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Journal

Cognitive, Affective, & Behavioral Neuroscience, 14(3)

ISSN

1530-7026

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Publication Date

2014-09-01

DOI

10.3758/s13415-013-0245-8

Peer reviewed

Some markers of mirroring appear intact in schizophrenia: evidence from mu suppression

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Abstract Although schizophrenia is associated with impairments in social cognition, the scope and neural correlates of these disturbances are largely unknown. In this study, we investigated whether schizophrenia patients show impaired functioning of the mirror neuron system (MNS), as indexed by electroencephalographic (EEG) mu (8–13 Hz) suppression, a hypothesized biomarker of MNS activity that is sensitive to the degree of social interaction depicted in visual stimuli. A total of 32 outpatients and 26 healthy controls completed an EEG paradigm that included six action observation or execution conditions that differed in their degrees of social interaction. Participants also completed a validated empathy questionnaire. Across both groups, we found a significant linear increase in mu suppression across the conditions involving greater levels of social engagement and interaction, but no significant group or interaction effects. Patients self-reported diminished empathic concern and perspective taking, which showed some moderate relations to mu suppression levels. Thus, the schizophrenia group showed generally intact modulation of MNS functioning at the electrophysiological level, despite self-reporting empathic disturbances. The disturbances commonly seen on self-report, performance, and neuroimaging measures of mentalizing in schizophrenia may largely reflect difficulties with higher-level inferential processes about others' emotions, rather than a basic incapacity to share in these experiences.

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Introduction

Schizophrenia is characterized by social cognitive impairments in areas such as emotion processing, social perception, and theory of mind (Savla, Vella, Armstrong, Penn, & Twamley, 2012). These impairments account for unique variance in functional outcome above and beyond nonsocial neurocognitive deficits and clinical symptoms (Green & Horan, 2010). Although these findings demonstrate the unique functional significance of social cognition, our understanding of the scope (e.g., whether automatic processes are also impaired; Lieberman, 2007), and neural correlates of these impairments in schizophrenia is limited (Brunet-Gouet et al., 2011). Guided by findings from social neuroscience, recent studies in schizophrenia have begun to extend work in this area to investigations of empathy (e.g., M. C. Davis et al., 2013; Harvey, Zaki, Lee, Ochsner, & Green, 2013; Smith et al., 2012). Empathy is a multifaceted construct that can be broadly defined as the ability to understand and share the emotional experiences of others (Decety, 2010; Iacoboni, 2009). The capacity to accurately empathize is believed to involve both effortful "mentalizing" processes and relatively automatic "mirroring" processes. In the present study, we evaluated whether people with schizophrenia show impairments in mirroring processes at the electrophysiological level.

Social neuroscience models indicate that accurate empathizing involves two components with distinct neural correlates that typically work in concert to promote adaptive functioning (Zaki & Ochsner, 2011, 2012). The first, *mentalizing*, refers to understanding another person's emotions by making inferences about his/her mental states. Mentalizing tasks are strongly associated with activation of the dorsomedial PFC and, in a somewhat

more task dependent manner, on other regions such as the temporal–parietal junction and temporal pole.

The second, *mirroring*, refers to automatic "simulation" of others' actions, which is believed to facilitate understanding of the actions and even emotions of others (Iacoboni, 2009). It has been proposed that the mirror neuron system (MNS) provides a neurophysiological basis for imitative behavior, which is believed to constitute a prerequisite for social cognitive development. First described in the ventral premotor and inferior parietal cortices of monkeys (Rizzolatti & Craighero, 2004), neurons with mirroring properties fire both when producing and merely observing goal-directed actions performed by another agent. An analogous system in the human brain—incorporating the pars opercularis of the inferior frontal gyrus and adjacent ventral premotor cortex, as well as the anterior inferior parietal lobe—has been identified in many studies (see Caspers, Zilles, Laird, & Eickhoff, 2010; Iacoboni, 2009). For example, fMRI studies show that these regions activate both while producing and observing relatively low-level hand movements performed by others (e.g., Iacoboni et al., 1999; Iacoboni et al., 2001). This common coding of motor perception and motor action is believed to enable us to represent and understand the actions of others in terms of our own actions. Consistent with the notion that MNS regions activated during low level motor perception tasks support higher-level social cognitive processes such as empathizing with the emotions of others, similar regions show mirroring properties during tasks involving higher level socioemotional stimuli, such as observing/producing facial emotion expressions and observing complex goal-directed movements (see Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Caspers et al., 2010; Dapretto et al., 2006). Thus, observing another person automatically activates corresponding motor and mental representations in the observer, enabling him/her to share in and understand the actions and experiences of others (Rizzolatti & Craighero, 2004).

In addition to fMRI, the neural substrates of the MNS can be assessed with electroencephalographic (EEG) studies of mu frequency band oscillations (Pineda, 2005). At rest, sensorimotor neurons spontaneously fire in synchrony, leading to large amplitude EEG oscillations in the 8–13 Hz (Mu) frequency band over sensorimotor areas. mu rhythm oscillations are suppressed or desynchronized by voluntary movements, but are minimally affected by visual stimulation. Mu rhythms fall in the same frequency range as alpha rhythms, but they differ in key ways. Alpha rhythms are thought to primarily reflect visual processing in occipital networks, whereas mu rhythms are thought to reflect sensorimotor processing in frontoparietal networks. Mu rhythms also display several functional characteristics that differ from occipital alpha rhythms. In addition to voluntary movements, mu frequency band oscillations are suppressed during mere observation of or imagined human movement, and are quite sensitive to higher-level cognitive and emotional stimuli. For example, mu rhythms show greater suppression for goal-directed than non-goal directed actions (Muthukumaraswamy, Johnson, & McNair, 2004) and are modulated by the degree of social interaction depicted in stimuli (Oberman, Pineda, & Ramachandran, 2007). These properties support the validity of the mu rhythm as an index of MNS activity.

Although the mentalizing and mirroring systems typically work in a coordinated manner, emerging evidence suggests that they can dissociate in different ways across neuropsychiatric disorders. For example, fMRI studies of autism spectrum disorders indicate mirroring disturbances in response to simple hand movements and facial expressions, as well as mentalizing disturbances (Chung, Barch, & Strube, 2013; Dapretto et al., 2006; Iacoboni & Dapretto, 2006; Oberman et al., 2005; Perkins, Stokes, McGillivray, & Bittar, 2010; Williams et al., 2006). Furthermore, disturbances in mu suppression are found in autism and individual differences in mu suppression have been found to correlate with level of functioning in this population (Dapretto et al., 2006; Oberman et al., 2005). In contrast, psychopathy has been associated with diminished mirroring but intact mentalizing (Cheng, Hung, & Decety, 2012; Marsh et al., 2013; Meffert, Gazzola, den Boer, Bartels, & Keysers, 2013), whereas borderline personality disorder is associated with enhanced mirroring and aberrant mentalizing (Dziobek et al., 2011; Ripoll, Snyder, Steele, & Siever, 2013).

