

Social neuroscience in psychiatry: unravelling the neural mechanisms of social dysfunction

A.-K. J. Fett^{1,2*}, S. S. Shergill² and L. Krabbendam^{1,2}

¹Department of Educational Neuroscience & Research Institute LEARN!, Faculty of Psychology and Education, VU University Amsterdam, Van der Boechorststraat 1, Amsterdam, The Netherlands

²Department of Psychosis Studies, Institute of Psychiatry, King's College London, De Crespigny Park, London, UK

Social neuroscience is a flourishing, interdisciplinary field that investigates the underlying biological processes of social cognition and behaviour. The recent application of social neuroscience to psychiatric research advances our understanding of various psychiatric illnesses that are characterized by impairments in social cognition and social functioning. In addition, the upcoming line of social neuroscience research provides new techniques to design and evaluate treatment interventions that are aimed at improving patients' social lives. This review provides a contemporary overview of social neuroscience in psychiatry. We draw together the major findings about the neural mechanisms of social cognitive processes directed at understanding others and social interactions in psychiatric illnesses and discuss their implications for future research and clinical practice.

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Introduction

Human beings choose to exist in social environments that necessitate countless social interactions on a daily basis. Although these interactions are routine for most people, the social world we live in is highly complex and navigating it successfully requires a set of sophisticated skills. The importance of these skills becomes most obvious when they go awry. This is evident in the phenomenology of various psychiatric disorders and reflected in their diagnostic criteria in the DSM-V (APA, 2013). Autism spectrum disorders (ASD), for example, are characterized by a lack of social or emotional reciprocity and an inability to regulate social interactions. Difficulties in interpersonal relations, social dysfunction and isolation accompany schizophrenia (SZ) and anti-social personality disorder/psychopathy (hereafter PP) is associated with aggressive or deceitful behaviour and a failure to conform to social norms. Obviously, this list is not exclusive and other disorders such as social anxiety disorder, borderline personality disorder and disorders without primary social diagnostic criteria also impact on the ability to engage in social interactions.

There is growing evidence that difficulties in social interactions and poor functional outcomes in patients suffering mental health disorders are underpinned by deficits in social cognitive information processing and that these deficits are also important factors in the instantiation and maintenance of other illness symptoms (Dodge, 1993; Burns, 2006; Fett *et al.* 2011; Roepke *et al.* 2013). The increasing acknowledgement of the functional and therapeutic significance of social cognition has led to an increased interest in its neurobiological mechanisms (Adolphs, 1999, 2003, 2006; Anckarsäter, 2006; Neuhaus *et al.* 2010; Herpertz, 2013). Social neuroscience has evolved to take an interdisciplinary approach to unravel these mechanisms (Cacioppo & Berntson, 1992). Its methods are broad and include techniques from social psychology, anthropology, neuroeconomics, cognitive neuroscience and classical neuropsychology; the application of neurobiological techniques [e.g. functional magnetic resonance imaging (fMRI), positron emission tomography, transcranial magnetic stimulation (TMS) and electroencephalography]; the assessment of bio-signals, such as eye movements; endocrinology, immunology, and animal models. While social neuroscience has employed many ways to investigate the biological substrate of social cognition and functioning, this review will focus on investigations of human social brain mechanisms with fMRI.

Since social neuroscience made its official entry into science in the early 1990s, an ever-increasing rate of studies has been published in the field (for reviews

* Address for correspondence: Dr A.-K. J. Fett, Department of Educational Neuroscience, Faculty of Psychology and Education, VU University Amsterdam, Van der Boechorststraat 1, 1081 BT Amsterdam, The Netherlands.
(Email: a.j.fett@vu.nl)

see e.g. [Adolphs, 2003, 2010](#); [Amodio & Frith, 2006](#); [Cacioppo *et al.* 2007](#); [Lieberman, 2007](#); [Norman *et al.* 2011](#); [Frith & Frith, 2012](#)) and has led to the instantiation of dedicated journals such as *Social Neuroscience* and *SCAN*. Initially, research focused on social brain mechanisms in healthy individuals, which were mostly investigated by means of so called ‘off-line’ measures that assessed social cognition from a third-person perspective. These studies are the basis of normative models of social brain function. In the last decade more and more research started to use social interactive paradigms, which are superior in the assessment of online mechanisms of social behaviour. In addition, researchers began to explore the underlying biological substrate of social cognitive deficits in psychiatric populations, as well as the biological substrate of social risk factors to identify how they drive psychiatric symptoms and social dysfunction with the ultimate aim to apply this knowledge in the development and evaluation of treatment interventions ([Adolphs, 2010](#); [Mendez & Manes, 2011](#); [Frith & Frith, 2012](#); [Meyer-Lindenberg & Tost, 2012](#); [Pemment, 2013](#)).

Social cognition and its neural substrate

Social cognition refers to information processing within social-emotional contexts. It is essential for the understanding of social stimuli and interpersonal cues and guides actions appropriate for the social environment. This review focuses on social cognitive domains that are directed at understanding others’ social signals and social interactions. However, other lower level (social) cognitive mechanisms, which are not the focus of this review, also contribute to social functioning and have been elegantly described by others ([Lieberman, 2007](#); [van der Meer *et al.* 2010](#); [van Veluw & Chance, 2014](#)). Research in psychiatry investigating social cognitive processes aimed at understanding others has mostly focused on emotion recognition (ER) and aspects of perspective-taking ([Grady & Keightley, 2002](#)). ER, the ability to perceive and interpret emotions, is fundamental in deciphering others’ social signals ([Gonzalez-Liencre *et al.* 2013](#)). Perspective-taking can be broadly distinguished into two closely related cognitive-affective processes. The first, more cognitive process is the ability to take another person’s standpoint into account and to make attributions about their intentions, desires and beliefs. It is most commonly referred to as theory of mind (ToM) or cognitive empathy ([Ang & Pridmore, 2009](#)) and is highly relevant to normal social interactions and functioning in the social community ([Frith, 2007, 2008](#)). The second, more affective process is the ability to share others’ feelings in absence of emotional

stimulation to oneself. It is crucial for altruistic behaviour and referred to as empathy or affective ToM (e.g. see [Singer, 2006](#); [Decety *et al.* 2009](#)). This review focuses on emotional empathy, excluding motor empathy (i.e. the unconscious mirroring of the facial or gestural expressions of others). In the remainder of this article we will use ToM to refer to cognitive perspective-taking processes and empathy to refer to affective perspective-taking processes. The social cognitive processes directed at understanding others are closely related ([Ochsner, 2008](#); [Frith & Frith, 2012](#)). This is reflected in the identification of a surprisingly homogeneous pattern of associated brain activation – which is now frequently referred to as the ‘social brain network’ ([Brothers, 1990](#); [Frith, 2007](#); [Blakemore, 2008](#); [Kennedy & Adolphs, 2012](#)) – through experiments across a variety of social cognitive tasks. This network comprises several prefrontal cortex (PFC) areas including dorsolateral (dlPFC), medial (mPFC), ventral medial, lateral (vm/vlPFC) and orbitofrontal (OFC) regions and temporal lobe regions [temporal poles, posterior superior temporal sulcus (pSTS)]. Closer examination of the involvement of specific regions suggests a preferential role for medial frontal brain areas in ToM. The temporal poles and OFC play a role in the processing of (social) reward-related information and the integration of social conceptual knowledge ([van Overwalle, 2009](#); [van Overwalle & Baetens, 2009](#)). The (p)STS has been associated with the perception of biological movement and features of human faces, which have been suggested to be important for ToM ([Allison *et al.* 2000](#); [Pelphrey *et al.* 2003](#)). The ‘social brain network’ also includes other parts of the parietal cortex [e.g. temporo-parietal junction (TPJ), inferior parietal lobule (IPL), precuneus], which have been implicated in change of perspective from self to other and ToM, and several deeper brain structures (i.e. insula, amygdala, striatum), which have been associated with arousal, empathy, emotional processing, and social reward learning ([Mitchell *et al.* 2005](#); [Ross & Olson, 2010](#)). In addition, several brain areas, including the inferior frontal gyrus (IFG), the premotor and parietal cortices (e.g. IPL and postcentral/somatosensory), are implicated in decoding actions and emotional states of others by subserving ‘mirror mechanisms’ in which the neural activation underlying others’ behaviour is thought to be mimicked in the brain of the observer ([Rizzolatti & Craighero, 2004](#); [Dinstein *et al.* 2007](#); [Kilner *et al.* 2007](#); [van der Gaag *et al.* 2007](#); [Keysers *et al.* 2010](#); [Molenberghs *et al.* 2012](#)). There is accumulating evidence showing that the brain areas that are typically activated during social-cognitive processing often overlap with brain regions of the default mode network (DMN) that are active during the resting

state. This resting state is conventionally considered an index of unconstrained non-task-related cognition. However, given the observed overlap with social cognition, it has been suggested that in the absence of any specific task-related focus, people's thoughts are likely to focus on themselves and others – and that this overlap in brain activation reflects the inherently social nature of humans and their evident predisposition for social cognition (Schilbach *et al.* 2008, 2012; Mars *et al.* 2012; Amft *et al.* 2014).

The current review

In this review we aim to outline the major findings of the body of work covering behavioural and neuroimaging research on social cognitive mechanisms directed at understanding others (specifically ER, ToM and empathy) and social interactions, and implications for treatment and future research. Clinically, the review is focused on a comparative approach of three disorders where most of the work has been done to date; SZ, ASD and PP. Studies focusing on subclinical expressions of these phenotypes were not included. Across the included studies PP is defined using the Psychopathy Checklist – Revised (PCL-R; Hare & Vertommen, 2003). We identified the relevant literature by means of PubMed searches including the search terms: *schizophrenia*, *psychopathy*, *anti-social**, or *autism* for the three different groups of psychopathology, *theory of mind*, *mentalizing*, *emotion recognition* or *empathy* for the social cognitive domains, and *neuroimaging* or *fMRI*; and through searches of reference lists of the retrieved articles. Studies that have been included in the recent meta-analyses that we review (Li *et al.* 2010; Sugranyes *et al.* 2011; Anticevic *et al.* 2012; Taylor *et al.* 2012) have not been reviewed separately.

We classified studies into the domain of ER if they required passive viewing of facial emotional expressions (implicit tasks) or the identification of emotions from facial expressions (explicit tasks, independent of situational circumstances). Research that required the inference of mental or emotional states of others based on descriptions or graphic illustrations of particular situations has been categorized as ToM. Studies that required seeing or reading about others in pain or other negative emotions or that asked participants to indicate how much they were feeling with others have been classified into the domain of empathy. To allow for comparison between the findings of behavioural studies, we transformed all reported effect sizes to Cohen's *d* and such that higher positive effect sizes indicate stronger impairments in the patient population. See Supplementary online Tables for the neuroimaging findings in the three social cognitive

domains ER, ToM and empathy and for the findings pertaining to social interactive designs. Within the Tables, the findings are sorted according to the nature of the task or fMRI contrast and sample size, with the largest studies and meta-analyses being reported first. To allow for optimal comparability of the neuroimaging literature, we checked all labels of the reported coordinates in the Talairach client (version 2.4.3, <http://talairach.org/client.html>). We report the Talairach-based labels with the labels as reported by the original research in brackets. Tables and graphical displays of the neuroimaging findings show spatial coordinates in the Montreal Neurological Institute standardized brain template. We used conversion tools *icbm_spm2_tal/other* and *tal2icbm_spm/other* (<http://brainmap.org> and <http://noodle.med.yale.edu/~papad/mni2tal/>). The graphical displays of the neuroimaging findings have been generated in Matlab by means of the meta-analysis toolbox point plotting function (<http://wagerlab.colorado.edu/files/tools/meta-analysis.html>) and are shown in the online Supplementary material (Supplements 1–3). The majority of research in the field, and studies that we reviewed here, followed a traditional neurological lesion approach that aims to associate specific brain areas with specific social cognitive functions. However, the findings from neuroimaging research, as in many psychological domains, are more likely to reflect a complex interaction between different brain regions, emphasizing connectivity. Although the heuristic of a social brain is useful for the developing field, it is clear that none of the previously mentioned and reviewed brain areas are specific to social cognition and that social cognitive processes are contingent on widely distributed structure-function networks, rather than particular topographical areas (Menon, 2011; Barrett & Satpute, 2013).

