Consciousness and Cognition 41 (2016) 64–71

Contents lists available at ScienceDirect

Consciousness and Cognition

journal homepage: www.elsevier.com/locate/concog

Individuals with pronounced schizotypal traits are particularly successful in tickling themselves

Anne-Laure Lemaitre, Marion Luyat, Gilles Lafargue *

Univ. Lille, EA 4072 – PSITEC – Psychologie: Interactions, Temps, Émotions, Cognition, F-59000 Lille, France

ARTICLE INFO

Article history:
Received 23 September 2015
Revised 6 January 2016
Accepted 8 February 2016
Available online 15 February 2016

Keywords:
Schizotypy
Schizophrenia
Agency
Delusions
Passivity experiences
Ticklishness
Efference copy
Predictive sensorimotor process

ABSTRACT

We assessed self-tickling sensations in a group of participants high in schizotypal traits ($n = 27$) and group of participants low in schizotypal traits ($n = 27$). The groups were formed by screening a pool of 397 students for extreme scores in the French version of the Schizotypal Personality Questionnaire. As observed in a previous study involving psychiatric people with auditory hallucinations and/or passivity experiences our results showed that self-applied tactile stimulations are felt to be more ticklish by healthy individuals high in schizotypal traits. In contrast, there were no significant intergroup differences in the mean tickle rating in the externally-produced tickling condition. Furthermore, more successful self-tickling was associated with more frequent self-reports of unusual perceptual experiences (such as supernatural experiences) and passivity experiences in particular (such as a feeling of being under the control of an outside force or power).

1. Introduction

It is well known that tickling oneself fails to elicit the sensations produced when tickled by someone else. Experimentally, a range of studies have confirmed that self-produced somatosensory stimulation results in less ticklishness than externally produced (but otherwise identical) stimulation (Bays, Flanagan, & Wolpert, 2006; Claxton, 1975; Weiskrantz, Elliott, & Darlington, 1971). For instance, a single tactile stimulus (such as a feather) used for tickling is felt to be less intense when it is self-applied than when applied by someone else (Wolpert & Flanagan, 2001). When we perform a voluntary act, our brain is thought to create “efference copies” of the outgoing motor commands and use them to optimize motor control (Sperry, 1950; von Holst & Mittelstaedt, 1950). On this basis, it has been suggested that a “forward model” (Miall, Weir, Wolpert, & Stein, 1993; Wolpert, Ghahramani, & Jordan, 1995; Wolpert & Miall, 1996) helps us to anticipate the sensory consequences of our actions. One aspect of this predictive process (which has obvious adaptive value) involves the sensory attenuation of voluntary action effects and thus enhancement of the salience of externally induced sensations (Claxton, 1975). Efference copies reduce the cognitive load by decreasing the processing of predictable (and thus irrelevant) sensory stimuli (Pynn & DeSouza, 2013). Consequently, an individual is more likely to focus on the rapid detection of unexpected and/or potentially threatening environmental stimuli. A second role may relate to the sense of agency, i.e. the sense that “I’m the one who is causing or generating an action” (Blakemore, Wolpert, & Frith, 2002; Gallagher, 2012). More generally, a sense of agency enables events to be classified as being caused by oneself or by an external source. Consequently,

* Corresponding author.
E-mail address: gilles.lafargue@univ-lille3.fr (G. Lafargue).

http://dx.doi.org/10.1016/j.concog.2016.02.005
1053-8100/

impairment of the predictive process might reduce attenuation of the sensory consequences of voluntary actions and thus prompt the incorrect attribution of a self-generated event to an external cause. This is exactly what happens in people with schizophrenia. Firstly, the attenuation of self-applied stimuli normally observed in healthy subjects is absent (Blakemore, Smith, Steel, Johnstone, & Frith, 2000; Shergill, Samson, Bays, Frith, & Wolpert, 2005). Secondly, some people with schizophrenia feel as if external agents are controlling their own actions; this has been referred to as a "passivity experience" (Blakemore et al., 2002; Frith, Blakemore, & Wolpert, 2000). This abnormal, subjective, sensory experience might be critically involved in the emergence and persistence of delusions of control (Frith et al., 2000; Sugimori, Asai, & Tanno, 2011). This (first-rank) subset of symptoms (Schneider, 1955) is closely related to the diagnosis of schizophrenia.

Interestingly, schizophrenia-like "schizotypal traits" are present to various extents in many people not classified as having clinical disease (Fletcher & Frith, 2009). Schizotypy refers to a cluster of personality traits that includes unusual perceptual experiences, bizarre behavior, odd beliefs and social anhedonia. Most researchers have adopted a dimensional model of schizotypy (Claridge & Davis, 2003) in which schizotypal traits vary continuously throughout the overall population. This creates a spectrum that ranges from normal psychological characteristics and milder forms of schizophrenic symptoms to the overexpression of these traits and thus the emergence of schizophrenia (Claridge, 1994, 1997). Schizotypy has been considered to encompass cognitive–perceptual, interpersonal and disorganized factors, which roughly correspond to the positive, negative and disorganized dimensions of schizophrenia, respectively (Raine, 1991). Given that drug treatment, long hospital stays and psychosis-induced cognitive impairments are potential sources of experimental bias in studies of the link between symptoms and neurocognitive functions in schizophrenia, assessment of the same functions in healthy individuals constitutes a valuable, complementary approach (Raine & Lencz, 1995).