Research on empathic processes in schizophrenia has thus far predominantly focused on mentalizing. Individuals with schizophrenia have consistently been found to show diminished mentalizing on self-report, behavioral, and fMRI measures (e.g., Chung et al., 2013; Derntl et al., 2012; Smith et al., 2014; Smith et al., 2012). Relatively little research has examined whether schizophrenia is also associated with impairments in mirroring. Although behavioral studies have shown impaired imitation of complex hand movements and facial emotional expressions in schizophrenia (e.g., Kohler et al., 2008; Matthews, Gold, Sekuler, & Park, 2013; Park, Matthews, & Gibson, 2008; Varcin, Bailey, & Henry, 2010), the two prior EEG studies of MNS activity, as indexed by mu suppression, have provided mixed results. One study focused on observation/execution of hand movements, and found no overall group differences between patients with schizophrenia spectrum disorders and healthy controls (McCormick et al., 2012). However, a subgroup of patients with acute positive symptoms showed significantly enhanced mu suppression, though no significant correlations with other clinical symptoms or self-reported empathy emerged. Another study showed comparable mu suppression in recent-onset schizophrenia outpatients and healthy controls during two experimental conditions that involved observing hand movements and observing people interacting (Singh, Pineda, & Cadenhead, 2011). However, patients showed significantly

reduced mu suppression during a third condition that involved observing biological motion stimuli (point-light animations), and greater reduction in mu suppression correlated with more negative symptoms and reduced social functioning. Thus, further research is needed to help clarify the differences noted between these two studies and to identify patient characteristics that may modulate the mu suppression.

In the present study, we applied a validated EEG mu suppression paradigm (Oberman et al., 2005; Oberman et al., 2013; Oberman et al., 2007; Oberman, Ramachandran, & Pineda, 2008) that included the observation or execution of hand movements, as well as the observation of people in three different levels of social interaction with stable outpatients with schizophrenia and healthy controls. Subjects also completed a self-report measure of empathy, and patients completed assessments of clinical symptoms and functioning. The goals of the study were to evaluate (1) whether schizophrenia patients show altered mu suppression across a range of relatively simple (hand movement) and more complex (social stimuli) experimental tasks, and (2) whether mu suppression levels among patients relate to individual differences in self-reported empathy, symptom levels, and community functioning.

Method

Subjects

A total of 32 outpatients with schizophrenia and 26 healthy controls participated in the study. The schizophrenia patients were 18–60 years of age and recruited from outpatient clinics at the VA Greater Los Angeles Healthcare System and through local board and care facilities. The patients received the Structural Clinical Interview for the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Axis I Disorders (SCID; First, Gibbon, Spitzer, & Williams, 1996) in order to confirm the diagnosis of schizophrenia. Patients were medicated at clinically determined dosages, with 26 receiving atypical antipsychotics, one receiving typical antipsychotics, and five receiving both types of antipsychotic medication. The mean dose of antipsychotic medication was equivalent to 282.51 mg/day of chlorpromazine ($SD = 162.49$). All of the patients were clinically stable, as defined by no hospitalizations in the past 3 months, no changes in living situation in the past 2 months, and no medication changes in the past 6 weeks. The exclusion criteria for patients included (1) substance abuse or dependence in the last 6 months, (2) IQ < 70, (3) history of loss of consciousness for >1 h, (4) identifiable neurological disorder, and (5) not sufficiently fluent in English.

The healthy control participants were recruited through website postings. Exclusion criteria for the control participants included (1) history of schizophrenia or other psychotic disorder, bipolar disorder, recurrent depression, history of

substance dependence, or any substance abuse in the last 6 months, based on the SCID; (2) avoidant, paranoid, schizoid, and schizotypal disorders, based on the SCID for Axis II (First, Spitzer, Gibbon, Williams, & Benjamin, 1994) disorders; (3) history of loss of consciousness for >1 h; (4) schizophrenia or other psychotic disorder in a first-degree relative; (5) significant neurological disorder or head injury; and (6) not sufficiently fluent in English.

All of the interviewers were trained through the Treatment Unit of the VA Desert Pacific Mental Illness Research, Education, and Clinical Center. SCID interviewers were trained to a minimum kappa of .75 for key psychotic and mood items, and symptom raters were trained to a minimum intraclass correlation of .80 (Ventura, Green, Shaner, & Liberman, 1993). Participants were evaluated for their capacity to give informed consent and provided written informed consent after all procedures had been fully explained, according to procedures approved by the institutional review boards at the VA Greater Los Angeles Healthcare System and the University of California, Los Angeles (UCLA).

Symptom ratings

For all patients, psychiatric symptoms during the previous two weeks were rated using the expanded 24-item UCLA version of the Brief Psychiatric Rating Scale (BPRS; Lukoff, Nuechterlein, & Ventura, 1986; Overall & Gorham, 1962). Ratings from the positive, depression, agitation, and negative symptom subscales, as well as total scores, were examined (Kopelowicz, Ventura, Liberman, & Mintz, 2008).

Community functioning

The Role Functioning Scale (RFS; McPheeters, 1984) was used to assess functional status. It is based on a semistructured interview with the participant, and includes subscales for work, independent living, family relations, and social functioning. The RFS ratings range from 1 (*severely impaired functioning*) to 7 (*optimal functioning*). Each RFS subscale provides anchored descriptions for all levels of functioning that capture both the quantity and quality of functioning in that domain.

Experimental paradigm

Stimulus materials

EEG data were collected while subjects completed six experimental conditions, five of which involved watching videos from previously published experiments (Oberman et al., 2005; Oberman et al., 2013; Oberman et al., 2007; Oberman et al., 2008). As is displayed in Fig. 1, the videos ranged from inanimate movement (baseline condition) to a high degree of human interaction involving the viewer (Condition 5) and
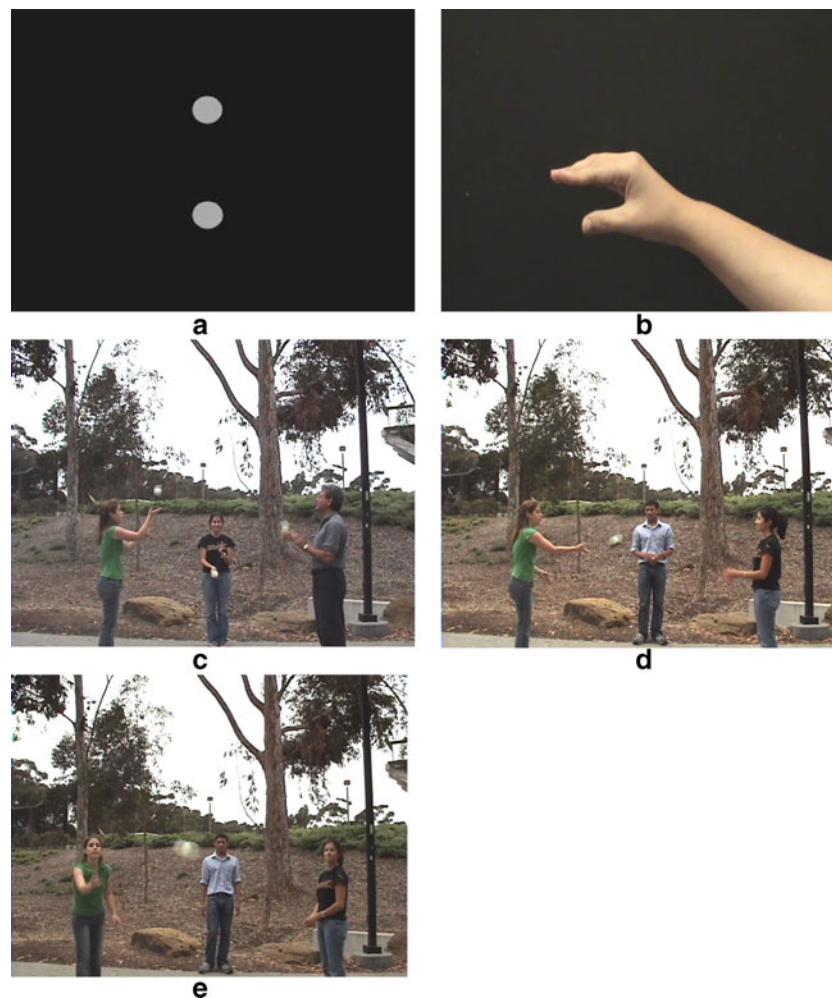
Fig. 1 Screenshots of stimuli for the baseline and experimental conditions: (a) baseline, (b) Watch Moving Hand condition, (c) Social Noninteracting condition, (d) Social Spectator condition, and (e) Social Interacting condition.

have been show to elicit increasingly larger levels of mu suppression in healthy subjects. All videos were 80 s long, and each video was presented twice in a random order. The following conditions were presented:

Baseline condition: Video of two bouncing balls Two light gray balls (32.9 cd/m^2) on a black background (1.0 cd/m^2) moved vertically toward each other, touched in the middle of the screen, and then moved apart to their initial starting position. The motion was visually equivalent to the trajectory taken by the tips of the fingers and thumb in Conditions 1 and 2. This condition of two moving inanimate objects has been used as a baseline condition in previous studies of mu suppression (e.g., Oberman et al., 2005; Singh et al., 2011).

