Research Essay

On the Role of Mirror Neurons in the Sense of Self

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Abstract

Although great progress has been made in the identification of the neural systems involved in the sense of self, very little is known about the mechanisms by which these systems give rise to this experience. This paper is an attempt to address this gap and proposes a model suggesting that the self-experience is sustained by two "mirror neuron systems" involved in the simulation of the self-face and the self-voice, both of which are implicated in self-recognition and self-concept. The proposed model is not intended to be exhaustive or complete but, rather, serves as a guiding framework that future research can test and expand upon.

Keywords: Mirror neuron, sense of self, self-experience, self-consciousness.

1. Introduction

Until recently, the phenomenon of self has been the subject of inquiry for philosophers and psychologists as well as spiritual traditions. However, with the increasing availability of functional brain imaging and other techniques, this phenomenon has become an important topic of investigation in neuroscience. In a study by Uddin et al. (2007), the authors pointed out that research findings suggest that there are two brain systems involved in the representation of self. The first is a "mirror neuron system" (MNS) that underlies the physical (or embodied) self, namely, its face and its voice. The second is a large-scale network of "cortical midline structures" (CMS) that "seem to represent a less bodily grounded self as shaped by its social relationships". These findings are in line with the philosophical and psychological literature on the self, which generally draws a distinction between two distinct but inseparable aspects of this phenomenon: the *I-self* and the *Me-self*. As described by James (1890/1950), the *I-self* is the agent of experience (the thinker); the *Me-self* is the object of experience (the thoughts). These two aspects are also highlighted by Lewis (2011) who distinguishes between what he refers to as the "machinery of self" and the "the mental state of the idea of 'me'" The same distinction is made by Gallagher & Zahavi (2015) but with different terminologies, namely, pre-reflective self-consciousness and self-consciousness. As explained by the authors, "In the most basic sense of the term, self-consciousness is not something that comes about the moment one attentively inspects or reflectively introspects one's experiences, …or refers to oneself with the use of the first-person pronoun, or constructs a self-narrative. Rather, these different kinds of self-consciousness are to be distinguished from the pre-reflective self-consciousness which is present whenever I am living through or undergoing an experience..."

The above-mentioned "mirror neuron system" was first discovered in the premotor cortex and inferior parietal lobule of macaque monkeys (di Pellegrino et al., 1992; Gallese et al., 1996), and

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later in human pre-supplementary motor cortex and hippocampus (Mukamel et al., 2010). "Mirror neurons" are active during both the performance and observation of a given action, which has led to promoting them as "motor neurons" that allow direct action understanding (see Rizzolatti et al. 2001). However, more recent reviews, such as Oztop et al. (2013), highlight the fact that "In the majority of mirror neuron literature, functions associated with a mirror system in humans are attributed to 'direct matching' or 'motor resonance' and sometimes with 'motor simulation' as a mechanism to underlie action/intention understanding…and theory of mind…without either a precise definition of such a 'mechanism' nor a clear account of how it contributes to the observed function." The review also pointed out that many of the functions attributed to the human "mirror neuron system" (such as imitation, action understanding, intention attribution and the evolution of language) are not observed in monkeys, suggesting "evolution within the mirror systems or within the wider networks of which they are part." In support of this suggestion, Corballis (2012) pointed out that "Mirror neurons are now considered part of a more extensive mirror system, involving regions in the ventral prefrontal cortex, parietal cortex, and superior temporal sulcus…", and that this mirror system overlaps extensively with the aforementioned network of "cortical midline structures".

Although great progress has been made with regard to identifying the neural systems implicated in the sense of self, there has so far been no breakthrough as to how these systems give rise to this phenomenon. Accordingly, this paper will propose a model that takes into consideration the recent findings in neuroscience, while providing at the same time a description of the mechanisms by which the aforementioned neural systems give rise to and sustain the sense of self. But it is important to note here that the proposed model does not view mirror neurons as *motor neurons* involved in *direct action understanding* (whether that action be visual or auditory), but rather as part of two "mirror neuron systems": one involved in the simulation of the self-face and the other in the simulation of the self-voice. It is these two internal simulation mechanisms which perpetuate the uninterrupted sense of self-recognition, and without which it would impossible to experience the presence of a self, as will be elaborated in the next two parts of the paper. In a study suggesting the presence of two "mirror neuron systems", Casile et al. (2011) stated that "possibly two different 'mirror' systems might underlie the development of action understanding and imitative abilities…More specifically, a possibly prewired system already present at birth but shaped by the social environment might underlie the early development of facial imitative abilities."

