face recognition) to today with more liberal interpretations which includes adding animals such as elephants, dolphins and magpies (Gallup & Anderson, 2018).

Non-Humans and Brain Symmetry

Unfortunately, in most of these cases, we do not have any evidence about the underlying neural components that give rise to self-face recognition in non-human animals. The notable exception is in chimpanzees where Bill Hopkins and his team examined Mirror Self-Recognizers (MSR+) vs Non-Recognizers (MSR-). Employing

diffusion tensor imaging, a lateralized MSR+ vs MSR- difference was found in the

Superior Longitudinal Fasiculus (SFL II and III which included frontal lobe areas):

> MSR was associated with greater rightward asymmetry of the SLFII
>
> white matter body and of SLFII and SLFIII's gray matter terminations
>
> within Broca's area. To disentangle the interacting contributions of sex,
>
> non-MSR contingent behaviors and neuroanatomy, we performed a
>
> regression analysis. This revealed that over and above the effects of
>
> sex and frequency of contingent behaviors, MSR was associated with
>
> greater rightward asymmetry in SLFIII's terminations in the gray matter
>
> of Broca's area (Hecht, Mahovetz, Preuss, & Hopkins, 2017).

A follow up study found that "chimpanzees. MSR+/+ apes were found to have increased

cortical thickness bilaterally in the caudal ACC and rostral (mostly right hemisphere)

ACC and thinner cortex in the central portion of the pre- and postcentral gyri (primarily

in the left hemisphere) and left rostral lateral frontal cortex compared to MSR+/− and

MSR−/− apes." (Hopkins, Latzman, Mahovetz, Li, & Roberts, 2019).

These data are too sparse to draw distinct evolutionary patterns, but they are

consistent in the rightward symmetry observed in humans. That is, it is unclear if the

neural architecture that provides MSR in non-humans is homologous to what occurs in

humans and even less clear if there is a direct evolutionary path.

On their own, these data seem to tell us little. However, taken with what we find

in humans, they data suggest that at least in chimpanzees, there are homologies rather

than analogies. That is, the same rightward bias for MSR that exists in chimpanzees also exists in humans.

Functional Imaging Indicates Right Hemisphere dominance in Self-face Recognition

In the early 1990's through today, research has examined how the brain actually allows MSR, treating it as an exceptional ability. Before neuroimaging, however, there were indicators of a possible right-hemisphere (RH) bias as disorders of RH neural structures sometimes lead to a lack of own-body recognition (Feinberg, 2001) and disorders with self-awareness deficits appeared to be similar to RH Disorder. Early attempts to determine the correlates of self-face recognition did occur by pioneers such as Prielowski (1977) who was the first to suggest a RH bias but his methods involved indirect indicators.

Some of the non-functional methods included using the WADA method in which the anterior portion of one hemisphere is anesthetized at a time. The patient remains awake and alert giving researchers the ability to isolate the activity of each hemisphere. Using self-face morphs (e.g., self morphed to Marylin Monroe) it was found that without a RH patients had significant difficulty recognizing their own-face (Keenan, Nelson, O'Connor, & Pascual-Leone, 2001; see Figure 1). Along with patient data (see below), these findings became critical in identifying RH dominance. These studies included brain differences translating in to contra-lateral hand differences in responding Keenan, Freund, Hamilton, Ganis, & Pascual-Leone, 2000; Keenan et al., 1999) .However, as is

the case in much of Cognitive Neuroscience, fMRI (functional Magnetic Resonance

Imaging) dominates the literature.

Functional MRI (fMRI) of the self-face commenced in the mid-1990s when simple

designs involved either unaltered self-faces contrasting with other faces or basic

morphs (Keenan, Wheeler, Gallup, & Pascual-Leone, 2000). Over time, the designs

became more sophisticated including examining affect (Liu et al., 2020; Oikawa et al.,

2012; Quevedo et al., 2018), psychiatric disorders (Kim, Yoon, Shin, Lee, & Kim, 2016;

Kurth, Moyse, Bahri, Salmon, & Bastin, 2015; Morita et al., 2012; Pujol et al., 2013;

Uddin et al., 2008), and family (Platek & Kemp, 2009). While there is an overwhelming

bias for RH activity in these studies, fRMI also reveals both a wide distribution of

regions as well as the notion that many variables influence how the brain processes

one's own face.