Social cognitive brain mechanisms of psychiatric illness

Emotion recognition

Behavioural research

ER is fundamental for understanding others' affective signals. It is typically assessed with tasks that require the identification or discrimination of facial emotions in pictures or the recognition of emotional prosody in speech. The tasks include the emotions regarded as universal, i.e. happiness, sadness, anger, fear, disgust and surprise and also neutral expressions, which in neuroimaging studies are mainly used as control condition. ER has extensively been researched in SZ. There is strong evidence for behavioural impairments from meta-analyses with large effect sizes of $d = 0.85$

($N=1820$) and 0.89 ($N=3822$) (Chan *et al.* 2010; Kohler *et al.* 2010) and deficits that seem particularly pronounced for negative emotions (Hoekert *et al.* 2007). ER deficits in SZ are present at all stages of the illness, including at-risk states, but deteriorate further during acute illness phases (Mandal *et al.* 1998; Edwards *et al.* 2001; Bediou *et al.* 2007; Alfimova *et al.* 2009; Kohler *et al.* 2010). The evidence for ER impairment is somewhat more equivocal in ASD. This may be partly due to a greater heterogeneity of samples, which included children and adults with classical and high functioning forms of the condition. A meta-analysis of 48 studies on ER in ASD ($N=932$) indicated a large effect of $d=0.80$ that was reduced to a moderate, although significant effect of $d=0.41$ when publication bias was controlled for. Against an emotion-specific account of ER impairment in ASD, the study revealed no significant differences between emotions (Uljarevic & Hamilton, 2013). The findings are supported by a recently published meta-analysis that showed an overall ER impairment with an effect size of $d=0.77$ ($N=1545$; Lozier *et al.* 2014). Deficits in ER have also been associated with PP. It has been proposed that particularly problems with the recognition of fear and sadness contribute to interpersonal difficulties and a lack of empathic behaviour in the condition. In support of this hypothesis a meta-analysis on children and adults ($N=1244$) with different anti-social conditions (including antisocial personality disorder, conduct disorder, externalizing behaviour disorders and psychopathy) showed the strongest impairments in the recognition of fear, followed by sadness. However, impairments were also present in the recognition of surprise, albeit to a lesser degree. Effect sizes ranged from $d=0.22$ to 0.72 . No consistent ER deficits were found for other emotions ($d=0.20$ – 0.24 ; Marsh & Blair, 2008). A meta-analysis ($N=1387$), which focused exclusively on psychopathy revealed only weak ER impairments for all emotions ($d=0.14$ – 0.24). However, again the strongest deficits were present in the recognition of fear ($d=0.20$) and sadness ($d=0.24$; Wilson *et al.* 2011). More recent work on ER in adults, children and adolescents with PP ($N=1376$) revealed an effect of $d=0.17$ for facial ER and $d=0.28$ for voice ER deficits, once more with the strongest impairments in the recognition of fear and sadness (both $d=0.30$). Interestingly, specific analyses by subgroup revealed small effects of $d=0.08$ in adults ($N=376$), with the only significant deficits in ER of happiness and surprise. Indicative of differential developmental effects, substantially larger impairments ($d=0.36$) were found in children and adolescents ($N=343$), who had significant impairments in the recognition of anger, fear and sadness;

but not disgust, happiness and surprise (Dawel *et al.* 2012).

Neuroimaging research

The results of the neuroimaging studies on ER are displayed in Supplementary Table S1. Four meta-analyses have been conducted to summarize the work on the neural mechanisms of ER in SZ. Li *et al.*'s (2010) meta-analysis of ER studies ($N=498$) that compared SZ patients to healthy controls (HC) showed decreased brain activation in SZ in areas including the bilateral parahippocampal gyrus, amygdala, right superior frontal gyrus and middle occipital gyrus. There were no significant clusters showing higher activation in SZ (Li *et al.* 2010). A second meta-analysis ($N=414$) by Sugranyes *et al.* (2011) showed decreased activation in the right vIPFC and posterior cingulate (PCC), left amygdala, right occipito-temporal regions including the fusiform gyrus (FFG) and the left thalamus in SZ compared to HC (Sugranyes *et al.* 2011). In line with Li *et al.* (2010) there were no activation clusters showing greater activation in SZ than in HC. A third meta-analysis ($N=872$), which only included studies that used whole brain analyses, was conducted by Taylor *et al.* (2012). The results also revealed large clusters of decreased activation in SZ compared to HC in the bilateral amygdala/hippocampal region. Reduced activation was also present in occipital regions associated with early visual processing, the *anterior cingulate cortex* (ACC), dIPFC, mPFC, and several sub-cortical areas, including the thalamus, caudate and midbrain (Taylor *et al.* 2012). Other studies which have been conducted since support the general pattern of these meta-analytical findings (Lepage *et al.* 2011; Derntl *et al.* 2012; Mier *et al.* 2014b). A fourth meta-analysis by Anticevic *et al.* (2012) which focused exclusively on ER in the amygdala, showed reduced amygdala activation in SZ compared to HC when negative emotion was contrasted with neutral expressions, as opposed to baseline. A normal amygdala response when viewing negative emotions and an elevated response to neutral information might reflect a mechanism of aberrant salience of neutral events (Anticevic *et al.* 2012). However, other research also reported reduced activation of the amygdala when emotion expressions were compared to the implicit baseline (Mier *et al.* 2014b). Taken together, the vast amount of imaging research on ER in SZ suggests that a robust and widespread pattern of reduced activation in brain areas that are regarded as part of the 'social brain network', might be underlying ER deficits in the disorder. However, some studies also revealed significantly higher activation in SZ than HC, which might indicate alternative or compensatory processing

strategies (Taylor *et al.* 2012; Mier *et al.* 2014b; Mothersill *et al.* 2014). A few contradicting findings that warrant further clarification have been made for the superior temporal gyrus (STG), IPL, ACC and medial frontal gyrus (meFG), with some studies showing more activation in HC than SZ and others reporting the opposite activation pattern.

Sugranyes *et al.* (2011) also meta-analysed ER in ASD (including autism, Asperger's syndrome and pervasive developmental disorder NOS, $N=110$). ASD showed more activation than HC in the left STG and less activation in the left postcentral gyrus. Several other studies on ER have been conducted in ASD, but were not included in Sugranyes *et al.*'s meta-analysis for methodological reasons (see also Harms *et al.* 2010). Here we report studies that employed an ER task in ASD and HC, and either compared ER performance to baseline, a control condition (e.g. scrambled faces) or neutral facial expressions. The majority of studies showed reduced brain activation in ASD compared to HC in the frontal cortex [i.e. middle frontal gyrus (miFG), meFG, superior frontal gyrus (SFG) and IFG], the temporal, parietal and occipital cortex (i.e. middle TG, insula, TPJ, FFG), and subcortical areas, including the putamen and amygdala (Ogai *et al.* 2003; Piggot *et al.* 2004; Pelphrey *et al.* 2007; Kleinhans *et al.* 2011; Wicker *et al.* 2008; Corbett *et al.* 2009; Doyle-Thomas *et al.* 2013). However, in line with differential or compensatory processing strategies in ASD, several studies showed patterns of increased brain activation in inferior, middle and medial frontal, temporal-, parahippocampal- and superior parietal areas and the striatum, amygdala and insula (Corbett *et al.* 2009; Weng *et al.* 2011; Doyle-Thomas *et al.* 2013; Tottenham *et al.* 2013).

Sugranyes *et al.* (2011) also directly compared ER in SZ and ASD. In support of differential mechanisms of ER impairment in the two disorders, their findings revealed increased activation in SZ compared to ASD in the IFG, the parahippocampal gyrus, the TPJ, occipital gyrus and cerebellum. By contrast, individuals with ASD showed higher activation in superior temporal regions, the ACC and PCC. Group differences in brain activation were not accounted for by the use of antipsychotics by SZ patients.

To date, imaging research on ER in PP is still scarce and the conducted research yielded mixed findings. Lower activation in PP in the bilateral FFG, the cerebellum and the left pre- and postcentral gyrus was found by an early study during processing of happy and fearful faces (Deeley *et al.* 2006). However, more recent research did not find reduced, but increased brain activation in PP compared to HC in lateral and medial frontal areas, the FFG and visual cortex (Contreras-Rodríguez *et al.* 2013). Results by Decety

et al. (2013c) indicated both; extended patterns of decreased activation in the FFG, medial and middle occipital gyrus, IFG, meFG, OFC, dmPFC and ventral PFC, supplementary motor area (SMA), inferior and temporal poles in PP during ER of happy, fearful, painful and sad expressions and increased activation in the amygdala, insula, middle cingulate and the superior temporal poles (Decety *et al.* 2013c). Finally, a recent study by Mier *et al.* (2014a) reported no group differences in neural activation between PP and HC during ER.

In summary, the findings show that SZ is associated with the most profound deficits in ER on the behavioural and neural level, with widespread patterns of decreased brain activation across the social brain network. Behaviourally, ASD has been associated with less severe deficits and imaging research indicates fewer differences in neural processing in comparison to HC. However, the findings in ASD are largely based on small and potentially underpowered studies with more heterogeneous samples and should therefore be regarded with some caution. Behaviourally, PP is associated with mild ER deficits. Here, the differences ER might reflect a processing bias specific to negative emotions, rather than an inability to recognize emotions. The evidence regarding the neural processes of ER in PP is still limited; however, in general the neural activation patterns appear to be less disturbed than in SZ and ASD. Finally, it needs to be noted that the overall findings on the neural mechanisms of ER vary considerably between and, albeit to lesser degree, within disorders. Factors that account for this heterogeneity are sample composition, e.g. including various diagnoses, ability levels and differential age ranges of participants; and methodological differences, such as nature of the ER tasks (e.g. implicit or explicit, different emotions), the utilized analysis strategies (ROI *v.* whole brain) and the differential contrasts, which compared emotion expressions to either neutral expressions, objects, shapes or the implicit baseline. In addition, the majority of studies included largely male samples, which limits the generalizability of the current findings.

Theory of mind

Behavioural research

The tasks that are used to measure ToM typically require the interpretation of mental states of characters in cartoons or vignettes, ranging from relatively simple false-belief identification or picture sequencing to more intricate measures that require the interpretation of indirect speech (hints), sarcasm, irony or humour. ToM disturbances have been reported in numerous psychiatric illnesses (Ang & Pridmore, 2009), but the

deficits are probably most profound and most consistently found in SZ and ASD (Baron-Cohen, 2000; Brune, 2005; Sprong et al. 2007). Two meta-analyses on ToM in SZ reported large effect sizes of $d=1.21$ and $d=1.26$ ($N=1181$ and 1518 , respectively; Sprong et al. 2007; Bora et al. 2009). Meta-analyses on ToM in ASD yielded evidence for somewhat smaller effect sizes of $d=0.88$ in children and adolescents (Yirmiya et al. 1998). However, similarly large impairments were found in adults with SZ and ASD ($N=1922$, verbal ToM tasks: SZ $d=1.09$, ASD $d=1.17$; visual ToM tasks: SZ $d=1.07$, ASD $d=0.89$; Chung et al. 2014). In both disorders deficits are evident in tasks that assess simple and higher order ToM.

ToM deficits have also been suggested to underlie social deficits in PP. However, the current evidence only supports very mild impairments, if any at all (Richell et al. 2003; Dolan & Fullam, 2004; Murphy, 2006; Sharp & Vanwoerden, 2014). Dolan et al. (2004) found no differences between HC and PP in simple ToM tasks. But, the PP group performed worse than HC on more complex ToM tasks. Research by Richell et al. (2003) did not show ToM performance differences between incarcerated men with and without PP (Richell et al. 2003) and recently, Sharp et al. (2014) even presented evidence showing that certain traits of PP are associated with excessive ToM, whereas others are associated with reduced or absent ToM. Research that compared simple and higher-order ToM in ASD, SZ and personality disorders (mainly PP) showed that ASD and SZ performed similarly and significantly worse compared to individuals with personality disorders (Murphy, 2006).

Neuroimaging research

The results of the neuroimaging studies on ToM are displayed in Supplementary Table S2. At the neural level, Sugranyes et al.'s meta-analysis ($N=273$), which included a variety of ToM-related tasks that also involved empathy, moral reasoning and certain aspects of ER, found lower activation in the mPFC, temporal cortices and the right PCC in SZ compared to HC. Higher activation in SZ was present in the left PCC and the paracentral lobule. As for ER, other studies also mostly support a pattern of lower activation in SZ than HC including the meFG, STG, temporal poles, IPL and somatosensory areas (Lee et al. 2011a; Das et al. 2012; Pedersen et al. 2012; Rapp et al. 2013). In line with the idea of differential or compensatory processing strategies in SZ, research by Varga et al. (2013) and Pedersen et al. (2012) also reported higher activation compared to HC in the miFG and IFG, IPL, STG, precuneus and cerebellum.

Even though ToM has long been regarded as key factor underlying social disturbances in ASD, relatively little research has investigated the neural mechanisms of ToM in the condition. Sugranyes et al.'s meta-analytical work ($N=186$) associated ASD with reduced activation in medial, temporal, parietal and limbic brain areas. In contrast to SZ, no areas were significantly more activated in ASD than HC. Kana et al. (2014) and Lombardo et al. (2011) also showed patterns of decreased activation in the IPL, IFG, cuneus, TPJ, pSTS, insula and in motor and somatosensory areas. One study, however, that investigated irony comprehension indicated the opposite pattern with increased activation in ASD compared to HC in the precentral gyrus and IFG (Wang et al. 2006). A direct comparison between SZ and ASD showed more insula activation in ASD than SZ and greater activation likelihood in the mPFC and somatosensory areas in SZ than ASD. The difference in mPFC activation was partly explained by age differences between the SZ and ASD sample (Sugranyes et al. 2011). The authors speculated that higher somatosensory activation might reflect possible compensatory mechanisms or a process of 'overmentalization' in SZ compared to ASD. The idea that paranoid SZ is associated with the excessive interpretation of others' behaviour and intentions as malevolent and self-referent (Abu-Akel & Bailey, 2000; Frith, 2004) has been supported by research showing that specifically positive symptoms were related to 'overmentalizing' ToM errors, whereas negative symptoms were more strongly related to a lack of ToM (Montag et al. 2011). However, Sugranyes et al. (2011) did not specifically investigate the associations between brain activation and symptoms or behavioural performance.