The role of the self-face and self-voice in self-recognition and self-concept is explored by Kaplan et al. (2008), who stated that "The Neuroimaging studies of self-recognition are also generally consistent with our data…Interestingly, they did not find a difference in activity in the IFG for viewing one's own body. It may be that the body shape is not as prominent a cue for self concept as one's face or voice." What is referred to as IFG, and which stands for inferior frontal gyrus, is a brain region associated with "mirror neurons", as indicated in this and other studies such as Kilner et al. (2009).

Before proceeding to elaborate on how the sense of self arises from the above-mentioned mirroring processes, it is worth mentioning that the model proposed in this paper encompasses two self-experiences. The first experience is that of a thinking self, the characteristics of which are fivefold: "First of all continuity: a sense of unbroken thread running through the whole fabric of our experience with the accompanying feeling of past, present and future. Second is the idea

of unity or coherence…Third is the sense of embodiment or ownership. Fourth is a sense of agency… Fifth…the self, almost by its very nature, is capable of reflection – of being aware of itself."(Ramachandran, 2004) As will be detailed in the first part of this paper, this self-experience encompasses an *I-self* generated by the internal simulation of the self-voice, and a *Me-self* that arises from the integration of the internally spoken words with the multisensory memories associated with them.

The second self-experience - mainly addressed in Eastern traditions (particularly Hinduism) and recently in New-Age spirituality (see for ex., Wilber, 1998; Tolle, 2005) – is that of a "seer" or "watcher". This experience (which, as will be described later, is driven by the mirroring of the self-face) becomes more prominent when the thinking self gets disrupted, an experience referred to in spirituality as "No-Mind" and pursued through special meditation techniques. The spiritual literature on this self-experience is quite extensive. However, for the purpose of this paper, the discussion will only focus on the mirroring process underlying it. But it may be worth mentioning here that the so-called "seer"/"watcher" has been traditionally conceived of as being a Formless Self, which, as will be seen, is not the case. For lack of a specific term, the remainder of the paper will refer to this self-experience as Self-Awareness while the other self-experience (i.e. the thinking self) will be referred to with the term Self-Consciousness (as used in the above study by Gallagher & Zahavi).

2. Self-Consciousness: The Thinker

According to Perrone-Bertolotti et al. (2014), "The little voice inside our head…plays a central role in human consciousness at the interplay of language and thought." However, despite this centrality, the inner self-voice (also referred to as "inner speech") has not received the attention it deserves. As expressed by Scott et al. (2013), "This stream of inner speech is a core aspect of our mental lives and is linked to a wide array of psychological functions. Despite this centrality, inner speech has received little scientific attention." This is attributed partly to methodological problems involved in the study of this phenomenon, as highlighted by Alderson-Day and Fernyhough (2015), who also pointed out that "Despite a growing body of knowledge…approaches to the scientific study of inner speech have remained diffuse and largely unintegrated." Accordingly, the discussion which follows will attempt to integrate the findings of different fields of neuroscience research. The aim is not to provide an exhaustive review of the literature, but rather to build up an overall picture of the mechanisms by which the inner self-voice gives rise to and sustain the continuity of Self-Consciousness.

Characteristics of the Inner Voice

In a study by Corley et al. (2011), the authors maintained that "The three experiments reported in the present paper suggest that, far from being underspecified, our 'inner voice' sounds much like our overt speech, and is produced in much the same way, whether overtly articulated or not." However, most research work in this area overlooks an important aspect of the inner voice, namely, its invariant identity. It is this characteristic which sustains the sense of self-recognition, and without which it would be impossible for one to perceive the internally spoken words as

being one's own, as evident from research on auditory voice hallucinations (AVH). An example is the study by Andreason & Pierson (2008), who suggested that AVH may result from a misidentification of the inner self-voice.

The integrated processing of one's "inner speech" with the self-voice identity seems to mirror the way the brain processes the others' speech. In a study entitled "Neural correlates of adaptation to voice identity", Schweinberger et al. (2011) stated that "Apart from speech content, the human voice also carries paralinguistic information about speaker identity." The authors added that "Our results suggest that voice identity is contrastively processed by specialized neurons in auditory cortex within ~250 ms after stimulus onset, with identity processing becoming less dependent on speech content after ~300 ms."

