Self-face and self-voice representation: insights for and from autism

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Abstract

Ever since the different aspects of self were proposed by William James over a century ago, self-representation has remained a focus of empirical and theoretical interest. In this chapter, we focus on Jamesian 'bodily self', or physical self-representation. We describe a set of studies on the representation of self-face and self-voice, where participants were explicitly asked to label different morphed stimuli as 'self' or 'other'. Across studies in two cultures, we note that the boundary for self-other judgement is significantly different between face and voice stimuli. Beyond testing the cultural generalisability of these results, we note the impact of autism-related symptomatic variation on self-face and self-voice processing. Here too, we see a culturally generalisable pattern that demonstrates a more distinct self-representation in individuals with high autistic traits, specifically for voice stimuli. The chapter concludes by proposing two competing theoretical models to explain these findings and pointing to future directions.

Keywords: self-face, self-voice, autism, psychophysics

Introduction

Following the initial foundation laid down by James (1890) of the central awareness of being, the concept of 'self' with its multiple dimensions has been the focus of research in philosophy, psychology, and neuroscience (Gallagher, 2000; Leary & Tangney, 2011). The minimal self-awareness present at birth interacts with its environment to allow the development of perceptual, conceptual, and ethical aspects of self, much of which is defined by and related to social relations (Rochat, 2011).

The innermost core of the material 'self', as proposed by James (1890), is the physical (bodily) self. The mental representation of the physical self refers to the representation of the bodily features and their spatial relationship to each other (Blakemore, Frith, & Wolpert, 1999; Prinz, 2013). Investigation of physical self-representation has primarily focussed on recognition of the physical self through external representations, i.e. mirror-images, video recordings and still photographs (Amsterdam, 1972; Brédart, Delchambre, & Laureys, 2006; Devue et al., 2009; Keenan, Gallup, & Falk, 2003; Keenan et al., 2000; Kircher et al., 2001; Nielsen & Dissanayake, 2004; Pannese & Hirsch, 2011; Platek et al., 2008; Sugiura et al., 2000; Sui, Zhu, & Han, 2006; Uddin et al., 2005). To detect an external stimulus as 'self', the external stimulus is compared to the mental representation of the physical self, thereby engaging the physical self-representation.

The visual recognition of physical self is often the study of self-awareness of 'me' or the objective self-awareness instead of "I" or the subjective experience of self. For example, one can misidentify an image wrongly as self ('this is me'); however, one cannot misidentify the self-thought generated in the process ('I think this is me') (Gallagher, 2000). Investigating objective self-awareness allows studying the misidentification of physical 'self' to understand self-related cognition in typical and atypical populations. While the awareness of what is 'I' does not allow for misidentification; the study of self often involves self as an object or a cause of action, as it is challenging to carry out experimental manipulation or measurement of the subjective self-experience. In addition to the studies of visual self-recognition, the physical self is often studied as the agency that causes actions (Blakemore & Frith, 2003; Decety et al., 1994; Fourneret & Jeannerod, 1998; Jeannerod, 2003).

Self-face: A marker of physical self-representation

There is an internal representation of body schema in the brain. While elements of this internal representation might be present from birth, a fully developed representation of the physical self is built through sensory experience and proprioceptive feedback (Jeannerod, 2003). The development of the awareness of the physical self as a unique object is believed to be a precursor to higher-order self-awareness (Rochat, 2011). Developmentally, the most common method of investigating physical-self representation is the self-face recognition in the mirror (mirror self-recognition; MSR; Anderson, 1984; Gallup, 1982; Gallup Jr, 1983).

In developmental studies of self-awareness, MSR is the ability of a child to detect a mark on their face using a mirror. MSR emerges in the 18–24-month period of typical development (Brooks-Gunn & Lewis, 1984). The onset of MSR coincides with preferential looking towards self-image, indicating that MSR is a reliable measure of the development of salience of the ‘self’ as an entity (Nielsen & Dissanayake, 2004). The underlying cognitive processes involved in MSR include kinaesthetic-visual matching and understanding of mirror correspondence (Mitchell, 1993). Looking at the mirror reflection of self leads to attention allocation to self-image, and this attention to self is theorised to lead to introspection and awareness of one’s mind (Lewis & Ramsay, 2004).

MSR is also associated with the emergence of pretend play and personal pronouns, which are aspects of self-representation essential for developing general self-awareness and theory of mind (Lewis & Ramsay, 2004). This has led to the theory that physical self-recognition in general, and MSR, in particular, is closely linked with the development of psychological self-representation and higher-order self-awareness (Gallup, 1998; Lewis, 2012; Lewis & Ramsay, 2004). Examination of the physical self in a mirror provides a helpful mechanism to analyse how one appears in the eyes of others and can provide a clearer picture of self-image, augmenting the internal abstract representation of the self (Prinz, 2013). Thus, mirrors are important cultural tools that help build self-representation. The capacity to self-evaluate through mirrors provides a basis for development of the self's physical and psychological domains.

Self-face recognition studies using the serial presentation of self and other faces have routinely found a self-face advantage as indexed by faster reaction time and higher accuracy (Keenan et al., 1999; Tong & Nakayama, 1999). These early results have been largely supported by a meta-analysis of behavioural studies demonstrating a quick recognition of self-faces in western cultures, irrespective of the head angle of stimuli, laterality (i.e. hand with which the participant performs the task), as well as familiarity with or identity of 'other faces' (Bortolon and Raffard, 2018). Interestingly, the initial studies demonstrating self-face advantage in accuracy and reaction time had demonstrated a right hemispheric dominance for self-face recognition (Keenan et al., 1999).

The right hemispheric involvement in self-face recognition has also been demonstrated by functional neuroimaging. A meta-analysis of functional neuroimaging studies showed that self-face recognition has a dominant right-hemispheric involvement along with a bilaterally distributed network (Platek et al., 2008). An event-related fMRI study showed activation of the right hemisphere 'frontoparietal' mirror network (inferior parietal lobule, inferior frontal gyrus, and inferior occipital gyrus) when labelling a morphed face as 'self' from self-familiar face morphs (Uddin et al., 2005). The right hemispheric bias in self-face recognition has also gained support from clinical studies (Keenan et al., 2003; Uddin, 2011a). In a split-brain patient, lateralized visual presentation (to contralateral visual hemifield) of self and other faces resulted in the highest skin conductance (indicating physiological arousal) in response to self-face when self-face was presented in the left visual hemifield indicating right hemisphere dominance (Preilowski, 1979). In a patient with complete callosotomy, there was a higher percentage of correct searches for self-face for left-handed responses indicating right hemisphere involvement (Keenan et al., 2003).

