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Touch and personality: Extraversion predicts somatosensory brain response

Michael Schaefer *, Hans-Jochen Heinze, Michael Rotte

Department of Neurology, Otto-von-Guericke University Magdeburg, 39120 Magdeburg, Germany

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ABSTRACT

The Five-Factor-Model describes human personality in five core dimensions (extraversion, neuroticism, agreeableness, conscientiousness, and openness). These factors are supposed to have different neural substrates. For example, it has been suggested that behavioral differences between introverts and extraverts can be explained by the fact that introverts exhibit an inherent drive to compensate for overactive cortical activity in reticulo-thalamo-cortical pathways. The current study examined if responses in somatosensory cortices due to tactile stimulation are affected by personality traits. Based on previous studies and theoretical models we hypothesized a relationship of extraversion with somatosensory responses in primary somatosensory cortex (SI). In order to test this hypothesis we applied nonpainful tactile stimulation on the fingers of both hands of 23 healthy young participants (mean 25 years, standard deviation ± 2.8 years). Personality traits were assessed according to the Five-Factor-Model (NEO-FFI). Neuromagnetic source imaging revealed that the cortical activity (dipole strengths) for sources in SI were closely associated with the personality trait extraversion. Thus, the less extraverted the participants were, the higher was the cortical activity in SI. This relationship was in particular valid for the right hemisphere. We conclude that personality seems to depend on primary cortex activity. Furthermore, our results provide further evidence for an inter-hemispheric asymmetry of the social brain.

Introduction

Based on a factor-analytic approach the Five-Factor-Model describes human personality in five core dimensions. These factors are extraversion, neuroticism, agreeableness, conscientiousness, and openness (Costa and McCrae, 1992; McCrae and Costa, 1991). It has been argued that these dimensions of personality have different neural substrates. For example, Eysenck (1967) suggested that behavioral differences between introverts and extraverts are caused by variability in cortical arousal. According to his theory introverts are chronically more cortically aroused than extraverts. Therefore, introverts exhibit an inherent drive to compensate for this high cortical arousal or overactive reticulo-thalamo-cortical pathways. In contrast, extraverts require more external stimulation than introverts, because they have lower cortical arousal. According to Eysenck cortical arousal can be produced from the reticular formation and from the visceral brain (e.g., hypothalamus, hippocampus, amygdala, cingulum, and septum). It is assumed that introverts have lower thresholds in the ascending reticular activating systems (ARAS) than extraverts, whereas unstable subjects (scoring high on neuroticism) are hypothesized to have lower thresholds in the visceral brain than stable subjects (scoring low on neuroticism) (Eysenck, 1967).

Advances in neuroimaging approaches now allow testing hypotheses on neural correlates for personality factors. Most of the recent neuroimaging studies focused on the role of extraversion. Several studies using magnetic resonance imaging (MRI) showed extraversion related with structural variability in gray matter volume, density, or thickness. Wright et al. (2006) showed that the thickness of specific prefrontal regions is associated with extraversion and neuroticism. Omura et al. (2005) reported that amygdala gray matter concentration is correlated with extraversion and neuroticism. DeYoung et al. (2010) report correlations of extraversion with volume of medial orbitofrontal cortex. Furthermore, studies employed functional MRI (fMRI) to link brain regions with personality factors, similar predominantly for extraversion. The extraversion dimension is related to the social dimension of personality. Extraverts behave more assertively; they enjoy social situations, and have a tendency to experience positive affects (Lucas and Diener, 2001; Lucas et al., 2000). Consequently, fMRI studies have shown an amygdala response to happy faces as a function of extraversion (e.g., Canli, 2004; Canli et al., 2002). Furthermore, numerous studies suggest that extraversion is related to dopaminergic brain regions (e.g., Cohen et al., 2005; Depue and Collins, 1999; Fischer et al., 1997; Hutcherson et al., 2008; Vaidya et al., 2007).

In his theory Eysenck assumed a relation between cortical arousal and sensitivity. Thus, he hypothesized that "arousal messages" from the ARAS and the visceral brain may facilitate the detection of weak stimulation by raising the cortical arousal (Eysenck, 1967). Several psychophysiological studies provided support for this model. Smith

* Corresponding author. Fax: +49 391 6715233.
E-mail address: mischa@neuro2.med.uni-magdeburg.de (M. Schaefer).

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(1968) reported that introverts had lower auditory thresholds. Siddle et al. (1969) found a significant positive correlation between a measure of visual sensitivity and extraversion. This is in line with a behavioral study demonstrating that introverts have lower tactile detection thresholds for tactile stimuli (Edman et al., 1979). Using a neuroimaging approach, an early study by Shagass and Schwartz (1965) provided further support for the findings of Edman et al. (1979). Shagass and Schwartz (1965) examined somatosensory evoked potentials (SEPs) and suggested that somatosensory processing in SI may interact with the personality factor extraversion (Shagass and Schwartz, 1965).

A possible relationship of activity in SI with personality dimensions has also been suggested in studies on social perception. This is based on reports of vicarious activation in the somatosensory cortices when subjects witness the sensations, actions and somatic pain of others (Keysers et al., 2010). Recent studies suggest that these mirror-like responses in SI seem to be affected by interindividual differences (empathy) (e.g., Avenanti et al., 2009; Gazzola et al., 2006 for sensorimotor activations; Schaefer et al., in press for seeing nonpainful touch events).