The research on the inner voice shows that inner signing in deaf people activates identical regions to inner speech in hearing individuals (Atkinson, 2006). According to this study, which was conducted to investigate the perceptual characteristics of voice-hallucinations in the deaf, the author found that deaf subjects "…were usually able to relay the message received, identify 'voice' ownership, and attach affective connotations." However, the author also noted that "There is greater uncertainty about the exact nature of the 'voices' reported by prelingually deaf people", and that "Research has been sparse, and to date little headway has been made in determining subjective experiences of how deaf people experience 'voices' in terms of precise perceptual characteristics."

"Inner Speech" & "Mind Wandering"

Generally, "verbal mind-wandering" refers to the self-generated thought which consumes a substantial percent of our waking hours. However, and as explained by Fox et al. (2015), the term mind-wandering "should in no way suggest that spontaneous forms of thought are *random* or *meaningless*...In fact, first-person content reports indicate that, however inexplicable its origin may seem, spontaneous thought is strongly related to one's goals, concerns, and experiences in everyday life…"

The process of "verbal mind wandering" is associated, as highlighted by Corballis (2012), with activation of both the "mirror neuron system" (MNS) and the aforementioned network of "cortical midline structures" (CMS), commonly referred to as the "default mode network" (DMN). According to several studies, the DMN is implicated in social cognition, such as Theory of Mind (i.e., the ability to attribute mental states to oneself and to others), as well as mental time-travel (which refers to the ability to mentally project oneself backward in time to re-live past experiences, or forward to pre-live possible future events); see, for example, Spreng & Grady (2010); Buckner & Carroll (2007).

The DMN was originally considered as a "task-negative" network because it is mainly activated when a person is not engaged in a specific task (often called resting-state activity). However, more recent studies indicate that: First, "the DMN may not only support a 'default' mode but may play a greater role in both internal and external tasks through flexible coupling with task-relevant brain regions." (Elton & Gao, 2015). Secondly, "verbal mind wandering", and contrary to what is commonly believed, does not occur in the resting-state only, but also, intermittently,

during periods of sustained attention (see Perrone-Bertolotti et al., 2014). Taken together, this may explain why Self-Consciousness is experienced as a "stream of thought", as described by William James, rather than a succession of "ideas".

The nature of the interaction between MNS and CMS and its role in the sense of self is highlighted by Uddin et al. (2007) who maintained that "We review evidence that suggests that … MNS is involved in understanding the multimodal embodied self (e.g. its face and its voice), whereas CMS seem to represent a less bodily grounded self as shaped by its social relationships. Interactions between these two systems are likely to be crucial to social functioning and might be compromised in conditions such as autism, where self-awareness and social cognition are impaired." It is worth mentioning here that the impairment of social cognition in autistic children is attributed to multisensory integration deficits (Curti et al., 2015) which, in turn, result from an immature DMN (Martinez-Sanchis, 2014). According to the latter study, the impairment of cross-modal integration results "in a collection of disconnected fragments instead of a coherent global perception".

The next two sections will discuss the role and function of the self-voice mirroring process (referred to hereafter as the Self-Voice Mirror) and how it creates the sense of Self-Consciousness. The term "Self-Voice Mirror" is used here to encompass two integrated systems. The first is a core mirror system involved in the simulation of the inner self-voice. The second is an extended multisensory system comprised of the "cortical midline structures" referred to as the "Default Mode Network" (DMN).

The Self-Voice Mirror

In a study indicating the presence of a "mirror neuron system" that resonates selectively in response to speech sounds (referred to as the "echo-mirror-neuron system"), Rizzolatti & Craighero (2004) maintained that "…neurons developed able to both generate the sound and discharge (resonate) in response to that sound (echo-neurons)". According to the authors, "There are two possible accounts of the functional role of the echo-neuron system. A possibility is that this system mediates only the imitation of verbal sounds. Another possibility is that the echo-neuron system mediates, in addition, speech perception…" In support of the second hypothesis, Iacoboni (2008) stated that "It is proposed that the perception of speech is enabled –at least in part – by a process that simulates speech production."