Functional MRI provides only a correlational relationship between brain activity

and behavior. By the 2000s', work was regularly appearing demonstrating a causal

relationship. That is, by disrupting regions of the RH, researchers were discovering that

MSR was not just correlated with the RH but was actually involved in a causal

relationship. The main methods employed thus far involve a version of 'virtual lesion' in

which a brain are is either temporarily taken off line or temporarily severely inhibited

(Pascual-Leone, Walsh, & Rothwell, 2000; Weissman-Fogel & Granovsky, 2019;

Ziemann, 2010). Basically, different regions of the brain are disrupted and the

subsequent changes in self-face recognition are measured which established causality.

While early attempts using TMS did distinguish the right hemisphere as being necessary for self-face recognition (Keenan, Nelson, O'Connor, & Pascual-Leone, 2001), the most elegant of these studies was provided by Lucina Uddin and her colleagues (Uddin, Molnar-Szakacs, Zaidel, & Iacoboni, 2006). She found that right parietal TMS disrupted self-face recognition whereas left parietal did not. Working in a somewhat 'backwards' manner, Uddin took these causal data and supported them (i.e., RH dominance) with correlational imaging data (Kaplan, Aziz-Zadeh, Uddin, & Iacoboni, 2008; Uddin et al., 2008).

More recent studies have found that disruption of the RH is more dramatic for those individuals with sub-clinical grandiose narcissism (Kramer et al., 2020). An even more interesting study revealed that the RH bias for self-faces may in fact be subconscious, below one even needing to identify if the face is their own. Using a mental rotation task involving either one's own-face or the face of another, Zeugin and his colleagues found that RH parietal TMS disrupted mental rotation of self-face compared to familiar faces in general (Zeugin, Notter, Knebel, & Ionta, 2020). Confirming these TMS studies, a similar technique known as tDCS (transcranial Direct Cortical Stimulation) was employed to alter the brain with self-face identification being measured. It was found that disruption of the temporo-parietal lobe in the RH disrupted self-face perception (Payne & Tsakiris, 2017).

As is often the case in neuroscience, we have to ask if we can extrapolate the data from the lab to the clinic to the 'real world'. While patient data from post-callosotomy (split-brain) surgical individuals (Keenan, Wheeler, Platek, Lardi, & Lassonde, 2003; Uddin, Rayman, & Zaidel, 2005) to those with Autism (Chakraborty &

Chakrabarti, 2015; Morita et al., 2012; Uddin et al., 2008) suggested a possible RH

bias, a more specific method for detailing potential asymmetries is need. Specifically,

we need to turn to those that lose self-face recognition in the absence of Prosopagnosia

(i.e., general face-recognition loss).

Patient Data: Delusional Misidentification Syndrome

While TMS and other neuroimaging points towards a RH bias in SFR, the data

become infinitely stronger if matched within a patient population. Losing the ability to

recognize the self is a hallmark of late-stage dementia. However, this deficit tells us little

about the locality of Self-Face Recognizers (SFR). Like prosopagnosia which is a

general face-recognition deficit, the loss of SFR as a cause of a greater cognitive

problem is not revealing. Though rare, there are in fact cases where the loss of SFR

occurs against the background of relatively stable cognitive processing.

Delusional Misidentification Syndrome (DMS) refers to circumstances in which

patients form a fixed, distorted belief regarding the identity of a person, place, or object.

These disorders include Capgras Syndrome in which a person that was once very

familiar to the patient (e.g., their husband) is now perceived as a stranger. Amazingly,

there are cases where Capgras exists *exclusively* for the self in which a patient

misidentifies him/herself as being either a stranger they have not met or a different

person. This disorder is rare and there are only a few cases in the existing literature. It

is not agreed upon yet what the naming of this disorder is, but it tends to be referred to

as "mirror-sign" or "Capgras for the self".