The current study employed neuromagnetic source imaging to further investigate the relationship of somatosensory activation with personality traits. We hypothesized a relationship of extraversion with somatosensory responses in SI. This hypothesis was grounded on theoretical models, which suggest that behavioral differences between introverts and extraverts can be explained by the fact that introverts exhibit an inherent drive to compensate for overactive reticulo-thalamo-cortical pathways (Eysenck, 1967). Based on the above mentioned results of Shagass and Schwartz (1965) and Edman et al. (1979) we assumed that this high cortical arousal may also affect somatosensory processing in SI, the first major cortical site where somatic touch stimuli are processed. Hence, we hypothesized that introverts have higher cortical activity in SI compared with extraverts.

In order to test our hypothesis we conducted a magnetoencephalography (MEG) study in which we stimulated passively and nonpainfully the index and the little fingers of both hands of twenty-three participants. The results of neuromagnetic source imaging were then used to test for possible relationships between cortical activity in SI and personality dimensions according to the Five-Factor-Model. In addition, we examined empathy measures of the participants. Since previous studies on social perception found a relationship between mirror-like responses in SI when observing someone else being touched (both painfully and nonpainfully) and interindividual differences in empathy (e.g., Osborn and Derbyshire, 2010; Schaefer et al., in press), we here wanted to examine possible relationships of SI activity with empathy measures when receiving simple nonpainful touch. However, the participants in our study did not observe touch to someone else. Thus, we did not expect any relationship of SI activity with empathy measures.

Our experimental design included tactile stimulation of the left and right hands. This was implemented because recent studies on empathy and mirror-like responses in somatosensory cortex suggested different roles for left and right SI (e.g., Ebisch et al., 2008; Ruby and Decety, 2004).

Materials and methods

Participants

Twenty-three subjects (12 females) with a mean age of 25 years (standard deviation ±2.8 years, range 23–29) participated in the study. All subjects were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). The participants gave informed written consent to the study, which adhered to the Declaration of Helsinki and was approved by the local human subjects' committee. All participants had no history or current of neurological or psychiatric disorders history such as DSM IV axis I pathology, taking of psychoactive drugs, or major internal disorder.

For the right hand two subjects were excluded due to poor signal-to-noise ratios. Furthermore, for one subject (left hand) we were unable to calculate dipoles with sufficient goodness-of-fits.

Procedure

While the subjects sat comfortably on a chair with their head placed in the mould of the dewar of the whole-head MEG system in a magnetically shielded room, a pneumatically driven stimulator was used for delivering tactile stimuli at the distal phalanges of the second (D2) and fifth (D5) fingers of both hands. The stimulation device consisted of a diaphragm with a 10-mm diameter causing a distinct tactile sensation when inflated toward the skin by a pulse of pressed air of 2.5 atm for 20 ms (see Fig. 1).

During each experiment, four blocks of stimulation were applied (right D2, left D2, right D5, and left D5). We stimulated different fingers of the hands in order to avoid habituation effects and to optimize signal-to-noise ratios. D2 and D5 were chosen as established stimulation locations of the hands. In each block the finger received 400 pneumatical stimuli. Stimuli were presented with an interstimulus interval of 650±50 ms. The order of blocks was pseudorandomized. Participants were instructed to ignore all tactile stimuli, not to move their head, and to focus on a fixation cross. Participants were not able to watch or hear the tactile stimulation. To support fixation of the subjects' head, we used small cushions placed in the gap between the head and the mould of the dewar. Eye movements of the subjects were monitored with a video camera. Participants demonstrating extensive eye movements were excluded from further data analysis.

To explore whether individual differences in the personality dimensions correlate with activations in the somatosensory cortices, we used a German version of the NEO Five-Factor Inventory (NEO-FFI, Borkenau and Ostendorf, 1993). Furthermore, we asked subjects to complete a German version of the Interpersonal Reactivity Index (IRI, Davis, 1983), which has been previously used in imaging studies to examine empathy-related brain activations (e.g., Avenanti et al., 2009; Singer et al., 2004). These questionnaires were applied at the end of the experiment.

Magnetic source imaging

Somatosensory evoked magnetic fields (SEFs) were recorded using a whole-head MEG system with 148 first-order gradiometers (4D-Neuroimaging, San Diego, CA, USA). The MEG data were acquired with a sampling rate of 2034 Hz and high-pass filtered at 0.1 Hz. Using a trigger signal that was recorded simultaneously at the onset of the pneumatic stimulation, the MEG record of each trial was

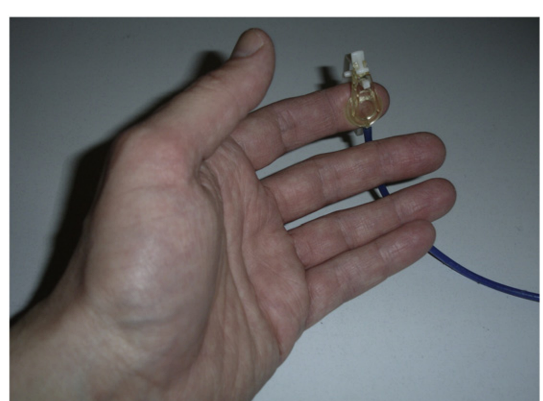

Fig. 1. Pneumatical stimulation device.

epoched into 400 ms windows and averaged across trials for finger type. For further analysis the data were filtered offline with a bandpass from 0 to 60 Hz.