Before discussing the role of the Self-Voice Mirror, it must be emphasized that the inner self-voice is not driven by a *motor* mirroring process, as commonly believed, but an *auditory* one. This is supported by Perrone-Bertolotti et al. (2014) who stated that "Some electromyography (EMG) and neuroimaging studies are coherent with the view that 'inner speech is a kind of action', involving motor commands. An alternative interpretation, in lines with mirror system…The motor activity observed during inner speech could simply be an epiphenomenon of a sensory (auditory) processing of the inner voice."

According to the model proposed in this paper, the Self-Voice Mirror plays two distinct but complementary roles:

1) In the learning stage, this mirror facilitates the integrated processing of speech. So whereas the core mirror system allows the internal echoing of the words produced by others, the extended system integrates the sensory perceptions accompanying the learning event into a "multimodal representation". This multisensory integrative process is described by Barsalou (2008) who stated that "As an experience occurs (e.g., easing into a chair), the brain captures states across the modalities and integrates them with a multimodal representation stored in memory (e.g., how a chair looks and feels, the action of sitting, introspections of comfort and relaxation)." He added that "Later, when knowledge is needed to represent a category (e.g., chair), multimodal representations captured during experiences with its instances are reactivated to simulate how the brain represented perception, action, and introspection associated with it." It is this multisensory integrative process which provides the echoed words with meaning. This view is in line with recent research findings, such as the study by D'Angiulli et al. (2015), which found that "…for concrete and abstract words, meaning in young children depends on variably complex visualization processing in integrating visuo-auditory experiences and supramodal embodying representations.

2) In the post-learning stage, the Self-Voice Mirror begins to function the other way round (i.e. it turns to processing the sensory perceptions, including speech sounds, in association with their spoken word representations. In other words, the Self-Voice core mirror starts acting as a relay station that keeps on translating the non-conscious perceptions and irrespective of their modality (i.e. whether they are auditory, visual, somatic/tactile, etc.) in terms of the spoken words associated with them. This, in turn, activates the extended system which simulates the corresponding "multimodal representations", allowing the recognition (or knowing) of what has been non-consciously perceived. The importance of this shift in the role of the Self-Voice Mirror in the post-learning stage is that, by enabling the simulation of the spoken word representations associated with what is being perceived, this mirror allows the retrieval of the corresponding multisensory past events, which in turn facilitates the integration of the current perceptions into the existing networks of memories. This is supported by Perrone-Bertolotti et al. (2014) who stated that "…inner speech may interact with working memory in order to enhance the encoding of new material…" It is this mechanism that allows the accumulation of knowledge, without which one would be unable to interact intelligently with the world.

The next section will describe how the Self-Voice Mirror gives rise to and maintains the sense of Self-Consciousness. But before proceeding, it should be noted that, due to scarcity of research on the nature of the inner "voice" experienced by the deaf, the following discussion will be limited to describing how the Self-voice Mirror gives rise to Self-Consciousness in people using verbal communication, with the hope that future research will shed more light on how this mirror functions in deaf and deaf-blind individuals who communicate through visual and tactile (sign) languages. But it may be worth mentioning here that the cortical areas activated in deaf-blind subjects using tactile sign languages are consistent with characteristic cortical regions previously implicated with language, as highlighted by Obretenova et al. (2010).

How the Sense of Self-Consciousness Gets Constructed

As mentioned in the introduction, the phenomenon of Self-Consciousness encompasses two distinct but inseparable aspects: a pre-reflective self-consciousness or *I-self* (being the subject or knower) and a *Me-self* (being the object or the known). Based on the model presented in the

previous section, the *I-self* is sustained by the continuity of the inner self-voice, whether this voice is overtly articulated or not. This is in line with the study by Morin (2011), who stated that "Loss of inner speech following brain damage produces self-awareness deficits." Now, as previously described, the simulation of "inner speech" is followed by the simulation of the corresponding "multimodal representations", which in turn allows the recognition (or *knowing*) of what is being perceived. It is this ongoing *knowing* experience - or what James (1890/1950) refers to as the "function of knowing" - that constitutes the so-called *objective* aspect of the self (or *Me-self*). Put differently, Self-Consciousness is driven by two successive, unrelated recognition experiences that get perceived as a unitary event. The first experience is that of self-recognition, or *I-self*, generated by the uninterrupted recognition of one's incessant inner voice (i.e., the recognition of one's vocal identity). The second is that of a *Me-self* perpetuated by the continuous recognition (or *knowing*) of what is being perceived.