In line with the data obtained in schizophrenia patients (Blakemore, Smith, et al., 2000; Shergill et al., 2005) the results of two correlational studies of healthy people have shown that individuals who score highly on schizotypal scales tend to have trouble predicting the sensory consequences of their actions. In the first of the two studies, Asai, Sugimori, and Tanno (2008) observed a negative correlation between the schizotypy score on one hand and performance in a simple pointing task (involving the prediction of movement) on the other. In the second study, Teufel, Kingdon, Ingram, Wolpert, and Fletcher's (2010) analysis of a force-matching task revealed a relationship between poor prediction of the sensory consequences of self-applied forces on one hand and a tendency to show delusional ideation on the other. On the basis of these findings, we reasoned that if healthy individuals high in schizotypal traits are indeed poorly able to predict the sensory consequences of their own actions, they should be able to tickle themselves more successfully than healthy individuals with low schizotypal scores. We also formed two other hypotheses concerning individuals high in schizotypal traits; that the ability to self-tickle would be (i) more strongly correlated with positive schizotypy than with other aspects of schizotypy – in line with Teufel et al. (2010, see above) – and (ii) correlated with a greater tendency to report passivity experiences. Indeed, we saw above that abnormal predictive mechanism has been linked to delusions of control in schizophrenic patients. Moreover certain manifestations of positive schizotypy can be regarded as non-clinical analogues of schizophrenia first rank symptoms.

2. Experiments

2.1. Methods

2.1.1. Participants

A total of 397 students completed a 7-items questionnaire extracted from the Schizotypy Personality Questionnaire (SPQ, Raine, 1991) at the end of university courses. Eighty participants with extreme scores (40 with high and 40 with low scores) on this mini-questionnaire were then invited to complete the full French version of the SPQ. The participants' scores were transformed in *Z* scores relative to the SPQ French normative data (Dumas et al., 2000; mean: 23.6; standard deviation: 12.09). The 27 individuals (17 women and 10 men; mean ± SD age: 23.4 ± 3.9) who scored in the upper quartile (SPQ *Z*-score $\geqslant .69$) were selected to participate to the main study. They constituted a group high in schizotypal traits ($High_{Schiz}$) with raw SPQ scores between 32 and 54 (mean: 38). We also selected for the main study 27 individuals (16 women and 11 men; mean age: 23 ± 4.32) who scored in the lower quartile (SPQ *Z*-score $\leqslant -.71$). They constituted a group low in schizotypal traits (Low_{Schiz}) with raw SPQ scores between 0 and 15 (mean: 9).

We chose to contrast two groups because the possible differences existing between sets of data are likely to be revealed using an extreme group design. Our purpose was first of all to compare the two distributions (low and high-schizotypical groups) and not to test correlations between the expression of schizotypal traits, on the full schizotypy distribution, and other variables. We are aware that such a design can artificially dichotomize continuous variables, but given the subjective nature of our task we wanted to give us the best chance to detect differences between subjects.

Our aim was not to address the issue of whether schizotypy should be understood in terms of normal set of personality traits in the global population (full dimensional approach) or attenuated form of mental disease (quasi-dimensional approach) (Asai, Sugimori, & Tanno, 2009; Claridge, 1994; Smyrnis et al., 2007). However, in order to form two extreme groups, our measure of interest was the degree of expression of schizotypal traits and, *de facto*, our approach could be viewed as more *quasi* than *fully* dimensional. Note also that the participants in the Low_{Schiz} group had a narrow range of very low SPQ scores. This low variability made it very difficult to detect correlations with other variables. In fact our Low_{Schiz} group could be considered as a control non-schizotypal group.

The $High_{Schiz}$ and Low_{Schiz} groups did not differ significantly with regard to age ($t_{52} = .43$; $p = .67$) or laterality according to the Edinburgh Handedness Inventory (Oldfield, 1971) ($t_{52} = 1.42$; $p = .16$) but did have significantly different SPQ Z-scores ($t_{52} = 19.81$; $p < .0001$).

None of the participants showed motor or sensory impairments or reported a history of neurological or psychiatric disorders. So as not to skew the data collection, none of the participants were aware of the study's objectives. Each person provided his/her prior, written, informed consent to participation and was fully debriefed on the study's objectives after having completed the experiment.

2.1.2. Materials

2.1.2.1. Questionnaires. Two questionnaires were used:

- The SPQ (Raine, 1991) is a 74-item forced choice (Yes/No) self-reported questionnaire consisting of 9 subscales based on the *Diagnostic and Statistical Manual of Mental Disorders* (APA, 1987) criteria for schizotypal personality disorder: ideas of reference, excessive social anxiety, odd beliefs or magical thinking, unusual perceptual experiences, odd or eccentric behavior, no close friends, odd speech, constricted affect, and suspiciousness. The SPQ is also subdivided into three dimensions, which are respectively regarded as non-clinical analogues of the positive, negative and disorganized symptoms of schizophrenia (Raine & Lencz, 1995): Cognitive–Perceptual (positive schizotypy, e.g. unusual perceptual experience and magical thinking), Interpersonal (negative schizotypy, e.g. social anxiety and constricted affect) and Disorganized (e.g. odd speech and bizarre behavior).
- The Scale for Assessment of Passivity Experiences in the General Population (SAPE-GP) (Jones, de-Wit, Fernyhough, & Meins, 2008). Each of the questionnaire's five items is scored on a five-point scale (0: never; 1: occasionally; 2: many times; 3: very often; 4: always), yielding a total score of between 0 and 20. The higher the score, the more frequently the subject has passivity experiences. Only the 54 subjects that were selected for the main experiment were asked to complete this questionnaire.