The first prominent peak in the time window from 35 to 85 s (M60 component) was examined for calculating the root mean square (RMS) values of SI (mean global field power) (all sensors were included). The generator of the M60 component has been related to neural sources in SI by previous work (e.g., Braun et al., 2001; Elbert et al., 1995a,b; Hari et al., 1993; Schaefer et al., 2006). Furthermore, RMS values for the secondary somatosensory cortex (SII) were taken from the second prominent peak (time window 85 to 150 s) (Hari et al., 1993). Neuromagnetic source localization of the stimulated fingers was carried out for the first prominent activity peak, the M60 component, which is supposed to reflect activity in SI. Individual magnetic resonance (MR) images (GE MR 1.5T scanner) were used to overlay the dipole localizations with the individual anatomic structure of the subjects' cortex. To achieve the overlays and to determine the source localizations of the SEFs, CURRY multi-modal neuroimaging software (Neuroscan, El Paso, TX, USA) was used. If present, ipsilateral activity was modeled by an extra source that was excluded in further analysis (Zhu et al., 2007). Localization results were accepted only if the explained variance was above 90%.

The dipole moment is assumed to be an index of the amount of neuronal synchronized activity in phase with the stimulus. To test our hypothesis dipole moments and SEF values (RMS scores and latencies for SI and SII) were entered as predictors in standard multiple linear regression models to analyze the relation between somatosensory activity and personality (extraversion). Sex was included as an additional predictor (by using a dummy variable). D2 and D5 values were pooled (mean), because we did not either assume or found systematic differences of single fingers of the hand with regard to their relationship with personality traits.

Logarithmic transformation was applied to amplitude values, dipole strengths and personality dimensions before entering in regression analysis in order to normalize data distribution. P values less than 0.05 were considered statistically significant. The software package SPSS was used for all statistical analysis.

Results

NEO-FFI and IRI results

The scores for the NEO-FFI are depicted in Table 1. There was a significant difference between males and females in neuroticism ($p=0.03$) and openness ($p=0.03$). In addition, neuroticism correlated significantly with extraversion ($r=0.63$, $p<0.05$). There were no other significant correlations between the personality factors.

Table 2 depicts the analysis of the IRI questionnaire. There was a significant difference between males and females in the empathy subscale empathic concern ($p=0.00$) and perspective taking ($p=0.03$). The subscales revealed no significant correlations. Furthermore, IRI subscores and NEO-FFI dimensions showed no significant correlations.

The Edinburgh Handedness Inventory mean score was 81.16 ± 12.06, indicating that all participants were right-handed.

Table 2
Mean values and standard deviation (SD) for results of empathic subscales of IRI.

	IRI			
	Personal distress	Perspective taking	Empathic concern	Fantasy
Mean and SD	9.04 ± 5.34	16.96 ± 2.23	14.91 ± 2.29	13.39 ± 2.84

MEG results

Table 3 depicts the results of the RMS analysis of the SEFs. Statistical analysis revealed no significant effects for hemisphere or location of stimulation (D2 or D5).

Results of a linear regression analysis for stimulation of the left hand and sex revealed a significant effect ($R=0.66$, adjR^2 $r=0.38$, $F(2,22)=7.77$, $p=0.003$). The RMS scores for stimulation of the left hand were a significant (negative) predictor of the extraversion scores ($\beta=-0.66$, $t\ (22)=-3.90$; $p=0.001$). Sex had no influence on the results ($\beta=0.17$, $p=$n.s.). A linear regression model with RMS scores elicited by right hand stimulation and sex as predictors failed to reach the level of significance ($R=0.37$, adjR^2 $r=0.04$, $F(2,20)=1.43$, $p=0.27$). Thus, the more introverted the participants were, the stronger was their SEF response, in particular for the right hemisphere. No other personality dimension was associated with SEF responses. Analysis of the latencies showed no significant relationships with personality factors (extraversion, right hand: $F(2,21)=0.09$, $p=$n.s.; left hand: $F(2,20)=0.13$, $p=$n.s.). Furthermore, RMS values and latencies of SII showed no significant correlations with personality dimensions (all $p>0.10$).

The results of the RMS analysis were supported by the outcome of the neuromagnetic source imaging. A single equivalent dipole contralateral to the side of tactile stimulation with polarity reversal in the region over the central sulcus was identified (see Figs. 2 and 3). An example of the time course of the evoked magnetic activity and the corresponding scalp topography is shown in Fig. 2. Results of the analysis of the dipole moments are depicted in Table 3.

A linear regression analysis for stimulation of the left hand and sex as predictors revealed a significant relationship ($R=0.63$, adjR^2 $r=0.33$, $F(2,21)=6.27$, $p=0.008$). Dipole strengths had a significant (negative) effect on the personality dimension extraversion ($\beta=-0.62$, $t\ (21)=-3.50$; $p=0.002$), whereas sex did not show any significant influence on the results ($\beta=0.06$, $t\ (21)=0.33$; $p=$n.s.). When using dipole strengths elicited by stimulation of the right hand and sex as predictors, the regression model failed to reach the level of significance ($R=0.30$, adjR^2 $r=-0.007$, $F\ (2,20)=0.93$, $p=0.41$). Thus, dipole strengths related to tactile stimulation of the left hand successfully predicted the magnitude of the personality factor extraversion (negatively). For the right SI the relationship was similarly negative, but failed to reach the level of significance.

To explore if the relationship between SI activity and extraversion can be better predicted by D2 or D5, we calculated separate regression models with D2 and D5, respectively. Results (mean of RMS and dipole strengths, left side only) revealed that the model using scores of D5 as predictors explained 42% of the variance (corrected), while the model using values of D2 explained 23% of the variance

Table 1
Mean values and standard deviation (SD) for results of NEO-FFI.