In summary, evidence from neuroimaging and clinical studies suggest a right hemisphere bias for self-face processing, while the behavioural evidence for the laterality of responding remains inconclusive. One potential explanation for this observed right hemisphere bias can be the stronger affective response that is often associated with recognition of a visual stimulus as oneself (e.g., this is me!) than the recognition of neutral objects (e.g., this is a table). A series of earlier studies have suggested a right hemisphere bias for processing affect from facial stimuli (Innes et al., 2016; Bourne, 2010).

Studies investigating the cross-modal interaction of physical self in the visual and auditory modalities have reported both facilitation and inhibition in one sensory modality when presented with self-primes in other sensory modalities (Hughes & Nicholson, 2010; Platek, Thomson, & Gallup, 2004). In an event-related potential (ERP) study, reduced P300 amplitude, an index of attention, was observed for self-voice compared to other voices indicating fewer attentional resources to recognising self-voice. Reduced attention to self-voice may indicate self-voice may not act as a salient stimulus in relation to self (Graux et al., 2015). In a self-other recognition study using morphed auditory stimuli, participants required lower levels of self-related information to stop categorising a voice morph as a famous voice using their left hand than right hand (Rosa et al., 2008). At a neural level, the right inferior frontal gyrus, previously shown to be active in response to self-face recognition, was also activated in recognition of self-voice (Kaplan et al., 2008). There is hence some neural evidence from studies of both self-face and self-voice recognition to suggest a right hemispheric bias.

Behavioural psychophysics studies provide a complementary set of quantifiable insights into self-face and voice representation. Quantitative representation of the self through measurement of psychophysical variables that change as a function of stimulus features allows one to draw conclusions on the subjective self-other boundary. In typical such paradigms, two different faces or voices (example, self and unfamiliar voice) are morphed together in different percentages, ranging from 100% self to 100% other. The percentage of trials judged as self for each morph level generates a self-response curve, to which a logistic function is fit. There are two metrics of interest from this curve. First is the point of subjective equality (PSE), which corresponds to the point at which the participant is equally likely to respond 'self' or 'other' to a given stimulus morph. This point corresponds to a category shift in response (self or other). The second parameter of interest is the slope of this self-response curve, which provides an estimate of the change in responses as a function of stimulus characteristics. PSE provides a point estimate, whereas slope provides a measure of the distribution and how distinct this self-related distribution is from the other-related distribution.

In the following sections, we summarise a few studies using the psychophysics approach described above to probe physical self-representation using face and voice stimuli. We test the cultural generalisability, as well as the impact of autism-related variation on these metrics of self-representation.

Self-recognition across sensory domains

The concept of ‘bodily-self ’or ‘physical-self’ is fundamental to the development of self-awareness and enables the distinction of self from others. The conceptual understanding of the physical self and the physical self-representation in the brain emerge early in development. Theoretical and experimental accounts of the development of self-awareness hold physical self-recognition as a precursor to general self-awareness (Bertenthal & Fischer, 1978; Gallup, 1982; Lewis, 2012). Self-awareness, in turn, shares underlying processes with mental state attribution and recognition of emotional states in others - aspects of behaviour that allow for introspection, leading to the development of metallising or theory of mind (Bird & Viding, 2014; Keenan et al., 2003; Keenan et al., 2003; Lombardo et al., 2010).

Consequently, the investigation of physical self-representation is fundamental to understanding the architecture of social behaviour, most forms of which require a distinction between self and others. While the mirror self-recognition (MSR) test has been a primary vehicle for testing physical self-representation in young children, most studies investigating physical self-representation in adults have used self-face recognition paradigm (Keenan et al., 1999; Kircher et al., 2001; Uddin et al., 2005). Understandably, this focus on the visual representation of the physical self reflects on the universal human ability to recognise self-face from mirror-reflection and photographs. Typically in such paradigms, prototypes of self and other faces are presented in a random serial order (Brady et al., 2004; Keenan et al., 2003; Keenan et al., 1999) as well as self-other face-morph continua (Keenan et al., 2000). However, there has been little or no investigation of psychophysical properties of self-face and self-voice recognition or their relationship with each other.

Considering that the sensory perception and representation of the physical self is the underlying basis of higher-order self-representation, we conducted a set of studies in a white western European sample investigating physical self-representation across visual and auditory modalities. We used self-other morphs in both visual (face) and auditory (voice) modalities for this investigation, through manipulating the extent of physical self-related information presented in each sensory modality. We measured self-recognition responses for morphed faces and voices in white European young adult neurotypical participants. Participants took part in a 2-alternative forced-choice (self/other) experiment where they were presented with one morphed stimulus at a time. Their 'self' responses were recorded, and a logistic function fitted to estimate the psychometric function. (See Fig. 1 and Chakraborty & Chakrabarti, 2015 for further methodological details).

The PSE for self and other differed significantly as a function of sensory modality (Fig. 2). Individuals shift the category from 'self' to 'other' at higher levels of other-related information in self-other face morphs compared to self-other voice morphs. One possible reason for this observation is that visual self-representation allows for more flexibility, possibly due to the generally greater familiarity for self-face than self-voice. We can draw further support from the observation that self-face recognition, in general, has greater accuracy than self-voice recognition (Hughes & Nicholson, 2010). Several studies have shown that personal identity is more accessible from faces than voices (Ellis, Jones, & Mosdell, 1997; Hanley, Smith, & Hadfield, 1998; Joassin et al., 2004). Accuracy and reliability of self-voice recognition increase with exposure to the recordings of self-voice, as in the cases of radio presenters and professional recording artists (Holzman et al., 1966). There is also increasing familiarity with the recordings of one's voice through voice messages, voice mails, and other media in the current social world.