Condition 1 **Watch moving hand** The subjects viewed a video of an experimenter opening and closing the right hand. The fingers and the thumb were held straight, opening and closing the palm of the hand at a rate of approximately 1 Hz.

Condition 2 **Move own hand** The subjects opened and closed their right hand at a rate of approximately 1 Hz in the same manner described in Condition 1. Subjects watched their hand at a comfortable viewing distance with their hand held at eye level.

Condition 3 **Social noninteracting** A color video depicted three people (showing the entire body and face) standing in a triangle formation. Each individual had a ball that he or she threw up in the air just above the head to him- or herself.

Condition 4 **Social spectator** Thee people, again in a triangle formation, are shown tossing a single ball back and forth to each other.

Condition 5 **Social interacting** This was similar to Condition 4, with three people shown throwing a single ball back and forth to each other, except that occasionally the ball would be thrown off the screen, seemingly toward the viewer—the three people look at the subject, one would throw the ball toward the subject, and the ball

would then be thrown back to the group from the subject's perspective. Thus, it appeared is if the viewer were part of the game being played.

The movements in each video occurred at a frequency of 1 Hz, and a continuous performance task was included to ensure that subjects were attentive to the stimulus. With the exception of the Move Own Hand condition, the stimuli stopped moving four to eight times for 1 s in each video, and participants reported the number of times that the stimuli stopped moving at the end of each video. We compared the groups by evaluating the proportions of videos in which reports fell within ±1 of the correct answer. We observed no significant difference between the patients ($M = .88$, $SE = .03$) and controls ($M = .94$, $SE = .03$), $t = 0.81$, $p > .05$. We also found no significant difference in the proportions of videos in which patients ($M = .62$, $SE = .05$) and controls ($M = .71$, $SE = .05$) demonstrated perfect performance, $t = 1.38$, $p > .05$. These data suggest generally comparable levels on the performance task across groups.

EEG data acquisition and analysis

Participants had their EEG activity continuously recorded from 64 electrodes based on the 10–20 system placed in an electrode cap (Cortech Solutions, Wilmington, North Carolina, USA) and the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). The signal was preamplified at the electrode with a gain of 1; the EEG was digitized at 24-bit resolution with a sampling rate of 1024 Hz with a bandpass of 0–100 Hz. Recordings were taken from the 64 electrodes, as well as from two electrodes placed on the left and right mastoids. The electro-oculogram was recorded from four facial electrodes: two 1 cm above and below the left eye, one 1 cm to the left of the left eye, and one 1 cm to the right of the right eye. Each electrode was measured online with respect to a common-mode sense electrode that formed a monopolar channel.

Offline analysis was performed using the Brain Vision Analyzer software (Brain Products, Munich, Germany). All of the EEG data were re-referenced to the average of the mastoids and bandpass filtered with cutoffs of 0.1 and 30 Hz. Data were collected for 80 s per condition at a sampling rate of 500 Hz. Per standard protocols, the data from the first and last 10 s of each block were removed in order to eliminate attentional transients due to initiation or termination of the stimulus. A 1-min segment of data following removal of the initial and terminal 10 s was obtained and combined with the other trial of the same condition, resulting in one 2-min segment of data per condition. Each EEG segment was corrected for blinks and eye movements using the method developed by Gratton, Coles, and Donchin (1983). Specific channels were rejected in each trial using a semiautomated procedure, with physiological artifacts being identified by the following criteria: a step of more than 50

μV between sample points, and an amplitude that exceeded ±150 μV. The data were segmented into epochs of 1 s beginning at the start of the segment, and were only analyzed if at least 40 epochs were available after rejection of artifacts. For each segment, integrated power in the 8–13 Hz range was computed using a fast Fourier transform performed on the epoched data (1,024 points). A cosine window was used to control for artifacts resulting from data splicing.

Mu suppression ratios were calculated for central (C3, Cz, and C4) sites over sensorimotor cortex, using the equation mu suppression = $\log_{10}$(mu power of experimental condition/mu power of ball condition) (Oberman et al., 2008). Ratio data are inherently nonnormal as a result of lower bounding, and we therefore used a log transform for the analysis. A log ratio less than zero indicates mu suppression, a log ratio equal to zero indicates lack of mu wave suppression, and a log ratio greater than zero indicates mu enhancement. The ratio was used to control for variability in absolute mu power as a result of individual differences, such as scalp thickness and electrode impedance. The ratio to the ball condition was computed in order to control for attention to counting or any effects due to the stimulus stopping during the performance task and processing of directional motion (Oberman et al., 2008). The EEG data for one patient and two controls were excluded because of mu suppression ratios in one or more conditions that differed by more than three standard deviations from their respective group means; these subjects were excluded prior to examining the continuous performance task data. The final sample in this report consisted of 58 participants (32 patients, 26 controls).

Self-report measure

All subjects filled out the widely used Interpersonal Reactivity Index (IRI; M. Davis, 1983), indicating to what extent short phrases described them, on a 5-point scale (from *does not describe me at all* to *describes me very well*). This measure was chosen because it taps a variety of aspects of empathy and is not limited to either emotional or cognitive components, although it does not directly address such motoric aspects as mimicry. Sample items from each of the four subscales included "Sometimes I don't feel very sorry for other people when they are having problems" (Empathic Concern, reverse coded), "Being in a tense emotional situation scares me" (Personal Distress), "I sometimes try to understand my friends better by imagining how things look from their point of view" (Perspective Taking), and "I really get involved with the feelings of the characters in a story" (Fantasy). Two patients and two controls did not complete the IRI due to scheduling constraints.

Data analysis

For demographic data, group differences for continuous variables were evaluated with t tests, and differences for

categorical variables with chi-square tests. To investigate group differences in mu suppression, a repeated measures analysis of variance (ANOVA) with condition (five levels) and electrode site (C3, Cz, C4) as the within-subjects variables and diagnostic group (schizophrenia, control) as a between-subjects variable was performed. Effect sizes are presented as partial eta-squared (η_p^2), which corresponds to the following conventions: small (.01), medium (.06), and large (.14) (Cohen, 1988). Group differences on the self-report scales were evaluated with t tests. Correlational analyses were conducted on an exploratory basis. Spearman correlation coefficients examined the associations among mu suppression ratios, symptoms, functioning, and self-reported empathy.

Results

Demographic and clinical characteristics

The demographic information for both groups and clinical data for the schizophrenia group are presented in Table 1.