Sommer et al. (2010) investigated the neural mechanisms of ToM in PP and found more activation in the OFC compared to HC during mental state attribution in ToM cartoons. Given that the OFC has been associated with more cognitive, as opposed to affective reasoning strategies, the authors suggest that this could reflect more rational, outcome oriented ToM reasoning strategies in PP (Sommer et al. 2010). By contrast, a recent study by Mier et al. (2014a) found less brain activation in PP compared to HC in the FFG and Declive, but no significant clusters for the reverse contrast during a ToM task that involved intention attribution to facial emotion pictures. Neuroimaging research comparing ToM performance of HC children and adolescents with ASD and PP (research diagnosis conduct problems/high callous-unemotional traits) found no behavioural differences between the groups and no differences in neural activation patterns between PP and HC. ASD, however, was associated with reduced activation in three clusters in the mPFC and vmPFC, compared to HC and PP (O'Nions et al.

2014). Behaviourally, these findings point towards similar, intact ToM mechanisms in children and adolescents with PP traits and adults with a clinical diagnosis of PP. However, the neuroimaging findings suggest differential neural processing in adults, which could be due to a variety of factors, for example clinical characteristics, age or the employed ToM paradigms.

In sum, the current evidence from neuroimaging research indicates partly overlapping neural mechanisms of ToM impairment in SZ and ASD, particularly with reduced activation in the left meFG, middle temporal gyrus (MTG), precuneus, right IFG, IPL and precentral gyrus and increased activation in the left IFG and right meFG. This could imply similar pathological mechanisms, such as changes in neural connectivity, grey-matter volumes and neurotransmitter abnormalities, which have been associated with both disorders (Cheung *et al.* 2010; Neuhaus *et al.* 2010; Kana *et al.* 2011; Coghlán *et al.* 2012; Coyle *et al.* 2012; Fitzsimmons *et al.* 2013; Greimel *et al.* 2013). However, in support of disease specific mechanisms, the current evidence also shows differential patterns of increased and reduced brain activation. Differential neural irregularities in ASD could be explained by the fact that social (brain) mechanisms are disrupted early in life. Individuals with ASD might therefore acquire alternative strategies to process social information. In SZ a relatively normal social development until illness onset, which typically occurs in late adolescence or early adulthood, is likely to be associated with differential mechanisms of impairment. The current evidence with regard to PP is scarce, yet points towards relatively unimpaired ToM, with minor behavioural and neural deviations. With respect to the current research it is important to note that the heterogeneity between studies is even higher than for research on ER, due to the nature of ToM tasks, which are more complex and which partly included a conglomerate of related processes, such as ER and empathy.

Empathy

Behavioural research

Empathy is assessed by having participants observe or read about physical or social pain in other people. Other studies use facial expressions of negative emotions and instruct participants to judge the emotional state of self and others. Performance indices reflect the self-reported affective response to distress cues or compare the emotion indicated by the participant with the correct emotion; some studies have taken into account the emotional state as rated by the target (other), which allows the measurement of empathic

accuracy (i.e. the congruence between emotions rated by the participant and the target; Zaki & Ochsner, 2011). In SZ, the evidence for abnormal empathy is mostly based on studies using self-report questionnaires on trait empathy. The most consistent finding is that patients report higher personal distress when others are in difficult situations (Montag *et al.* 2007; Derntl *et al.* 2009; Achim *et al.* 2011; Lee *et al.* 2011b); some studies also report lower self-reported empathic concern (Lee *et al.* 2011b; Smith *et al.* 2012). Some studies have used performance-based measures of empathy, suggesting that patients show reduced empathic accuracy (Lee *et al.* 2011b) and are less able to indicate the correct affective response to emotional scenarios (Derntl *et al.* 2009; Smith *et al.* 2013).

Findings on empathy in ASD are mixed. As in SZ, studies have relied on self-report questionnaires, some showing normal (Rogers *et al.* 2007; Dziobek *et al.* 2008) others reduced (Mathersul *et al.* 2013; Grove *et al.* 2014) self-reported empathic concern in adults with high-functioning ASD. Similar to SZ, self-reported personal distress may be higher than in HC (Rogers *et al.* 2007; Dziobek *et al.* 2008). Performance-based studies showed normal behavioural (Jones *et al.* 2010; Schwenck *et al.* 2012; Scheeren *et al.* 2013; Deschamps *et al.* 2014) and psychophysiological (Shalom *et al.* 2006) responses to others' distress in school-age children with ASD, as well as in adults (Dziobek *et al.* 2008). There is some evidence, however, for a reduced affective response to parents' distress in toddlers at risk for ASD (McDonald & Messinger, 2012). Little is known about empathic accuracy in ASD; one older study suggested somewhat lower congruence between the affective response of the participant and the emotional state of the protagonist in children with ASD compared to HC (Yirmiya *et al.* 1992).

Deficits in empathy have been suggested to be at the core of PP, and may underlie the instrumental aggression characteristic of this disorder (Blair, 2008; Derntl *et al.* 2012; Meffert *et al.* 2013). Probing the deficit behaviourally, however, has proven difficult, possibly because individuals with PP may use their relatively intact ToM skills to compensate for the lack of affective sharing of emotions. Accordingly, studies using self-report questionnaires showed normal levels of self-reported empathy in individuals with PP (Shamay-Tsoory *et al.* 2010; Domes *et al.* 2013a). Male offenders with high levels of PP did not show a reduced affective response to others' distress when compared to male offenders with low PP; however as a group the offenders scored lower than HC (Domes *et al.* 2013a). Another study indicated that male violent offenders with high PP traits had similar self-reported affective responses to others' distress as HC despite

lower psychophysiological responses, possibly suggesting that they were able to respond to the distress cues on the basis of cognitive rather than affective processes (Pfabigan et al. 2014). Empathic accuracy, however, was reduced as a function of PP in a group of male offenders (Brook & Kosson, 2013). In children, PP tendencies were associated with lower affective response to distress (Jones et al. 2010); this study showed a double dissociation with empathy being preserved in boys with ASD but impaired in boys with PP tendencies, and ToM impaired in boys with ASD but preserved in boys with PP tendencies. A similar pattern of results was reported by Schwenck et al. (2012). Another study reported reduced psychophysiological response to an emotion evocative film, in conjunction with lower self-reported affective response in children with callous-unemotional traits (Anastassiou-Hadjicharalambous & Warden, 2008). Reduced psychophysiological responses to distress cues have been reported previously both in children (Blair, 1999) and in adults (Blair et al. 1997) with PP traits. Taken together, the results suggest that PP is associated with a deficit in empathy in the context of relatively intact ToM. In contrast, there is little consistent evidence for a deficit in empathy in ASD. In SZ, evidence for reduced empathy is mostly based on self-report questionnaires, but some studies have shown that empathic accuracy is impaired.

Neuroimaging research

Imaging studies have investigated patterns of brain activation during observation of pain or emotion scenarios compared to neutral scenarios; some studies have further examined the effect of explicit instructions to feel with the other or imagine oneself in the situation.

The results of the neuroimaging studies on empathy are displayed in Supplementary Table S3. Only two studies have investigated the neural correlates of empathy in SZ, suggesting a reduced neural response across cortical and subcortical areas (Derntl et al. 2012; Harvey et al. 2013). Derntl et al. (2012) used sentences describing real-life situations; participants were asked to imagine how they would feel if they were experiencing this situation. The study by Harvey et al. (2013) focused on empathic accuracy, and had participants rate the affective state of another person (target) shown in a series of videos and compared these with the self-rated affect of the target. Given the widespread abnormalities in ER and ToM in this disorder, it can be hypothesized that any abnormal brain response to empathy has to be considered in the context of these other deficits.

Abnormal brain responses to empathy are also seen in individuals with ASD, but the findings are

contradictory. Some studies found little evidence for abnormal neural responses to pain scenarios (Bird et al. 2010; Schneider et al. 2013; Hadjikhani et al. 2014), whereas others did observe reduced activation in areas associated with face processing and empathy (Greimel et al. 2010; Schulte-Ruther et al. 2011). Fan et al. (2014) similarly observed reduced activation in anterior insula and ACC in response to pain scenarios, but an *increased* response in the somatosensory cortex, possibly indicating heightened empathic arousal in individuals with ASD, which may trigger an increased reliance on cognitive reappraisal (Hadjikhani et al. 2014). There is also some evidence that atypical processing of one's own emotions ('alexithymia') contributes to the empathic deficits in ASD (Bird et al. 2010). Finally, comparing inflicted *v.* accidental pain showed reduced activation in areas associated with ToM, suggesting that impaired social understanding may also play a role in the empathy deficit in ASD (Fan et al. 2014). Taken together, while the overall picture remains ambiguous, the existing research suggests that the empathic deficit in ASD should be considered in the context of other deficits, such as self-related emotion processing and ToM.

Four studies have investigated the neural basis of the lack of empathy in individuals with PP using fMRI (Decety et al. 2013a, b; Marsh et al. 2013; Meffert et al. 2013). Three studies suggest that in individuals with PP the normal response in the empathy for pain network (including anterior insula, dorsal ACC and amygdala) is reduced when imagining the other in a painful situation (Decety et al. 2013a) or when simply watching interacting hands (Meffert et al. 2013). However, deliberate vicarious responding was intact, as became clear when subjects were explicitly told to imagine oneself in the situation of the other (Decety et al. 2013a; Marsh et al. 2013), or to feel with the other person (Decety et al. 2013a; Meffert et al. 2013). Accordingly, it has been argued that the distinction between ability (what one does under optimal situations) and propensity (what one actually does as a function of the situation) is important in the understanding of the neural mechanisms of reduced empathy in psychopathy (Keysers et al. 2014). The fourth study (Decety et al. 2013b) surprisingly reported higher activation the anterior insula and the dorsal ACC in PP *v.* HC during the observation of interactions involving pain, while at the same time activation in other pain- and emotion-related areas, such as periaqueductal grey and vmPFC was reduced. This suggests that the role of anterior insula and ACC in the reduced empathy response in PP is not yet well understood. The same study also observed higher activation in cognitive ToM areas such as pSTS and mPFC in PP, possibly indicating a more cognitive approach to the processing

Table 1. Main neuroimaging findings on ER, ToM and empathy

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- **SZ** is robustly associated with widespread patterns of reduced brain activation especially during ER and ToM, and to a lesser degree empathy, but there has been little research in this domain.
 - Areas with reduced activation that overlapped between ER and ToM include the bilateral IFG, IPL, postcentral gyrus and thalamus, the left precuneus (thalamus and precuneus also show lower activation during empathy), right FFG and parahippocampal gyrus, PCC, SFG and STG, suggesting that these areas belong to a wider network that underlies general processes relevant for social cognition.
 - Each social cognitive domain was also associated with specific areas of reduced activation. For ToM these areas were located in medial frontal, cingulate and mid temporal regions. ER was associated with reduced activation in the bilateral amygdala and insula, and several mid temporal and occipital areas.
 - Across social cognitive domains, few studies yielded brain areas that showed increased activation in SZ compared to HC; these included the left STG and IPL.
 - Contradictory findings, which have been made with respect to activation patterns in the left IPL, IFG and right PCC in ToM and the left IPL and right ACC in ER warrant further investigation.
 - **ASD** is associated with widespread patterns of reduced activation compared to HC, especially during ER and empathy. Unlike SZ, ASD was also associated with extensive patterns of higher activation compared to HC.
 - In ASD areas with reduced activation that overlapped between ER and ToM included the left MFG, mid temporal regions and the amygdala. Indicative of related mechanisms of empathy and ER impairment in ASD, there was a high degree of overlap of reduced activation in the left medial, middle and inferior FG, insula, mid temporal and precentral regions and the right ACC, thalamus, medial and superior FG, IPL, STG.
 - **PP** was associated with differential patterns of reduced and increased brain activation during ER and empathy, but not during ToM. The differences in brain activation between PP and HC seem less pronounced than for ASD and SZ and the current evidence is still equivocal.
 - Few studies also showed patterns of reduced activation in the left medial, mid and superior frontal and mid temporal regions, ACC, insula, the pre- and postcentral gyrus and the right ACC, caudate, inferior, superior and medial FG and STG.
 - **ER** is associated with the greatest overlap in reduced brain activation between SZ, ASD and PP in areas that are viewed as part of the social brain network; the bilateral insula and IFG, the left postcentral gyrus, and the right ACC, IFG, SFG, IPL, STG. SZ and ASD but not PP showed reduced activation in the left amygdala and FFG and the right thalamus. ASD and PP showed reduced activation in mid-frontal and temporal regions. SZ and PP were associated with reduced activation in the left ACC, precentral gyrus, right FFG and mid occipital and cerebellar regions.
 - During **ToM** ASD and PP showed reduced activation in the left amygdala. SZ and ASD were associated with reduced activation in the left MFG, MTG, precuneus, right IFG, IPL and precentral gyrus and increased activation in the left IFG and right MFG. SZ and PP showed reduced activation in the culmen.
 - During **Empathy** ASD and PP overlapped in reduced activation in the bilateral SFG, the right STG, MFG, IFG, ACC, and left precentral gyrus, MG, IFG, insula, IPL and culmen. Activation in both disorders was increased in the bilateral SFG and STG. ASD and SZ showed reduced activation in the thalamus, precuneus and left PCC and MFG.
 - In support of disease specific processing mechanisms, all disorders were also associated with specific patterns of reduced and increased activation.
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of the pain scenarios. As mentioned before in the section on ToM, stronger activation in brain areas that are thought to reflect an increased reliance on cognitive processes was also observed when individuals with PP had to infer emotional states of cartoon characters (Sommer *et al.* 2010). Compared to forensic controls, individuals with PP showed more ToM-related brain activation and less vicarious responding.