Mean and SD	NEO-FFI				
	Neuroticism	Extraversion	Openness	Agreeableness	Conscientiousness
All	16.09 ± 7.00	30.26 ± 6.58	33.41 ± 6.25	32.95 ± 5.90	35.64 ± 5.34
Females	18.43 ± 7.38	30.00 ± 7.45	35.57 ± 5.23	33.00 ± 5.55	36.29 ± 5.03
Males	12.00 ± 4.00	30.75 ± 4.95	29.63 ± 6.39	32.88 ± 6.88	34.50 ± 6.02

Table 3
Mean values and standard deviation (SD) of RMS scores (in fT), latencies (in ms), and dipole strengths (in nAm) in SI and SII.

Mean and SD	SI			SII	
	RMS	Latency	Dipole strength	RMS	Latency
Right D2	57.14 ± 16.15	81.00 ± 4.32	13.42 ± 5.85	49.10 ± 17.11	140.00 ± 12.30
Right D5	56.63 ± 15.61	81.00 ± 6.29	13.26 ± 4.81	47.00 ± 19.22	133.50 ± 19.60
Left D2	65.35 ± 22.88	81.59 ± 5.84	14.70 ± 5.51	53.45 ± 24.22	135.23 ± 11.76
Left D5	60.00 ± 23.23	81.68 ± 8.55	14.59 ± 4.96	49.22 ± 19.15	138.60 ± 14.46

(corrected). However, future studies are needed to examine if these results may point to systematic differences of somatosensory activity of the fingers with regard to their relationship with personality traits.

Fig. 4 displays the relationship between extraversion and dipole moments. Dipole strengths reflect the information about synchronized evoked activity independent of the source position with respect to the MEG channels. In contrast, RMS scores depend on whether the participant's head is nearer or farer from the helmet in the region of interest. Thus, although the RMS scores yielded slightly higher correlation values, we show in Fig. 4 results of the link with dipole moments, since these data theoretically quantitatively estimate the amount of neuronal synchronized evoked activity independent of MEG helmet location with respect to the subject's head. Results show negative relationships for all fingers with SI activity. Hence, the more introverted the participants were, the stronger was their response in dipole strengths.

Linear regression analysis for other personality dimensions failed to express significant relationships with somatosensory activation in right or left SI (neuroticism, RMS scores for left hand: $F(1,22)=1.83$, $p=$ n.s., dipole strengths: $F(1,21)=1.08$, $p=$ n.s.; right hand, RMS scores: $F(1,20)=0.39$, $p=$ n.s., dipole strengths: $F(1,20)=0.07$, $p=$ n.s.; openness to experience, RMS scores for left hand: $F(1,22)=2.89$, $p=$ n.s., dipole strengths: $F(1,21)=0.38$, $p=$ n.s.; RMS scores for right hand: $F(1,20)=0.004$, $p=$ n.s., dipole strengths: $F(1,20)=0.06$, $p=$ n.s.; agreeableness, RMS scores for left hand: $F(1,22)=0.77$, $p=$ n.s., dipole strengths: $F(1,21)=1.17$, $p=$ n.s.; RMS scores for right hand: $F(1,20)=0.03$, $p=$ n.s., dipole strengths: $F(1,20)=0.007$, $p=$ n.s.; conscientiousness, RMS scores for left hand: $F(1,22)=0.00$, $p=$ n.s., dipole strengths: $F(1,21)=0.00$, $p=$ n.s.; RMS scores for right hand: $F(1,20)=1.98$, $p=$ n.s.; dipole strengths: $F(1,20)=0.00$, $p=$ n.s.).

Furthermore, regression analyses for IRI sub scores with somatosensory activation (amplitudes and dipole moments) in right or left SI (or SII) revealed no significant relationships (subscore personal distress, dipole strengths for left hand: $F(1,21)=0.13$, $p=$ n.s., right hand: $F(1,20)=0.20$, $p=$ n.s.; subscore empathic concern: $F(1,21)=0.93$, $p=$ n.s., right hand: $F(1,20)=0.00$, $p=$ n.s.; subscore fantasy: $F(1,21)=0.36$, $p=$ n.s., right hand: $F(1,20)=0.08$, $p=$ n.s.; subscore perspective taking: $F(1,21)=0.36$, $p=$ n.s., right hand: $F(1,20)=0.32$, $p=$ n.s.)

Regression analyses with handedness scores and SI activity (amplitudes and dipole moments) showed no significant relationships (dipole strengths for left hand: $F(1,21)=0.77$, $p=$ n.s., right hand: $F(1,20)=0.22$).

Discussion

Since it has been reported that tactile thresholds are lower in introverts (Edman et al., 1979) and studies provided first hints that brain responses in SI may be modulated by extraversion (Shagass and Schwartz, 1965), the current study employed MEG to test the hypothesis that somatosensory responses due to nonpainful and passive tactile stimulation correlate with the personality factor extraversion. The results demonstrate signficant negative correlations of dipole strenghts and amplitudes of D2 and D5 with the extraversion dimension.