2.1.2.2. Experimental material. The experimental device (see Fig. 1) could be adjusted to compensate for differences in morphology and thus maintain the brush in contact with the skin at a constant pressure. The area of tickling (total horizontal displacement: 6 cm) was accurately defined for each participant. At the beginning of the experiment, the height of the brush was adjusted so that only the tips of the bristles touched the skin of the forearm.

A virtual metronome (GiveMeTac software, version 1.1) was set to produce a rhythm of 45 beats per minute.

2.1.3. Procedures

Each participant was tested individually. A mask was placed over the eyes so that somaesthesia was not influenced by vision (Whiteley, Kennett, Taylor-Clarke, & Haggard, 2004). The participant placed his/her non-dominant forearm flat on the table (with the sleeve rolled up above the elbow) and performed three trials under each of the three following experimental conditions:

- **Self-tickling (ST)**: participant used his/her dominant hand to make back and forth movements of the paintbrush on her/his non-dominant forearm, to each "tick" and "tack" of the metronome. The duration of the stimulation was 8 s (i.e. 6 beats). Both the participant and the experimenter could hear the sound of the metronome.
- **Predictable, externally-produced tickling (ET_P)**: the experimenter applied the tactile stimulation on the participant's forearm with the same rhythm that in the ST condition. Both could hear the sound of the metronome.

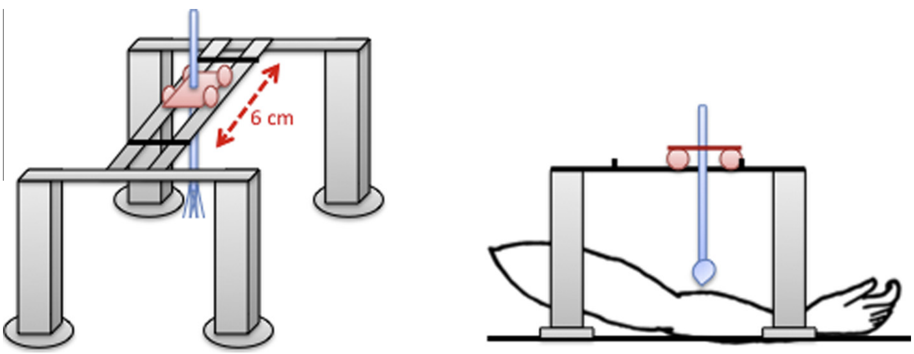

Fig. 1. 2D and 3D views of the device. The experimental material consisted of a wooden frame affixed to a table via four suckers. A paintbrush was mounted on rails to enable it to be moved horizontally back and forth over the participant's forearm. The paintbrush's height could be adjusted with a screw. The rails were blocked on each side, to delineate the area of tickling (total horizontal displacement: 6 cm).

– **Unpredictable, externally-produced tickling (ET_{UN})**: the procedure was the same as in the ET_P condition except that only the experimenter could heard the sound of the metronome through headphones connected to the computer. Here, "unpredictable" means unpredictable on the basis of an effective external signal because the participant couldn't hear the sound of the metronome. In such a condition, at least for the subjects with the less efficient predictive mechanisms, the rhythm of the tactile stimulation should be less easily predictable. Note that the two different externally tickle conditions were also included to add some variety to what was essentially a very repetitive task for the participants.

At the end of each trial, the participant had to rate his/her perceived sensation of tickling on a scale from 0 ("not at all tickly") to 10 ("extremely tickly"). The experiment lasted about 10 min for each participant and (as already mentioned) each trial lasted only 6 metronome beats. It is well known that when the senses are exposed to a continuing stimulus, sensory adaptation occurs, particularly when tactile receptors are stimulated (Adrian, 1928). Thus, in order to diminish adaptation, and also because the task was very subjective in nature, we thought that 3 trials by conditions were a good compromise in order that the subjects could stay on their first sensations.

2.1.4. Data analyses

For each experimental condition, the participant's tickle ratings from the three trials were averaged. We analyzed the ratings in a 2×3 repeated-measures analysis of variance (schizotypal traits [$High_{Schiz}$, Low_{Schiz}] $\times$ tickling condition [ST, ET_P, ET_{UN}]) with schizotypal traits as a category-specific predictor. The Greenhouse–Geisser correction was applied because the data violated the sphericity assumption. Post-hoc comparisons were conducted using Tukey's multiple comparisons test.

Moreover, an index of somatosensory attenuation (ISA) was calculated as follows:

$$\mathrm{ISA} = \frac{\frac{ET_{UN}+ET_P}{2} - ST}{\frac{ET_{UN}+ET_P}{2} + ST}$$

A score of 1 indicates complete somatosensory attenuation, whereas a score of 0 indicates the absence of any attenuation. A Student's t test for independent samples was used to compare the ISA as a function of the degree of schizotypy.

