Psychopathy and the mirror neuron system: Preliminary findings from a non-psychiatric sample

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Abstract

Recent advances in social neuroscience suggest a link between empathy and the mirror neuron system (MNS). Impaired empathy is one of the core diagnostic features of psychopathic personality disorder. In the present study, we investigated whether psychopathic personality traits in a non-psychiatric sample were related to MNS function. Healthy participants viewed short videos known to activate the sensorimotor MNS for pain (a needle penetrating a human hand) while transcranial magnetic stimulation (TMS)-induced motor evoked potentials (MEP) were recorded as a measure of motor cortex excitability. Individual psychopathic personality traits were assessed using the Psychopathic Personality Inventory (PPI) and correlated with the MEP findings. Consistent with previous data, observation of the painful stimulus was associated with a significant reduction in the amplitude of the TMS-induced MEP. Interestingly, the level of corticospinal excitability modulation was positively correlated with individual scores on the coldheartedness subscale of the PPI, such that individuals with the greatest MEP reduction were the ones scoring highest on the coldheartedness measure. These data suggest the existence of a functional link between 'motor empathy' and psychopathy.
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1. Introduction

The discovery of mirror neurons – cells that discharge when an individual executes, sees or hears a specific action or its corresponding action-related sound – in the macaque monkey and the subsequent description of a mirror neuron system (MNS) in humans (see Rizzolatti and Craighero, 2004) has led to unprecedented interest in

the neural basis of social cognition. According to the *embodied simulation* view (Gallese, 2003), the neural circuits that are activated during the observation of actions, emotions and sensations share critical, common substrates with those that are involved in the execution and experiencing of the same actions, emotions and sensations. If so, the mirror matching mechanisms that explain action (Fadiga et al., 1995; Hari et al., 1998; Iacoboni et al., 1999) and emotional (Carr et al., 2003; Leslie et al., 2004) recognition may also underlie key aspects of social behavior, such as mentalizing (the cognitive mechanism that allows one to ascribe goals and intentions to others;

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Iacoboni et al., 2005) and empathy (Gazzola et al., 2006). The term 'empathy' has been defined in a wide variety of ways in the scientific literature. Whereas some have argued that empathy is a unitary phenomenon, others have suggested that it encompasses distinct processes. For example, Blair (2005) describes three dissociable forms of empathy, each subtended by partially distinct neural mechanisms: cognitive, motor and emotional empathy. Here, we define empathy as the capacity to understand other's actions, sensations and emotions. MNS involvement in empathy has received support from functional magnetic resonance imaging (fMRI) studies. For example, Gazzola et al. (2006) showed that execution of hand and mouth actions and passive listening to their associated sounds produces activations in similar areas of the temporo–parieto–premotor cortex. Critically, activations in these mirror areas were positively correlated with scores on an empathy scale.

If the link between simulation mechanisms and the empathic response holds true, pathological conditions in which empathy is impaired may be associated with a dysfunctional MNS. Psychopathy is a good model for the study of empathy because of its prominent role in the symptomatology of the disorder (Blair, 2005), where autonomic responses to sad expressions, vicarious conditioning, and recognition of emotions in others are impaired ('affective empathy'; see Blair, 2005). Despite the wealth of information detailing the clinical aspects of psychopathy, the neuronal mechanisms underlying this disorder as they relate to empathy remain unclear. Of particular interest considering the nature of the disorder is how this population perceives – and understands – pain when it occurs in someone else. Numerous studies support the idea that MNS mechanisms are involved in understanding pain in others. Singer et al. (2004) used fMRI to assess brain activity while healthy participants were receiving painful stimulation or received a signal indicating that a loved one was receiving a painful stimulus. They found that the affective components of the pain matrix (the anterior insula and the anterior cingulate cortex) were activated in both conditions. Importantly, empathy scores were correlated with the level of activation in the insula and cingulate cortex. It was subsequently shown that the 'sensorimotor' aspects of empathy for pain were also subserved in part by a resonance mechanism, whereby sensorimotor components of the pain matrix are activated both when an individual *feels* pain or *observes* pain in others. Using TMS, Avenanti et al. (2005) showed that passive observation of a needle penetrating the hand of a human model produced a reduction of corticospinal excitability in the motor cortex representation of the specific muscle that was pricked, an effect closely resembling that which occurs