The relationship of SI activation with extraversion confirms the early work of Shagass and Schwartz (1965). The authors recorded

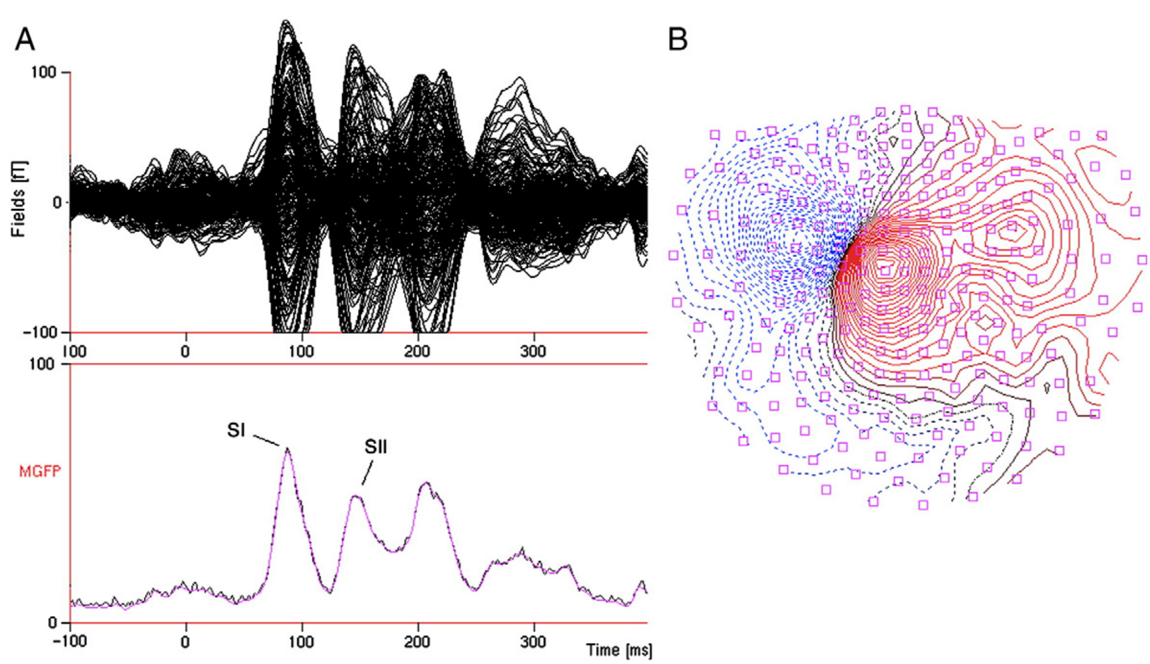

Fig. 2. Topographic map and waveform of magnetic activity evoked by stimulation of the right D2 (representative subject, rest condition). A: Time courses of single MEG channels are superimposed from 148 sensors. The lower picture displays the mean global field power (MGFP). B: Isocontour maps show the magnetic potential pattern at the first prominent peak (SI) after stimulus onset (nasion up, right side displays the right hemisphere, left side the left hemisphere).

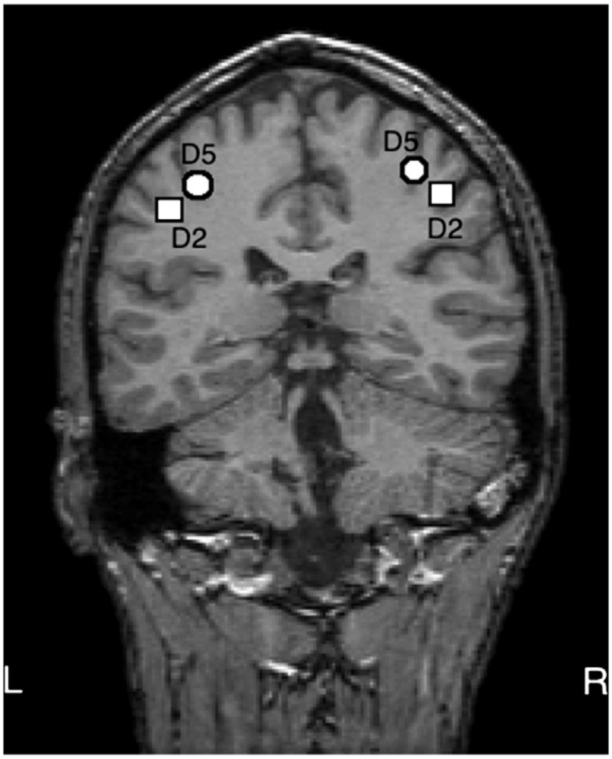

Fig. 3. Dipole localizations of the SEFs for one representative subject overlaid onto a coronal MRI slice. D2 = index fingers (squares); D5 = fifth fingers (circles).

SEPs to stimulation of the median nerve in 89 subjects, aged 15 to 80 years. Shagass and Schwartz (1965) reported an interaction between age and extraversion. The present study supports these results by demonstrating a significant relationship between extraversion and somatosensory response measured with MEG. However, since the range of age of our participants was limited, we were not able to test the interaction with age. Moreover, Shagass and Schwartz (1965) used the Maudsley Personality Inventory (MPI), whereas the present study employed the NEO-FFI, which is based on the now established Five-Factor-Model. Furthermore, we used MEG and a neuromagnetic source imaging approach, which may have resulted in a more precise detection of somatosensory brain responses compared with SEPs (e.g., Schaefer et al., 2004). These differences may account for the lack of a direct correlation of SI activity with extraversion in the study by Shagass and Schwartz (1965).