The Thinker and the Thoughts

When the internally spoken words are not accompanied by overt speech they become noticeable and experienced as *silent* words. Consequently, the "I" becomes perceived as being a *silent* speaker. It is *silent* speaker that we come to know and experience as the *thinker*. In other words, the *thinker* is not experienced through the internally spoken words themselves, but rather through the sense of "I" sustained by the auditory recognition of one's incessant inner voice. However, since, as mentioned in the previous section, the *I-self* is not experienced on its own but in association with the *Me-self*, one comes to perceive those two distinct experiences as one unitary event. This, in turn, creates the feeling that the *thinker* is the author (or *agent*) of the internally spoken words and the multisensory perceptual states that they stimulate, which is in fact an illusion. But if this is the case, then who or what is actually running the thinking process?

Thinking is in itself a misleading term. While it is often associated with the conscious processing of thoughts (or what is referred to as "cognition"), evidence from neuroscience research indicates that most cognitive processing occurs outside of conscious perception. An example is a study by Dehaene (2009) who maintained that "Given this wealth of evidence which indicates that subliminal processing can extend to a high cognitive level, one may reasonably ask if there are any limits to subliminal processing. Are there mental processes that can be executed only once conscious perception has occurred?"

Thus, what is referred to as "cognition" is not the result of thinking, as often thought, but rather precedes it. What we call thinking, and contrary to how it is experienced, is a delayed *knowing* process arising from the simulation of the spoken word representations and the corresponding multisensory memories associated with what would have already been non-consciously processed and perceived. Nonetheless, since we have no direct access to the actual cognitive (i.e. thought-based) processing that occurs prior to the rise of Self-Consciousness, what happens is that the internally spoken words and the accompanying multisensory perceptions become mistaken for *thoughts*. In this context, Berlin (2011) stated that "Unconscious processes appear capable of doing many things previously thought to require deliberation, intention, and conscious awareness, such as processing complex information and emotions, goal pursuit, self-regulation, and cognitive control". The author concluded saying: "This research reveals a new vision of the mind and questions traditional concepts of the self, control of action, and free will."

The Body-Self Relationship

In a study discussing the neural mechanisms of "body ownership", Petkova (2011) maintained that "…conscious qualia of body 'mineness' further relies on the activity of an extended brain network that supports self-consciousness. In addition to the multisensory visuo-somatic areas, this network would also include the mirror neuron system…" As can be inferred from this study, the body experience is driven by the same multisensory integrative process that sustains Self-Consciousness. This, in turn, demands the repetitive simulation of the spoken word representations and, subsequently, the multisensory past events associated with whatever body part or parts one might be attending to at any moment. Accordingly, what we experience as an ever-present body is not actually a continuous entity, but is rather generated by variant states of body Self-Consciousness that are constructed by the Self-Voice Mirror on a moment-to-moment basis. Nevertheless, since those states arise in association with the continuous and invariant sense of "I" maintained by this mirror, they get falsely perceived as being a unitary and continuous experience.

Taking the above into account and the fact that the "I" is not recognized for what it is, but rather gets identified with the accompanying *Me-self*, what happens then is that the body and the self become perceived as one cohesive and continuous entity. It is this illusory perception that gives rise to the sense of "body ownership" (i.e. the sense that the body belongs to *me*). The fact that "body ownership" is not as robust as it seems is confirmed by recent experiments in neuroscience where it has been possible through multisensory stimulation to induce the sense of ownership over artificial body parts, out-of-body experiences, and even the identification with another body.

3. Self-Awareness: The Watcher

As mentioned in the introduction, mirror neurons are involved in the simulation of the self-face and the self-voice, both of which are implicated in self-recognition and self-concept (Uddin et al.; Kaplan et al.). This part will discuss the "mirror neuron system" underlying the processing of the self-face, and how it gives rise to the self-experience of a "watcher" (referred to in this paper as Self-Awareness). But before doing that, a brief description is given of an event that provided me with the opportunity to observe the way this facial mirror functions, especially that the relevant literature (ex., Del Giudice et al., 2009; Casile et al., 2011; Oztop et al. et al., 2013) does not offer much insight in this regard. This event started with a panic attack that ended, unexpectedly, with the cessation of the inner self-voice and, with it, what is experienced as thinking. I suddenly found myself in a state where I was still aware of myself, but without the usual sense of body, self, or past life. Although this only lasted for a short time, its impact was profound and irreversible. What used to be a continuous flow of Self-Consciousness has been since then continuously disrupted.

