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Lost for emotion words: What motor and limbic brain activity reveals about autism and semantic theory

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ABSTRACT

Autism spectrum conditions (ASC) are characterised by deficits in understanding and expressing emotions and are frequently accompanied by alexithymia, a difficulty in understanding and expressing emotion words. Words are differentially represented in the brain according to their semantic category and these difficulties in ASC predict reduced activation to emotion-related words in limbic structures crucial for affective processing. Semantic theories view 'emotion actions' as critical for learning the semantic relationship between a word and the emotion it describes, such that emotion words typically activate the cortical motor systems involved in expressing emotion actions such as facial expressions. As ASC are also characterised by motor deficits and atypical brain structure and function in these regions, motor structures would also be expected to show reduced activation during emotion-semantic processing. Here we used event-related fMRI to compare passive processing of emotion words in comparison to abstract verbs and animal names in typically-developing controls and individuals with ASC. Relatively reduced brain activation in ASC for emotion words, but not matched control words, was found in motor areas and cingulate cortex specifically. The degree of activation evoked by emotion words in the motor system was also associated with the extent of autistic traits as revealed by the Autism Spectrum Quotient. We suggest that hypoactivation of motor and limbic regions for emotion-word processing may underlie difficulties in processing emotional language in ASC. The role that sensorimotor systems and their connections might play in the affective and social-communication difficulties in ASC is discussed.

Introduction

Inherent in Kanner's first description of autism as a 'disturbance of affective contact' (Kanner, 1943), the domain of emotion has been cardinal throughout the history of autism research. Disturbances in the affective domain may help to explain why individuals with autism spectrum conditions (ASC) have difficulty in connecting, socializing, communicating, and understanding the hidden mental world of others that drives much of social behaviour (Baron-Cohen, 1995). A recent, methodologically rigorous meta-analysis of the emotion recognition literature in autism suggests that a pervasive deficit exists (Uljarevic and Hamilton, 2013), extending to understanding emotions in vocal cues and nonverbal gestures (Braverman et al., 1989; Hobson, 1986a, b; Rutherford et al., 2002; Golan et al., 2007; Humphreys et al., 2007; Philip et al., 2010). In terms of emotional expression, studies in autism also indicate lower responsivity to emotional displays of others (Sigman et al., 1992; Kasari et al., 1993), a lack of spontaneous mimicry of others' facial expressions (McIntosh et al., 2006; Beall et al., 2008; Oberman et al., 2009), and attenuated physiological response to emotional expressions, pain and distress in others (Corona et al., 1998; Ben Shalom et al., 2006; Bölte et al., 2008; Minio-Paluello et al., 2009). Vocalisations and facial expressions of affect in autism are characteristically flat or neutral (Snow et al., 1987; Yirmiya et al., 1989; Capps et al. 1993), and may be inappropriately disconnected from the social context in which they appear (Neuman and Hill, 1978; Dawson and McKissick, 1984; Hobson et al., 2006). Finally, difficulty in

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identifying and describing emotions verbally, known as alexithymia, is much more prevalent in people with ASC (Lombardo et al., 2007; Hill et al., 2004) and their parents (Szatmari et al., 2008). In summary, it seems that individuals with ASC are atypical in how they express emotions in comparison to typically-developing peers and that, likewise, their perception and mirroring of emotions are reduced, if not impaired.

This pattern of emotion expression and perception deficits is one component of the difficulty in mentalising, the ability to represent one's own emotional states and thought processes and those of others (Happé, 1994; Baron-Cohen, 1995; Lombardo et al., 2007; Silani et al., 2008; White et al., 2009; Lombardo and Baron-Cohen, 2011). In this sense, deficits in self-referential processing may alter an individual's ability to use the self as a proxy for simulating the mental lives of others. A deficit in representation and/or recognition of one's own emotions would impair attempts to accurately simulate others via oneself (Lombardo and Baron-Cohen, 2011).

The more generalized role of simulation in mental operations is increasingly recognised in the field of cognitive neuroscience, where Barsalou (2008) names it "a core form of computation in the brain" (pp. 618–619). A proposal which has recently gained speed with much empirical support is that self-performed actions (including those involved in emotional expression) and the perceptual consequences of the same lead to linked action–perception representations that are later used in cognitive processing and social interaction (Pulvermüller, 2013). In action cognition, for example, researchers have suggested that action goals are simulated in the motor systems of observers in order to understand the intentions underlying actions, such as whether or not the actor intends to eat the object (Cattaneo et al., 2007). In the context of the mirror neuron theory, these joint action–perception circuits, consisting of these self-same sensorimotor neurons with visual and/or auditory properties, have been found underactive in autism (Williams et al., 2001; Cattaneo et al., 2007; Rizzolatti and Fabbri-Destro, 2010; Moseley et al., 2013a).