The groups did not differ significantly in sex, age, or ethnicity. The patients had lower personal education levels than did the controls, but the groups did not differ in parental education. Both groups were predominantly right-handed, with comparable proportions across groups. The schizophrenia group had a typical age of onset and was chronically ill. They showed mild to moderate levels of clinical symptoms at the time of testing that were comparable to those in prior studies of stabilized outpatients (Green, Hellemann, Horan, Lee, & Wynn, 2012; Kern et al., 2013).

Between-group comparison of mu suppression

A graphical summary of the results is presented in Fig. 2. We found a significant main effect of condition, $F(4, 224) = 6.56$, $p < .001$, $\eta_p^2 = .11$. Consistent with the overall means depicted in the figure, the linear contrast effect across the five experimental conditions was significant within both the patient, $F(1, 31) = 15.59$, $p < .001$, $\eta_p^2 = .34$, and control, $F(1, 31) = 6.22$, $p < .05$, $\eta_p^2 = .20$, groups, and did not differ significantly between the groups, $F(1, 56) = 0.06$, $p > .05$, $\eta_p^2 = .001$. No significant main effects emerged for electrode site, $F(2, 112) =$

Table 1 Demographic and clinical data

	Schizophrenia ($n = 32$)	Controls ($n = 26$)	Statistic
Sex (% male)	81.3%	73.1%	$\chi^2(1, 58) = 0.55$
Age (years, with SD)	47.9 (9.6)	44.4 (7.9)	$t(57) = 1.48$
Ethnicity			
White	56.3%	76.0%	$\chi^2(3, 58) = 4.23$
African American	31.3%	24.0%	
Hispanic	6.3%		
Asian	3.1%		
Marital status			
Never married	65.6%	56.0%	$\chi^2(2, 58) = 5.32$
Currently married	6.3%	28.0%	
Ever married	28.1%	16.0%	
Education (years, with SD)	12.9 (1.6)	14.9 (1.6)	$t(57) = -4.25*$
Parental education (years, with SD)	12.4 (2.4)	13.4 (2.4)	$t(57) = -1.65$
Handedness (% right)	81.3%	80%	$\chi^2(1, 58) = 0.02$
Age of onset (years, with SD)	20.8 (5.5)		
Duration of illness (years, with SD)	26.8 (11.5)		
Brief Psychiatric Rating Scale			
Positive symptoms (SD)	1.5 (0.5)		
Depression (SD)	1.6 (0.6)		
Negative symptoms (SD)	1.7 (0.8)		
Agitation (SD)	1.1 (.2)		
Total (SD)	33.7 (6.4)		

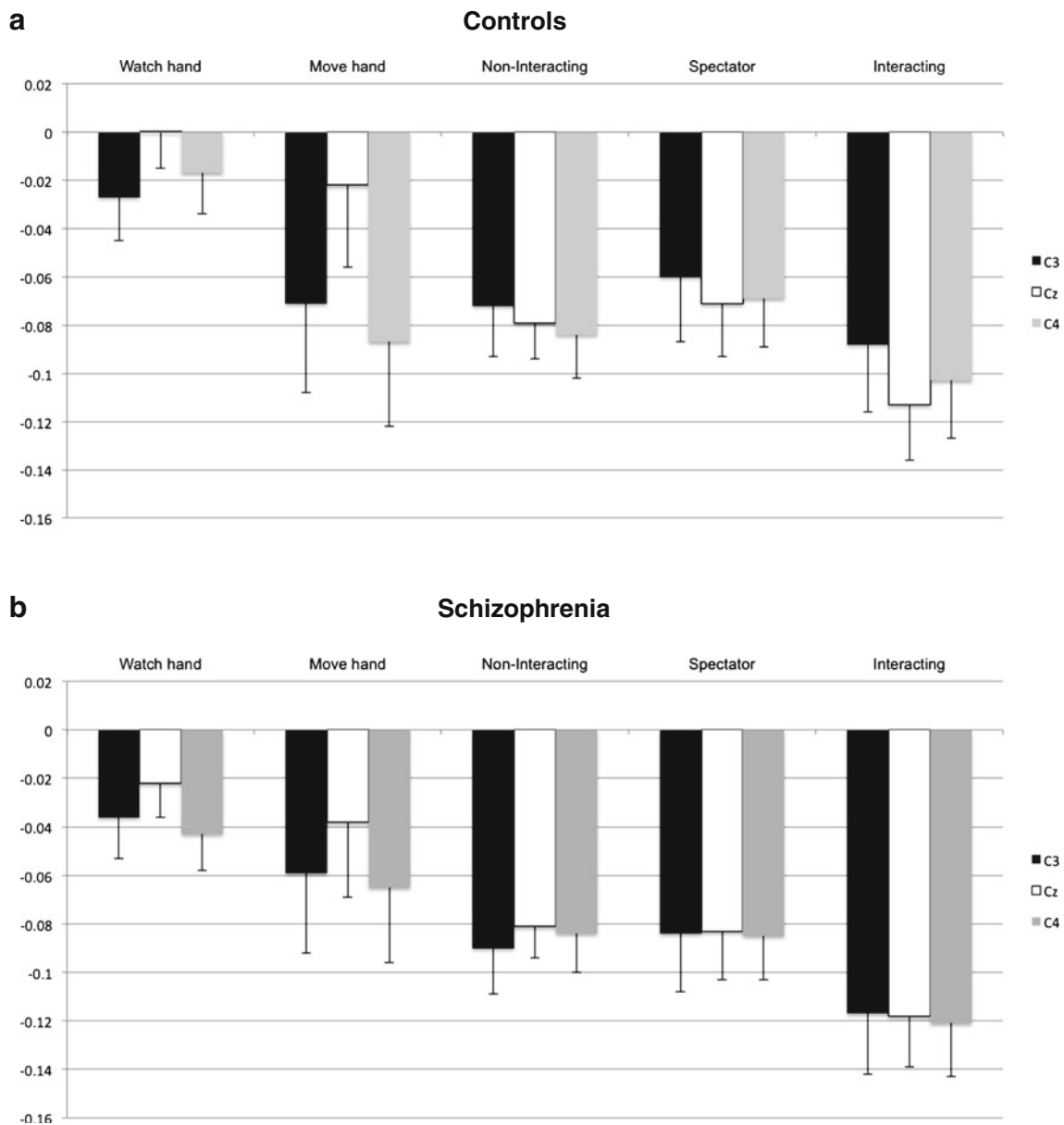[*] $p < .005.$ [**] $p < .001.$

a

b

Fig. 2 Mu suppression ratio means for each electrode site and condition within each group (error bars reflect standard errors).

1.48, $p > .05$, $\eta_p^2 = .03$, or group, $F(1, 56) = 0.24$, $p > .05$, $\eta_p^2 = .004$. We also observed no significant effects for the two-way interactions of Group × Condition, $F(4, 224) = 0.19$, $p > .05$, $\eta_p^2 = .003$, and Group × Electrode Site, $F(2, 56) = 0.09$, $p > .05$, $\eta_p^2 = .002$. Notably, the effect sizes for results involving the Group factor were uniformly small.

We observed a significant two-way Condition × Electrode Site interaction, $F(2, 448) = 6.03$, $p < .05$, $\eta_p^2 = .10$. This interaction was accounted for by a difference across electrodes during the hand movement conditions (Conditions 2 and 3). Specifically, significantly greater mu suppression was apparent at the lateral sites (C3 and C4) than at the central site (Cz) for the Watch Hand and Move Own Hand conditions ($ps <$

.05), but no significant differences across electrodes emerged for the other three conditions.