Following the above-described event, I started noticing that whenever the flow of the inner self-voice was disrupted, I would see an image of my face projected in front of me. After close observation, it became evident that what this image was actually doing is a moment-by-moment simulation of my facial gestures; as if I was looking in a mirror. It was this experience that piqued my interest to find out if this biological mirror is mentioned anywhere, which led, in turn,

to the research resulting in this paper. The following discussion will begin with my observations of how the afore-described facial mirror functions (referred to hereafter as the Self-Face Mirror). This will be followed by a comparison of these observations with research findings, in an attempt to provide an explanation for this phenomenon.

The Self-Face Mirror

Despite the extensive experimental research pertaining to the study of self and consciousness, it has been difficult in many cases to verify the results that have been reached. This is because such verification depends largely on obtaining verbal reports from human subjects, which is not always possible. In an article entitled "Consciousness, accessibility, and the mesh between psychology and neuroscience", Block (2007) draws on a specific type of brain injury which causes a syndrome known as "*visuo-spatial extinction*" and whereby "If the patient sees a single object on either side, the patient can identify it, but if there are objects on both sides, the patient can identify only the one on the right and claims not to see the one on the left." However, Block gives an example of a patient with the aforementioned syndrome indentified as "G.K." who "...when G.K. claims not to see a face on the left, his fusiform face area (on the right, fed strongly by the left side of space) lights up almost as much as when he reports seeing the face..." Block comments on this by saying "Should we conclude that G.K. has face experience that – because of lack of attention – he does not know about? Or that the fusiform face area is not the whole of the core neural basis for the experience, as of a face? ... How are we to answer these questions, given that all these possibilities predict the same thing: no face report?"

Perhaps one of the most striking features of the Self-Face Mirror is its simple, but elusive, nature. So despite the crucial role that the projected self-face image plays in maintaining our sense of Self-Awareness, as will be explained later on, it goes mostly unnoticed. The reason for this is that this image has a rather transparent and, consequently, non-intrusive form that allows it to sustain a continuous presence without disrupting the flow of visual perception. But what is more elusive is the way that this transparent image is perceived. So although it is projected as a mirror-like reflection, it creates the feeling that one is looking through it and not at it. This feeling arises because the image's position does not follow the direction of the head, but rather that of the eye gaze, as described next.

What the Self-Face Mirror simply does is that it maintains the projection of the same self-face image, but with varying facial expressions that mirror the moment-to-moment expressions of the physical face, and with dynamic face positions that are simulated to match the eye gaze direction rather than the direction of the head. The self-face image described here is to be distinguished from the mental images that we often form of the self-face, such as when we try to visualize how our face looks like at a certain moment, or if we perceive it as beautiful, ugly, etc. It is, rather, an invariant representation of the self-face identity.

Now, with regard to the mirroring of facial expression, what became apparent from observation is that the Self-Face Mirror has the amazing capability to perform an online simulation of the most subtle facial movements. This, in turn, creates a continuity of transient self-face expressions, most of which do not fall into the range of what is referred to as emotional expressions (such as fear, anger, surprise, etc.). Thus, what the Self-Face Mirror seems to be

concerned with is not the mirroring of the self-face's emotions, but rather the moment-to-moment physical expressions intended to be overtly produced, regardless of their emotional or social valence. Those expressions may arise in response to internal bodily sensations, as well as external stimuli such as the exposure to bright light, noise, strong odors, and so on. In addition, the mirroring process is equally stimulated by the volitional contraction of facial muscles; as a matter of fact this is how it became possible for me to explore the way the Self-Face Mirror functions.

As a final remark, it is worth noting that the simulated self-face gestures are not experienced as a sequence of static, distinct images, but as a continuous dynamic event. This issue will be addressed later in the next section.

Non-Verbal Communication

As can be deduced from the previous observations, the Self-Face Mirror is involved in processing three aspects of the self-face, namely, its identity, its expression, and the eye gaze direction. This seems to mirror the way in which the brain processes the others' faces, as apparent from the research on face perception. An example is the study by Hoffman & Haxby (2000), who maintained that "Face perception requires representation of invariant aspects that underlie identity recognition as well as representation of changeable aspects, such as eye gaze and expression, that facilitate social communication." According to Haxby et al. (2000), "…the representation of invariant aspects is mediated more by the face-responsive region in the fusiform gyrus, whereas the representation of changeable aspects is mediated more by the face-responsive region in the superior temporal sulcus."