Given that alexithymia in autism is a *linguistic* deficit in processing the emotions of self and others, this implies that there is atypical processing of words semantically related to emotions. Prior work in autism suggests that these individuals do indeed show difficulty in understanding and using emotional and cognitive mental state terms (such as "dread", "thought": see Hobson & Lee, 1987; Capps et al., 1992; Tager-Flusberg, 1992; Baron-Cohen et al., 1994, Baron-Cohen et al., 1986; Happé, 1994; Tager-Flusberg and Sullivan, 1994, 1995; Jolliffe and Baron-Cohen, 1999) as well as an inability to link mental state terms to emotional information present in features of the eyes (Baron-Cohen et al., 1997, 2001a). The neural correlates of this deficit are, however, unknown. In the present study we used event-related fMRI to investigate brain systems activated when people with ASC process abstract emotion words. Our hypotheses about atypical cortical emotion word processing focused on two key areas.

In typically developing (TD) individuals, the meaning of action and emotion words and concepts seems to involve the cortical motor system (Pulvermüller and Fadiga, 2010; Moseley et al., 2012). Our prior work has shown that individuals with autism show hypoactivity of cortical motor systems when they process action words and concepts (Moseley et al., 2013a), and this is consistent with atypical structure of the motor cortex (Mostofsky et al., 2007) and movement impairments in ASC (see Fournier et al., 2010, for review). The motor regions unexpectedly inactive during action word processing in ASC were the same as those found particularly active when TD individuals processed abstract emotion words (Moseley et al., 2012). Theoretically, this 'motor embodiment' of emotion words suggests that the link between an emotion word and the emotional state it expresses depends on emotion expression in action (Wittgenstein, 1953; Pulvermüller, 2012, 2013). In early language acquisition, emotion expression by infants provides a natural context for teaching emotion words and, therefore, the motor and limbic regions for emotion expression may be woven into the semantic representations of abstract emotion-related words. As TMS and work in brain-damaged patients shows that somatosensory and motor regions along with limbic emotion processing areas in insular cortex are necessary for the perception of emotion-related information immanent to the face (Pitcher et al., 2008; Adolphs et al., 2000), and these same areas are also active in emotion word processing (Moseley et al., 2012; Vigliocco et al., 2013), we hypothesised that these cortical motor and limbic systems would be affected in autism during emotion word processing and might reflect the degree of autistic traits in ASC.

An additional hypothesis focuses on limbic areas involved in emotion processing (Calder et al., 2001). A range of these regions, including orbitofrontal and frontopolar cortex, anterior cingulate gyrus, insula, and basal ganglia (putamen, caudate, and globus pallidum), are involved in emotion *word* processing (for review see Moseley et al., 2012; Vigliocco et al., 2013). Because these regions are specifically activated by *emotion-related* language, this subset of limbic areas, along with motor systems, provides a putative cortical basis for 'simulation' of word meaning and affective semantics more generally. It has been suggested that, at the neurobiological level, strong emotional-affective associations of emotion words are mechanistically organised as 'limbic tails' of cortical cell assemblies reaching into subcortical structures of the limbic system (Pulvermüller and Schumann, 1994). Since, in addition to the aforementioned abnormalities of cortical motor systems, people with ASC also show atypical activity and structure in many of these limbic regions (Raymond et al., 1995; Bauman and Kemper, 1994; Haznedar et al., 1997, 2000; Aylward et al., 1999; Howard et al., 2000; Ohnishi et al., 2000; Salmond et al., 2003; Barnea-Goraly et al., 2004; Schumann et al., 2004; Schumann and Amaral, 2006; Girgis et al., 2007; Bonilha et al., 2008; Cheung et al., 2009; McAlonan et al., 2009; Pugliese et al., 2009; Uddin and Menon, 2009) we predict additional hypo-activity in limbic systems when people with ASC process emotion-related words.

In summary, activation of motor and limbic areas during abstract emotion word processing seen in TD individuals may be atypical in ASC, partly due to their deficits in emotion processing and thus limbic activation, and to deficits in emotion expression and thus motor system activity. Whereas limbic hypoactivation might be predicted by the common emotion processing deficits in ASC, the additional prediction of motor hypoactivity in emotion word processing rests on the semantic link between emotion words and motor systems (Moseley et al., 2012). If the semantic link between an emotion and the word denoting it is via emotion expression in motor behaviour, the motor difficulties reported in ASC imply that this link will be atypical even during single word reading and comprehension, a task unrelated to overt emotion processing. Therefore, if words denoting abstract emotional states draw on cortical motor and limbic regions during processing, atypical functioning may be apparent in both of these regions when individuals with ASC simply read these words. In comparison with words denoting animals or abstract verbs, neither of which are especially linked with motor or limbic regions, we predicted that individuals with ASC would show a category-specific atypical pattern during emotion word processing that should be specific to the motor and limbic areas that are atypical in ASC and associated with emotion word processing in typical controls.

Materials and methods

Participants

Right-handed, native English-speaking participants comprising 18 high-functioning adults with an ASC (mean age: 30.4 years [standard deviation (SD): 10]; mean IQ: 113.5 [SD: 23]) and 18 age- and IQ-matched TD controls (mean age: 28.6 years [SD: 11.7]; mean IQ: 110.2 [SD: 12.3]). Data from TD participants were previously published in Moseley et al. (2012); here, a new and independent analysis compares these participants and individuals with ASC who were recruited from the volunteer database at www.autismresearchcentre.

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