during the sensation of pain. Importantly, scores on *sensory* empathy scales – contrary to *emotional* or *affective* empathy scales – were correlated with the degree of corticospinal inhibition occurring during pain observation. In other words, subjects that rated pain as more intense in the observed model were the ones showing the greater stimulus-induced modulation of motor cortex excitability (Avenanti et al., 2005). A subsequent study by the same group showed that shared representations of pain were also present in primary somatosensory cortex (Bufalari et al., 2007). The pattern of somatosensory-evoked potentials (SEPs) during observation of a painful stimulus applied to a model hand was found to be highly similar to that occurring during a painful experience. Furthermore, SEP amplitude was correlated with intensity ratings of the observed pain event. Taken together, these study clearly highlight the sensorimotor aspects of empathy for pain and argue in favor of an understanding of empathy that involves, at a basic level, the motor system and the classical MNS.

In the present study, we aimed at exploring the link between the MNS and psychopathy by relating activity within the sensorimotor MNS for pain to psychopathic personality traits. To this end, the Psychopathic Personality Inventory (PPI; Lilienfeld and Andrews, 1996) was administered to a group of healthy individuals from the general population following the evaluation of corticospinal excitability of the motor cortex during passive observation of a needle penetrating the hand of a human model. Excitability of the motor cortex was evaluated when the needle was halfway through the skin or before it made contact with the model hand. This was done to determine the temporal course of excitability changes related to pain observation as complex time interactions have been reported for action observation (Gangitano et al., 2001). It was hypothesized that *i*) as in a previous study (Avenanti et al., 2005), passive observation of a needle penetrating the hand of a human model would significantly reduce the amplitude of the TMS-induced motor-evoked potentials (MEP); *ii*) these changes in excitability would be modulated in time, such that effects would be maximum when the needle was seen penetrating the model's skin; and *iii*) such changes in motor cortex excitability would be correlated with psychopathic personality traits.

2. Methods

2.1. Subjects

Eighteen male, right-handed college students (mean age=23.8 years, ±3.7) participated in the study. All participants gave written informed consent and the study
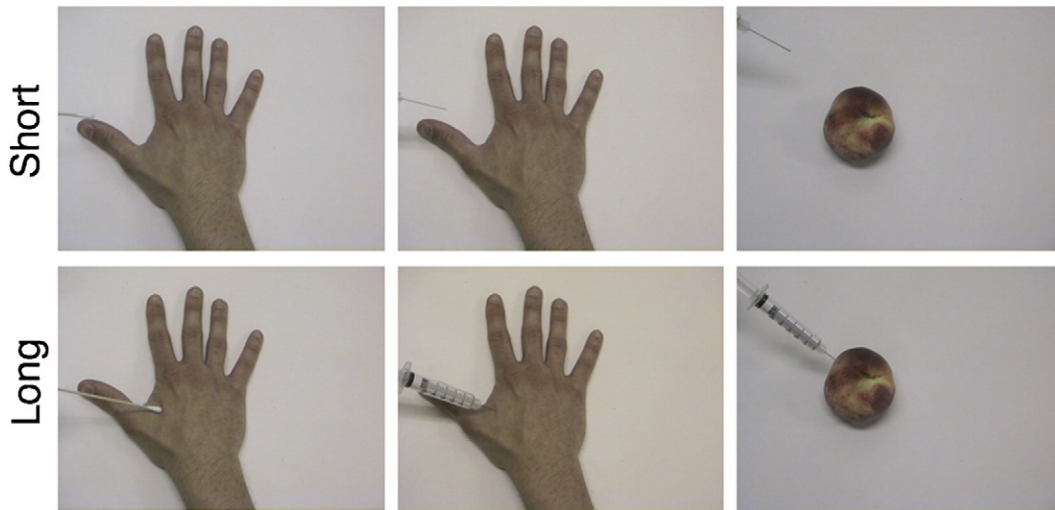
Fig. 1. Still images from the video stimuli corresponding to the time point when the TMS pulse was discharged.