Lastly, Pearson's coefficient (two-tailed) was calculated for the correlations between the ISA and the questionnaire scores (the SPQ scales and subscales and the SAPE-GP). As our investigations were based on a priori hypotheses, no correction was made for multiple comparisons to avoid increasing the risk of a type II error. Note that Bonferroni correction would be too conservative and not appropriate here, firstly because the SPQ scales and subscales scores are not independent measures. Moreover, some statisticians defend the idea that if all the individual *p* values are reported, it is not necessary and even not recommended to adjust for multiple comparisons; but in this case the researchers have to make it clear that no corrections for multiple comparisons were made (Feise, 2002; Perneger, 1998; Savitz & Olshan, 1995).

2.2. Results

Overall, the $High_{Schiz}$ and Low_{Schiz} groups did not differ significantly in terms of the mean tickle rating; hence, schizotypal traits did not have a significant effect [$F(1,52) = 2.13$, $p = .15 > .05$]. In contrast, there was a significant effect of the tickling condition [$F(2,104) = 15.75$, $\eta_p^2 = 0.23$; $p < .0001$]. Overall, the tickle rating differed as a function of the type of stimulation. A post-hoc comparison of the pairs of means showed that tickling sensation was significantly more intense in the ET_{UN} condition (3.99) than in the ST condition (2.83) ($p < .0001$). Likewise, the tickling sensation was significantly more intense ($p < .001$) in the ET_P condition (3.67) than in the ST condition (2.83). However, the tickle ratings in the ET_{UN} and the ET_P conditions did not differ significantly ($p = .29$).

Our key finding was a significant interaction between schizotypal traits and the tickling condition (Fig. 2): [$F(2,104) = 6.20$; $\eta_p^2 = 0.11$; $p < .01$.

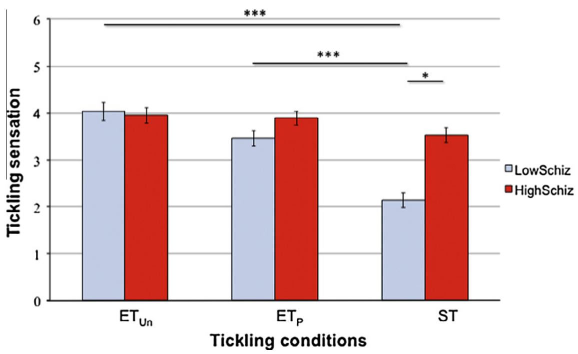

Fig. 2. Mean tickle rating as a function of the tickling conditions in participants low in schizotypal traits and in participants high in schizotypal traits. The error bars correspond to the standard error of the mean. $^{***}p < .001$; $^{*}p < .05$.

Post-hoc comparisons showed that in the ST condition, there was a significant difference in the mean tickle rating between the $High_{Schiz}$ and Low_{Schiz} groups (3.53 and 2.14, respectively; $p = .041$). In contrast, there were no significant intergroup differences in the ET_P condition (3.89 and 3.46, respectively; $p = .94$) or the ET_{UN} condition (3.95 and 4.04, respectively; $p = .99$).

For the Low_{Schiz} group, the post-hoc analysis revealed significant differences between the ET_{UN} and ST conditions ($p < .001$) and between the ET_P and ST conditions ($p < .001$). In contrast, no significant difference was found between the ET_{UN} condition and the ET_P condition ($p = .40$).

For the $High_{Schiz}$ group, no significant difference was found between the different Tickling Conditions: ET_{UN} vs. ET_P ($p = .99$), ET_P vs. ST ($p = .84$), and ET_{UN} vs. ST ($p = .73$).

An analysis of the ISA values (see Fig. 3) showed that the attenuation of the self-tickling sensation was 3.67 times greater in the Low_{Schiz} group than in the $High_{Schiz}$ group ($ISA_{HighSchiz} = 0.09$ and $ISA_{LowSchiz} = 0.33$; $t_{52} = 2.80$, $p < .01$).

Lastly, when considering the $High_{Schiz}$ group alone, we observed significant correlations between the ISA on one hand and the cognitive–perceptual factor ($r = -.58$), the unusual perceptual experiences subscale ($r = -.44$) and suspiciousness ($r = -.56$) on the other. There was also a significant negative correlation between the ISA and the SAPE-GP score ($r = -.41$). None of the other correlations with the ISA were statistically significant. The correlations carried out and the associated p-values (two-tailed) are listed in Table 1. All significant correlations plots are shown in Fig. 4.

3. Discussion

It is well known that tickling oneself usually fails to elicit a marked tickling sensation. This phenomenon has been linked to the attenuation of the sensory consequences of self-generated movements by a predictive sensorimotor process (Blakemore, Wolpert, & Frith, 1998, 2000). As mentioned in the Introduction, it has been shown that impairment of this process may (i) reduce the attenuation of the sensory consequences of self-generated movements and (ii) lead to the erroneous attribution of a self-generated event to an external source. Accordingly, Blakemore, Smith, et al. (2000) showed that psychiatric patients with auditory hallucinations and/or passivity experiences felt the consequences of self-applied tactile stimulation (such as tickling) to be more intense, when compared with patients lacking these symptoms. Correlational studies subsequently showed that non-pathological individuals with high schizotypal scores were poor at predicting the sensory consequences of their own actions in a pointing task (Asai et al., 2008) and in a self-producing force task (Teufel et al., 2010). However, to the best of our knowledge, our study is the first to have focused on whether or not non-pathological individuals with high schizotypal scores experience self-tickling more intensely.