The role of facial expression and eye gaze in social communication is addressed by Engell & Haxby (2007) who maintained that "The perception of facial expression and gaze-direction are important aspects of non-verbal communication. Expressions communicate the internal emotional state of others while gaze-direction offers clues to their attentional focus and future intentions." According to this study, a comparison of the responses within the right superior temporal sulcus revealed that gaze-direction and expression are represented by dissociable overlapping neural systems. It is important to recall here that, as mentioned in the introduction of this paper, the superior temporal sulcus is considered part of the "mirror neuron system" (Corballis, 2012).

Based on the above findings, and taking into account that the mirroring of the self-face involves the processing of the same "invariant" and "changeable" aspects underlying the perception of another's face, it can be assumed that the Self-Face Mirror serves as a simulation mechanism that provides the visual feedback necessary for imitating the perceived gestures of others. This is in line with Casile et al., who suggest that a separate mirror system might underlie the early development of facial imitative abilities. According to the authors, this facial mirror is possibly an innate system already present at birth but shaped by the social environment. This, in turn, may explain why congenitally blind children produce at a very early age the same facial expressions as sighted children. However, in comparison to sighted children, blind children have difficulty in either fine-tuning or masking their facial expressions as they grow older (due to lack of visual access to another's facial expressions), as highlighted by several studies (ex. Wu et al., 2009).

Now, as described in the previous section, the simulated self-face gestures are not experienced as a sequence of static images, but as a continuous dynamic event. This seems, again, to mirror the way in which the others' faces are perceived, as can be inferred from the study by Schultz et al. (2012). In this study, entitled "What the Human Brain Likes About Facial Motion", the authors say that "Facial motion carries essential information about other people's emotions and intentions…In addition, facial motion can facilitate the encoding and recognition of facial identity." The study confirmed a previously suggested two-pathway model of biological processing: "a form pathway appears to analyze stimuli as discrete event snapshots, whereas a motion pathway analyzes information based on optic-flow information." According to the authors, the results "suggest that at lower frame rates, the brain processes each frame of a movie as a distinct event, yielding a percept of nonfluid motion. In contrast, when the low-level properties between successive frames are small enough and the frame rate is high enough, the successive images are successfully integrated into the percept of a single dynamic event." The authors concluded that "Such a percept can boost the encoding of information, for example, faces learned in motion are better recognized than static faces."

The "Correspondence Problem"

Although the main focus of this part is on the role of the facial mirror system in the sense of self, the previous description of how this mirror functions may contribute to the solution of what Froese et al. (2012) refer to as the "correspondence problem". As explained by the authors, the problem of "correspondence" concerns how is an agent able to match its bodily expression to the observed bodily expression of another agent when there is no possibility of external self-observation (e.g., imitation of a facial expression)? According to this study, this problem is more pronounced in neonatal facial imitation - referred to as the "strong correspondence problem" - (i.e., how can neonates "imitate arbitrary facial gestures that are unlikely to be innate reflexes" when they have never seen their own face, and have little experience of other faces?) The solution to this problem is considered by Meltzoff & Decety (2003) as the "Holy Grail" of imitation research.

The finding of facial imitation in neonates has led, according to Del Giudice et al. (2009), "to the idea that a mirror system for facial expressions might be inborn…" However, the authors raise the question of whether neonatal imitation can be considered an inborn component of a mature "mirror neuron system" (MNS) or a distinct mechanism, and suggest that "Studies investigating the neural network underpinning imitation in newborns and older children could help to address this issue". The authors concluded saying: "Either way, the existence of neonatal imitation is fully compatible with our model: we do not claim that the MNS is either fully inborn or fully acquired, but that the brain is equipped with mechanisms that facilitate the acquisition of novel visuomotor associations."