Finally, the three-way Condition × Electrode Site × Group interaction was not significant, $F(8, 448) = 1.92$, $p < .10$, and demonstrated a small effect size ($\eta_p^2 = .04$). This nonsignificant effect reflected a subtle group difference within the Move Hand condition—although both groups showed numerically greater mu suppression at lateral (C3, C4) than at central (CZ) electrodes in the Move Own Hand condition, this effect was somewhat more pronounced within the control group, with controls showing a large effect size [electrode effect: $F(2, 50) = 5.25$, $p = .008$, $\eta_p^2 = .17$], relative to a medium effect size in the schizophrenia group [electrode effect: $F(2, 62) = 3.02$, $p = .06$, $\eta_p^2 = .11$]. No

Table 2 Correlations between mu suppression, symptoms, and functioning within the schizophrenia group ($n = 32$)

	Watch Hand	Move Hand	Noninteracting	Spectator	Interacting
Brief Psychiatric Rating Scale					
Positive	–.11	–.24	–.08	–.23	–.03
Depression	–.41*	–.21	–.28	–.22	–.09
Negative	.13	.05	.04	.02	–.03
Agitation	–.18	–.24	–.25	–.16	–.16
Total	–.12	–.13	–.13	–.18	.01
Role Functioning Scale					
Work Productivity	.22	–.06	.24	.09	.17
Independent Living	–.19	–.12	–.19	–.06	–.26
Family Network	–.30	–.01	–.27	–.18	–.23
Social Network	–.33	.08	–.21	–.05	–.14

* $p < .05$.

significant Group × Electrode Site interaction emerged for the other four experimental conditions.[1] Supplemental analyses examined potential confounding variables. The pattern of results was unchanged when the analyses were restricted only to subjects who were right-handed, and within the schizophrenia group, we found no significant correlations between CPZ equivalents and mu suppression ratios.

Correlations with symptoms and functioning in the schizophrenia group

As is shown in Table 2, among the patients mu suppression ratios showed minimal relations to symptoms or functioning. Higher levels of depression correlated with more mu suppression during the Watch Hand condition, but no other significant relations were apparent with any of the symptom scales. We also found no significant correlations with any of the functioning scales.

Self-reported empathy: Group differences and relations with mu suppression

As is shown in Table 3, the schizophrenia group reported significantly lower scores than did controls on the IRI

Table 3 Comparisons between the schizophrenia ($n = 30$) and control ($n = 24$) groups on the Interpersonal Reactivity Inventory subscales

	Schizophrenia	Controls	t Value ($df = 53$)	Effect Size (Cohen's d)
Perspective Taking	15.43 (4.07)	19.13 (5.70)	–2.77*	–0.76
Empathic Concern	17.40 (5.01)	21.25 (4.02)	–3.06**	–0.84
Fantasy	13.44 (4.57)	13.29 (5.37)	0.11	0.03
Personal Distress	10.27 (5.45)	8.33 (4.82)	1.36	0.37

Standard deviations appear in parentheses. * $p < .01$. ** $p < .05$.

Perspective Taking and Empathic Concern subscales. The magnitudes of these differences were medium to large. The groups did not differ significantly on the Personal Distress and Fantasy subscales.

To limit the number of correlational analyses with mu suppression ratios, we focused on the IRI Perspective Taking and Empathic Concern subscales, because they showed group differences. As is shown in Table 4, among patients the correlations were generally negative, indicating that more mu suppression was generally associated with higher self-reported scores on the IRI subscales, though only the correlation between Perspective Taking and mu suppression during the Interacting condition reached significance. Among the controls, the correlations were generally positive. Although we observed a few moderate correlations, none were statistically significant.

Table 4 Correlations between Interpersonal Reactivity Inventory (IRI) subscales and mu suppression (averaged across electrodes C3, Cz, and C4) across conditions within the schizophrenia ($n = 30$) and control ($n = 24$) groups

	Watch Hand	Move Hand	Noninteracting	Spectator	Interacting
Schizophrenia					
IRI Perspective Taking	–.20	–.20	–.29	–.25	–.37*
IRI Empathic Concern	–.20	–.17	–.04	–.02	–.07
Controls					
IRI Perspective Taking	.15	.37	.03	.09	.03
IRI Empathic Concern	.33	.06	.37	.36	.23

* $p < .05$.

Conclusions

In this study, we examined EEG mu suppression, a hypothesized biomarker of MNS activity that is sensitive to the degree of social engagement depicted in visual stimuli, in clinically stable outpatients with schizophrenia. Despite self-reporting empathic disturbances, the schizophrenia patients as a group demonstrated generally normal modulation of mu suppression by the degree of social engagement depicted in video stimuli, which ranged from observing simple hand movements to observing coordinated movements in simulated interactions during a ball-tossing game. The nonsignificant differences between groups were accompanied by small effect sizes, and if anything, the effect size for the linear increase in mu suppression across conditions was slightly larger in the patient group. These findings suggest that automatic activation of the MNS in response to relatively simple human movements in a neutral context appears intact in schizophrenia across a range of experimental conditions at the electrophysiological level. They also shed light on how different aspects of the social brain involved in the component processes of empathic responding can be differentially impacted across different forms of psychopathology.

Our EEG paradigm included more experimental conditions than have prior mu suppression studies in schizophrenia or in healthy adult control subjects. As expected, controls showed a significant overall linear increase in mu suppression from observing simple hand movements to observing videos of people appearing to toss a ball to each other and to the subject him- or herself. Mu suppression, however, did not differ significantly between videos that depicted people tossing balls to themselves versus tossing balls to each other (Conditions 3 and 4), indicating lower sensitivity to these conditions than has been found in prior studies (Oberman et al., 2007). It is also notable that although the groups performed comparably and reasonably well on the concomitant continuous performance task, their less-than-perfect scores reflect some variability in attention across conditions. Overall, the paradigm elicited a sensible pattern of mu suppression that is consistent with prior studies using only hand movement or only social interaction stimuli.

Similar to controls, the schizophrenia group showed a significant overall linear increase in mu suppression across conditions, which is generally consistent with two prior studies that used partially overlapping stimuli in schizophrenia. The normal modulation of mu suppression for observing versus executing hand movements converged with prior studies in chronically ill and recent-onset patients (McCormick et al., 2012; Singh et al., 2011), suggesting that activation of the MNS for observation and execution of basic human movements appears intact throughout early and late phases of schizophrenia. The patients' normally enhanced mu suppression in the social interaction conditions converges with the results of the study by Singh et al., which used the same video as our Condition 5 (Conditions 3 and 4 were not administered).

However, two areas of discrepancy between the present results and those from prior studies of mu suppression in schizophrenia remain to be explained. First, Singh et al. (2011) found that recent-onset patients showed diminished mu suppression while observing basic biological motion using point-light stimuli. It is somewhat counterintuitive that patients would show impaired modulation of mu suppression while observing stimuli that are presumably more basic than those used in the present study. Speculatively, the more ecologically valid hand and interaction stimuli might provide additional cues that facilitate activation of the MNS, and patients may be worse at processing relatively impoverished biological-motion stimuli (Kim, Park, & Blake, 2011). Impairments in gestalt perception of apparent motion (Tschacher & Kupper, 2006) may also interact with how patients perceive and process these impoverished stimuli.

The second area of discrepancy concerns the relationship between mu suppression and individual differences in clinical symptoms and self-reported empathy. Although McCormick et al. (2012) found enhanced mu suppression in hospitalized patients with acute psychotic symptoms, in the present study mu suppression ratios showed no significant associations with positive or negative symptoms or with community functioning. This suggests that MNS functioning may covary with clinical state, a possibility that is consistent with some theoretical models of the relation between social cognitive processes (e.g., mentalizing) and psychotic symptoms (e.g., Frith & Corcoran, 1996). In addition, Singh et al. (2011) found that diminished mu suppression during biological-motion condition correlated with more negative symptoms and impaired social functioning in their outpatient sample. This could reflect differences in experimental conditions, stage of illness, or the measures used to assess negative symptoms.