By using an extreme-group design, we tested the hypothesis whereby non-pathological individuals with high schizotypal traits share the greater self-tickling ability observed in psychiatric patients with passivity experiences (Blakemore, Smith, et al., 2000). As expected (on the basis of the literature data), we observed that subjects low in schizotypal traits (the Low_{Schiz} group) felt a self-applied tactile stimulation to be less ticklish than the same stimulation applied by someone else (Wolpert & Flanagan, 2001). In contrast (and in agreement with our starting hypothesis), subjects high in schizotypal traits (the $High_{Schiz}$ group) rated a self-applied tactile stimuli to be more tickly than the low schizotypal subjects did. Our findings suggest that the $High_{Schiz}$ participants were less able to generate neural predictions that match the sensory consequences of their voluntary acts (Wolpert & Miall, 1996; Wolpert et al., 1995). In the task used in the present study, the participants used their dominant hand to move a paintbrush back and forth over the skin of the contralateral forearm; one can hypothesize that Low_{Schiz} participants generated efference copies in relation to the motor commands sent to the arm muscles. On this basis, a forward model could then predict the hand movements' sensory impact on the contralateral forearm. The sensory feedback from the forearm (i.e. the re-afference) will then be compared with the sensory predictions. In the Low_{Schiz} group, these predictions were accurate and thus could be used to attenuate the sensory effects of the self-produced movement. In contrast, the sensory predictions might have had been less accurate in the $High_{Schiz}$ group, with much less attenuation (by a factor of 3.67, on average).

Given that sensory prediction mechanisms are supposedly used to differentiate between self-produced and externally-produced sensations (Wolpert & Flanagan, 2001), the lack of attenuation of tickly sensations in $High_{Schiz}$ participants might have been associated with a lower sense of agency. This is exactly what was found in a correlation analysis of the participants in the $High_{Schiz}$ group: the more able a participant was to tickle him/herself, the more he/her reported passivity-like experiences (evidenced by the negative correlation between the SAPE-GP score and the ISA) and paranoid ideas (suspiciousness).

Our current findings corroborate the pattern of results previously reported in psychiatric patients with auditory hallucinations and/or passivity experiences by Blakemore et al. and extend them to schizotypy (Blakemore, Smith, et al., 2000). The findings of a few other studies (based on different experimental designs) are also in line with the hypothesis whereby the sensory consequences of voluntary actions are abnormally attenuated in people with schizophrenia (Lindner, Thier, Kircher, Haarmeier, & Leube, 2005; Shergill et al., 2005). More generally, it has been suggested that people with schizophrenia have a reduced sense of "voluntariness" (for a review, see (Lafargue & Franck, 2009), as characterized by greater awareness of afferent (bottom-up) neural information (Blakemore, Smith, et al., 2000; Shergill et al., 2005) and lesser awareness of efferent (top-down) neural information (Lafargue, Franck, & Sirigu, 2006; Lafargue & Sirigu, 2006; Pirio Richardson et al.,

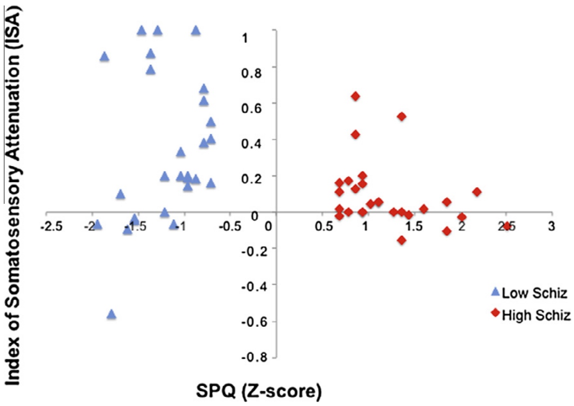

Fig. 3. Individual Index of Somatosensory Attenuation (ISA) values as a function of the expression of schizotypal traits (SPQ *Z*-scores). A score of 0 indicates a lack of attenuation for self-tickling; the higher the ISA, the greater the attenuation. Note that the data points for the HighSchiz group are shifted toward lower values.

2006). This abnormal subjective experience of willed actions might be related to impaired frontoparietal functioning (Jardri et al., 2011) and might predispose to delusions of being controlled by an external agent.

Maher (1999) suggested that "a major critical difference between delusional beliefs and non-delusional beliefs is the nature and intensity of the phenomenological experience that is being explained". Furthermore, this researcher has also stated (Maher, 1974) that "where the patient may differ from a normal observer is not in the manner of drawing inference from evidence but in the kinds of perceptual experience that provide the evidence from which the inference is to be drawn". In line with Shergill et al. (2005), our data show that non-clinical subjects with schizophrenia-like symptoms have an abnormal subjective experience of willed actions. The greater this anomaly, the more the subjects tended to (i) report paranoid ideas and unusual perceptual experiences, and (ii) score highly on the SAPE-GP. In more concrete terms, successful self-tickling is related to more frequent self-reports of suspiciousness and unusual perceptual experiences (such as SPQ item 9 "I'm sure I'm being talked about behind my back" and SPQ item 31 "I often hear a voice speaking my thoughts aloud"), passivity experiences (such as SAPE-GP item 1 "feeling as if you were under the control of some force or power other than yourself" and SAPE-GP item 4 "feeling as if you were a robot or zombie without a will of your own").