As can be discerned from the above, the phenomenon of facial imitation raises two issues. The first is that of "correspondence". The second is whether the facial mirror system is innate or acquired. These issues were indirectly addressed in the previous sections where it was shown that the facial mirror system is involved in the simulation of the self-face gestures, providing, in turn, the visual feedback necessary for matching these gestures to the observed gestures of others. In other words, the so-called "correspondence problem" is not actually a problem. It is

rather a misconception arising from the assumption that one has no direct access to one's facial gestures. As for the issue of innateness, the fact that congenitally blind children produce the same facial expressions as sighted children indicates that the production of these expressions is not dependent on observational learning (Matsumoto & Willingham, 2009), but genetically programmed. This does not mean, however, that facial expressions are fixed or unchanging. Rather, as already discussed, these expressions are modulated or fine-tuned by social interaction, which in turn is not possible without there being a mirroring mechanism already in operation. This is in line with Simpson et al. (2014), who conclude that "The interaction of genes and experience through learning can only occur if the basic neural circuitry is there to support such learning. The authors contend that mirror neurons "may provide the scaffolding for these interactions early in life, having themselves been remodeled by epigenetic processes across evolution."

To conclude this section, it would be interesting if future research investigate the ontogeny of the facial mirror system (as suggested in the above study by Del Giudice et al.), but my observations indicate that this mirror functions in adulthood as a self-perpetuating process that keeps on mirroring one's facial gestures, even in the absence of any social interaction. It is this continuous mirroring of the self-face that maintains the sense of Self-Awareness, as will be discussed next.

How the Sense of Self-Awareness Gets Constructed

In light of what has been presented so far, this section will suggest that the experience of Self-Awareness arises mainly as a result of the way the mirrored self-face is perceived. By sustaining the continuous simulation of the self-face identity, the Self-Face Mirror creates the felt presence of an invariant and continuous "I". Now since the simulated image's position follows the eye gaze direction, this gives rise to the illusory sense of looking or watching, which leads in turn to the misperception of the "I" as being the "watcher". So taking this into account, and that the time lag separating the simulation of the self-face gesture and its overt execution is not detected on the experiential level, what happens then is that the executed gesture gets misperceived as being performed by the simulated "watcher". Consequently, the "watcher" becomes experienced as being not only a self-aware subject but an intentional one as well. Now, as previously discussed, the simulated self-face gestures are not experienced as a sequence of static, distinct images, but as a continuous dynamic event. This, in turn, creates the feeling that the "watcher" is a continuous, dynamic entity.

In sum, it is suggested that Self-Awareness is driven by two experiences, the interaction of which creates the sense of a continuous and intentional "watcher". The first experience is that of an uninterrupted sense of self-recognition, or "I"-awareness, generated by the recognition of the simulated self-face image (i.e. one's facial identity). The second is a continuous *watching* experience arising from the integration between the self-face image's position and gaze direction. However, since, as described earlier, the mirrored self-face image has a transparent form that makes it go unnoticed, the "watcher" is mostly perceived as a *feeling*.

As mentioned in the introduction of this paper, the "watcher" (also called the "seer") becomes more prominent when the thinking self gets disrupted; an experience referred in Eastern spiritual traditions as "No-Mind" and pursued through special meditation practices, such as

"Mindfulness" (i.e., watching the mind or the thinker). Taking this experience into account, and that the "watcher" is mostly perceived as a *feeling*, this "watcher" has been traditionally conceived of as a Formless Self or Pure Consciousness (often referred to as the feeling "I AM"). An example is the following quote from spiritual author Tolle (2005): "The good news is that you can free yourself from your mind...Start listening to the voice in your head as often as you can...This is what I mean by 'watching the thinker'...You'll soon realize: *there* is the voice, and here *I am* listening to it, watching it."(p.15) The "I am", highlighted by the author in italics, is attributed to what he calls the "silent watcher", who is portrayed as "pure consciousness beyond form" (p.83).

4. Conclusion

Although great progress has been made in the identification of the neural systems involved in the sense of self, very little is known about the mechanisms by which these systems give rise to this phenomenon. This paper attempted to address this gap by proposing a model that takes into account the recent neuroscience findings on the self, while providing at the same time a description of the mechanisms underlying it. The proposed model does not claim to be exhaustive or complete but, rather, serves as a guiding framework that future research can test and expand upon. As suggested in this paper, the sense of self is sustained by two "mirror neuron systems". The first is a Self-Voice Mirror involved in the integrated simulation of the spoken words and the corresponding "multimodal representations" associated with what is being perceived. The second is a Self-Face Mirror involved in the simulation of one's facial gestures.

By highlighting the role that the mirror systems might play in the sense of self, it is hoped that this paper will also contribute to a better understanding of those disorders which involve either alterations or impairments in self-experience, such as schizophrenia, autism and dissociative disorders.

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