was approved by the local institutional review board. We limited our study to male participants because psychopathic traits are more prevalent in males than females (Lykken, 1984). Furthermore, PPI scores are known to be higher in men than in women, on total PPI score and scores on all 8 subscales (Lilienfeld and Andrews, 1996).

2.2. Procedure

TMS-induced MEPs from the right first dorsal interosseus (FDI) and abductor digiti minimi (ADM) muscles were recorded while participants passively viewed 4-s movie clips on a 17-in high-resolution computer screen set at eye level at a distance of one meter. Four different clips, closely matching those used by Avenanti et al. (2005) were randomly presented to participants (see Fig. 1): 1) right hand at rest (rest); 2) needle penetrating the skin overlying the right FDI muscle (needle); 3) Q-tip touching the skin overlying the right FDI muscle (Q-tip); 4) needle penetrating an apple (apple). Each movie clip was presented 32 times and a single TMS pulse was delivered during each clip presentation. TMS pulses were delivered at two possible time points following initiation of the movie clip. In the short condition, the TMS pulse was

Table 1

	Total score (163 items)	Machiavellian egocentricity (30 items)	Social potency (24 items)	Fearlessness (19 items)	Coldheartedness (21 items)	Impulsive nonconformity (17 items)	Alienation (18 items)	Carefree nonplanfulness (20 items)	Stress immunity (11 items)
S1	412	73	64	63	39	59	37	38	31
S2	417	80	65	63	29	49	56	42	24
S3	395	75	70	51	41	39	41	34	33
S4	351	65	57	42	41	34	34	45	27
S5	312	39	64	44	31	38	27	35	31
S6	410	74	81	42	31	59	38	44	34
S7	400	76	68	47	37	51	52	34	30
S8	340	65	44	53	33	37	41	35	23
S9	341	61	52	47	45	37	28	49	15
S10	375	71	52	43	49	42	35	43	32
S11	406	82	58	65	34	50	31	49	29
S12	382	69	67	52	55	26	29	45	33
S13	391	61	63	49	44	46	39	48	34
S14	438	96	72	46	62	47	34	39	33
S15	312	42	53	34	38	41	28	42	27
S16	381	80	71	33	38	45	37	40	30
S17	416	85	66	48	41	51	39	47	32
S18	401	68	66	50	45	60	24	47	35

delivered approximately 1 s after clip initiation. In the *long* condition, the TMS pulse was delivered when the needle was halfway through the skin or apple, when the Q-tip was touching the hand or 3 s after clip initiation for the static hand. Timing condition order (*short*, *long*) was counterbalanced across subjects. In total, each participant received 128 TMS pulses (4 conditions×16 pulses×2 delays). The interstimulus interval between pulses was at least 10 s in order to minimize possible carry-over effects. Presentation of the stimuli and delivery of TMS pulses was achieved through Matlab (The Mathowrks Inc., Natick, MA, USA) running on a Macintosh G5 computer (Apple Inc., Cuppertino, CA, USA).