However, the observed difference in self-representation in the visual and auditory modalities may also result from the perceptual differences in self-face and self-voice processing. Perceptually, self-voice representation is qualitatively different from that of self-face representation. The pictorial representation of the self-face is similar in visual features to the mirror reflection of the self-face, which is the most familiar exteroceptive self-face stimulus. This allows the assumption that typical individuals can reliably and accurately recognise the pictorial representation of the self-face. Self-voice, however, differs in the way it is perceived when it is self-generated compared to when it is recorded. This is primarily because the self-generated voice is conducted through both air and bone, whereas the recorded self-voice is perceived through air conduction alone. This phenomenon results in the somewhat different perceptual experience of listening to recordings of self-voice compared to when self-voice is perceived during the speech (Holzman, Rousey, & Snyder, 1966).

Interestingly, we did not observe any correlation between the slope of the psychometric function for self-recognition response in the auditory and visual domains, i.e. individuals with a narrower overlap of representation of self-other faces (or a more distinct self-face representation) do not have a corresponding narrow overlap between self and other voice. Implications of this finding are discussed in the final section of this chapter.

Self-representation is a dynamic and multi-level construct; it is continuously under the influence of different contextual factors of which culture is a significant contributor (Han & Northoff, 2008; Markus & Kitayama, 1991; Markus & Kitayama, 2010). Most previous work on cultural factors influencing the self-concept has focussed on the psychological self-construct (Harter, 2012). In contrast to these seminal studies, we chose to investigate the impact of culture on physical self-representation. To this end, we replicated the study described above in a group of young adults in India to test the cultural generalisability of our findings.

Cultural generalisability of self-face and self-voice recognition

Self-construal is an individual-level index of self-representation and comprises independent and interdependent selves. Independent self-construal represents the self as a unique entity with goals and aims separate from close others and the broader community. Interdependent self-construal defines a more elaborate self–schema inclusive of close others and community members with the purpose to integrate individual values and goals with the collective goals. The independent and interdependent self–schemas coexist in most individuals, but the dominant baseline self is either independent or interdependent. There is a close link between the independent and interdependent selves and the levels of individualist-collectivist cultural values (Cross, Bacon & Morris, 2000; Cross, Hardin, & Gercek-Swing, 2011).

In recent years, there is increasing awareness of the *WEIRD (Western, Educated, Industrialized, Rich, and liberal Democratic countries/regions)* issue in psychology/neuroscience where most of the participants are drawn from these populations (Arnett, 2008; NASEM, 2018, p. 317; see also Henrich, Heine, & Norenzayan, 2010; Rad, Martingano, & Ginges, 2018). Findings from the WEIRD samples arguably are unrepresentative of the varied socio-cultural contexts of our world. It is therefore critical that cognitive neuroscience and psychology research (and researchers) actively investigate samples from different cultural settings. Research into the 'self' is one such area that has taken some steps in researching self-representation in different cultural contexts. However, more extensive work remains to be done (See Oyserman et al., 2002 for meta-analysis).

Studies investigating self-processing have shown that the majority of WEIRD populations and East Asians (mainly Chinese, Japanese and Korean populations) often present markedly different self-construal (Hofstede, 1980; Markus & Kitayama, 1991; Triandis, 1989). While the majority of WEIRD populations exhibit a dominant independent self-construal, East Asians primarily exhibit an interdependent self-construal and often have a more collectivist focus (Hofstede, 1980; Triandis, 1989). This difference in self-construal affiliation links to differences in cognitive processing styles as well as social behaviour between cultures at both behavioural (Lin, Lin, & Han, 2008; Oyserman & Lee, 2008) and neural levels (Cheon, Mathur, & Chiao, 2010; Chiao et al., 2010; Han & Northoff, 2008). The individualistic and collectivistic values of the Indian population lie in between those of East Asians and American Europeans. For example, compared to Hong Kong and China, India has been found to have more individualistic values but compared to German and American individualism, Indian individualism scores lower (Oyserman et al., 2002, p 15, Table. 2).

While cultural differences in the self-construal discussed above relate to psychological aspects of the self, their impact on physical self-representation is less well known. External sensory signals and proprioceptive feedback help build the physical self-representation and create the embodied physical entity that constitutes body ownership. A previous study on cultural differences in exteroceptive self-awareness has shown that individuals from different cultural affiliations process external bodily features differently (Maister & Tsakiris, 2014). Self-face recognition and viewing can activate a greater level of self-awareness in western participants compared to East Asian participants (Sui, Liu, Wang, & Han, 2009), which was attributed to higher levels of self-focus in westerners. A recent meta-analysis of behavioural studies of self-face recognition supported this finding by demonstrating a significant reaction time advantage for self faces in western cultures, but not in eastern cultures (primarily East Asian) (Bortolon & Raffard, 2018).

Body image is the mental image we hold of our body, and this construct influences how we assess and relate to others within a social environment (Jung & Lee, 2006). Individuals who value physical appearance to a greater level also develop more elaborate self-schema for appearance. Negative physical self-perception is also related to low self-esteem and a higher incidence of depression and anxiety, varying across cultures (Bohne et al., 2002; Jung & Lee, 2006). Notably, most of these previous studies have primarily examined the emotional appraisal of physical self-representations (e.g., through attractiveness ratings) rather than its psychophysical parameters.

Considering the suggestive cultural influence on self-representation, we investigated the psychophysical properties of physical self-representation in a culture where it has not been widely studied t (India). Using an identical self-other morphing paradigm to the one described in the previous section on a sample of young adults, we tested a) the physical self-representation across visual and auditory modalities through the measurement of self-recognition and b) the relationship (if any) in self-other representation between visual and auditory modalities. Like the western European sample, we found that the self-other boundary varies significantly as a function of sensory modality (Fig. 2). The category boundary from 'self' to 'other' was at a significantly higher morph level (containing higher other-related information) for visual self-recognition than auditory self-recognition.

Additionally, there was no association between the slope of the psychometric function for faces and voices in this sample. Notwithstanding the involvement of putatively common brain regions such as the inferior frontal gyrus (IFG) in both self-face and self-voice processing (Kaplan et al., 2008), this result suggests that self-related signals processing and consequent representations in the different sensory modalities might be sufficiently distinct. The results reported above replicated those obtained from the western European sample, thus demonstrating cultural generalisability.

While culture represents one primary potential source of variance, psychopathology represents another primary source of individual differences. To this end, autism occupies a unique niche in the study of self. The word autism derives from the Greek word 'autos', meaning self. Bleuler first used the term 'autism' in the early 20th century to describe symptoms in schizophrenia where individuals demonstrated atypical patterns of self-absorption. Leo Kanner first used the term to describe children in his clinic who exhibited social detachment with heightened self-focus (Kanner, 1943). In an independent description, Asperger (1944) defined 'extreme egocentrism' in specific individuals. Atypical self-representation in autism has been suggested to be related to the challenges in social behaviour involving self and others experienced by many individuals on the spectrum. For example, autistic adults with the greatest extent of social impairments in early childhood showed the least self-other distinction in the ventromedial prefrontal cortex during a mentalizing task (Lombardo et al., 2010).