In summary, the existing research on empathy reveals shared and distinct neural processes in different disorders. PP is associated with distinct deficits in empathic processing which co-occur with relatively intact cognitive ToM processes. The empathic deficit in PP seems to be amendable, given that explicit instructions to imagine the self in the painful situation or to feel with the other tend to normalize the brain

response. In ASD, the evidence for an impaired empathic brain response is contradictory, but the findings suggest that any empathic deficit occurs in the context of deficits in self-related emotion processing and ToM. The evidence in SZ is scarce, but similarly to ASD it can be surmised that any deficit in empathy will have to be considered against other social cognitive deficits. Future studies could usefully vary task conditions to systematically investigate if explicit instructions or situational factors (i.e. intentional *v.* accidental pain; familiar *v.* non-familiar faces) influence brain response to empathy. Further, as for ER and ToM, research so far has almost exclusively focused on males; this limits the generalizability of the findings, particularly since there is some evidence that gender may influence the neural correlates of

empathy in psychopathology (Schneider *et al.* 2013). The main findings of the neuroimaging studies on ER, ToM and empathy have been summarized in Table 1.

The dynamics of disturbed social interaction: neuroeconomics in psychiatry

The previously discussed studies investigated the neural mechanisms of social cognition by means of paradigms that require participants to interpret social stimuli in stories, cartoons or pictures. These studies yielded important insights into social cognitive brain mechanisms, but could not capture the most intrinsic and interactive aspect of social behaviour (De Jaegher *et al.* 2010). In the last decade, interactive game-theoretical exchange paradigms from experimental economics made an exciting addition to social neuroscience. These paradigms allow for the 'online' investigation of social processes (e.g. trust, reciprocity or fairness) and offer a new way to study social dysfunction in psychopathology (Sripada *et al.* 2009; Sharp *et al.* 2011; Fett *et al.* 2012; Gromann *et al.* 2013, 2014; Joyce *et al.* 2013). It has been suggested that these paradigms could signify quantitative biomarkers for psychiatric assessment and genotyping (Hasler, 2012; King-Casas & Chiu, 2012; Montague *et al.* 2012). Given these attractive prospects, the rapid increase of research using game theoretical paradigms in psychiatry is not surprising. Most frequently researchers made use of the trust game (Berg *et al.* 1995; Tzieropoulos, 2013). In this paradigm the first player (investor) receives an endowment and then has to decide how much of it he wants to share with the second player. The transferred amount is multiplied during the transaction. Subsequently, the second player (trustee) decides how much of the total amount he wants to send back. Cooperation yields the best pay-off for both. However, initially the best pay-off for the trustee is reached through defection. Hence, sharing money requires the investor's trust in his or her benevolence. Research in HC implies a human tendency to trust and to reciprocate trust, and shows that trusting behaviour is influenced by the rewarding effects of social cooperation and knowledge about the interaction partner (Bowles & Gintis, 2002; Fehr & Gächter, 2002; Fehr & Fischbacher, 2003; Delgado *et al.* 2005; Fehr, 2009). The investment phase, during which the partner's behavioural cues are interpreted to anticipate future behaviour, has been associated with activation in ToM related brain areas (Rilling *et al.* 2004; King-Casas, 2005; King-Casas *et al.* 2008; van den Bos *et al.* 2011). The outcome phase, during which cooperation or non-cooperation of the game partner is revealed has been associated with activation in dopamine-governed brain areas of reward

processing (King-Casas, 2005; Phan *et al.* 2010). These findings make the trust game highly interesting for the investigation of social interaction in SZ. SZ is accompanied by deficits in ToM and dopamine function (Kapur *et al.* 2005), which might explain reductions in trust and the motivation to engage in (pro-)social behaviour. Recent behavioural research showed lower levels of trust (i.e. lower investments) in patients and their healthy first-degree relatives with a heightened illness-risk compared to controls. Besides, reduced trust was associated with psychotic symptoms. Crucially, patients' levels of trust did not increase when they were informed that their game partner was trustworthy, neither did they increase in response to their game partners' trustworthy behaviour. Relatives, however, modified their trust towards the levels of controls. This designates the behavioural flexibility in response to social cues as protective mechanism against the transition to psychosis (Fett *et al.* 2012). Research by Gromann *et al.* (2013) linked reduced trust in SZ to lower activation in the caudate, which was also associated with higher levels of paranoia. In addition the TPJ, which is implicated in ToM, was less activated in patients when they received their game partner's repayment. The findings suggest that the loss of trust in SZ might be caused by an aberrant sensitivity to the rewarding propensity of social contact and aberrant ToM (Gromann *et al.* 2013). This hypothesis is in line with the suggestion that the reduced experience of social reward limits reciprocal provision of care and social connection to others and offers an explanatory mechanism for social impairment in SZ (Eisenberger & Cole, 2012). Chiu *et al.* (2008) used the trust game to study social interactions in ASD. Interestingly, their findings indicated no behavioural differences between ASD and HC. However, suggestive of different cognitive strategies, individuals with ASD exhibited reduced activation of the cingulate. A greater reduction in brain activation was associated with ASD symptom severity (Chiu *et al.* 2008). Research in healthy individuals implicated the cingulate in the detection of social agency (e.g. distinguishing outcomes for the self from outcomes for the other; Tomlin *et al.* 2006), which could point to a disturbed a mechanism in self-other distinction in ASD. Research in healthy individuals associated psychopathic traits with abnormal social behaviour in interactive paradigms, such as higher defection rates (Rilling *et al.* 2007; Mokros *et al.* 2008; Koenigs *et al.* 2010; Vieira *et al.* 2013). Neuroimaging associated PP with reduced amygdala activation in response to defection, which could account for reduced social learning as a consequence of a lack of negative reinforcement (Rilling *et al.* 2007).

In conclusion, this body of research on neuroeconomics in psychiatry illustrates the cross-diagnostic

value of interactive paradigms in the investigation of disturbed social behaviour during interactions with others. The results are particularly informative when viewed in conjunction with additional questionnaires, non-social control paradigms and symptom measures that can aid the interpretation of the behavioural and neuroimaging findings with these intricate paradigms. In addition, the results show how neuroeconomic paradigms can be helpful in informing interventions that are aimed at altering mechanisms of interpersonal dysfunction and social symptoms (Supplementary Table S4).

Social cognitive enhancement: improving social brain mechanisms

The functional importance of social cognition has generated great interest in cognition enhancing interventions (Millan *et al.* 2012; Minzenberg & Carter, 2012), which may restore functional deficits or induct compensatory mechanisms (Millan *et al.* 2012). A vast amount of research investigated the effects of oxytocin (OT), a neuropeptide that is naturally implicated in social behaviours, as for example social attachment and affiliation (for reviews see e.g. Insel, 2010; Meyer-Lindenberg *et al.* 2011; Norman *et al.* 2011; Crockett & Fehr, 2013; Wigton *et al.* in press). The mechanism of action of OT is not fully understood but it is known to influence neurotransmission in the dopamine and serotonin systems (e.g. Bethlehem *et al.* 2013). Research also suggested that OT may promote social behaviour by increasing functional connectivity between social brain areas including the amygdala, insula and caudate (Rilling *et al.* 2012). OT administration in healthy individuals increases trust (Kosfeld *et al.* 2005) and cooperation (Declerck *et al.* 2010) and exerts a positive effect on social cognitive functions (Domes *et al.* 2007; Evans *et al.* 2010). This makes OT a promising agent for conditions that are characterized by social anxiety or problems with the perception of social salience and reward (Bethlehem *et al.* 2013). An ameliorating effect of the neuropeptide on symptomatology and social cognitive impairments has been found in SZ (MacDonald & Feifel, 2012). Research on OT in ASD is still scarce (Stavropoulos & Carver, 2013), but tentatively suggests positive effects on ER (Hollander *et al.* 2007; Guastella *et al.* 2010; Domes *et al.* 2013b). Domes *et al.* (2013b) found that improvement in ER is associated with increased reactivity to facial stimuli in the left amygdala and an overall increase in activation in the social brain network, suggesting that these areas mediate the positive effect. In support of positive effects that may transfer to real-life social interactions, OT has been shown to impact positively on ASD patients' cooperativeness

within social interactions in an interactive experimental paradigm (Andari *et al.* 2010). OT seems to have many positive effects but it becomes increasingly clear that the neuropeptide does not simply enhance pro-sociality. Research by De Dreu *et al.* (2011), which has been conducted in healthy individuals showed that OT increases in-group favouritism and, albeit to a lesser extent, out-group derogation and as such may contribute to intergroup conflicts. Other research reported adverse effects of OT on trust and cooperation in social interactions of individuals with borderline personality disorder (Bartz *et al.* 2011; Ebert *et al.* 2013). The effects of OT in this study were mediated by attachment style and experiences of childhood trauma, suggesting that it increases prepotent interpersonal behavioural style rather than pro-social behaviour, *per se*. Overall the findings seem promising, yet they also highlight the need for large-scale controlled research to determine optimal OT dosages, frequency of administration, its long-term effects, the neural substrates it is supposed to act upon, and its effects in specific patient subgroups before OT could possibly be recommended as supplementary treatment.

Another promising approach for the improvement of social cognitive brain function that is increasingly studied in social neuroscience is cognitive training (Gabbard, 2000; Wykes *et al.* 2002; Minzenberg & Carter, 2012). The underlying rationale is to improve social cognition through neuroplasticity and functional normalization (Cramer *et al.* 2011). Eack and colleagues found that 2 years of social skills group therapy combined with cognitive remediation for early SZ lead to cognitive improvement, which was associated with increases in grey matter volume in the left hippocampus and amygdala (Eack *et al.* 2010). Encouraging findings in SZ have also been made with regard to the effect of a cognitive intervention in combination with ER training. The intervention group showed increased neural activation in the bilateral amygdala, right putamen and mPFC, compared to the control group and the increase in brain activation was linked with improvement on an independent ER task. However, the intervention did not improve functional outcome (Hooker *et al.* 2012, 2013). Further, preliminary evidence for a normalizing effect of ER training on neural activation in ASD comes from a small study by Bolte *et al.* (2006). The training improved task performance and increased neural activation in the superior parietal lobule and the medial occipital gyrus, which suggests that patients learn to use compensatory strategies (Bolte *et al.* 2006). These initial findings stress the clinical significance of neuromodulation and highlight its potential to improve patients' social lives. Clearly, researchers have only just begun to explore the neural effects of interventions that tackle

social (cognitive) impairment – a difficult task, given that the underlying pathological mechanisms are not yet understood. There is renewed interest in neuromodulatory techniques such as transcranial magnetic or transcranial direct current stimulation to improve cognition (Demirtas-Tatlidede *et al.* 2010; Tracy *et al.* 2010; Levkovitz *et al.* 2011; Gromann *et al.* 2012; Minzenberg & Carter, 2012). However, thus far these methods have not been extensively studied in social neuroscience, although preliminary reports suggest some benefit on social cognition (Santesteban *et al.* 2012). Research shows that it is possible to improve social cognition (and to normalize social brain function) but it is also evident that this effect does not automatically translate into improved real-life social functioning. Clearly, the young field of neuromodulation still faces great challenges and future research will show whether it can hold up to the expectations with respect to treatment options that can improve real-life social dysfunction.

Discussion and future directions

As a whole, what have we learnt from social neuroscience in psychiatry? Undoubtedly, the field has made a notable contribution to the understanding of the neural basis of social (cognitive) impairments in psychiatric illness. Research to date has shown that social cognitive deficits are partly associated with similar neural processes in different disorders. Overlapping mechanisms between disorders can inform disease classification. However, while the findings could indicate similar pathological mechanisms (e.g. reduced neural connectivity or irregular neurotransmission) they may also reflect different processes that affect social brain function, cognition and behaviour in similar ways. It is not until the underlying processes are elucidated that we will know whether similar neural activation patterns really reflect shared pathological substrates. The interpretation of imaging findings where different disorders are associated with a similar behavioural task performance, but present with differential patterns of brain activation aided the clarification of disease specific processing mechanisms. For instance, cognitive models of social dysfunction in psychiatry have been informed by the finding that empathic reasoning in PP engages neural mechanisms that are typically associated with ToM. This suggests a different mechanism of empathic impairment in PP and SZ or ASD, where deficits are associated with more widespread neurofunctional disturbances. Furthermore, neuroeconomic studies have provided important insights into the mechanisms of disturbed social interaction; for example by showing that a reduced sensitivity to social reward and social context are explanatory factors of distrust and social dysfunction in

SZ. Increasing the sensitivity to social reward and social contexts will be a useful goal for new interventions that aim to ameliorate social dysfunction in SZ. In the future, the field of neuroeconomics will advance psychiatry with computational models of social (cognitive) dysfunction, which will further our understanding of pathological mechanisms and the current conceptualization of mental illness (Hasler, 2012; Montague *et al.* 2012; Sharp *et al.* 2012; Lee, 2013). In addition, there is a strong clinical relevance in the approaches of social neuroscience with their ability to inform novel treatments and techniques that aid in the evaluation of treatment outcomes. Together with evidence from other lines of research within social neuroscience (e.g. lesion studies, animal literature) that have not been covered in this review, the neuroimaging research in psychiatric populations has led to important insights about the dysfunctional ‘social brain’.