The present study sheds further light on how the social brain can "splinter" across different forms of psychopathology. Overall, our results converge with prior studies to suggest that MNS functioning, as indexed by mu suppression ratios, appears intact in schizophrenia across both simple hand movement and neutral social interaction stimuli. The patients' intact EEG mu suppression differs sharply from the substantial impairments seen in schizophrenia across self-report, performance, and fMRI measures of mentalizing and empathic abilities (e.g., Achim, Ouellet, Roy, & Jackson, 2011; Bora, Yucel, & Pantelis, 2009; Lee, Zaki, Harvey, Ochsner, & Green, 2011; Smith et al., 2014; Smith et al., 2012). This pattern of intact mirroring and impaired mentalizing is notably different from other neuropsychiatric disorders. As we noted earlier, autism spectrum disorders are typically associated with decreased abilities in both components, whereas emerging evidence suggests that psychopathy is associated with selectively decreased mirroring, and borderline personality disorder is

associated with selectively increased mirroring (Cheng et al., 2012; Chung et al., 2013; Dziobek et al., 2011; Iacoboni & Dapretto, 2006; Marsh et al., 2013; Meffert et al., 2013; Oberman et al., 2005; Perkins et al., 2010; Ripoll et al., 2013). These findings suggest that the mirroring and mentalizing components of the social brain can dissociate in multiple ways to impact empathic functioning. For schizophrenia, disturbances seen on mentalizing and empathic accuracy tasks may reflect difficulties with higher-level inferential processes about others' emotions and beliefs, rather than an incapacity to share in these experiences.

Regarding self-reported empathy, the schizophrenia group in this study reported diminished perspective taking and empathic concern. The magnitudes of these differences were medium to large, which is consistent with a number of prior studies (Achim et al., 2011). Consistent with McCormick et al. (2012), self-reported empathy among patients was not significantly related to mu suppression during the hand movement conditions. We did find that patients' reports of higher perspective taking were related to more mu suppression during the Interacting condition. It is interesting that we found this relationship only for the condition involving the highest level of social interaction; perhaps the other conditions may have been too remote from the types of empathic behaviors assessed by self-report measures to detect correlations. However, this relationship would not be significant with correction for multiple comparisons, and should be interpreted cautiously. In contrast to the patients, self-reported empathy showed generally positive associations with mu suppression among controls, although none of the correlations was significant with the present sample size. The direction of these correlations is somewhat difficult to explain, since higher self-reported empathy would intuitively be expected to relate to more, not less, mu suppression (as was seen in the patients). However, one's beliefs about his or her empathic abilities may not always relate to performance on experimental measures of empathy in a straightforward manner. Further work on this topic will be needed, since similarly counterintuitive relations have been reported in some studies of healthy subjects (e.g., Woodruff, Martin, & Bilyk, 2011).

Although the present findings support the notion that some aspects of relatively low-level mirroring are intact in schizophrenia, several additional factors should be considered when interpreting these findings. First, the stimuli in the present study involved relatively simple motor activities that occurred in a neutral context. Although mu suppression is sensitive to observing emotional facial expressions in humans (Moore, Gorodnitsky, & Pineda, 2012), and even facial gestures in newborn monkeys (Ferrari et al., 2012), it remains to be determined how schizophrenia patients would perform on mu suppression tasks involving more complex socioemotional stimuli. Second, studies using other methods have suggested that mirroring-related processes are not fully intact in schizophrenia. As was mentioned above, patients have shown impaired

voluntary imitation of facial expressions and complex gestures, as well as diminished spontaneous mimicking of others' behaviors (e.g., yawning, face expressions; Kohler et al., 2008; Matthews et al., 2013; Park et al., 2008; Varcin et al., 2010). The apparent discrepancy between intact mirroring, as indexed by mu suppression, versus overt mirroring-related impairments requires further research attention.

Finally, it is important to consider the present findings in the context of the complex mechanisms that likely contribute to simulation and empathic functioning. In particular, since the mu rhythm is generated by activity in sensorimotor areas, and mirror neurons have been located primarily in premotor areas, it is believed that mu rhythms index downstream modulation of primary sensorimotor areas by mirror neuron activity (Pineda, 2005). It is possible that the relatively normal downstream modulation seen in schizophrenia could be achieved through mechanisms that differ from those seen in healthy subjects. Future studies combining EEG with other methods can provide a more comprehensive account of when empathic processes do and do not appear to function normally in schizophrenia. For example, a few recent studies using magnetoencephalography and transcranial magnetic stimulation paradigms have reported evidence of diminished MNS during observation of human face or hand movements (Enticott et al., 2008; also see Mehta, Basavaraju, Thirthalli, & Gangadhar, 2012; Schurmann et al., 2007). Some fMRI studies have also implicated abnormalities in cortical regions associated with the MNS (e.g., Quintana, Davidson, Kovalik, Marder, & Mazziotta, 2001), indicating that additional research using methods with higher anatomical resolution is clearly needed.

In summary, the present findings suggest that relatively automatic MNS responses to several types of evocative stimuli are intact at the electrophysiological level in schizophrenia. A limitation of the study is that the patients were taking various antipsychotic medications at clinically determined dosages. Although CPZ equivalents were not significantly related to mu suppression, it is possible that the medications normalized mu suppression in this sample. In addition, we did not systematically exclude for all potentially relevant conditions among the control subjects, such as antisocial and borderline personality disorders. Our finding that some relatively low-level, bottom-up social cognitive processes may be intact in schizophrenia suggests that efforts to target higher-level, integrative processes may be particularly useful in clinical intervention studies. A number of psychosocial interventions currently being evaluated show promise for helping patients develop this type of social cognitive processing (e.g., Horan et al., 2011; Kurtz & Richardson, 2012; Roberts & Penn, 2009).

References

Achim, A. M., Ouellet, R., Roy, M. A., & Jackson, P. L. (2011). Assessment of empathy in first-episode psychosis and meta-analytic comparison with previous studies in schizophrenia. *Psychiatry Research, 190,* 3–8. doi:10.1016/j.psychres.2010.10.030

Bora, E., Yucel, M., & Pantelis, C. (2009). Theory of mind impairment in schizophrenia: meta-analysis. *Schizophrenia Research, 109,* 1–9. doi:10.1016/j.schres.2008.12.020

Brunet-Gouet, E., Achim, A. M., Vistoli, D., Passerieux, C., Hardy-Bayle, M. C., & Jackson, P. L. (2011). The study of social cognition with neuroimaging methods as a means to explore future directions of deficit evaluation in schizophrenia? *Psychiatry Research, 190,* 23–31. doi:10.1016/j.psychres.2010.11.029

Carr, L., Iacoboni, M., Dubeau, M. C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: a relay from neural systems for imitation to limbic areas. *Proceedings of the National Academy of Sciences, 100,* 5497–5502. doi:10.1073/pnas.0935845100

Caspers, S., Zilles, K., Laird, A. R., & Eickhoff, S. B. (2010). ALE meta-analysis of action observation and imitation in the human brain. *NeuroImage, 50,* 1148–1167. doi:10.1016/j.neuroimage.2009.12.112

Cheng, Y., Hung, A. Y., & Decety, J. (2012). Dissociation between affective sharing and emotion understanding in juvenile psychopaths. *Developmental Psychopathology, 24,* 623–636. doi:10.1017/S095457941200020X

Chung, Y. S., Barch, D., & Strube, M. (2013). A meta-analysis of mentalizing impairments in adults with schizophrenia and autism spectrum disorder. *Schizophrenia Bulletin. Advance online publication.*. doi:10.1093/schbul/sbt048