Individuals with autism[1] often exhibit a deficit in lab-based tasks of monitoring self-related intention during social exchanges that depend on theory of mind, introspection and self-referential processes (Keysers & Gazzola, 2007; Lewis, 2012; Meltzoff & Brooks, 2001; Chiu et al., 2008; Frith & Frith, 2008; Lyons & Fitzgerald, 2013, Lombardo & Baron-Cohen, 2010). In the following section, we present findings from studies investigating individual differences in physical self-representation in association with autistic symptoms in the general and a clinically diagnosed autistic population.

The impact of autistic symptoms on self-face and self-voice recognition

Autism (interchangeably used with Autism Spectrum Condition (ASC) in the text) is a neurodevelopmental disorder with a complex and heterogeneous symptom profile. It is commonly characterised using two sets of features: one set comprising atypicalities in social and communicative behaviour and another set comprising a restricted range of interests and

[1] We use person-first and identity-first language interchangeably to discuss research findings to appropriately reflect the diversity views within the autism community. We also use the terms 'autism' and 'Autism Spectrum Conditions' interchangeably.

repetitive behaviour (American Psychiatric Association, 2013). No single causal biological phenomenon can fully explain the different domains of impairment observed in autism (Happé, Ronald, & Plomin, 2006). The different symptoms observed in autism show low correlations between themselves, indicating the separable underlying dimensions of the autistic phenotype (Ronald et al., 2006).

The observation of group differences in the understanding of the self-concept in ASC has led to the 'absent self' hypothesis (Baron-Cohen, 2005; Frith & De Vignemont, 2005; Frith & Happé, 1999; Lombardo & Baron-Cohen, 2010; Lombardo et al., 2010). Here, 'absent self' does not refer to a lack of self in autistic individuals but instead refers to the differences in specific aspects of self-awareness observed in autism, e.g., the reduced distinction between self and others. Self-other overlaps and self-other discrimination in the physical domain are vital processes involved in social functioning (Bird & Viding, 2014; Lombardo & Baron-Cohen, 2010). Key processes of social behaviour such as emotional contagion (Hatfield, Cacioppo, & Rapson, 1994; Laird et al., 1994), action imitation (Rizzolatti, Fogassi, & Gallese, 2001) and empathy (Decety& Jackson, 2006) are believed to be achieved through self-other interactions in the physical domain (Meltzoff & Brooks, 2001), all of which shows some form of disruption in ASC (Lombardo et al., 2007; Williams, 2010; Williams, Whiten, & Singh, 2004).

In the domain of physical self-representation, MSR paradigms have yielded conflicting reports in autism, possibly resulting from heterogeneity in symptom severity. In children, one study observed that the degree of speech and communication impairment in autistic children could predict impaired visual self-recognition in MSR (Spiker & Ricks, 1984). The study argued that developmental delay in visual self-recognition mirrors developmental delay in language functions in autism. However, there is a contrasting report of intact MSR and a preference for mirror reflection compared to a taped video of self in autistic children (Neuman & Hill, 1978). Another study of MSR reported a perfect performance in mirror self-recognition for typically developing children compared to fifty-five per cent in autistic children (Carmody & Lewis, 2012). Notably, and like every other phenotypic assay in autism, atypical self-recognition is not seen to the same extent across all autistic children (Dunphy-Lelii & Wellman, 2012; Lind & Bowler, 2009).

In neurotypical adults, event-related potential responses to self-face and self-name (as well as close, famous, and unfamiliar conditions) show significant positive responses at 300ms (P300) for self-face/self-name than other conditions (Cygan et al., 2014). However, autistic participants showed comparable P300 responses for self and close other conditions, indicating that when compared to close others, ‘self’-related information is not preferentially attended to by autistic individuals. This evidence has been interpreted to suggest a reduced distinction between self and close others in autism. The same study also observed reduced lateralized responses (the right hemisphere advantage) in the self-face condition in individuals with autism, indicating a possible lack of self-face advantage at the neural level (Cygan et al., 2014).

However, there are not many studies characterising physical self-representation in adults with ASC. An early fMRI study that used a morphed self-other face paradigm to investigate self-other face processing in autistic children found a lack of self-other distinction in the physical domain like that observed in the psychological domain (Uddin et al., 2008). While differences in brain activation to self versus other faces were more pronounced in non-autistic than autistic children, no behavioural differences in reaction time were found between the two groups.

While the studies mentioned above tend to use a case-control design, there is growing recognition that autistic symptoms exist in a continuum. Those who have a clinical diagnosis of autism represent an end of this distribution (Baron-Cohen et al., 2001). Different self-report (or caregiver-report) questionnaires have been developed to capture the dimensional features of autism, such as the Autism Spectrum Quotient (AQ) (Baron-Cohen et al., 2001), Social Responsiveness Scale (SRS) (Constantino & Gruber, 2007), Autism Spectrum Screening Questionnaire (ASSQ) (Ehlers, Gillberg, & Wing, 1999), Childhood Autism Rating Questionnaire (CARS) (Schopler, Reichler, & Renner, 2002) and the modified Checklist for Autism in Toddlers (CHAT) (Robins, Fein, Barton, & Green, 2001). Individuals scoring thirty-two or higher on the AQ scale have an eighty per cent or higher chance of ASC diagnosis (Baron-Cohen et al., 2001). Measuring autistic traits in the general population allows one to estimate associations between trait features and experimental manipulations, providing the initial foundation for undertaking follow-up investigation with the clinically diagnosed tail of the autism distribution (Robinson et al., 2014).

To this end, we collected AQ data in both the studies described in the previous sections. We sought to test if individual differences in autistic traits were associated with self-face or self-voice representation differences. In both the studies, we found that individuals with higher autistic traits were associated with a steeper slope of the psychometric function. In other words, individuals with higher autistic traits showed a more distinct self-representation (or a narrower self-other overlap) in the auditory modality (Fig. 3). We did not observe any associations between self-face representation and autistic traits in either of the two cultures (Fig. 3). These culturally replicated results indicate that individuals high in autistic traits may have a 'narrower' physical self-representation. This narrow physical self-representation can be interpreted such that any deviation from it is perceived to be an 'other', which might limit flexibility and make it difficult to simulate others.