Obviously, the field of social neuroscience is still in its infancy and many studies warrant replication; notwithstanding the current accomplishments, the progress in the field is also still hampered by several methodological problems. First of all, the method of neuroimaging comes with its own limitations. For example subtraction methods are not comprehensive and make the interpretation of fMRI findings challenging. In addition, the frequent use of reverse inference (i.e. backwards reasoning from the presence of brain activation in a certain area to the engagement of a particular cognitive function) is a problematic issue in the field (Poldrack, 2006). Also, many studies made use of hypothesis-driven region-of-interest (ROI) analysis. While there are obvious advantages to this method (Poldrack, 2007), it is prone to overlooking important patterns of brain activation and to inflate the weight that is assigned to specific brain areas with a presumed function (e.g. the amygdala for ER). One of the most crucial points of criticism is probably that particular brain structures do not correspond to single psychological processes. While this fact is widely acknowledged, the vast majority of studies to date continue to map cognitive processes to brain regions. Given the limitations of this neurological lesion based approach predicated on regionally specific functional localization – there is a re-emergence of studies examining brain connectivity. One prominent area has been examination of resting state connectivity measures – which not only focuses on neural connectivity but also dispenses with the need to overcome issues of matching task performance between clinical and non-clinical samples. Similarly, there is an increased interest in applying the parameters derived from computational behavioural modelling approaches to understand the core psychological processes and underlying neural substrates in clinical disorders

(O'Doherty *et al.* 2007; Joyce *et al.* 2013). Computational models of brain function overcome limitations of more traditional fMRI analysis approaches, because they do not only show where but also how a specific cognitive function is implemented in the brain. However, model-based approaches also follow highly specific hypotheses that may overlook unexpected results and their utilization in conjunction with more traditional methods is therefore recommendable (O'Doherty *et al.* 2007).

Another methodological issue impeding progress in the field is the heterogeneous definition of the different social cognitive functions and the associated quest for suitable measures. The comparison and integration of research findings from social neuroscience is complicated by the variability of the paradigms that are used to elicit social cognitive processes. The need for better definitions and measures of social cognition has recently been declared a principal matter in the field of SZ research (Green *et al.* 2008). However, the terminology also varies between fields. We hope that future interdisciplinary consensus initiatives will facilitate the integration of social neuroscience findings across different areas of research. Another measurement issue that deserves attention is that many studies do not investigate association between neural activation, symptom measures and performance on the respective social cognitive task and that social neuroscience paradigms have little predictive power with respect to real-life social functioning (Olbert *et al.* 2013). This is important because ultimately the meaning of social neuroscience findings lies in their ability to elucidate these processes. While the ecological validity of measurements has been significantly improved with the use of economic paradigms, there is an obvious need for research to further the integration of real-life social context into empirical research. Important initial steps have been made by studies linking neuroimaging findings to daily-life experiences with techniques such as experience sampling (Morelli *et al.* 2012).

Future studies are also challenged to consider the complex relationships between the neural social mechanisms in individuals and broader social contexts (Forbes & Grafman, 2013). The social environment influences neural mechanisms in many ways, for instance important effects have been found for early traumatic experiences, urbanicity, and social stressors, such as living in minority groups (Davidson & McEwen, 2012; Meyer-Lindenberg & Tost, 2012; Krabbendam *et al.* 2014). Functional connectivity and structure of brain networks or neurotransmission are changed in response to epigenetic processes (e.g. DNA methylation or histone modification), which offer an explanation for how the social environment 'gets into' the mind (Toyokawa *et al.* 2012). Chronic

social disconnection, moreover, has been shown to alter biological systems (e.g. the immune system or HPA axis; Eisenberger & Cole, 2012) and the architecture of the human brain, for instance the amygdala, which has been found to correspond to social networks size. Future research will show whether this suggests that brain structure is influenced by the exposure to social stimuli, or, vice versa that people with more active or extended social brain areas are more 'wired to be social' (Bickart *et al.* 2011; Meyer-Lindenberg & Tost, 2012).

We used the examples of SZ, ASD and PP to illustrate how the thriving, young field of social neuroscience has made a successful start in elucidating the neural correlates of social (cognitive) dysfunction in psychiatric illnesses. However, being in its infancy the field is still facing lots of challenges (see also Adolphs, 2010). There are great expectations with respect to the ability of social neuroscience to pinpoint the complex pathological substrates of social dysfunction. Exciting technical and methodological developments, such as high field strength neuroimaging, more sophisticated computational approaches applied to psychiatry, in combination with the mounting aspiration of scientists to consider the complexity of social cognitive brain mechanisms in the context of wider cultural neuroscience offers bright perspectives to the field.

Supplementary material

For supplementary material accompanying this paper visit <http://dx.doi.org/10.1017/S0033291714002487>.

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Declaration of Interest

None.

References

- Abu-Akel A, Bailey AL (2000). Letter. *Psychological Medicine* 30, 735–738.
- Achim AM, Ouellet R, Roy M-A, Jackson PL (2011). Assessment of empathy in first-episode psychosis and meta-analytic comparison with previous studies in schizophrenia. *Psychiatry Research* 190, 3–8.

- Adolphs R** (1999). Social cognition and the human brain. *Trends in Cognitive Sciences* **3**, 469–479.
- Adolphs R** (2003). Cognitive neuroscience of human social behaviour. *Nature Reviews Neuroscience* **4**, 165–178.
- Adolphs R** (2006). How do we know the minds of others? Domain-specificity, simulation and enactive social cognition. *Brain Research* **1079**, 25–35.
- Adolphs R** (2010). Conceptual challenges and directions for social neuroscience. *Neuron* **65**, 752–767.
- Alfimova MV, Abramova LI, Barhatova AI, Yumatova PE, Lyachenko GL, Golimbet VE** (2009). Facial affect recognition deficit as a marker of genetic vulnerability to schizophrenia. *Spanish Journal of Psychology* **12**, 46–55.
- Allison T, Puce A, McCarthy G** (2000). Social perception from visual cues: role of the STS region. *Trends in Cognitive Sciences* **4**, 267–278.
- Amft M, Bzdok D, Laird AR, Fox PT, Schilbach L, Eickhoff SB** (2014). Definition and characterization of an extended social-affective default network. *Brain Structure and Function*. Published online 8 January 2014.
- Amodio DM, Frith CD** (2006). Meeting of minds: the medial frontal cortex and social cognition. *Nature Reviews Neuroscience* **7**, 268–277.
- Anastassiou-Hadjicharalambous X, Warden D** (2008). Physiologically-indexed and self-perceived affective empathy in conduct-disordered children high and low on callous-unemotional traits. *Child Psychiatry and Human Development* **39**, 503–517.
- Anckarsäter H** (2006). Central nervous changes in social dysfunction: autism, aggression, and psychopathy. *Brain Research Bulletin* **69**, 259–265.
- Andari E, Duhamel J-R, Zalla T, Herbrecht E, Leboyer M, Sirigu A** (2010). Promoting social behavior with oxytocin in high-functioning autism spectrum disorders. *Proceedings of the National Academy of Sciences USA* **107**, 4389–4394.
- Ang GK, Pridmore S** (2009). Theory of mind and psychiatry: an introduction. *Australasian Psychiatry* **17**, 117–122.
- Anticevic A, van Snellenberg JX, Cohen RE, Repovs G, Dowd EC, Barch DM** (2012). Amygdala recruitment in schizophrenia in response to aversive emotional material: a meta-analysis of neuroimaging studies. *Schizophrenia Bulletin* **38**, 608–621.
- APA** (2013). *Diagnostic and Statistical Manual of Mental Disorders*. American Psychiatric Publishing: Arlington, VA.
- Baron-Cohen S** (2000). Theory of mind and autism: a review. *International Review of Research in Mental Retardation* **23**, 169–184.
- Barrett LF, Satpute AB** (2013). Large-scale brain networks in affective and social neuroscience: towards an integrative functional architecture of the brain. *Current Opinion in Neurobiology* **23**, 361–372.
- Bartz J, Simeon D, Hamilton H, Kim S, Crystal S, Braun A, Vicens V, Hollander E** (2011). Oxytocin can hinder trust and cooperation in borderline personality disorder. *Social Cognitive and Affective Neuroscience* **6**, 556–563.
- Bediou B, Asri F, Brunelin J, Krolak-Salmon P, D'Amato T, Saoud M, Tazi I** (2007). Emotion recognition and genetic vulnerability to schizophrenia. *British Journal of Psychiatry* **191**, 126–130.
- Berg J, Dickhaut J, McCabe K** (1995). Trust, reciprocity and social history. *Games and Economic Behavior* **10**, 122–142.
- Bethlehem RAI, van Honk J, Auyeung B, Baron-Cohen S** (2013). Oxytocin, brain physiology, and functional connectivity: a review of intranasal oxytocin fMRI studies. *Psychoneuroendocrinology* **38**, 962–974.
- Bickart KC, Wright CI, Dautoff RJ, Dickerson BC, Barrett LF** (2011). Amygdala volume and social network size in humans. *Nature Neuroscience* **14**, 163–164.
- Bird G, Silani G, Brindley R, White S, Frith U, Singer T** (2010). Empathic brain responses in insula are modulated by levels of alexithymia but not autism. *Brain* **133**, 1515–1525.
- Blair R** (1999). Responsiveness to distress cues in the child with psychopathic tendencies. *Personality and Individual Differences* **27**, 135–145.
- Blair RJ, Jones L, Clark F, Smith M** (1997). The psychopathic individual: a lack of responsiveness to distress cues? *Psychophysiology* **34**, 192–198.
- Blair RJR** (2008). Fine cuts of empathy and the amygdala: dissociable deficits in psychopathy and autism. *The Quarterly Journal of Experimental Psychology* **61**, 157–170.
- Blakemore S-J** (2008). The social brain in adolescence. *Nature Reviews Neuroscience* **9**, 267–277.
- Bolte S, Hubl D, Feineis-Matthews S, Prvulovic D, Dierks T, Poustka F** (2006). Facial affect recognition training in autism: can we animate the fusiform gyrus? *Behavioural Neuroscience* **120**, 211–216.
- Bora E, Yucel M, Pantelis C** (2009). Theory of mind impairment in schizophrenia: meta-analysis. *Schizophrenia Research* **109**, 1–9.
- Bowles S, Gintis H** (2002). Behavioural science: homo reciprocans. *Nature* **415**, 125–128.
- Brook M, Kosson DS** (2013). Impaired cognitive empathy in criminal psychopathy: evidence from a laboratory measure of empathic accuracy. *Journal of Abnormal Psychology* **122**, 156.
- Brothers L** (1990). The social brain: a project for integrating primate behavior and neurophysiology in a new domain. *Concepts in Neuroscience* **1**, 27–51.
- Brune M** (2005). 'Theory of mind' in schizophrenia: a review of the literature. *Schizophrenia Bulletin* **31**, 21–42.
- Burns J** (2006). The social brain hypothesis of schizophrenia. *World Psychiatry* **5**, 77–81.
- Cacioppo JT, Amaral DG, Blanchard JJ, Cameron JL, Carter CS, Crews D, Fiske S, Heatherton T, Johnson MK, Kozak MJ, Levenson RW, Lord C, Miller EK, Ochsner K, Raichle ME, Shea MT, Taylor SE, Young LJ, Quinn KJ** (2007). Social neuroscience: progress and implications for mental health. *Perspectives on Psychological Science* **2**, 99–123.
- Cacioppo JT, Berntson GG** (1992). Social psychological contributions to the decade of the brain: doctrine of multilevel analysis. *American Psychologist* **47**, 1019–1028.
- Chan RCK, Li H, Cheung EFC, Gong Q-Y** (2010). Impaired facial emotion perception in schizophrenia: a meta-analysis. *Psychiatry Research* **178**, 381–390.
- Cheung C, Yu K, Fung G, Leung M, Wong C, Li Q, Sham P, Chua S, McAlonan GM** (2010). Autistic disorders and schizophrenia: related or remote? An anatomical likelihood estimation. *PLoS ONE* **5**, e12233.