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Dapretto, M., Davies, M. S., Pfeifer, J. H., Scott, A. A., Sigman, M., Bookheimer, S. Y., & Iacoboni, M. (2006). Understanding emotions in others: mirror neuron dysfunction in children with autism spectrum disorders. *Nature Neuroscience, 9,* 28–30. doi:10.1038/nn1611

Davis, M. H. (1983). Measuring individual differences in empathy: evidence for a multidimensional approach. *Journal of Personality and Social Psychology, 44,* 113–126. doi:10.1037/0022-3514.44.1.113

Davis, M. C., Lee, J., Horan, W. P., Clarke, A. D., McGee, M. R., Green, M. F., & Marder, S. R. (2013). Effects of single dose intranasal oxytocin on social cognition in schizophrenia. *Schizophrenia Research, 147,* 293–297. doi:10.1016/j.schres.2013.04.023

Decety, J. (2010). The neurodevelopment of empathy in humans. *Developmental Neuroscience, 32,* 257–267. doi:10.1159/000317771

Derntl, B., Finkelmeyer, A., Voss, B., Eickhoff, S. B., Kellermann, T., Schneider, F., & Habel, U. (2012). Neural correlates of the core facets of empathy in schizophrenia. *Schizophrenia Research, 136,* 70–81. doi:10.1016/j.schres.2011.12.018

Dziobek, I., Preissler, S., Grozdanovic, Z., Heuser, I., Heekeren, H. R., & Roepke, S. (2011). Neuronal correlates of altered empathy and social cognition in borderline personality disorder. *NeuroImage, 57,* 539–548. doi:10.1016/j.neuroimage.2011.05.005

Enticott, P. G., Hoy, K. E., Herring, S. E., Johnston, P. J., Daskalakis, Z. J., & Fitzgerald, P. B. (2008). Reduced motor facilitation during action observation in schizophrenia: A mirror neuron deficit? *Schizophrenia Research, 102,* 116–121. doi:10.1016/j.schres.2008.04.001

Ferrari, P. F., Vanderwert, R. E., Paukner, A., Bower, S., Suomi, S. J., & Fox, N. A. (2012). Distinct EEG amplitude suppression to facial gestures as evidence for a mirror mechanism in newborn monkeys. *Journal of Cognitive Neuroscience, 24,* 1165–1172. doi:10.1162/jocn_a_00198

First, M. B., Gibbon, M., Spitzer, R. L., & Williams, J. B. W. (1996). Structured Clinical Interview for DSM-IV Axis I Disorders (Patient ed.). New York, NY: Biometrics Research.

First, M. B., Spitzer, R. L., Gibbon, M., Williams, J. B. W., & Benjamin, L. (1994). *Structured Clinical Interview for DSM-IV Axis II Personality Disorders (Version 2.0).* New York, NY: New York State Psychiatric Institute.

Frith, C. D., & Corcoran, R. (1996). Exploring "theory of mind" in people with schizophrenia. *Psychological Medicine, 26,* 521–530.

Gratton, G., Coles, M. G., & Donchin, E. (1983). A new method for off-line removal of occular artifact. *Electroencephalography and Clinical Neurophysiology, 55,* 468–484. doi:10.1016/0013-4694(83)90135-9

Green, M. F., Hellemann, G., Horan, W. P., Lee, J., & Wynn, J. K. (2012). From perception to functional outcome in schizophrenia: Modeling the role of ability and motivation. *Archives of General Psychiatry, 69,* 1216–1224. doi:10.1001/archgenpsychiatry.2012.652

Green, M. F., & Horan, W. P. (2010). Social cognition in schizophrenia. *Current Directions in Psychological Science, 19,* 243–248. doi:10.1177/0963721410377600

Harvey, P. O., Zaki, J., Lee, J., Ochsner, K., & Green, M. F. (2013). Neural substrates of empathic accuracy in people with schizophrenia. *Schizophrenia Bulletin, 39,* 617–628. doi:10.1093/schbul/sbs042

Horan, W. P., Kern, R. S., Tripp, C., Hellemann, G., Wynn, J. K., Bell, M., & Green, M. F. (2011). Efficacy and specificity of social cognitive skills training for outpatients with psychotic disorders. *Journal of Psychiatric Research, 45,* 1113–1122. doi:10.1016/j.jpsychires.2011.01.015

Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C., & Rizzolatti, R. (1999). Cortical mechanisms of human imitation. *Science, 286,* 2526–8.

Iacoboni, M., Koski, L. M., Brass, M., Bekkering, H.,Woods, R. P., Dubeau, M. C., Mazziotta, J. C., & Rizzolatti, G. (2001). Reafferent copies of imitated actions in the right superior temporal cortex. *Proc. Natl. Acad. Sci. USA 98,* 13995–99

Iacoboni, M. (2009). Imitation, empathy, and mirror neurons. *Annual Review of Psychology, 60,* 653–670. doi:10.1146/annurev.psych.60.110707.163604

Iacoboni, M., & Dapretto, M. (2006). The mirror neuron system and the consequences of its dysfunction. *Nature Reviews Neuroscience, 7,* 942–951. doi:10.1038/nrn2024

Kern, R. S., Penn, D. L., Lee, J., Horan, W. P., Reise, S. P., Ochsner, K. N., & Green, M. F. (2013). Adapting social neuroscience measures for schizophrenia clinical trials, part 2: trolling the depths of psychometric properties. *Schizophrenia Bulletin, 39,* 1201–1210. doi:10.1093/schbul/sbt127

Kim, J., Park, S., & Blake, R. (2011). Perception of biological motion in schizophrenia and healthy individuals: a behavioral and FMRI study. *PLoS ONE, 6,* e19971. doi:10.1371/journal.pone.0019971

Kohler, C. G., Martin, E. A., Stolar, N., Barrett, F. S., Verma, R., Brensinger, C., & Gur, R. C. (2008). Static posed and evoked facial expressions of emotions in schizophrenia. *Schizophrenia Research, 105,* 49–60. doi:10.1016/j.schres.2008.05.010

Kopelowicz, A., Ventura, J., Liberman, R. P., & Mintz, J. (2008). Consistency of Brief Psychiatric Rating Scale factor structure across a broad spectrum of schizophrenia patients. *Psychopathology, 41,* 77–84. doi:10.1159/000111551

Kurtz, M. M., & Richardson, C. L. (2012). Social cognitive training for schizophrenia: a meta-analytic investigation of controlled research. *Schizophrenia Bulletin, 38,* 1092–1104. doi:10.1093/schbul/sbr036

Lee, J., Zaki, J., Harvey, P. O., Ochsner, K., & Green, M. F. (2011). Schizophrenia patients are impaired in empathic accuracy. *Psychological Medicine, 41,* 2297–2304. doi:10.1017/S0033291711000614

Lieberman, M. D. (2007). Social cognitive neuroscience: a review of core processes. *Annual Review of Psychology, 58,* 259–289. doi:10.1146/annurev.psych.58.110405.085654

Lukoff, D., Nuechterlein, K. H., & Ventura, J. (1986). Manual for the expanded Brief Psychiatric Rating Scale. *Schizophrenia Bulletin, 12,* 578–602.