2.3. Transcranial magnetic stimulation

The participant sat comfortably during all TMS procedures and recording of MEPs. TMS was delivered over the left hemisphere with a commercially available 80-mm figure-of-eight coil and a Magpro X100 magnetic stimulator (Medtronic, Minneapolis, USA). The current waveform was biphasic and the orientation of the stimulation coil was 45° from the midline with the handle pointing backwards. All stimulation was performed at an intensity of 120% of the individual's resting motor threshold (MT; mean motor threshold was 34.2%, ±7.8). MT was defined as the minimum TMS intensity required to induce MEPs of >50 μV peak-to-peak amplitude in at least 5 of 10 trials in the contralateral FDI, determined with TMS delivered to the optimal scalp site for induction of MEPs. The electromyographic signal was recorded using a PowerLab 4/30 system (ADInstruments, Colorado Sproings, USA), filtered with a band pass of 20–1000 Hz and digitized at a sampling rate of 4 KHz. Data were stored on a computer for off-line analysis. MEPs were recorded and analyzed using Scope software (ADInstruments, Colorado Springs, USA). Peak-to-peak amplitudes of the collected MEPs were measured and averaged for each condition. Based on the procedure of Avenanti et al. (2005), mean MEP amplitude for each experimental condition (*needle*, *apple*, *Q-tip*) was expressed as a percentage of the 'static hand' (*rest*) mean.

2.4. Psychopathic Personality Inventory

To determine whether stimulus-specific corticospinal excitability modulation was related to psychopathic traits, participants were asked to fill out the Psychopathic Personality Inventory (PPI; Lilienfeld and Andrews, 1996), a self-report questionnaire designed to probe psychopathic traits in non-incarcerated, non-psychiatric populations. The PPI has been shown to correlate

positively with the Psychopathy Checklist — Revised (PCL-R; Hare et al., 1991), which is the clinical gold standard for assessing psychopathy. The PPI comprises the following six subscales: Machiavellian egocentricity, social potency, fearlessness, coldheartedness, impulsive nonconformity, blame externalization, carefree nonplanfulness, and stress immunity. Following the TMS procedures, all participants filled out the PPI in a quiet room (Table 1).
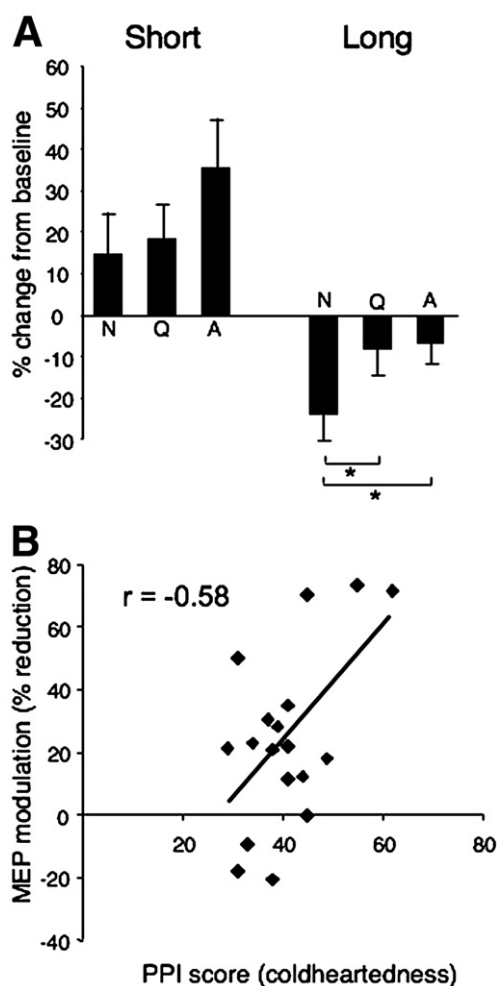

Fig. 2. (A) MEP amplitude values normalized to the static hand for the index finger. Asterisks indicate significant post-hoc comparisons ($P < 0.05$). N: needle penetrating the skin overlying the right FDI muscle. Q: Q-tip touching the skin overlying the right FDI muscle. A: Needle penetrating an apple. (B) Correlation between modulation of MEP amplitude in the long delay needle condition (for the FDI muscle) and score on the coldheartedness scale of the PPI.