However, as the relationship between autistic traits and narrower physical self-representation was only seen for self-voice and not for self-face, there might be an alternative explanation based on the sensory characteristics of self-face and self-voice stimuli. In contrast to faces, our familiarity with our voices as it sounds to others is usually lower. We hear our voices through bone conduction, which sounds different from recorded self-voice that we hear through air conduction. Previous reports have suggested that individuals focus on the grammar, syntax, and psychological characteristics of other speakers, while they focus on the tonal qualities when hearing their own voices (Holzman et al., 1966). The nature of the voice stimuli in our experiments was also devoid of any semantic information, a feature that makes recognition of self-voice further pitch dependent. The tonal qualities of a voice are more pitch dependent, and higher abilities in pitch discrimination have been reported in ASC (Bonnel et al., 2003). It is, therefore, possible that the enhanced perceptual functioning in the auditory domain, often seen in autistic individuals, may underlie the better recognition of self in the auditory domain by individuals with high autistic traits.

Since both studies described above were on neurotypical adults, we sought to formally test whether this pattern of data was seen in individuals with a clinical diagnosis of autism. Accordingly, we tested a sample of 68 autistic and non-autistic adults in the UK. We used the same paradigm for self-face and self-voice recognition as described earlier.

In line with earlier studies using this paradigm, we found no difference in self-other category shift with face stimuli but noted a significant difference for voice stimuli (Fig. 4). The non-autistic control group showed a significantly higher PSE for self-face compared to self-voice, replicating our previous findings (Chakraborty & Chakrabarti, 2015). Interestingly, the autism group did not show any significant difference in PSE between the two sensory modalities. A case-control comparison revealed a significant difference in PSE for self and other voices between autistic and non-autistic participants.

Autistic participants switched from self-voice to other-voice category at morph levels closer to the self-voice end of the self-other morph continuum compared to the controls. Autistic individuals required less other-related information in the morphed voice to switch from self to other categories than neurotypical adults. As evident from the above results, this observation may be driven by a superior ability in autistic individuals to discriminate between self-other voice morphs and is similar to previous results with autistic traits where individuals with higher autistic traits showed a more distinct self-voice representation.

Discussion

The preceding paragraphs discuss a few key results from our studies of physical self-representation using self-face and self-voice recognition paradigms. Additionally, we discuss the role of individual variation in autism-related symptoms and cultural generalisability of these results. Across cultural settings, these findings show that individuals can incorporate significantly more 'other'-related information before labelling a given visual stimulus as an 'other'. In contrast, individuals tolerate far less 'other'-related information in voice stimuli, before labelling the stimulus as that of another person. Additionally, these representations of the physical self in visual and auditory modalities appear sufficiently distinct, and unrelated to each other. We also note that autism-related symptoms were positively correlated with self-voice representation but not with the self-face representation; individuals with high autistic traits had a more distinct self-voice representation.

Based on the studies discussed above and other related studies, two alternative models for perceptual processing of physical self-related stimuli and evoking physical self-representation are presented below (Fig.5). One of these models (A) is hierarchical, involving supra-modal self-representation, while the other (B) is a non-hierarchical network model. According to model A, specific sensory systems within the brain process self-related stimuli (for example, self-face or self-voice) and relay information to a supramodal brain region[2]. If this region is sufficiently activated, it recognises the incoming information as belonging to the 'self' irrespective of the nature of the sensory channel that feeds into it.

In its hierarchical nature, model A is like the hierarchical predictive coding model for self-processing that has been proposed (Apps and Tsakiris, 2014). Model B in contrast, does away with the need for a supra-modal self-representation neurally. In this model, self-representation in each modality is represented by a node in a flat, fully connected causal network. Activating any node in this network automatically primes the other nodes, leading to increases in the signal-to-noise ratio for self-recognition in other sensory modalities.

Both of these models are able to explain observations related to cross-modal self-priming. An early study showed that cross-modal priming with self-odour and self-voice led to the facilitation of self-face recognition (Platek, Thomson, & Gallup, 2004). In model A, self-odor/voice primes would lead to the activation of a supramodal region, which in turn would increase the signal-to-noise ratio for the other sensory modalities. Model B would explain such observations similarly, without the need for a separate, supramodal self-representation. As such, model B is the more parsimonious of the two, and better according to the principle of Occam's razor.

[2] For simplicity, we use the singular 'region' to describe the model. We recognise that such a supramodal role can be performed by a set of coactivated brain regions.

The empirical results discussed earlier in this chapter showed no relationship between self-representation in the visual and auditory modality. If model A were true and a common self-representation existed neurally, one could potentially predict that self-representation across modalities will be related to each other. This was not found, providing some support for a more distributed non-hierarchical account of self-representation, like model B. It is worth noting though that such a distributed account does not rule out the overlap of brain regions involved in self-representation in two different modalities. Indeed, regions such as the inferior frontal gyrus have been shown to be involved in processing of both self-face and self-voice (Kaplan et al., 2008). Model B is also in line with previous theoretical accounts of modular or non-unitary nature of self-representations (Gillihan & Farah, 2005; Neisser, 1988; Williams, 2010).

The insight from the studies discussed above also show that the observed differences in self-representation in relation to autistic traits is specific to a sensory modality. If such differences were underpinned by a supramodal self-representation, then similar results would have been expected in both self-face and self-voice recognition paradigms. Higher autistic traits were associated with more distinct self-representation in voice stimuli, both in the UK and in India. Individuals with ASD might have enhanced pitch discrimination abilities (Bonnel et al., 2003). Enhanced perceptual abilities in the auditory domain likely drive the distinct representation of voices for individuals high in autistic traits.

However, to further investigate if self-voice is more distinctly represented in individuals with higher autistic traits due to better pitch discrimination abilities, future studies should use familiar voices as additional conditions. Identification of familiar identities from voices has been found to depend on aspects of the vocal features which are less dependent on low-level perceptual features; it could be hypothesised that the distinct representation of self-voice for individuals with high autistic traits may not generalise to other familiar voices (Hughes & Nicholson, 2010).