- Chiu PH, Kayali MA, Kishida KT, Tomlin D, Klinger LG, Klinger MR, Montague PR** (2008). Self responses along cingulate cortex reveal quantitative neural phenotype for high-functioning autism. *Neuron* **57**, 463–473.
- Chung YS, Barch D, Strube M** (2014). A meta-analysis of mentalizing impairments in adults with schizophrenia and autism spectrum disorder. *Schizophrenia Bulletin* **40**, 602–616.
- Coghlan S, Horder J, Inkster B, Mendez MA, Murphy DG, Nutt DJ** (2012). GABA system dysfunction in autism and related disorders: from synapse to symptoms. *Neuroscience & Biobehavioral Reviews* **36**, 2044–2055.
- Contreras-Rodríguez O, Pujol J, Batalla I, Harrison BJ, Bosque J, Ibern-Regàs I, Hernández-Ribas R, Soriano-Mas C, Deus J, López-Solà M, Pifarré J, Menchón JM, Cardoner N** (2013). Disrupted neural processing of emotional faces in psychopathy. *Social Cognitive and Affective Neuroscience* **9**, 505–512.
- Corbett BA, Carmean V, Ravizza S, Wendelken C, Henry ML, Carter C, Rivera SM** (2009). A functional and structural study of emotion and face processing in children with autism. *Psychiatry Research: Neuroimaging* **173**, 196–205.
- Coyle JT, Basu A, Benneyworth M, Balu D, Konopaske G** (2012). Glutamatergic synaptic dysregulation in schizophrenia: therapeutic implications. *Handbook of Experimental Pharmacology* **213**, 267–295.
- Cramer SC, Sur M, Dobkin BH, O'Brien C, Sanger TD, Trojanowski JQ, Rumsey JM, Hicks R, Cameron J, Chen D, Chen WG, Cohen LG, deCharms C, Duffy CJ, Eden GF, Fetz EE, Filart R, Freund M, Grant SJ, Haber S, Kalivas PW, Kolb B, Kramer AF, Lynch M, Mayberg HS, McQuillen PS, Nitkin R, Pascual-Leone A, Reuter-Lorenz P, Schiff N, Sharma A, Shekim L, Stryker M, Sullivan EV, Vinogradov S** (2011). Harnessing neuroplasticity for clinical applications. *Brain* **134**, 1591–1609.
- Crockett MJ, Fehr E** (2013). Social brains on drugs: tools for neuromodulation in social neuroscience. *Social Cognitive and Affective Neuroscience* **9**, 250–254.
- Das P, Lagopoulos J, Coulston CM, Henderson AF, Malhi GS** (2012). Mentalizing impairment in schizophrenia: a functional MRI study. *Schizophrenia Research* **134**, 158–164.
- Davidson RJ, McEwen BS** (2012). Social influences on neuroplasticity: stress and interventions to promote well-being. *Nature Neuroscience* **15**, 689–695.
- Dawel A, O'Kearney R, McKone E, Palermo R** (2012). Not just fear and sadness: meta-analytic evidence of pervasive emotion recognition deficits for facial and vocal expressions in psychopathy. *Neuroscience & Biobehavioral Reviews* **36**, 2288–2304.
- Decety J, Chen C, Harenski C, Kiehl KA** (2013a). An fMRI study of affective perspective taking in individuals with psychopathy: imagining another in pain does not evoke empathy. *Frontiers in Human Neuroscience* **7**. doi:10.3389/fnhum.2013.00489.
- Decety J, Michalska KJ, Akitsuki Y, Lahey BB** (2009). Atypical empathic responses in adolescents with aggressive conduct disorder: a functional MRI investigation. *Biological Psychology* **80**, 203–211.
- Decety J, Skelly LR, Kiehl KA** (2013b). Brain response to empathy-eliciting scenarios involving pain in incarcerated individuals with psychopathy. *JAMA Psychiatry* **70**, 638–45.
- Decety J, Skelly LR, Yoder KJ, Kiehl KA** (2013c). Neural processing of dynamic emotional facial expressions in psychopaths. *Social Neuroscience* **9**, 36–49.
- Declerck CH, Boone C, Kiyonari T** (2010). Oxytocin and cooperation under conditions of uncertainty: the modulating role of incentives and social information. *Hormones and Behavior* **57**, 368–374.
- De Dreu CK, Greer LL, van Kleef GA, Shalvi S, Handgraaf MJ** (2011). Oxytocin promotes human ethnocentrism. *Proceedings of the National Academy of Sciences USA* **108**, 1262–1266.
- Deeley Q, Daly E, Surguladze S, Tunstall N, Mezey G, Beer D, Ambikapathy A, Robertson D, Giampietro V, Brammer MJ, Clarke A, Dowsett J, Fahy TA, Philipps ML, Murphy DG** (2006). Facial emotion processing in criminal psychopathy: preliminary functional magnetic resonance imaging study. *British Journal of Psychiatry* **189**, 533–539.
- De Jaegher H, Di Paolo E, Gallagher S** (2010). Can social interaction constitute social cognition? *Trends in Cognitive Sciences* **14**, 441–447.
- Delgado MR, Frank RH, Phelps EA** (2005). Perceptions of moral character modulate the neural systems of reward during the trust game. *Nature Neuroscience* **8**, 1611–1618.
- Demirtas-Tatlidede A, Freitas C, Cromer JR, Safar L, Ongur D, Stone WS, Seidman LJ, Schmahmann JD, Pascual-Leone A** (2010). Safety and proof of principle study of cerebellar vermal theta burst stimulation in refractory schizophrenia. *Schizophrenia Research* **124**, 91–100.
- Derntl B, Finkelmeyer A, Toygar TK, Hülsmann A, Schneider F, Falkenberg DI, Habel U** (2009). Generalized deficit in all core components of empathy in schizophrenia. *Schizophrenia Research* **108**, 197–206.
- Derntl B, Finkelmeyer A, Voss B, Eickhoff SB, Kellermann T, Schneider F, Habel U** (2012). Neural correlates of the core facets of empathy in schizophrenia. *Schizophrenia Research* **136**, 70–81.
- Deschamps PKH, Been M, Matthys W** (2014). Empathy and empathy induced prosocial behavior in 6- and 7-year-olds with autism spectrum disorder. *Journal of Autism and Developmental Disorders* **44**, 1749–1758.
- Dinstein I, Hasson U, Rubin N, Heeger DJ** (2007). Brain areas selective for both observed and executed movements. *Journal of Neurophysiology* **98**, 1415–1427.
- Dodge KA** (1993). Social-cognitive mechanisms in the development of conduct disorder and depression. *Annual Review of Psychology* **44**, 559.
- Dolan M, Fullam R** (2004). Theory of mind and mentalizing ability in antisocial personality disorders with and without psychopathy. *Psychological Medicine* **34**, 1093–1102.
- Domes G, Heinrichs M, Michel A, Berger C, Herpertz SC** (2007). Oxytocin improves 'Mind-Reading' in humans. *Biological Psychiatry* **61**, 731–733.
- Domes G, Hollerbach P, Vohs K, Mokros A, Habermeyer E** (2013a). Emotional empathy and psychopathy in offenders: an experimental study. *Journal of Personality Disorders* **27**, 67–84.

- Domes G, Kumbier E, Heinrichs M, Herpertz SC** (2013b). Oxytocin promotes facial emotion recognition and amygdala reactivity in adults with Asperger syndrome. *Neuropsychopharmacology* **39**, 698–706.
- Doyle-Thomas KAR, Goldberg J, Szatmari P, Hall GBC** (2013). Neurofunctional underpinnings of audiovisual emotion processing in teens with autism spectrum disorders. *Frontiers in Psychiatry* **4**, 48.
- Dziobek I, Rogers K, Fleck S, Bahnemann M, Heekeren HR, Wolf OT, Convit A** (2008). Dissociation of cognitive and emotional empathy in adults with Asperger syndrome using the Multifaceted Empathy Test (MET). *Journal of Autism and Developmental Disorders* **38**, 464–473.
- Eack SM, Hogarty GE, Cho RY, Prasad KM, Greenwald DP, Hogarty SS, Keshavan MS** (2010). Neuroprotective effects of cognitive enhancement therapy against gray matter loss in early schizophrenia: results from a 2-year randomized controlled trial. *Archives of General Psychiatry* **67**, 674–682.
- Ebert A, Kolb M, Heller J, Edel MA, Roser P, Brune M** (2013). Modulation of interpersonal trust in borderline personality disorder by intranasal oxytocin and childhood trauma. *Social Neuroscience* **8**, 305–13.
- Edwards J, Pattison PE, Jackson HJ, Wales RJ** (2001). Facial affect and affective prosody recognition in first-episode schizophrenia. *Schizophrenia Research* **48**, 235–253.
- Eisenberger NI, Cole SW** (2012). Social neuroscience and health: neurophysiological mechanisms linking social ties with physical health. *Nature Neuroscience* **15**, 669–674.
- Evans S, Shergill SS, Averbach BB** (2010). Oxytocin decreases aversion to angry faces in an associative learning task. *Neuropsychopharmacology* **35**, 2502–2509.
- Fan YT, Chen C, Chen SC, Decety J, Cheng Y** (2014). Empathic arousal and social understanding in individuals with autism: evidence from fMRI and ERP measurements. *Social Cognitive and Affective Neuroscience* **9**, 1203–1213.
- Fehr E** (2009). On the economics and biology of trust. *Journal of the European Economic Association* **7**, 235–266.
- Fehr E, Fischbacher U** (2003). The nature of human altruism. *Nature* **425**, 785–791.
- Fehr E, Gächter S** (2002). Altruistic punishment in humans. *Nature* **415**, 137–140.
- Fett A-KJ, Shergill SS, Joyce DW, Riedl A, Strobel M, Gromann PM, Krabbendam L** (2012). To trust or not to trust: the dynamics of social interaction in psychosis. *Brain* **135**, 976–984.
- Fett A-KJ, Viechtbauer W, Dominguez MD, Penn DL, van Os J, Krabbendam L** (2011). The relationship between neurocognition and social cognition with functional outcomes in schizophrenia: a meta-analysis. *Neuroscience & Biobehavioral Reviews* **35**, 573–88.
- Fitzsimmons J, Kubicki M, Shenton ME** (2013). Review of functional and anatomical brain connectivity findings in schizophrenia. *Current Opinion in Psychiatry* **26**, 172–187.
- Forbes CE, Grafman J** (2013). Social neuroscience: the second phase. *Frontiers in Human Neuroscience* **7**, 20.
- Frith CD** (2004). Schizophrenia and theory of mind. *Psychological Medicine* **34**, 385–389.
- Frith CD** (2007). The social brain? *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences* **362**, 671–678.
- Frith CD** (2008). Social cognition. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences* **363**, 2033–2039.
- Frith CD, Frith U** (2012). Mechanisms of social cognition. *Annual Review of Psychology* **63**, 287–313.
- Gabbard GO** (2000). A neurobiologically informed perspective on psychotherapy. *British Journal of Psychiatry* **177**, 117–22.
- Gonzalez-Lieners C, Shamay-Tsoory SG, Brüne M** (2013). Towards a neuroscience of empathy: ontogeny, phylogeny, brain mechanisms, context and psychopathology. *Neuroscience & Biobehavioral Reviews* **37**, 1537–1548.
- Grady CL, Keightley ML** (2002). Studies of altered social cognition in neuropsychiatric disorders using functional neuroimaging. *Canadian Journal of Psychiatry* **47**, 327–336.
- Green MF, Penn DL, Bentall R, Carpenter WT, Gaebel W, Ruben GC, Kring AM, Park S, Silverstein M, Heinsen R** (2008). Social cognition in schizophrenia: an NIMH workshop on definitions, assessment, and research opportunities. *Schizophrenia Bulletin* **34**, 1211–1220.
- Greimel E, Nehr Korn B, Schulte-Rüther M, Fink G, Nickl-Jockschat T, Herpertz-Dahlmann B, Konrad K, Eickhoff S** (2013). Changes in grey matter development in autism spectrum disorder. *Brain Structure and Function* **218**, 929–942.
- Greimel E, Schulte-Rüther M, Fink GR, Piefke M, Herpertz-Dahlmann B, Konrad K** (2010). Development of neural correlates of empathy from childhood to early adulthood: an fMRI study in boys and adult men. *Journal of Neural Transmission* **117**, 781–791.
- Gromann PM, Heslenfeld DJ, Fett A-KJ, Joyce DW, Shergill SS, Krabbendam L** (2013). Trust versus paranoia: abnormal response to social reward in psychotic illness. *Brain* **136**, 1968–1975.
- Gromann PM, Shergill SS, de Haan L, Meewis D, Fett A-KJ, Korver-Nieberg N, Krabbendam L** (2014). Reduced brain reward response during cooperation in first-degree relatives of patients with psychosis: an fMRI study. *Psychological Medicine*. Published online 9 April 2014. doi:10.1017/S0033291714000737.
- Gromann PM, Tracy DK, Giampietro V, Brammer MJ, Krabbendam L, Shergill SS** (2012). Examining frontotemporal connectivity and rTMS in healthy controls: implications for auditory hallucinations in schizophrenia. *Neuropsychology* **26**, 127–132.
- Grove R, Baillie A, Allison C, Baron-Cohen S, Hoekstra R** (2014). The latent structure of cognitive and emotional empathy in individuals with autism, first-degree relatives and typical individuals. *Molecular Autism* **5**, 42.
- Guastella AJ, Einfeld SL, Gray KM, Rinehart NJ, Tonge BJ, Lambert TJ, Hickie IB** (2010). Intranasal oxytocin improves emotion recognition for youth with autism spectrum disorders. *Biological Psychiatry* **67**, 692–694.
- Hadjikhani N, Zurcher NR, Rogier O, Hippolyte L, Lemonnier E, Ruest T, Ward N, Lassalle A, Gillberg N,**