Marsh, A. A., Finger, E. C., Fowler, K. A., Adalio, C. J., Jurkowitz, I. T., Schechter, J. C., & Blair, R. J. (2013). Empathic responsiveness in amygdala and anterior cingulate cortex in youths with psychopathic traits. *Journal of Child Psychology and Psychiatry, 54,* 900–910. doi:10.1111/jcpp. 12063

Matthews, N., Gold, B. J., Sekuler, R., & Park, S. (2013). Gesture imitation in schizophrenia. *Schizophrenia Bulletin, 39,* 94–101. doi:10.1093/schbul/sbr062

McCormick, L. M., Brumm, M. C., Beadle, J. N., Paradiso, S., Yamada, T., & Andreasen, N. (2012). Mirror neuron function, psychosis, and empathy in schizophrenia. *Psychiatry Research, 201,* 233–239. doi:10.1016/j.pscychresns.2012.01.004

McPheeters, H. (1984). Statewide mental health outcome evaluation: a perspective of two southern states. *Community Mental Health Journal, 20,* 44–55. doi:10.1007/bf00754103

Meffert, H., Gazzola, V., den Boer, J. A., Bartels, A. A., & Keysers, C. (2013). Reduced spontaneous but relatively normal deliberate vicarious representations in psychopathy. *Brain, 136,* 2550–2562. doi:10.1093/brain/awt190

Mehta, U. M., Basavaraju, R., Thirthalli, J., & Gangadhar, B. N. (2012). Mirror neuron dysfunction—A neuro-marker for social cognition deficits in drug naive schizophrenia. *Schizophrenia Research, 141,* 281–283. doi:10.1016/j.schres.2012.07.005

Moore, A., Gorodnitsky, I., & Pineda, J. (2012). EEG mu component responses to viewing emotional faces. *Behavioural Brain Research, 226,* 309–316. doi:10.1016/j.bbr.2011.07.048

Muthukumaraswamy, S. D., Johnson, B. W., & McNair, N. A. (2004). Mu rhythm modulation during observation of an object-directed grasp. *Cognitive Brain Research, 19,* 195–201. doi:10.1016/j.cogbrainres.2003.12.001

Oberman, L. M., Hubbard, E. M., McCleery, J. P., Altschuler, E. L., Ramachandran, V. S., & Pineda, J. A. (2005). EEG evidence for mirror neuron dysfunction in autism spectrum disorders. *Cognitive Brain Research, 24,* 190–198. doi:10.1016/j.cogbrainres.2005.01.014

Oberman, L. M., McCleery, J. P., Hubbard, E. M., Bernier, R., Wiersema, J. R., Raymaekers, R., & Pineda, J. A. (2013). Developmental changes in mu suppression to observed and executed actions in autism spectrum disorders. *Social Cognitive and Affective Neuroscience, 8,* 300–304. doi:10.1093/scan/nsr097

Oberman, L. M., Pineda, J. A., & Ramachandran, V. S. (2007). The human mirror neuron system: a link between action observation and social skills. *Social Cognitive and Affective Neuroscience, 2,* 62–66. doi:10.1093/scan/nsl022

Oberman, L. M., Ramachandran, V. S., & Pineda, J. A. (2008). Modulation of mu suppression in children with autism spectrum disorders in response to familiar or unfamiliar stimuli: the mirror neuron hypothesis. *Neuropsychologia, 46,* 1558–1565. doi:10.1016/j.neuropsychologia.2008.01.010

Overall, J. E., & Gorham, D. R. (1962). The Brief Psychiatric Rating Scale. *Psychological Reports, 10,* 799–812.

Park, S., Matthews, N., & Gibson, C. (2008). Imitation, simulation, and schizophrenia. *Schizophrenia Bulletin, 34,* 698–707. doi:10.1093/schbul/sbn048

Perkins, T., Stokes, M., McGillivray, J., & Bittar, R. (2010). Mirror neuron dysfunction in autism spectrum disorders. *Journal of Clinical Neuroscience, 17,* 1239–1243. doi:10.1016/j.jocn.2010.01.026

Pineda, J. A. (2005). The functional significance of mu rhythms: translating "seeing" and "hearing" into "doing. *Brain Research Reviews, 50,* 57–68.

Quintana, J., Davidson, T., Kovalik, E., Marder, S. R., & Mazziotta, J. C. (2001). A compensatory mirror cortical mechanism for facial affect processing in schizophrenia. *Neuropsychopharmacology, 25,* 915–924. doi:10.1016/S0893-133X(01)00304-9

Ripoll, L. H., Snyder, R., Steele, H., & Siever, L. J. (2013). The neurobiology of empathy in borderline personality disorder. *Current Psychiatry Report, 15,* 344. doi:10.1007/s11920-012-0344-1

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27,* 169–192. doi:10.1146/annurev.neuro.27.070203.144230

Roberts, D. L., & Penn, D. L. (2009). Social cognition and interaction training in outpatients with schizophrenia: a preliminary study. *Psychiatry Research, 166,* 141–147.

Savla, G. N., Vella, L., Armstrong, C. C., Penn, D. L., & Twamley, E. W. (2012). Deficits in domains of social cognition in schizophrenia: a meta-analysis of the empirical evidence. *Schizophrenia Bulletin, 39,* 979–992. doi:10.1093/schbul/sbs080

Schurmann, M., Jarvelainen, J., Avikainen, S., Cannon, T. D., Lonnqvist, J., Huttunen, M., & Hari, R. (2007). Manifest disease and motor cortex reactivity in twins discordant for schizophrenia. *British Journal of Psychiatry, 191,* 178–179. doi:10.1192/bjp.bp.106.024604

Singh, F., Pineda, J., & Cadenhead, K. S. (2011). Association of impaired EEG mu wave suppression, negative symptoms and social functioning in biological motion processing in first episode of psychosis. *Schizophrenia Research, 130,* 182–186. doi:10.1016/j.schres.2011.04.004

Smith, M. J., Horan, W. P., Cobia, D. J., Korpouzian, T. M., Fox, J. M., Reilly, J. L., & Breiter, H. C. (2014). Performance-based empathy mediates the influence of working memory on social competence in schizophrenia. Schizophrenia Bulletin. doi:10.1093/schbul/sbt084

Smith, M. J., Horan, W. P., Karpouzian, T. M., Abram, S. V., Cobia, D. J., & Csernansky, J. G. (2012). Self-reported empathy deficits are uniquely associated with poor functioning in schizophrenia. *Schizophrenia Research, 137,* 196–202.

Tschacher, W., & Kupper, Z. (2006). Perception of causality in schizophrenia spectrum disorder. *Schizophrenia Bulletin, 32,* S106–S112.

Varcin, K. J., Bailey, P. E., & Henry, J. D. (2010). Empathic deficits in schizophrenia: the potential role of rapid facial mimicry. *Journal of the International Neuropsychological Society, 16,* 621–629. doi:10.1017/S1355617710000329

Ventura, J., Green, M. F., Shaner, A., & Liberman, R. P. (1993). Training and quality assurance with the brief psychiatric rating scale: "The drift busters. *International Journal of Methods in Psychiatric Research, 3,* 221–224.

Williams, J. H. G., Waiter, G. D., Gilchrist, A., Perrett, D. I., Murray, A. D., & Whiten, A. (2006). Neural mechanisms of imitation and "mirror neuron" functioning in autistic spectrum disorder. *Neuropsychologia, 44,* 610–621.

Woodruff, C. C., Martin, T., & Bilyk, N. (2011). Differences in self- and other-induced mu suppression are correlated with empathic abilities. *Brain Research, 1405,* 69–76. doi:10.1016/j.brainres.2011.05.046

Zaki, J., & Ochsner, K. (2011). Reintegrating accuracy into the study of social cognition. *Psychological Inquiry, 22,* 159–182.

Zaki, J., & Ochsner, K. (2012). The neuroscience of empathy: progress, pitfalls and promise. *Nature Neuroscience, 15,* 675–680. doi:10.1038/nn.3085