Extending the findings from Shagass and Schwartz (1965) the present study shows that the correlation between extroversion and SI is in particular valid for the left hand. For the right hand results demonstrated similar negative relationships between extraversion and SI activity, but express lower correlation coefficients or fail to reach the level of significance. Numerous studies suggest asymmetrical specialization of cognitive processes across the cerebral hemispheres. Moreover, an increasing body of evidence suggest right-hemispheric functional asymmetry for the “social brain” (Brancucci et al., 2009). For example, Semrud-Clikeman et al. (2011) employed fMRI to show videos depicting positive and negative social encounters to the participants. Results suggest that the right hemisphere was more active in the perception of social information processing than the left hemisphere. Decety and Lamm (2007) discuss a role of the right temporoparietal junction in theory of mind and empathy based on data of a meta-analysis. In an fMRI study Ruby and Decety (2004) found that empathy and perspective taking in complex social situations involve the right SI. The asymmetrical specialization of social perception seems to be valid even for animals (Daisley et al., 2009). Taken together, we argue that the right hemisphere and the right SI are particularly engaged in processes of social perception. Since extraversion is related to the social dimension of personality, this functional asymmetry may explain our hemispheric specific results.

One could object that our finding of a hemispheric asymmetry of the relationship with extraversion may also be explained by the factor handedness. Thus, right hand dominance may establish associations between SI activities with hand sensorimotor control that may overcome the link with extraversion. Nevertheless, since we did not find any significant relationships between handedness and SI activity, this explanation seems unlikely.

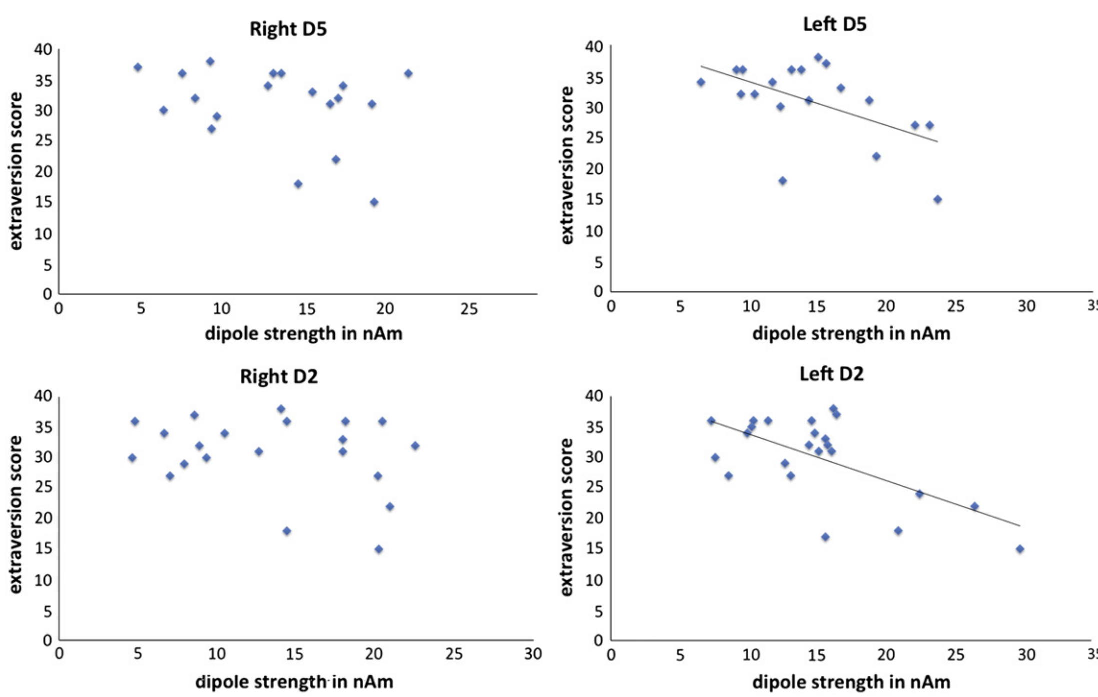

Fig. 4. Scatterplots of dipole moments of left and right hands and personality dimension extraversion. SI activity due to left hand stimulation could significantly predict extraversion scores.

The current study reports a negative relationship of extraversion with SI activation. Thus, the more introverted the participants were, the more SI was activated when receiving passive touch. So why have introverts stronger dipole strengths than extraverts? Eysenck's theory hypothesizes a relation between cortical arousal and sensitivity. His theory postulated that introverts exhibit an inherent drive to compensate for overactive reticulo-thalamo-cortical pathways. According to Eysenck “arousal messages” from the ARAS and the visceral brain may facilitate the detection of weak stimulation by raising the cortical arousal (Eysenck, 1967). Thus, subjects scoring high on introversion should have lower (tactile) thresholds. This is supported by behavioral studies (e.g., Edman et al., 1979; Siddle et al., 1969; Smith, 1968). In particular, Edman et al. (1979) demonstrated that introverts have lower tactile detection thresholds. In Eysenck's model this can be explained by high cortical arousal, which facilitated the detection of weak tactile stimulation. We hypothesized that this cortical arousal also includes activation of the somatosensory cortices. This is supported by the study of Shagass and Schwartz (1965). The present study is in line with these results and suggests higher somatosensory activity for introverts. Thus, introverts may have stronger somatosensory responses because they felt the stimulation more intensely, thereby supporting Eysenck's personality theory.