Using a different experimental strategy, our results replicate Teufel et al.'s (2010) finding that a reduced tendency to predict and attenuate the sensory consequences of self-generated action, in the general population, is associated with higher levels of delusional ideation. Our study also extends the results of this previous work because we also specifically examined the relationship between abnormal sensory prediction mechanisms and level of self-reported passivity experiences in the healthy population. We found that more successful self-tickling was associated with more frequent self-reports of passivity experiences. This finding is interesting since delusions of control are considered as "first rank" symptoms of schizophrenia, because they play a very important role in the diagnostic of this pathology (Schneider, 1955). Our results are in line with the

Table 1
The correlations (*r* values with associated two-tailed *p* values) between Index of Somatosensory Attenuation, SPQ factors and SAPE-GP for High and LowSchiz individuals.

	Index of Somatosensory Attenuation (ISA)			
	HighSchiz		LowSchiz	
	r	*P* value	*r*	*P* value
Cognitive Perceptual Factor	**−.58**	**.001**	.30	.13
Ideas of reference	−.28	.16	.29	.14
Magical think	−.01	.95	.01	.96
Unusual perceptual experiences	**−.44**	**.02**	.31	.12
Suspiciousness	**−.56**	**.002**	.22	.29
Interpersonal factor	.17	.38	.08	.70
Social anxiety	.22	.26	.06	.77
No close friends	−.05	.80	.02	.93
Constricted affect	.23	.24	.08	.69
Disorganized factor	−.03	.91	.07	.73
Odd speech	.05	.81	−.06	.79
Odd behavior	−.1	.63	.16	.44
SAPE-GP	**−.41**	**.036**	.07	.73

Correlations that are significant at the .05 level or less are reported in bold.

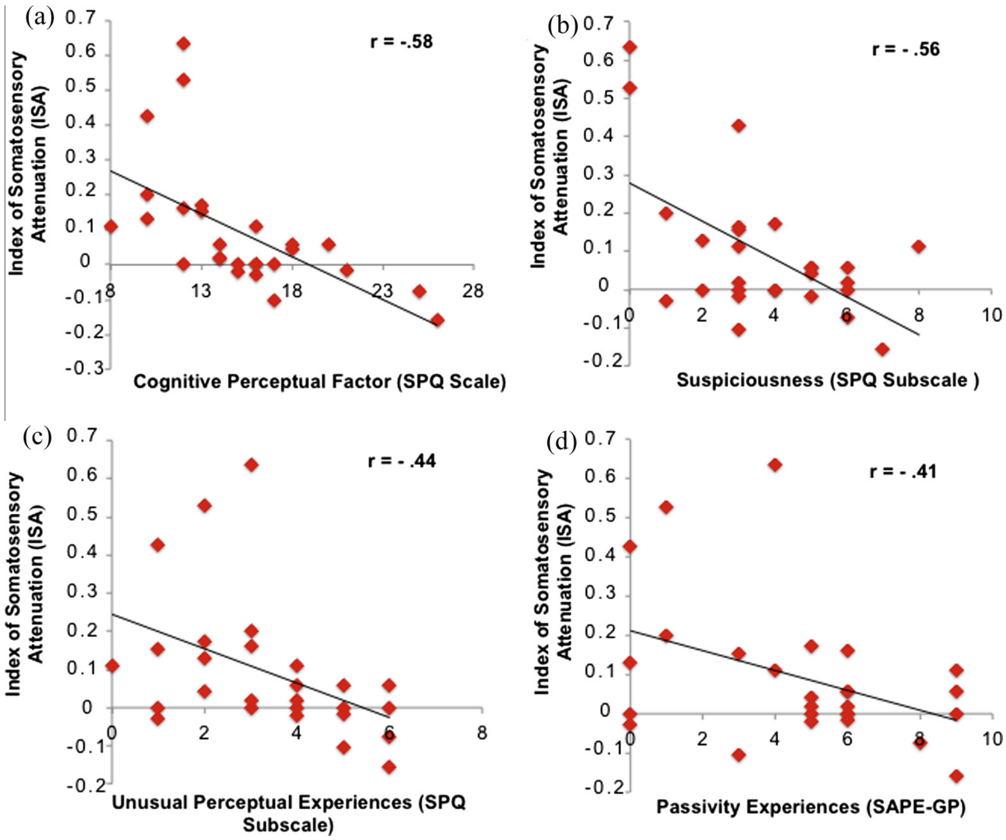

Fig. 4. Individual Index of Somatosensory Attenuation values as a function of (a) Cognitive Perceptual Factors scores; (b) Suspiciousness scores; (c) Unusual Perceptual Experiences scores and (d) Passivity Experiences (SAPE-GP) scores.

hypothesis that these false beliefs in an external control by supernatural agents arise as the result of a perceptual disorder (independent of neuroleptic medication) and not as the result of a thinking disorder *per se* (see Lafargue & Franck, 2009 for a complete discussion). The fact that the perceptual abnormality encompasses the very content of the delusion, might explain why delusions of control, in schizophrenia, are very difficult to correct and so resistant to rational counter-argument and psychotherapy.