One study investigating self-face recognition in autism using functional neuroimaging found similar activation levels for self-face in the right inferior frontal gyrus in ASC and control participants (Uddin et al., 2008). In another study using eye tracking, we found that gaze fixation to faces was inversely related to autistic traits, irrespective of self or other faces (Chakraborty & Chakrabarti, 2018). Both results argue against any specific deficit or difference in self-face representation in autism. The evidence for a supramodal self-processing deficit in autism is low, further highlighting the utility of model B. Modality-specific differences in self representation can also lead to differences in self-priming effects in autism, through atypical neural connectivity (Vissers et al., 2012).

In sum, this chapter has discussed physical self-representation through self-face and self-voice stimuli in two cultures. Autistic symptoms were found to be associated with self-voice representation but not self-face representation in both cultures. It also presents two potential theoretical models of self-representation, that future studies should attempt to disambiguate experimentally.

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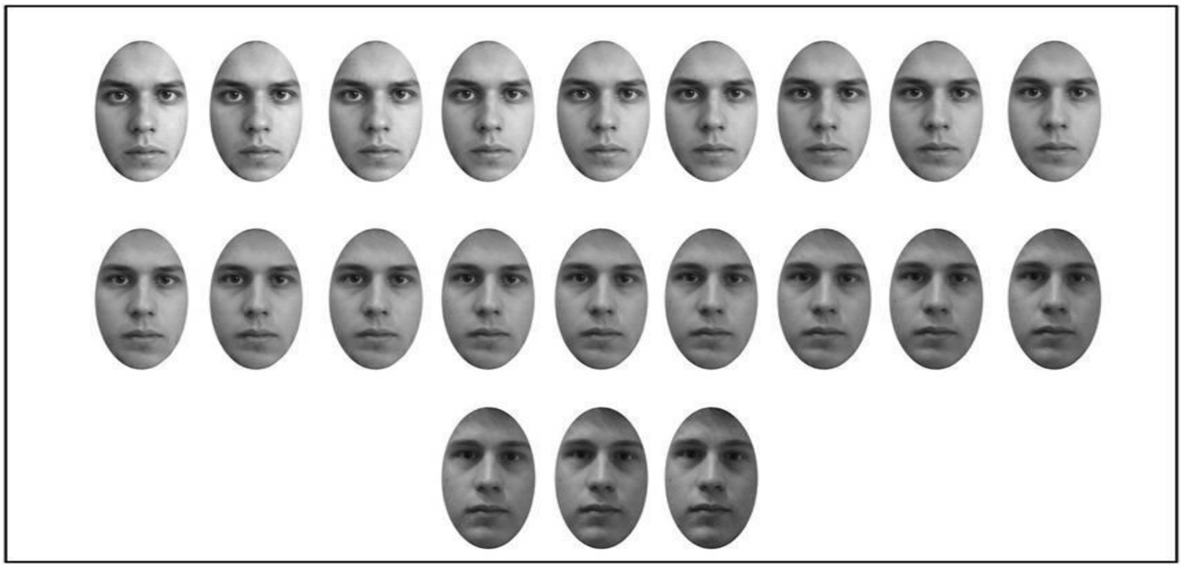


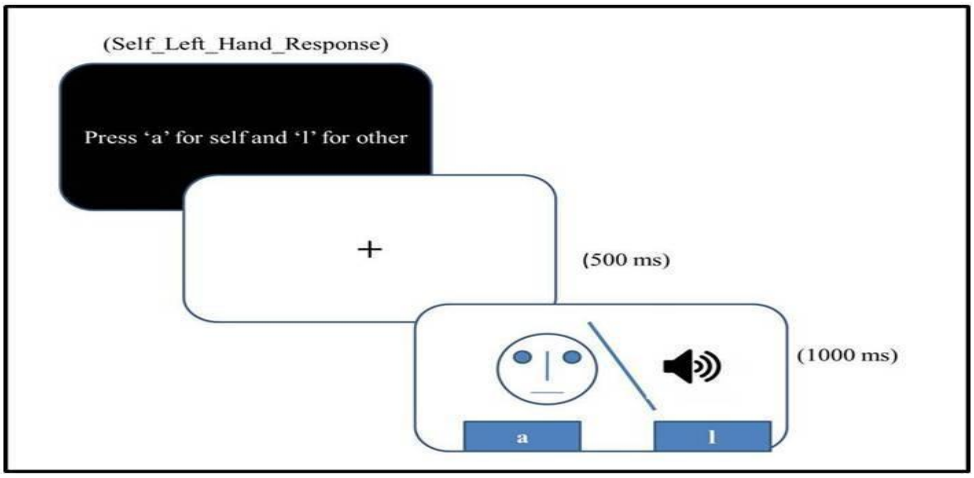


Figure 1. The upper panel shows a prototype stimulus set representing face morphs at a 5% step size, from 100% self-face to 100% other-face. The lower panel shows the schematic representation of the task design and an example trial of the face/voice block.