Nevertheless, alternative explanations for our results should also be taken into account. Thus, introverted may have a general higher arousal, which may not be limited to SI. However, since we found a correlation in particular for the right hemisphere, this explanation seems unlikely. In addition, SII was not associated with extraversion scores. Moreover, only extraversion and no other personality dimension or empathy measure was linked with SI activity, thus pointing to the specificity of the relation between extraversion and SI activation. Furthermore, one could object that we found stronger somatosensory responses for introverts because those subjects may have attended more strongly to the tactile stimuli (or experimental situation at all). So our findings could be a consequence of a personality trait rather than the basis of the trait. Again, we think this is unlikely because of the smaller correlation coefficients of the right hemisphere. If attention effects may have affected our results, both hemispheres should be affected similarly. In addition, recent studies suggest that attention to tactile stimuli induces a reduction rather than an increase of dipole strengths in SI and SEF amplitudes (Huonker et al., 2006). Another objection may point to the intensity of tactile stimulation, which was kept constant across all subjects. Since it is well known that activity in early SEP components increases as a function of stimulation intensity and it also has been demonstrated that introverts have lower tactile thresholds (Edman et al., 1979), one could argue that the results of the present study may also be explained by individual subjective tactile thresholds. We think that this explanation is unlikely because of three reasons. First, we found correlations predominantly for the right hemisphere. This bias to the right SI is not known in previous studies examining tactile thresholds. In particular, studies investigating perceptual thresholds and personality dimensions do not report this inter-hemispheric asymmetry (Edman et al., 1979; Siddle et al., 1969; Smith, 1968). Second, we report strong relationships only with extraversion, as hypothesized. In contrast, other personality dimensions were not predicted by SI activity. Third, the relationship of the intensity of tactile stimulation and its reflection in SI activity are predominantly reported for early SEPs (Hashimoto et al., 1988), while the current study focused on middle- or late latency responses (Elbert et al., 1995b). According to Hashimoto et al. (1988), early SEP components may represent neural coding of physical intensity, while later components are more closely related to the subjective judgment of the stimulus.

Whereas previous studies on mirror-like responses in SI report a correlation with IRI subscores (Avenanti et al., 2009; Gazzola et al., 2006), the present study failed to report significant correlations of SI activity with empathy. This result was expected since the participants of the present study did not observe someone else being touched but received tactile stimuli on their own. In contrast, paradigms of mirror-like responses show others being stimulated, but do not include touch to the observer.

Previous work has linked extraversion with structural variability in specific prefrontal regions (e.g., DeYoung et al., 2010). Furthermore, brain regions including the ventral striatum and the amygdala have been reported to be related to this pesonality dimension (Canli et al., 2002; Depue and Collins, 1999). The current study extends these results by demonstrating that introverts have stronger brain responses in SI when receiving passive touch. The results provide support for the assumptions of Eysenck's personality theory and encourage further studies in personality neuroscience.

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References

Avenanti, A., Minio-Paluello, I., Bufalari, I., Aglioti, S.M., 2009. The pain of a model in the personality of an onlooker: influence of state-reactivity and personality traits on embodied empathy for pain. Neuroimage 44, 275–283.

Borkenau, P., Ostendorf, F., 1993. NEO-Fünf-Faktoren Inventar (NEO-Five Factor Inventory). Psychologie, Göttingen.

Brancucci, A., Lucci, G., Mazzatenta, A., Tommasi, L., 2009. Asymmetries of the human social brain in the visual, auditory and chemical modalities. Philos. Trans. R. Soc. Lond. B Biol. Sci. 364, 895–914.

Braun, C., Heinz, U., Schweizer, R., Wiech, K., Birbaumer, N., Topka, H., 2001. Dynamic organization of the somatosensory cortex induced by motor activity. Brain 124, 2259–2267.

Canli, T., 2004. Functional brain mapping of extraversion and neuroticism: learning from individual differences in emotion processing. J. Pers. 72, 1105–1127.

Canli, T., Sivers, H., Whitfield, S.L., Gotlib, I.H., Gabrieli, J.D., 2002. Amygdala response to happy faces as a function of extraversion. Science 296, 2191.

Cohen, M.X., Young, J., Baek, J.M., Kessler, C., Ranganath, C., 2005. Individual differences in extraversion and dopamine genetics predict neural reward responses. Cogn. Brain Res. 25, 851–861.

Costa, P.T., McCrae, R.R., 1992. NEO PI-R. Professional manual. Psychological Assessment Resources, Inc., Odessa, FL.

Daisley, J.N., Mascalzoni, E., Rosa-Salva, O., Rugani, R., Regolin, L., 2009. Lateralization of social cognition in the domestic chicken (*Gallus gallus*). Philos. Trans. R. Soc. Lond. B Biol. Sci. 364, 965–981.

Davis, M.H., 1983. Measuring individual differences in emapthy: evidence for a multidimensional approach. J. Person. Soc. Psychol. 44, 113–126.

Decety, J., Lamm, C., 2007. The role of the right temporoparietal junction in social interaction: how low-level computational processes contribute to meta-cognition. Neuroscientist 13, 580–593.

Depue, R.A., Collins, P.F., 1999. Neurobiology of the structure of personality: dopamine, facilitation of incentive motivation, and extraversion. Behav. Brain Sci. 22, 491–569.

DeYoung, C.G., Hirsh, J.B., Shane, M.S., Papademetris, X., Rajeevan, N., Gray, J.R., 2010. Testing predictions from personality neuroscience: brain structure and the big five. Psychol. Sci. 21, 820–828.

Ebisch, S.J., Perruci, M.G., Ferretti, A., Del Gratta, C., Romani, G.L., Gallese, V., 2008. The sense of touch: embodied simulation in a visuotactile mirroring mechanism for observed animate or inanimate touch. J. Cogn. Neuroci. 20, 1–13.