3. Results

For the FDI, a repeated measures ANOVA with CONDITION (*needle*, *Q-tip*, *apple*) and DELAY (*short*, *long*) as within-subject factors revealed main effects of CONDITION ($F = 10.0$, $P < 0.01$) and DELAY ($F_{1,34} = 4.7$, $P < 0.05$; Fig. 2A). The interaction was also significant ($F_{1,34} = 11.4$, $P < 0.05$). Post-hoc analysis using the Bonferroni method revealed that in the long delay conditions, MEP amplitudes were significantly lower in the *needle* condition compared to both *Q-tip* ($t = -2.4$, $P < 0.05$) and *apple* ($t = -2.1$, $P < 0.05$), whereas this modulation was absent in the short delay conditions. For the ADM, the repeated measures ANOVA only revealed a main effect of DELAY.

To investigate the link between MNS function and psychopathic personality traits, individual data from *long* delay *needle* condition was submitted to a correlation analysis (Pearson) with PPI scores. There was a significant positive correlation between the level of FDI MEP amplitude decrease and the coldheartedness subscale of the PPI ($r = 0,58$, $P < 0.05$; Fig. 2B). Importantly, there was no significant correlation between any of the PPI subscales and TMS data from the ADM muscle. There was also no significant correlation between PPI scores and the short delay needle condition.

4. Discussion

The present study set out to explore the relationship between the sensorimotor MNS for pain and psychopathic personality traits. Motor cortex excitability was measured in male participants during passive observation of painful stimuli applied to a human model and correlated with individual scores on the PPI. Consistent with a previous study (Avenanti et al., 2005), motor cortex excitability was selectively reduced during observation of a needle penetrating a human hand compared to control conditions. This effect was found to be muscle-specific and dependent upon the timing of the TMS pulse. There was no stimulus-specific modulation of cortical excitability before physical contact with the hand occurred. Significantly, individuals scoring highest on the coldheartedness scale of the PPI showed the greatest modulation of cortical excitability.

4.1. Timing effects

Data suggesting that a simple sensorimotor resonance mechanism underlies parts of the empathic response to pain (Avenanti et al., 2005) were replicated here. This strengthens the idea that shared cortical representations are an important part of our empathic response to pain in others. Notably, this shared circuitry appears to involve, at a basic level, sensorimotor processes whereby the neural response that occurs when a painful stimulus is actually felt is automatically mapped onto the observer's sensorimotor system. Interestingly, motor cortex excitability was increased at the beginning of the videos, irrespective of condition. This suggests that mere observation of object movement, with implied human agency, is sufficient to elicit motor cortex activation. Motor cortex activation in the absence of observable human movement has been shown previously. For example, simple mental imagery of human movement can produce motor cortex excitability increases similar to those observed during actual movement (e.g. Abbruzzese et al., 1996; Vargas et al., 2004). In addition, recent data have shown that observation of a static hand implying action (picture of a precision grip halfway through completion) increases corticospinal excitability compared to a resting hand (Urgesi et al., 2006). Furthermore, the observation of 'realized goals of hand-object interactions' (simple observation of a static hand in a grasping position over an object) activates precentral and inferior frontal gyri, both important nodes of the parietofrontal MNS (Johnson-Frey et al., 2003).

Taken together, these data suggest that the human MNS is responsive to implied actions and results in modulation of motor cortical outputs, even in the absence of the interacting body part. In our study, it may be hypothesized that hand-object interactions (fingers holding the needle or Q-tip and moving towards the stimulated hand or apple) were sufficient in creating a motor representation in the brain of the passive observers. Repetitive presentation of the videos may have activated stored representations of the most likely hand movement underlying the action, which may have been automatically imagined online. The fact that this effect was present in both FDI and ADM muscles, however, argues against the idea that an implied simulation mechanism underlies this effect. Rather, general brain activation, or attentional effects, may explain the early increase in corticospinal excitability. Further studies are needed to better understand how object movement that is under human volitional control modulates motor cortex activity.