In the most substantive review to this point, David Roane et al. (2019) examined 24 case reports of the mirror sign. Of note is that within most of these cases, the patients were successful in correctly identifying the mirror images of *others*, signifying that they do not have a general impairment in recognition of familiar faces and they understand what a mirror does (Bauer, 1986). That is, the loss of face-recognition was exclusive to the self and not due to prosopagnosia or a lack of understanding of what a mirror does/how it functions. In terms of localization, there was a diverse range of methods employed to obtain anatomical and functional data. Of the 24 patients, nine of them had clear evidence for RH damage including the "parietal, temporoparietal, occipito-temporal, dorsolateral frontal cortex, basal ganglia, and thalamus" (Roane, 2019). Out of 24 cases detailing mirror sign, imaging was reported in 20 of them. Of the 18 MRI findings reported, 13 showed patients with mild generalized atrophy, as well as atrophy in specific regions within the right hemisphere of the brain. Further, PET and EEG findings supported right hemisphere dysfunction, displaying hypermetabolism in the right prefrontal, parietal, and occipito-temporal cortex and right temporal slowing.The significance of the RH on one's abilities of SF recognition can be observed within patients who display delusional misidentification syndromes (DMS). "[There is] increased recognition of the prevalence of DMS in association with brain disease, recent discussions have focused on neurocognitive factors such as visual perceptual impairment and right hemisphere dysfunction" (Feinberg, 1989).

In particular, a case report of the mirror image followed an elderly 77-year-old right-handed woman by the name of SP. SP was hearing impaired from a young age, and was known to have communicated through sign language and also by lip-reading

those around her. The patient's misidentification was regarded as highly selective as she was capable of readily identifying others in the mirror, though she regarded her own reflection as "the other SP", a companion of sorts. As expected, SP's lack of self-face recognition was supported upon her neurological examination; her MRI scan "demonstrated mild generalized atrophy and disproportionate right temporoparietal atrophy was apparent, as evidenced by enlargement of the right lateral ventricle and sylvian fissure… the EEG showed bilateral cerebral dysfunction with right temporal slowing " (Feinberg, 2001).

The authors conclude that the association of right hemisphere involvement is consistent with previous work linking self-recognition to the right prefrontal and right frontoparietal cortex (Keenan, 2000). Overall, the most common findings include "generalized or localized atrophy on MRI, ventricular dilatation on CT scan, and slowing on EEG" (Roane, 2019).

Why does this make sense?

Given the RH is biased for self-faces, the question remains why. Most suggest that the RH has a specialization for social processing, though this ability is not exclusive to the LH. Rather, the right hemisphere (specifically the right Temporal-Parietal Junction) appears to need to distinguish itself from others not just in terms of physical attributes but cognitive ones as well. In fact, it is now well established that the right TPJ is critical for empathy and the ability to apply one's own feelings to another.

Full treatment of the role of brain differences in self-awareness require book-length volumes. What is worth noting here is that many organisms appear to get to the

level of self-face recognition with very different brain mechanisms. Further, self-other distinguishing could be argued to be a basic life requirement (i.e, bacteria) and while self-face processing in humans may be different in what it represents in humans, it may in fact not be. We assume we have much to learn. That being said, we are convinced that along with language, other abilities appear to be enhanced by laterized placement in the human brain. Self-face-recognition is one of these.

Given the right hemisphere is biased for self-faces, the question remains "why?" Most suggest that the right hemisphere has a specialization for social processing (Chen et al., 2021; Gainotti, 2019; Hewetson, Cornwell, & Shum, 2021; O'Connell, Marsh, Edwards, Dromerick, & Seydell-Greenwald, 2021; Okubo, Ishikawa, & Kobayashi, 2013; Sinha, Dijkshoorn, Li, Manly, & Price, 2020), though this ability is not exclusive to the right hemisphere. Rather, the right hemisphere (specifically the right TPJ) appears to need to distinguish itself from others not just in terms of physical attributes but cognitive ones as well. In fact, it is now well established that the right TPJ is critical for empathy and the ability to apply one's own feelings to another (Cheng, Chen, Lin, Chou, & Decety, 2010).