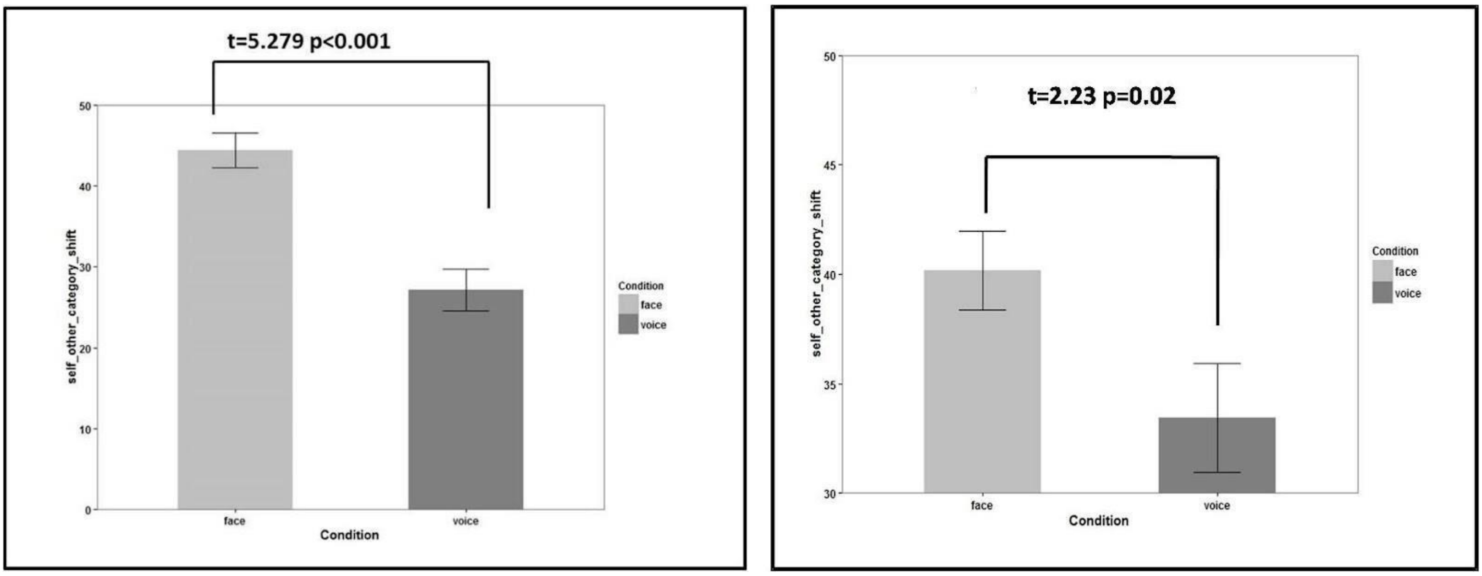
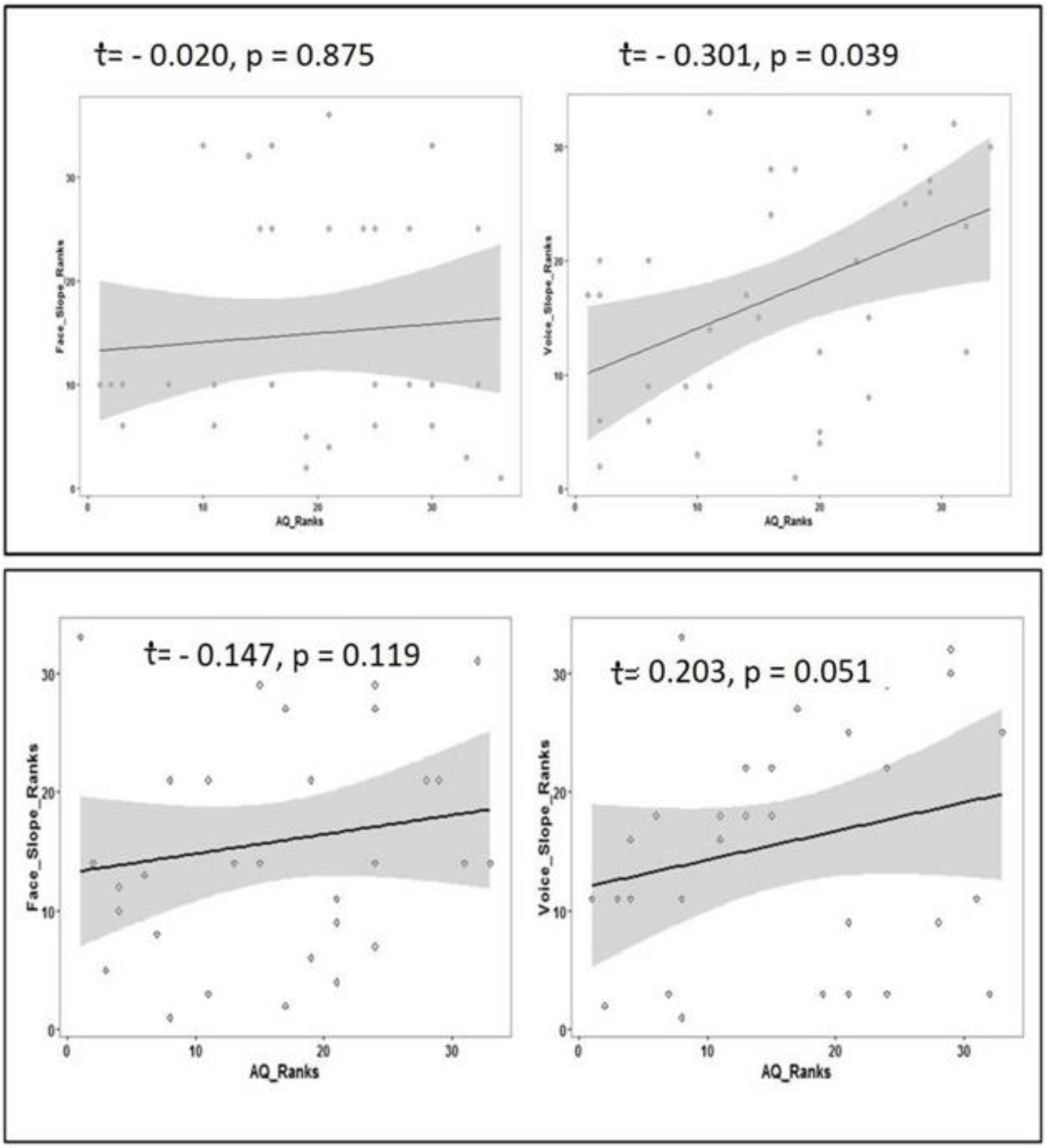


Figure 2. The left-hand panel shows the result from the UK sample, and the right-hand panel shows the result from the India sample. The charts represent the PSE for self and other identification with face and voice stimuli (mean ± SEM).

Figure 3. The upper panel shows results from the UK sample and the bottom panel shows results from the India sample. The left-hand side of both panels represents rank scatterplots of the slope for *self-face recognition* (y-axis) and AQ scores (x-axis). The right hand side of both panels represents rank scatterplots of the slope for *self-voice recognition* (y-



axis) and AQ scores (x-axis). The shaded portion represents the 95% confidence interval for the slope of the regression line.