4.2. Empathy, mentalizing, and psychopathy

The level of motor cortex modulation during observation of a painful stimulus did not correlate with the overall score on the PPI scale. However, the PPI is made up of eight subscales tapping different concepts related to the psychopathic personality (Lilienfeld and Andrews, 1996).

A significant correlation was observed between the level of corticospinal activity modulation during pain observation and individual scores on the coldheartedness scale. In other words, individuals showing the highest level of coldheartedness also displayed the greatest reduction in MEP amplitude compared to baseline. In their description of the instrument, Lilienfeld and Andrews (1996) define coldheartedness as 'a propensity toward callousness, guiltlessness, and unsentimentality.' Importantly, coldheartedness is one of four PPI subscales significantly correlated with the Hare Psychopathy Checklist — Revised (Hare, 1991), which is a gold standard in the psychopathy diagnosis (Poythress et al., 1998). Coldheartedness is also correlated with Factor 1 of the PCL-R, and not Factor 2, suggesting a specific association with psychopathy characteristics rather than nonspecific behavioral deviance (Poythress et al., 1998).

Critically, coldheartedness is one of the two PPI subscales correlated with a self-report measure of emotional empathy (Questionnaire Measure of Emotional Empathy (QMME); Mehrabian and Epstein, 1972), where coldheartedness shows the greatest correlation at −0.52 (Sandoval et al., 2000). The idea that PPI-defined coldheartedness and emotional empathy are related constructs is of great interest despite the fact that neurophysiological data presented here likely reflect sensory aspects of the empathy construct. Indeed, the correlation between the level of cortical excitability modulation elicited by pain observation was *positively* correlated with coldheartedness. This suggests that individuals displaying specific aspects of the psychopathic personality are actually more responsive, at the sensorimotor level, to the observation of a painful stimulus applied to a conspecific. How may this relate to the psychopathic construct, which is usually defined by a lack of empathy? It is important to note that the level of sensorimotor cortex modulation elicited by the painful stimulus is correlated with *sensory* empathy as opposed to 'emotional, state or trait empathy' (Avenanti et al., 2005). Indeed, it is the sensory quality of the pain projected onto the observed model that appears to drive the decrease in MEP amplitude. In light of the notorious manipulative nature of psychopaths, and their ability to exploit weaknesses in others, one may argue that a better understanding of another's mental or physical state would provide substantial advantage for manipulation or harm (Rogers et al., 2006). If this were to be true, empathy could be construed as involving two separate, serial levels. At first, embodied simulation at a sensory level would account for the strict ability to understand the affective, sensory or emotional state of another individual (an ability closer to mentalizing). Following on this, the necessary information would be available to the observer for an emotional/affective response, which may be maladaptive in psychopaths.

This idea is in line with previous data suggesting spared mentalizing abilities in psychopaths (Blair et al., 1996; Dolan and Fullam, 2004). When incarcerated criminal individuals with antisocial personality disorder with psychopathy were tested on basic theory of mind tasks, they did not differ from control subjects. In addition, psychopathic individuals performed equally well at detecting simple and complex mental states and emotions from facial expressions (Dolan and Fullam, 2004). Of great relevance to the present report is the fact that on some tasks, psychopaths actually performed slightly better than controls at complex emotional recognition. Indeed, in line with our physiological data, Dolan and Fullam (2004) suggest that «the key deficits appear to relate more to their lack of concern about the impact on potential victims than the inability to take a victim perspective». This idea fits with Blair's model of empathy (Blair, 2005), where 'motor empathy' and theory of mind are unaffected in psychopathy, whereas emotional empathy is severely impaired. In autism spectrum disorder, another well-known disorder associated with empathy deficits, theory of mind and motor empathy appear to be impaired, whereas emotional empathy is largely spared. This is again supported by neurophysiological evidence, where motor sensorimotor cortex responses to the passive observation of hand actions is impaired in individuals with ASD (Théoret and Fecteau, 2005; Oberman et al., 2005).