Full treatment of the role of brain differences in self-awareness is beyond the scope of this article. What is worth noting here is that many organisms appear to get to the level of self-face recognition with very different brain mechanisms (Gallup & Anderson, 2018). Further, self-other distinguishing could be argued to be a basic life requirement (i.e, bacteria) and while self-face processing in humans may be different in what it represents in humans, it may in fact not be. We assume we have much to learn. That being said, most are now convinced that along with language, other abilities

appear to be enhanced by lateralized placement in the human brain. Self-face-

recognition is one of these.

Figure 1:

Numerous methods have been employed to reach the conclusion that there is a right

hemsiphere lateralization in terms of MSR/SFR. Anesthesia (A) applied to brain in

either the right or left hemispheres leads to differences in SFR. Namely, patients without

a right hemisphere see morphed images at not themselves. These data are confirmed

in patients (B; see Nuara et al., 2020) and via numerous neuroimaging methods

including TMS (C) in which disrupting the right hemisphere leads to a lack of MSR/SFR.
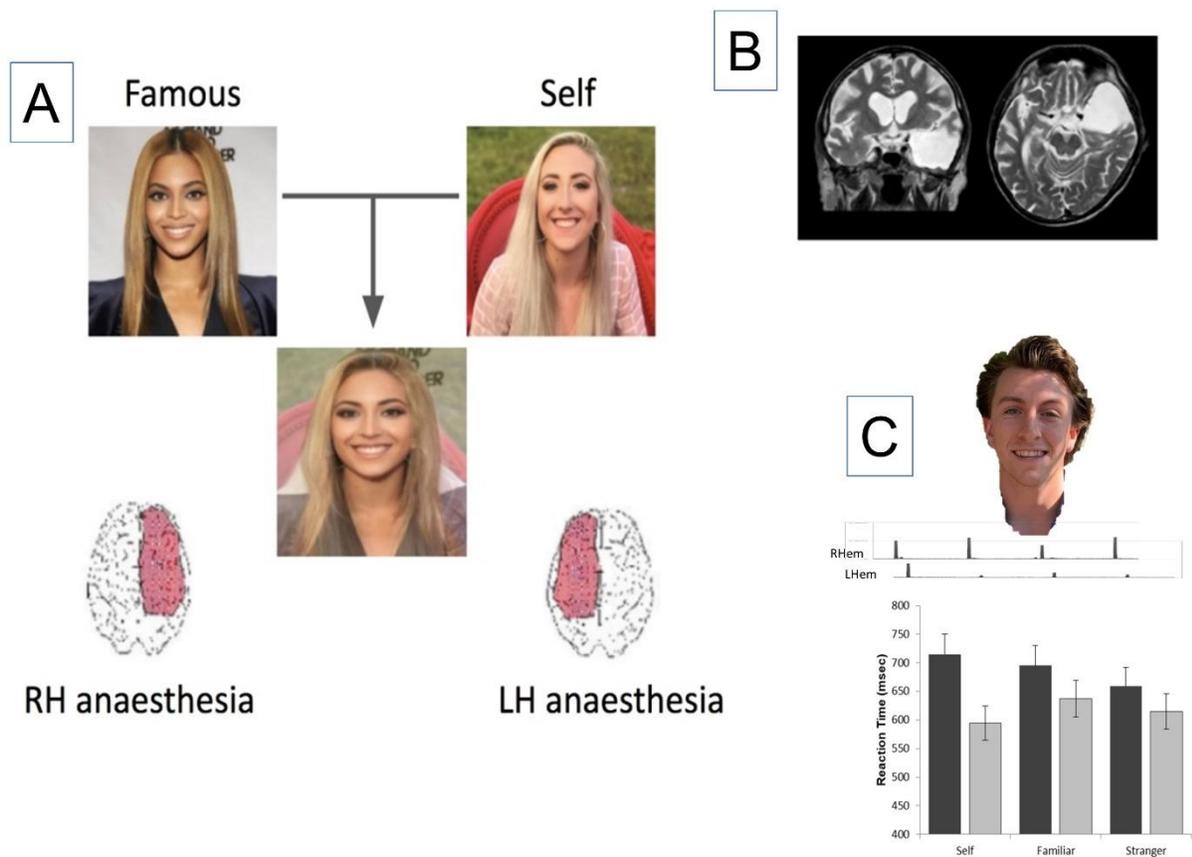
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