- Billstedt E, Helles A, Gillberg C, Solomon P, Prkachin KM** (2014). Emotional contagion for pain is intact in autism spectrum disorders. *Translational Psychiatry* **4**, e343.
- Hare RD, Vertommen H** (2003). *The Hare Psychopathy Checklist – Revised*. Toronto: Multi-Health Systems, Incorporated.
- Harms MB, Martin A, Wallace GL** (2010). Facial emotion recognition in autism spectrum disorders: a review of behavioral and neuroimaging studies. *Neuropsychology Review* **20**, 290–322.
- Harvey PO, Zaki J, Lee J, Ochsner K, Green MF** (2013). Neural substrates of empathic accuracy in people with schizophrenia. *Schizophrenia Bulletin* **39**, 617–628.
- Hasler G** (2012). Can the neuroeconomics revolution revolutionize psychiatry? *Neuroscience & Biobehavioral Reviews* **36**, 64–78.
- Herpertz SC** (2013). The social-cognitive basis of personality disorders: commentary on the special issue. *Journal of Personality Disorders* **27**, 113–124.
- Hoekert M, Kahn RS, Pijnenborg M, Aleman A** (2007). Impaired recognition and expression of emotional prosody in schizophrenia: review and meta-analysis. *Schizophrenia Research* **96**, 135–145.
- Hollander E, Bartz J, Chaplin W, Phillips A, Sumner J, Soorya L, Anagnostou E, Wasserman S** (2007). Oxytocin increases retention of social cognition in autism. *Biological Psychiatry* **61**, 498–503.
- Hooker CI, Bruce L, Fisher M, Verosky SC, Miyakawa A, D’Esposito M, Vinogradov S** (2013). The influence of combined cognitive plus social-cognitive training on amygdala response during face emotion recognition in schizophrenia. *Psychiatry Research* **213**, 99–107.
- Hooker CI, Bruce L, Fisher M, Verosky SC, Miyakawa A, Vinogradov S** (2012). Neural activity during emotion recognition after combined cognitive plus social cognitive training in schizophrenia. *Schizophrenia Research* **139**, 53–59.
- Insel TR** (2010). The challenge of translation in social neuroscience: a review of oxytocin, vasopressin, and affiliative behavior. *Neuron* **65**, 768–779.
- Jones AP, Happé FG, Gilbert F, Burnett S, Viding E** (2010). Feeling, caring, knowing: different types of empathy deficit in boys with psychopathic tendencies and autism spectrum disorder. *Journal of Child Psychology and Psychiatry* **51**, 1188–1197.
- Joyce DW, Averbeck BB, Frith CD, Shergill SS** (2013). Examining belief and confidence in schizophrenia. *Psychological Medicine* **43**, 2327–2338.
- Kana RK, Libero LE, Hu CP, Deshpande HD, Colburn JS** (2014). Functional brain networks and white matter underlying theory-of-mind in autism. *Social Cognitive and Affective Neuroscience* **9**, 98–105.
- Kana RK, Libero LE, Moore MS** (2011). Disrupted cortical connectivity theory as an explanatory model for autism spectrum disorders. *Physics of Life Reviews* **8**, 410–437.
- Kapur S, Mizrahi R, Li M** (2005). From dopamine to salience – to psychosis – linking biology, pharmacology and phenomenology of psychosis. *Schizophrenia Research* **79**, 59–68.
- Kennedy DP, Adolphs R** (2012). The social brain in psychiatric and neurological disorders. *Trends in Cognitive Sciences* **16**, 559–572.
- Keysers C, Kaas JH, Gazzola V** (2010). Somatosensation in social perception. *Nature Reviews Neuroscience* **11**, 417–428.
- Keysers C, Meffert H, Gazzola V** (2014). Reply: Spontaneous versus deliberate vicarious representations: different routes to empathy in psychopathy and autism. *Brain*. doi: 10.1093/brain/awt376.
- Kilner JM, Friston KJ, Frith CD** (2007). The mirror-neuron system: a Bayesian perspective. *Neuroreport* **18**, 619–623.
- King-Casas B** (2005). Getting to know you: reputation and trust in a two-person economic exchange. *Science* **308**, 78–83.
- King-Casas B, Chiu PH** (2012). Understanding interpersonal function in psychiatric illness through multiplayer economic games. *Biological Psychiatry* **72**, 119–125.
- King-Casas B, Sharp C, Lomax-Bream L, Lohrenz T, Fonagy P, Montague PR** (2008). The rupture and repair of cooperation in borderline personality disorder. *Science* **321**, 806–810.
- Kleinhans NM, Richards T, Johnson LC, Weaver KE, Greenon J, Dawson G, Aylward E** (2011). fMRI evidence of neural abnormalities in the subcortical face processing system in ASD. *Neuroimage* **54**, 697–704.
- Koenigs M, Kruepke M, Newman JP** (2010). Economic decision-making in psychopathy: a comparison with ventromedial prefrontal lesion patients. *Neuropsychologia* **48**, 2198–204.
- Kohler CG, Walker JB, Martin EA, Healey KM, Moberg PJ** (2010). Facial emotion perception in schizophrenia: a meta-analytic review. *Schizophrenia Bulletin* **36**, 1009–1019.
- Kosfeld M, Heinrichs M, Zak PJ, Fischbacher U, Fehr E** (2005). Oxytocin increases trust in humans. *Nature Neuroscience* **435**, 673–676.
- Krabbandam L, Hooker CI, Aleman A** (2014). Neural effects of the social environment. *Schizophrenia Bulletin* **40**, 248–251.
- Lee D** (2013). Decision making: from neuroscience to psychiatry. *Neuron* **78**, 233–248.
- Lee J, Quintana J, Nori P, Green MF** (2011a). Theory of mind in schizophrenia: exploring neural mechanisms of belief attribution. *Social Neuroscience* **6**, 569–581.
- Lee J, Zaki J, Harvey P-O, Ochsner K, Green MF** (2011b). Schizophrenia patients are impaired in empathic accuracy. *Psychological Medicine* **41**, 2297–2304.
- Lepage M, Sergerie K, Benoit A, Czechowska Y, Dickie E, Armony JL** (2011). Emotional face processing and flat affect in schizophrenia: functional and structural neural correlates. *Psychological Medicine* **41**, 1833–1844.
- Levkovitz Y, Rabany L, Harel EV, Zangen A** (2011). Deep transcranial magnetic stimulation add-on for treatment of negative symptoms and cognitive deficits of schizophrenia: a feasibility study. *The International Journal of Neuropsychopharmacology* **14**, 991–996.
- Li H, Chan RCK, McAlonan GM, Gong Q-Y** (2010). Facial emotion processing in schizophrenia: a meta-analysis of functional neuroimaging data. *Schizophrenia Bulletin* **36**, 1029–1039.
- Lieberman MD** (2007). Social cognitive neuroscience: a review of core processes. *Annual Review of Psychology* **58**, 259–289.

- Lombardo MV, Chakrabarti B, Bullmore ET, Baron-Cohen S** (2011). Specialization of right temporo-parietal junction for mentalizing and its relation to social impairments in autism. *Neuroimage* **56**, 1832–1838.
- Lozier LM, Vanmeter JW, Marsh AA** (2014). Impairments in facial affect recognition associated with autism spectrum disorders: a meta-analysis. *Development and Psychopathology* **10**, 1–13.
- MacDonald K, Feifel D** (2012). Oxytocin in schizophrenia: a review of evidence for its therapeutic effects. *Acta Neuropsychiatrica* **24**, 130–146.
- Mandal MK, Pandey R, Prasad AB** (1998). Facial expressions of emotions and schizophrenia: a review. *Schizophrenia Bulletin* **24**, 399.
- Mars RB, Neubert FX, Noonan MP, Sallet J, Toni I, Rushworth MFS** (2012). On the relationship between the ‘default mode network’ and the ‘social brain’. *Frontiers in Human Neuroscience* **6**, 189.
- Marsh AA, Blair RJR** (2008). Deficits in facial affect recognition among antisocial populations: a meta-analysis. *Neuroscience & Biobehavioral Reviews* **32**, 454–465.
- Marsh AA, Finger EC, Fowler KA, Adalio CJ, Jurkowitz IT, Schechter JC, Pine DS, Decety J, Blair RJ** (2013). Empathic responsiveness in amygdala and anterior cingulate cortex in youths with psychopathic traits. *Journal of Child Psychology and Psychiatry* **54**, 900–910.
- Mathersul D, McDonald S, Rushby JA** (2013). Understanding advanced theory of mind and empathy in high-functioning adults with autism spectrum disorder. *Journal of Clinical and Experimental Neuropsychology* **35**, 655–668.
- McDonald NM, Messinger DS** (2012). Empathic responding in toddlers at risk for an autism spectrum disorder. *Journal of Autism and Developmental Disorders* **42**, 1566–1573.
- Meffert H, Gazzola V, den Boer JA, Bartels AA, Keysers C** (2013). Reduced spontaneous but relatively normal deliberate vicarious representations in psychopathy. *Brain* **136**, 2550–2562.
- Mendez MF, Manes F** (2011). The emerging impact of social neuroscience on neuropsychiatry and clinical neuroscience. *Social Neuroscience* **6**, 415–419.
- Menon V** (2011). Large-scale brain networks and psychopathology: a unifying triple network model. *Trends in Cognitive Sciences* **15**, 483–506.
- Meyer-Lindenberg A, Domes G, Kirsch P, Heinrichs M** (2011). Oxytocin and vasopressin in the human brain: social neuropeptides for translational medicine. *Nature Reviews Neuroscience* **12**, 524–538.
- Meyer-Lindenberg A, Tost H** (2012). Neural mechanisms of social risk for psychiatric disorders. *Nature Neuroscience* **15**, 663–668.
- Mier D, Haddad L, Diers K, Dressing H, Meyer-Lindenberg A, Kirsch P** (2014a). Reduced embodied simulation in psychopathy. *World Journal of Biological Psychiatry* **15**, 479–487.
- Mier D, Lis S, Zygodnik K, Sauer C, Ulferts J, Gallhofer B, Kirsch P** (2014b). Evidence for altered amygdala activation in schizophrenia in an adaptive emotion recognition task. *Psychiatry Research* **221**, 195–203.
- Millan MJ, Agid Y, Brune M, Bullmore ET, Carter CS, Clayton NS, Connor R, Davis S, Deakin B, DeRubeis RJ, Dubois B, Geyer MA, Goodwin GM, Gorwood P, Jay TM, Joels M, Mansuy IM, Meyer-Lindenberg A, Murphy D, Rolls E, Saletu B, Spedding M, Sweeney J, Whittington M, Young LJ** (2012). Cognitive dysfunction in psychiatric disorders: characteristics, causes and the quest for improved therapy. *Nature Reviews Drug Discovery* **11**, 141–168.
- Minzenberg MJ, Carter CS** (2012). Developing treatments for impaired cognition in schizophrenia. *Trends in Cognitive Sciences* **16**, 35–42.
- Mitchell JP, Mason MF, Macrae CN, Banaji MR** (2005). *Thinking About Others: The Neural Substrates of Social Cognition*. MIT Press: Cambridge, MA.
- Mokros A, Menner B, Eisenbarth H, Alpers GW, Lange KW, Osterheider M** (2008). Diminished cooperativeness of psychopaths in a prisoner’s dilemma game yields higher rewards. *Journal of Abnormal Psychology* **117**, 406–413.
- Molenberghs P, Cunningham R, Mattingley JB** (2012). Brain regions with mirror properties: a meta-analysis of 125 human fMRI studies. *Neuroscience & Biobehavioral Reviews* **36**, 341–349.
- Montag C, Dziobek I, Richter IS, Neuhaus K, Lehmann A, Sylla R, Heekeren HR, Heinz A, Gallinat J** (2011). Different aspects of theory of mind in paranoid schizophrenia: evidence from a video-based assessment. *Psychiatry Research* **186**, 203–209.
- Montag C, Heinz A, Kunz D, Gallinat J** (2007). Self-reported empathic abilities in schizophrenia. *Schizophrenia Research* **92**, 85–89.
- Montague PR, Dolan RJ, Friston KJ, Dayan P** (2012). Computational psychiatry. *Trends in Cognitive Sciences* **16**, 72–80.
- Morelli SA, Rameson LT, Lieberman MD** (2012). The neural components of empathy: predicting daily prosocial behavior. *Social Cognitive and Affective Neuroscience* **9**, 39–47.
- Mothersill O, Morris DW, Kelly S, Rose EJ, Bokde A, Reilly R, Gill M, Corvin AP, Donohoe G** (2014). Altered medial prefrontal activity during dynamic face processing in schizophrenia spectrum patients. *Schizophrenia Research* **157**, 225–230.
- Murphy D** (2006). Theory of mind in Asperger’s syndrome, schizophrenia and personality disordered forensic patients. *Cognitive Neuropsychiatry* **11**, 99–111.
- Neuhaus E, Beauchaine TP, Bernier R** (2010). Neurobiological correlates of social functioning in autism. *Clinical Psychology Review* **30**, 733–748.
- Norman GJ, Hawkey LC, Cole SW, Berntson GG, Cacioppo JT** (2011). Social Neuroscience: the social brain, oxytocin, and health. *Social Neuroscience* **7**, 18–29.
- Ochsner KN** (2008). The social-emotional processing stream: five core constructs and their translational potential for schizophrenia and beyond. *Biological Psychiatry* **64**, 48–61.
- O’Doherty JP, Hampton A, Kim H** (2007). Model-based fMRI and its application to reward learning and decision making. *Annals of the New York Academy of Sciences* **1104**, 35–53.
- Osugi M, Matsumoto H, Suzuki K, Ozawa F, Fukuda R, Uchiyama I, Suckling J, Isoda H, Mori N, Takei N**