Edman, G., Schalling, D., Rissler, A., 1979. Interaction effects of extraversion and neuroticism on detection thresholds. Biol. Psychol. 9, 41–47.

Elbert, T., Pantev, C., Wienbruch, C., Rockstroh, B., Taub, E., 1995a. Increased cortical representation of the fingers of the left hand in string players. Science 270, 305–307.

Elbert, T., Junghöfer, M., Scholz, B., Schneider, S., 1995b. The separation of overlapping neuromagnetic sources in first and second somatosensory cortices. Brain Topogr. 7, 275–282.

Eysenck, H.J., 1967. The biological basis of personality. Charles Thomas: Springfield, Ill.

Fischer, H., Wik, G., Fredrikson, M., 1997. Extraversion, neurocitism an brain function: a PET study of personality. Pers. Individ. Differ. 23, 345–352.

Gazzola, V., Aziz-Zadeh, L., Keysers, C., 2006. Empathy and the somatotopic auditory mirror system in humans. Curr. Biol. 16, 1824–1829.

Hari, R., Karhu, J., Hämläinen, M., Knuutila, J., Salonen, O., Sams, M., Vilkman, V., 1993. Functional organization of the human first and second somatosensory cortices. A neuromagnetic study. J. Neurosci. 5, 724–734.

Hashimoto, I., Yoshikawa, K., Sasaki, M., 1988. Somatosensory evoked potential correlates of psychophysical magnitude estimations for tactile air-puff stimulation in man. Exp. Brain Res. 73, 459–469.

Huonker, R., Weiss, T., Miltner, W.H., 2006. Reduction of somatosensory evoked fields in the primary somatosensory cortex in a one-back task. Exp. Brain Res. 168, 98–105.

Hutcherson, C.A., Goldin, P.R., Ramel, W., McRae, K., Gross, J.J., 2008. Attention and emotion influence the relationship between extraversion and neural response. Soc. Cogn. Affect. Neurosci. 3, 71–79.

Keysers, C., Kaas, J.H., Gazzola, V., 2010. Somatosensation in social perception. Nat. Rev. Neurosci. 11, 417–428.
Lucas, R.E., Diener, E., 2001. Understanding extraverts' enjoyment of social situations: the importance of pleasentness. J. Pers. Soc. Psychol. 81, 342–356.
Lucas, R.E., Diener, E., Grob, A., Suh, E.M., Shao, L., 2000. Cross-cultural evidence for the fundamental features of extraversion. J. Pers. Soc. Psychol. 79, 452–468.
McCrae, R.R., Costa Jr., P.T., 1991. Pesonality in adulthood. Guilford, New York.
Oldfield, R.C., 1971. The assessment and analysis of handedness. The Edinburgh Inventory. Neuropsychologia 9, 97–113.
Omura, K., Todd, C.R., Canli, T., 2005. Amygdala gray matter concentration is associated with extraversion and neuroticism. Neuroreport 16, 1905–1908.
Osborn, J., Derbyshire, S.W., 2010. Pain sensation evoked by observing injury in others. Pain 148, 268–274.
Ruby, P., Decety, J., 2004. How would you feel versus how do you think she would feel? A neuroimaging study of perspective-taking with social emotions. J. Cogn. Neurosci. 16, 988–999.
Schaefer, M., Noennig, N., Karl, A., Heinze, H.-J., Rotte, M., 2004. Reproducibility and stability of neuromagnetic source imaging in primary somatosensory cortex. Brain Topogr. 17, 47–53.
Schaefer, M., Flor, H., Heinze, H.-J., Rotte, M., 2006. Dynamic modulation of the primary somatosensory cortex during seeing and feeling a touched hand. Neuroimage 15, 587–592.
Schaefer, M., Heinze, H.-J., Rotte, M., in press. Embodied empathy for tactile events: Interindividual differences and vicarious somatosensory responses during touch observation. Neuroimage 60, 952–957.
Semrud-Clikeman, M., Fine, J.G., Zhu, D.C., 2011. The role of the right hemisphere for processing of social interactions in normal adults using functional magnetic resonance imaging. Neuropsychobiology 64, 47–51.
Shagass, C., Schwartz, M., 1965. Age, personality, and somatosensory cerebral evoked responses. Science 148, 1359–1361.
Siddle, D.A., Morris, R.B., White, K.D., Mangan, G.L., 1969. Relation of visual sensitivity to extraversion. J. Exp. Res. Person. 3, 264–267.
Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R.J., Frith, C.D., 2004. Empathy for pain involves the affective but not sensory components of pain. Science 303, 1157–1162.
Smith, S.L., 1968. Extraversion and sensory threshold. Psychophysiology 5, 293–299.
Vaidya, J.G., Paradiso, S., Andreasen, N.C., Johnson, D.L., Boles Ponto, L.L., Hichwa, R.D., 2007. Correlation between extraversion and regional cerebral blood flow in response to olfactory stimuli. Am. J. Psychiatry 164, 339–341.
Wright, C.I., Williams, D., Feczko, E., Barrett, L.F., Dickerson, B.C., Schwartz, C.E., Wedig, M.M., 2006. Neuroanatomical correlates of extraversion and neuroticism. Cereb. Cortex 16, 1809–1819.
Zhu, Z., Nagarajan, S.S., Zumer, J.M., McGonigle, D.J., Disbrow, E.A., 2007. Spatiotemporal integration of tactile information in human somatosensory cortex. BMC Neurosci. 14, 21.