4.3. Study limitations

Limitations to the current study should be considered with respect to data interpretation. A first concern that must be addressed is the fact that the correlation between PPI score and MEP amplitude appears to be driven by some high and low PPI-scoring participants. For example, of the 9 PPI scores above 40, only 4 are correlated with MEP modulations above the best fit line. Inspection of individual data reveals that participants with the largest modulations in MEP size account for most of the correlation effect. This suggests that in the general population, it is individuals at the extremes in terms of motor cortex response to the observation of painful stimuli that show the greatest association with specific psychopathic personality traits. As a result, it may be useful to study individuals with high and low PPI scores to test specific hypotheses related to the psychopathy and MNS constructs. Further studies are needed to determine under which circumstances MNS function is modulated by psychopathic traits in non-psychiatric samples.

It is has been suggested that the coldheartedness subscale of the PPI probes «imaginative engagement» more than callousness, perhaps explaining why it falls out as its own in a factor analysis of the PPI (Benning et al., 2003). As a result, score on the coldheartedness scale of the PPI may not be the best measure of empathy. Indeed, the present data may reflect the fact that individuals with «imaginative engagement» personality traits are more inclined to engage in the sensory aspects of observing pain in others. Nevertheless, as mentioned previously, the coldheartedness scale is correlated with both Factor 1 of the PCL-R and a measure of emotional empathy. Thus, although the coldheartedness scale cannot be used as its own as a proxy for empathy scores, it remains that it is strongly associated with psychopathic personality traits. To clearly establish a link between sensory empathy, psychopathy and the MNS, additional self-report measures are needed. For example, reports of how aversive, unpleasant and intense the painful stimuli were to the participants, as well as what they thought the experience was for the model in the movie would help pinpoint the key elements underlying the effect of psychopathic personality traits on motor cortex excitability. Inclusion of sensory empathy and perspective taking scales would also help determine which aspects of the psychopathy construct are related to the MNS. Despite these shortcomings, the main finding of the current study remains that increased levels of psychopathic personality traits in healthy individuals are clearly *not* associated with reduced activity within the MNS for pain. Indeed, our preliminary findings suggest the presence of *increased* MNS activity levels in participants scoring high on a specific subscale of the PPI, which is well correlated with the gold standard measure of psychopathy. Furthermore, the present study highlights and illustrates the feasibility of studying this type of question by the methodology employed.

It may also be argued that administration of the PPI after the TMS study biased some participants' self-rated answers. Indeed, repetitive observation of a needle penetrating a human hand could have resulted in subtle modulations in the response to specific items of the questionnaire. This order was chosen to avoid contamination of TMS data by participants' thoughts about the study since TMS-induced MEPs are notoriously variable. Finally, in their original study, Avenanti et al. (2005) reported modulation of corticospinal excitability when the observed painful stimulus was applied to the ADM muscle. In that condition, MEPs were lower in the ADM whereas they were unchanged in the FDI. A similar 'double-dissociation', where PPI scores are correlated with ADM corticospinal excitability when the needle penetrates the little finger, would have strengthened the argument that specific resonance mechanisms are associated with some psychopathic traits. Nevertheless, one can assume that a comparable effect would have occurred in the ADM since both are intrinsic hand muscles and observation of a needle penetrating either muscles produces analogous effects in motor cortex (Avenanti et al., 2005).

In conclusion, we provide preliminary evidence for an association between MNS function and psychopathic personality traits in a non-psychiatric male sample. These data are in line with the suggestion that psychopaths have spared mentalizing abilities and may actually perform better on some tasks that involve understanding another person's physical, emotional or affective state. MNS function need to be investigated directly in individuals with a formal diagnosis of psychopathy to better understand the neurophysiology of their characteristic empathy impairments.

Acknowledgements

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