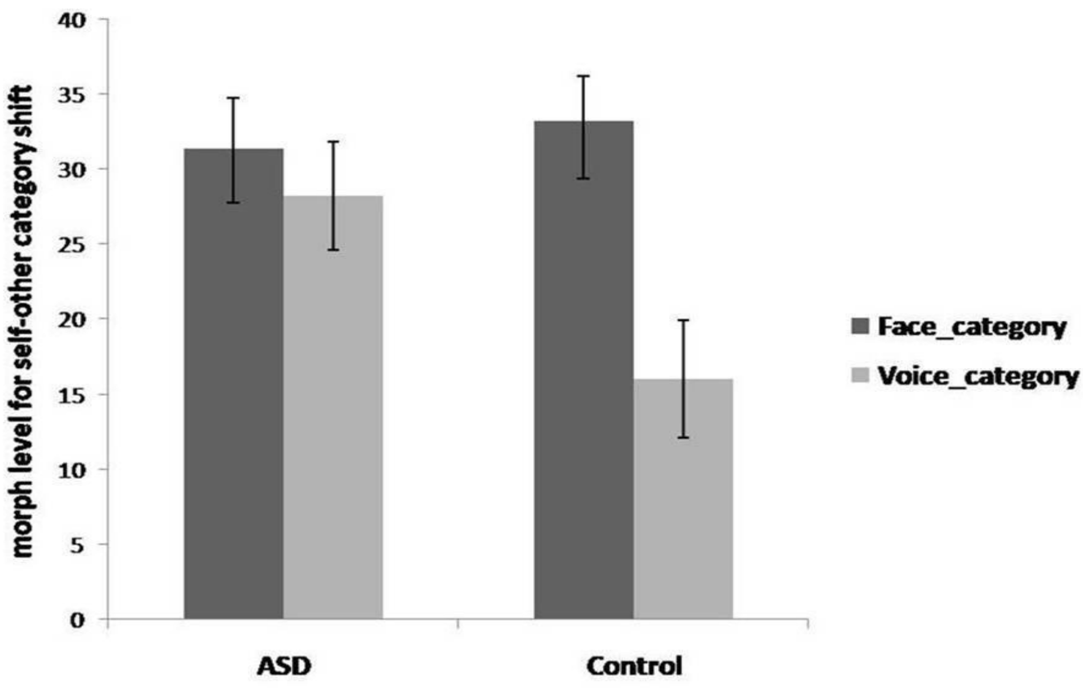


Figure 4. Mean PSE (± SEM) for self vs other identification for face and voice stimuli in autistic and non-autistic young adults.

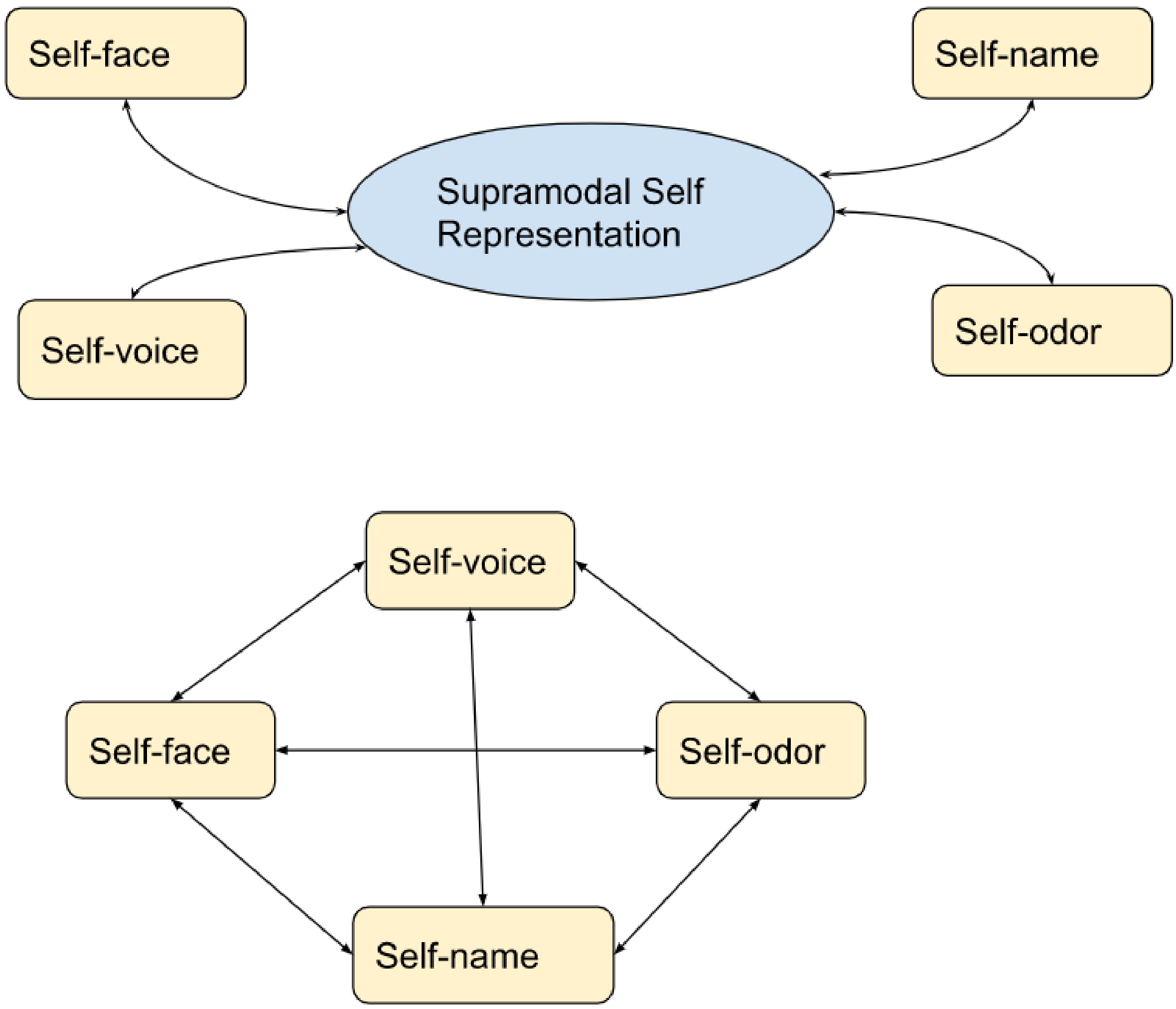


Figure 5

Upper panel:

Model 1: A supramodal self-representation is activated when any self-related information from any sensory modality is processed (e.g., self-face or self-voice). This representation, in turn, increases the signal-to-noise ratio for self-recognition in any of the other sensory modalities.

Lower panel:

Model 2: Self-representation in each modality is represented by a node in a fully connected flat causal network. Activating any node in this network automatically primes the other nodes, which can lead to increases in the signal-to-noise ratio for self-recognition in other sensory modalities.