A recent study (Parees et al., 2014) demonstrated that patients with functional movement disorders displayed low sensory attenuation. Nevertheless, these patients did not differ from healthy (control) participants in terms of their responses to questionnaires probing delusional beliefs. Other literature data have highlighted abnormal predictive mechanisms in non-psychotic patients. For example, healthy elderly adults tend to overestimate their physical capabilities (Lafargue, Noel, & Luyat, 2013). However, the latter study did not prove the putative link between faulty predictive mechanisms and proneness to passivity experiences.

Future research will have to characterize the types and intensities of abnormal perceptual experiences from which delusions and psychotic disorder emerge.

4. Conclusion

Our starting hypothesis was that healthy people high in positive schizotypal traits are characterized by poor prediction of the sensory consequences of their own movements. We further hypothesized that this would enabled these people to tickle themselves more particularly successfully. By applying three different standardized tickling conditions, we investigated predictive mechanisms in participants high in schizotypal traits and in participants low in schizotypal traits.

The $High_{Schiz}$ participants (but not the Low_{Schiz} participants) did not feel self-tickling to be less ticklish than tickling by a third party. This finding suggests that $High_{Schiz}$ participants had less efficient predictive mechanisms and were less able to predict the sensory consequences of their own actions. Given that the sensory prediction mechanism is supposedly involved in differentiating between self-produced and externally-produced sensations, a loss of attenuation of tickling sensations in $High_{Schiz}$ participants might be associated with a lesser sense of agency. This supposition was supported by the positive correlations between successful self-tickling, high positive schizotypal traits and the frequency of self-reported passivity experiences. When considering a continuum ranging from the absence of a disorder to the full-blown symptoms of schizophrenia, our data provide a basis for understanding the illusions of control experienced by schizophrenic patients.

Acknowledgments

We are grateful to Marion Ghyselen and Christopher Leroy for assistance in data collection and preparation of figures.

References

Adrian, E. D. (1928). *The basis of sensation*. New York, NY, US: WW Norton & Co.

APA (1987). *Diagnostic and statistical manual of mental disorders – Revised (DSM-III-R)*. Washington, DC: American Psychiatric Association.

Asai, T., Sugimori, E., & Tanno, Y. (2008). Schizotypal personality traits and prediction of one's own movements in motor control: What causes an abnormal sense of agency? *Consciousness and Cognition, 17*(4), 1131–1142.

Asai, T., Sugimori, E., & Tanno, Y. (2009). Schizotypal personality traits and atypical lateralization in motor and language functions. *Brain and Cognition, 71*(1), 26–37.

Bays, P. M., Flanagan, J. R., & Wolpert, D. M. (2006). Attenuation of self-generated tactile sensations is predictive, not postdictive. *PLoS Biology, 4*(2), e28.

Blakemore, S. J., Smith, J., Steel, R., Johnstone, E. C., & Frith, C. D. (2000). The perception of self-produced sensory stimuli in patients with auditory hallucinations and passivity experiences: Evidence for a breakdown in self-monitoring. *Psychological Medicine, 30*(5), 1131–1139.

Blakemore, S. J., Wolpert, D. M., & Frith, C. D. (1998). Central cancellation of self-produced tickle sensation. *Nature Neuroscience, 1*(7), 635–640.

Blakemore, S. J., Wolpert, D., & Frith, C. (2000). Why can't you tickle yourself? *NeuroReport, 11*(11), R11–R16.

Blakemore, S. J., Wolpert, D. M., & Frith, C. D. (2002). Abnormalities in the awareness of action. *Trends Cognitive Science, 6*(6), 237–242.

Claridge, G. (1994). Single indicator of risk for schizophrenia: Probable fact or likely myth? *Schizophrenia Bulletin, 20*(1), 151–168.

Claridge, G. (1997). *Schizotypy: Implications for illness and health*. Oxford University Press.

Claridge, G., & Davis, C. (2003). *Personality and psychological disorders*. Arnold.

Claxton, G. (1975). Why can't we tickle ourselves? *Perceptual and Motor Skills, 41*(1), 335–338.

Dumas, P., Bouafia, S., Gutknecht, C., Saoud, M., Dalery, J., & d'Amato, T. (2000). Validation of the French version of the Raine Schizotypal Personality Disorder Questionnaire–categorial and dimensional approach to schizotypal personality traits in a normal student population. *Encephale, 26*(5), 23–29.

Feise, R. J. (2002). Do multiple outcome measures require p-value adjustment? *BMC Medical Research Methodology, 2*, 8.

Fletcher, P. C., & Frith, C. D. (2009). Perceiving is believing: A Bayesian approach to explaining the positive symptoms of schizophrenia. *Nature Reviews Neuroscience, 10*(1), 48–58.

Frith, C. D., Blakemore, S. J., & Wolpert, D. M. (2000). Abnormalities in the awareness and control of action. *Philosophical Transactions of the Royal Society of London. Series B, Biological sciences, 355*(1404), 1771–1788.

Gallagher, S. (2012). Multiple aspects in the sense of agency. *New Ideas in Psychology, 30*(1), 15–31.

Jardri, R., Pins, D., Lafargue, G., Very, E., Ameller, A., Delmaire, C., et al (2011). Increased overlap between the brain areas involved in self-other distinction in schizophrenia. *PLoS ONE, 6*(3), e17500.