- (2003). fMRI study of recognition of facial expressions in high-functioning autistic patients. *Neuroreport* **14**, 559–563.
- Olbert CM, Penn DL, Kern RS, Lee J, Horan WP, Reise SP, Ochsner KN, Marder SR, Green MF** (2013). Adapting social neuroscience measures for schizophrenia clinical trials, Part 3: Fathoming external validity. *Schizophrenia Bulletin* **39**, 1211–1218.
- O’Nions E, Sebastian CL, McCrory E, Chantiluke K, Happé F, Viding E** (2014). Neural bases of theory of mind in children with autism spectrum disorders and children with conduct problems and callous-unemotional traits. *Developmental Science* **17**, 786–796.
- Pedersen A, Koelkebeck K, Brandt M, Wee M, Kueppers KA, Kugel H, Kohl W, Bauer J, Ohrmann P** (2012). Theory of mind in patients with schizophrenia: is mentalizing delayed? *Schizophrenia Research* **137**, 224–229.
- Pelphrey KA, Mitchell TV, McKeown MJ, Goldstein J, Allison T, McCarthy G** (2003). Brain activity evoked by the perception of human walking: controlling for meaningful coherent motion. *Journal of Neuroscience* **23**, 6819–6825.
- Pelphrey KA, Morris JP, McCarthy G, Labar KS** (2007). Perception of dynamic changes in facial affect and identity in autism. *Social Cognitive and Affective Neuroscience* **2**, 140–149.
- Pemmett J** (2013). Neurobiology of antisocial personality disorder: the quest for rehabilitation and treatment. *Journal of Aggression and Violent Behavior* **18**. doi: 10.1016/j.avb.2012.10.004.
- Pfابigan DM, Seidel E-M, Wucherer AM, Keckeis K, Derntl B, Lamm C** (2014). Affective empathy differs in male violent offenders with high-and low-trait psychopathy. *Journal of Personality Disorders* **28**, 1–20.
- Phan KL, Sripada CS, Angstadt M, McCabe K** (2010). Reputation for reciprocity engages the brain reward center. *Proceedings of the National Academy of Sciences* **107**, 13099–13104.
- Piggot J, Kwon H, Mobbs D, Blasey C, Lotspeich L, Menon V, Bookheimer S, Reiss AL** (2004). Emotional attribution in high-functioning individuals with autistic spectrum disorder: a functional imaging study. *Journal of the American Academy of Child and Adolescent Psychiatry* **43**, 473–480.
- Poldrack RA** (2006). Can cognitive processes be inferred from neuroimaging data? *Trends in Cognitive Sciences* **10**, 59–63.
- Poldrack RA** (2007). Region of interest analysis for fMRI. *Social Cognitive and Affective Neuroscience* **2**, 67–70.
- Rapp AM, Langohr K, Mutschler DE, Klingberg S, Wild B, Erb M** (2013). Isn’t it ironic? Neural correlates of irony comprehension in schizophrenia. *PLoS ONE* **8**, e74224.
- Richell RA, Mitchell DG, Newman C, Leonard A, Baron-Cohen S, Blair RJ** (2003). Theory of mind and psychopathy: can psychopathic individuals read the ‘language of the eyes’? *Neuropsychologia* **41**, 523–526.
- Rilling JK, DeMarco AC, Hackett PD, Thompson R, Ditzen B, Patel R, Pagnoni G** (2012). Effects of intranasal oxytocin and vasopressin on cooperative behavior and associated brain activity in men. *Psychoneuroendocrinology* **37**, 447–461.
- Rilling JK, Glenn AL, Jairam MR, Pagnoni G, Goldsmith DR, Elfenbein HA, Lilienfeld SO** (2007). Neural correlates of social cooperation and non-cooperation as a function of psychopathy. *Biological Psychiatry* **61**, 1260–1271.
- Rilling JK, Sanfey AG, Aronson JA, Nystrom LE, Cohen JD** (2004). The neural correlates of theory of mind within interpersonal interactions. *Neuroimage* **22**, 1694–1703.
- Rizzolatti G, Craighero L** (2004). The mirror-neuron system. *Annual Review of Neuroscience* **27**, 169–192.
- Roepke V, Preißler H, Dziobek I** (2013). Social cognition in borderline personality disorder. *Frontiers in Neuroscience* **6**, 195.
- Rogers K, Dziobek I, Hassenstab J, Wolf OT, Convit A** (2007). Who cares? Revisiting empathy in Asperger syndrome. *Journal of Autism and Developmental Disorders* **37**, 709–715.
- Ross LA, Olson IR** (2010). Social cognition and the anterior poles. *Neuroimage* **49**, 3452–3462.
- Santiesteban I, Banissy MJ, Catmur C, Bird G** (2012). Enhancing social ability by stimulating right temporoparietal junction. *Current Biology* **22**, 2274–2277.
- Scheeren AM, Koot HM, Mundy PC, Mous L, Begeer S** (2013). Empathic responsiveness of children and adolescents with high-functioning autism spectrum disorder. *Autism Research* **6**, 362–371.
- Schilbach L, Bzdok D, Timmermans B, Fox PT, Laird AR, Vogeley K, Eickhoff SB** (2012). Introspective minds: using ALE Meta-Analyses to study commonalities in the neural correlates of emotional processing, social and unconstrained cognition. *PLoS ONE* **7**, e30920.
- Schilbach L, Eickhoff SB, Rotarska-Jagiela A, Fink GR, Vogeley K** (2008). Minds at rest? Social cognition as the default mode of cognizing and its putative relationship to the ‘default system’ of the brain. *Consciousness and Cognition* **17**, 457–467.
- Schneider K, Regenbogen C, Pauly KD, Gossen A, Schneider DA, Mevissen L, Michel TM, Gur RC, Habel U, Schneider F** (2013). Evidence for gender-specific endophenotypes in high-functioning autism spectrum disorder during empathy. *Autism Research* **6**, 506–521.
- Schulte-Ruther M, Greimel E, Markowitsch HJ, Kamp-Becker I, Remschmidt H, Fink GR, Piefke M** (2011). Dysfunctions in brain networks supporting empathy: an fMRI study in adults with autism spectrum disorders. *Social Neuroscience* **6**, 1–21.
- Schwenck C, Mergenthaler J, Keller K, Zech J, Salehi S, Taurines R, Romanos M, Schecklmann M, Schneider W, Warnke A** (2012). Empathy in children with autism and conduct disorder: group-specific profiles and developmental aspects. *Journal of Child Psychology and Psychiatry* **53**, 651–659.
- Shalom DB, Mostofsky SH, Hazlett RL, Goldberg MC, Landa RJ, Faran Y, McLeod DR, Hoehn-Saric R** (2006). Normal physiological emotions but differences in expression of conscious feelings in children with high-functioning autism. *Journal of Autism and Developmental Disorders* **36**, 395–400.
- Shamay-Tsoory SG, Harari H, Aharon-Peretz J, Levkovitz Y** (2010). The role of the orbitofrontal cortex in affective theory of mind deficits in criminal offenders with psychopathic tendencies. *Cortex* **46**, 668–677.

- Sharp C, Ha C, Fonagy P** (2011). Get them before they get you: trust, trustworthiness, and social cognition in boys with and without externalizing behavior problems. *Development and Psychopathology* **23**, 647–658.
- Sharp C, Monterosso J, Montague PR** (2012). Neuroeconomics: a bridge for translational research. *Biological Psychiatry* **72**, 87–92.
- Sharp C, Vanwoerden S** (2014). Social cognition: empirical contribution. The developmental building blocks of psychopathic traits: revisiting the role of theory of mind. *Journal of Personality Disorders* **28**, 78–95.
- Silani G, Bird S, Brindley R, Singer T, Frith U** (2008). Levels of emotional awareness and autism: an fMRI study. *Social Neuroscience* **3**, 97–112. doi: 10.1080/17470910701577020.
- Singer T** (2006). The neuronal basis and ontogeny of empathy and mind reading: review of literature and implications for future research. *Neuroscience & Biobehavioral Reviews* **30**, 855–863.
- Smith MJ, Horan WP, Cobia DJ, Karpouzian TM, Fox JM, Reilly JL, Breiter HC** (2013). Performance-based empathy mediates the influence of working memory on social competence in schizophrenia. *Schizophrenia Bulletin* **40**, 824–834.
- Smith MJ, Horan WP, Karpouzian TM, Abram SV, Cobia DJ, Csernansky JG** (2012). Self-reported empathy deficits are uniquely associated with poor functioning in schizophrenia. *Schizophrenia Research* **137**, 196–202.
- Sommer M, Sodian B, Döhnel K, Schwerdtner J, Meinhardt J, Hajak G** (2010). In psychopathic patients emotion attribution modulates activity in outcome-related brain areas. *Psychiatry Research: Neuroimaging* **182**, 88–95.
- Sprong M, Schothorst P, Vos E, Hox J, van Engeland H** (2007). Theory of mind in schizophrenia: a meta-analysis. *British Journal of Psychiatry* **191**, 5–13.
- Sripada CS, Angstadt M, Banks S, Nathan PJ, Liberzon I, Phan KL** (2009). Functional neuroimaging of mentalizing during the trust game in social anxiety disorder. *Neuroreport* **20**, 984–989.
- Stavropoulos KKM, Carver LJ** (2013). Research review: social motivation and oxytocin in autism – implications for joint attention development and intervention. *Journal of Child Psychology and Psychiatry* **54**, 603–618.
- Sugranyes G, Kyriakopoulos M, Corrigall R, Taylor E, Frangou S** (2011). Autism spectrum disorders and schizophrenia: meta-analysis of the neural correlates of social cognition. *PLoS ONE* **6**. doi:10.1371/journal.pone.002532.
- Taylor SF, Kang J, Brege IS, Tso IF, Hosanagar A, Johnson TD** (2012). Meta-analysis of functional neuroimaging studies of emotion perception and experience in schizophrenia. *Biological Psychiatry* **71**, 136–145.
- Tomlin D, Kayali MA, King-Casas B, Anen C, Camerer CF, Quartz SR, Montague PR** (2006). Agent-specific responses in the cingulate cortex during economic exchanges. *Science* **312**, 1047–1050.
- Tottenham N, Hertzog ME, Gillespie-Lynch K, Gilhooly T, Millner AJ, Casey B** (2013). Elevated amygdala response to faces and gaze aversion in autism spectrum disorder. *Social Cognitive and Affective Neuroscience* **9**, 106–117.
- Toyokawa S, Uddin M, Koenen KC, Galea S** (2012). How does the social environment ‘get into the mind’? Epigenetics at the intersection of social and psychiatric epidemiology. *Social Science & Medicine* **74**, 67–74.
- Tracy DK, O’Daly O, Joyce DW, Michalopoulou PG, Basit BB, Dhillon G, McLoughlin DM, Shergill SS** (2010). An evoked auditory response fMRI study of the effects of rTMS on putative AVH pathways in healthy volunteers. *Neuropsychologia* **48**, 270–277.
- Tzieropoulos H** (2013). The Trust Game in neuroscience: a short review. *Social Neuroscience* **8**, 407–416.
- Uljarevic M, Hamilton A** (2013). Recognition of emotions in autism: a formal meta-analysis. *Journal of Autism and Developmental Disorders* **43**, 1517–1526.
- van den Bos W, van Dijk E, Westenberg H, Rombout SARB, Crone EA** (2011). Changing brains, changing perspectives: the neurocognitive development of reciprocity. *Psychological Science* **22**, 60–70.
- van der Gaag C, Minderaa RB, Keyers C** (2007). Facial expressions: what the mirror neuron system can and cannot tell us. *Social Neuroscience* **2**, 179–222.
- van der Meer L, Costafreda S, Aleman A, David AS** (2010). Self-reflection and the brain: a theoretical review and meta-analysis of neuroimaging studies with implications for schizophrenia. *Neuroscience & Biobehavioral Reviews* **34**, 935–946.
- van Overwalle F** (2009). Social cognition and the brain: a meta-analysis. *Human Brain Mapping* **30**, 829–858.
- van Overwalle F, Baetens K** (2009). Understanding others’ actions and goals by mirror mentalizing systems. *Neuroimage* **48**, 564–584.
- van Veluw S, Chance S** (2014). Differentiating between self and others: an ALE meta-analysis of fMRI studies of self-recognition and theory of mind. *Brain Imaging and Behavior* **8**, 24–38.
- Varga E, Simon M, Tényi T, Schnell Z, Hajnal A, Orsi G, Dóczy T, Komoly S, Janszky J, Füredi R** (2013). Irony comprehension and context processing in schizophrenia during remission—A functional MRI study. *Brain and Language* **126**, 231–242.
- Vieira JB, Almeida PR, Ferreira-Santos F, Barbosa F, Marques-Teixeira J, Marsh AA** (2013). Distinct neural activation patterns underlie economic decisions in high and low psychopathy scorers. *Social Cognitive and Affective Neuroscience* **9**, 1099–1107.
- Wang AT, Lee SS, Sigman M, Dapretto M** (2006). Neural basis of irony comprehension in children with autism: the role of prosody and context. *Brain* **129**, 932–943.
- Weng SJ, Carrasco M, Swartz JR, Wiggins JL, Kurapati N, Liberzon I, Risi S, Lord C, Monk CS** (2011). Neural activation to emotional faces in adolescents with autism spectrum disorders. *Journal of Child Psychology and Psychiatry* **52**, 296–305.
- Wicker B, Fonlupt P, Hubert B, Tardif C, Gepner B, Deruelle C** (2008). Abnormal cerebral effective connectivity during explicit emotional processing in adults with autism

- spectrum disorder. *Social Cognitive and Affective Neuroscience* 3, 135–143.
- Wigton R, Radua J, Allen P, Averbeck B, Meyer-Lindenberg A, McGuire P, Shergill SS, Fusar-Poli P** (in press). Neurophysiological effects of acute oxytocin administration: systematic review and meta-analysis of placebo-controlled imaging studies. *Journal of Psychiatry and Neuroscience.*
- Wilson K, Juodis M, Porter S** (2011). Fear and loathing in psychopaths: a meta-analytic investigation of the facial affect recognition deficit. *Criminal Justice and Behavior* 38, 659–668.
- Wykes T, Brammer M, Mellers J, Bray P, Reeder C, Williams C, Corner J** (2002). Effects on the brain of a psychological treatment: cognitive remediation therapy: functional magnetic resonance imaging in schizophrenia. *British Journal of Psychiatry* 181, 144–152.
- Yirmiya N, Erel O, Shaked M, Solomonica-Levi D** (1998). Meta-analyses comparing theory of mind abilities of individuals with autism, individuals with mental retardation, and normally developing individuals. *Psychological Bulletin* 124, 283.
- Yirmiya N, Sigman MD, Kasari C, Mundy P** (1992). Empathy and cognition in high-functioning children with autism. *Child development* 63, 150–160.
- Zaki J, Ochsner K** (2011). Reintegrating the study of accuracy into social cognition research. *Psychological Inquiry* 22, 159–182.