Jones, S. R., de-Wit, L., Fernyhough, C., & Meins, E. (2008). A new spin on the Wheel of Fortune: Priming of action-authorship judgements and relation to psychosis-like experiences. *Consciousness and Cognition, 17*(3), 576–586.

Lafargue, G., & Franck, N. (2009). Effort awareness and sense of volition in schizophrenia. *Consciousness and Cognition, 18*(1), 277–289.

Lafargue, G., Franck, N., & Sirigu, A. (2006). Sense of motor effort in patients with schizophrenia. *Cortex, 42*(5), 711–719.

Lafargue, G., Noel, M., & Luyat, M. (2013). In the elderly, failure to update internal models leads to over-optimistic predictions about upcoming actions. *PLoS ONE, 8*(1), e51218.

Lafargue, G., & Sirigu, A. (2006). The nature of the sense of effort and its neural substrate. *Nature et substratum neurologique du sens de l'effort. Revue Neurologique, 162*(6–7), 703–712.

Lindner, A., Thier, P., Kircher, T. T., Haarmeier, T., & Leube, D. T. (2005). Disorders of agency in schizophrenia correlate with an inability to compensate for the sensory consequences of actions. *Current Biology, 15*(12), 1119–1124.

Maher, B. A. (1974). Delusional thinking and perceptual disorder. *Journal of Individual Psychology, 30*(1), 98–113.

Maher, B. A. (1999). Anomalous experience in everyday life: Its significance for psychopathology. *The Monist, 82*, 547–570.

Miall, R. C., Weir, D. J., Wolpert, D. M., & Stein, J. F. (1993). Is the cerebellum a smith predictor? *Journal of Motor Behavior, 25*(3), 203–216.

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia, 9*(1), 97–113.

Parees, I., Brown, H., Nuruki, A., Adams, R. A., Davare, M., Bhatia, K. P., et al (2014). Loss of sensory attenuation in patients with functional (psychogenic) movement disorders. *Brain, 137*(Pt 11), 2916–2921.

Perneger, T. V. (1998). What's wrong with Bonferroni adjustments. *BMJ, 316*(7139), 1236–1238.

Pirio Richardson, S., Matsuhashi, M., Voon, V., Peckham, E., Nahab, F., & Mari, Z. (2006). Timing of the sense of volition in patients with schizophrenia (Abstract). *Clinical Neurophysiology, 117*(Suppl. 1).

Pynn, L. K., & DeSouza, J. F. (2013). The function of efference copy signals: Implications for symptoms of schizophrenia. *Vision Research, 76*, 124–133.

Raine, A. (1991). The SPQ: A scale for the assessment of schizotypal personality based on DSM-III-R criteria. *Schizophrenia Bulletin, 17*(4), 555–564.

Raine, A., Lencz, T. (1995). Conceptual and theoretical issues in schizotypal personality research. *Schizotypal personality* (pp. 1–18).

Savitz, D. A., & Olshan, A. F. (1995). Multiple comparisons and related issues in the interpretation of epidemiologic data. *American Journal of Epidemiology, 142*(9), 904–908.

Schneider, K. (1955). *Klinische psychopathologie*. Stuttgart: Thieme Verlag.

Shergill, S. S., Samson, G., Bays, P. M., Frith, C. D., & Wolpert, D. M. (2005). Evidence for sensory prediction deficits in schizophrenia. *American Journal of Psychiatry, 162*(12), 2384–2386.

Smyrnis, N., Evdokimidis, I., Mantas, A., Kattoulas, E., Stefanis, N. C., Constantinidis, T. S., et al (2007). Smooth pursuit eye movements in 1,087 men: Effects of schizotypy, anxiety, and depression. *Experimental Brain Research, 179*(3), 397–408.

Sperry, R. W. (1950). Neural basis of the spontaneous optokinetic response produced by visual inversion. *Journal of comparative and physiological psychology, 43*(6), 482–489.

Sugimori, E., Asai, T., & Tanno, Y. (2011). Sense of agency over speech and proneness to auditory hallucinations: The reality-monitoring paradigm. *Quarterly Journal of Experimental Psychology (Hove), 64*(1), 169–185.

Teufel, C., Kingdon, A., Ingram, J. N., Wolpert, D. M., & Fletcher, P. C. (2010). Deficits in sensory prediction are related to delusional ideation in healthy individuals. *Neuropsychologia, 48*(14), 4169–4172.

von Holst, E., & Mittelstaedt, H. (1950). Das reafferenzprinzip. *Naturwissenschaften, 37*(20), 464–476.

Weiskrantz, L., Elliott, J., & Darlington, C. (1971). Preliminary observations on tickling oneself. *Nature, 230*(5296), 598–599.

Whiteley, L., Kennett, S., Taylor-Clarke, M., & Haggard, P. (2004). Facilitated processing of visual stimuli associated with the body. *Perception, 33*(3), 307–314.

Wolpert, D. M., & Flanagan, J. R. (2001). Motor prediction. *Current Biology, 11*(18), R729–R732.

Wolpert, D. M., Ghahramani, Z., & Jordan, M. I. (1995). An internal model for sensorimotor integration. *Science, 269*(5232), 1880–1882.

Wolpert, D. M., & Miall, R. C. (1996). Forward models for physiological motor control. *Neural Networks, 9*(8), 1265–1279.