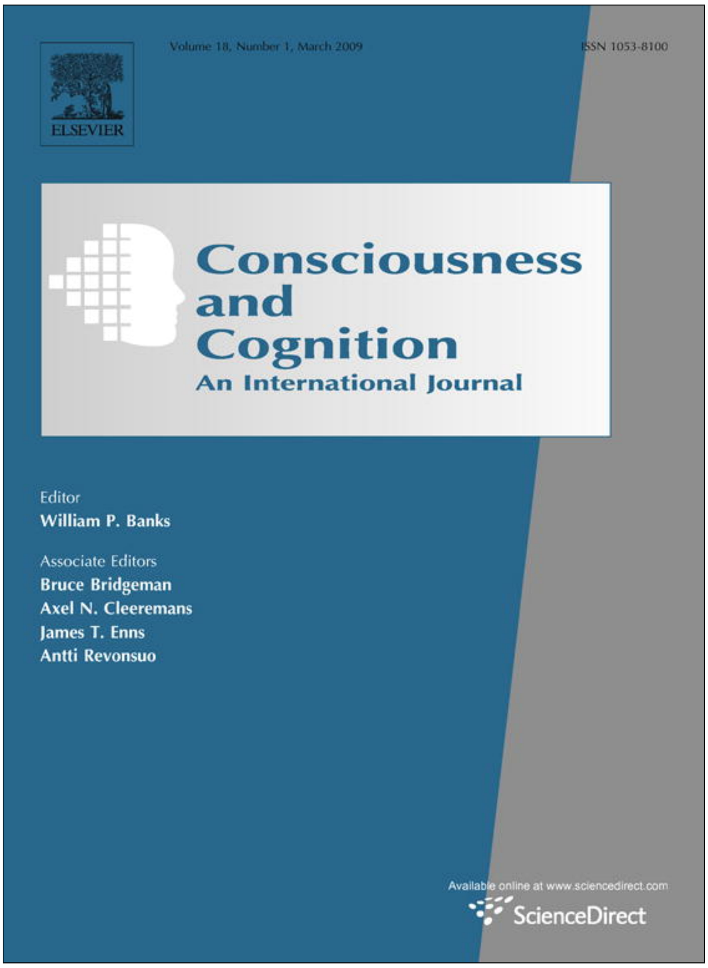
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Review

Effort awareness and sense of volition in schizophrenia

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ABSTRACT

Contemporary experimental research has emphasised the role of centrally generated signals arising from premotor areas in voluntary muscular force perception. It is therefore generally accepted that judgements of force are based on a central sense, known as the sense of effort, rather than on a sense of intra-muscular tension. Interestingly, the concept of *effort* is also present in the classical philosophy: to the French philosopher Maine de Biran [Maine de Biran (1805). Mémoire sur la décomposition de la pensée (Tome III), Vrin, Paris (1963)], the sense of effort is the fundamental component of self-experience, the landmark of the exercise of the will. In the present review, after a presentation of the nature and neurophysiological bases of effort sensation, we will examine its possible involvement in the neurocognitive process of agency. We will further focus on delusions of alien control in schizophrenic patients. Experimental data suggest that these patients have an abnormal awareness of effort caused by cerebral anomalies in the frontal and parietal lobes.

1. Introduction

Among healthy subjects, voluntary and involuntary movements are accompanied by perceptive contents different enough to be subjectively discriminated. For instance, the subjective experience that accompanies a movement triggered by electric (Penfield & Boldrey, 1937) or magnetic (Gandevia, Killian, McKenzie, Crawford, & Allen, 1993) stimulation of the primary motor cortex is not identical to that which accompanies the same movement voluntarily initiated. In the same way, a movement of the leg is not accompanied by the same feeling if it is triggered by a reflex hammer or if it is self-generated.[1]

At the beginning of the 19th century, the French philosopher Maine de Biran (1805) argued that the feeling of effort was the fundamental criterion of the self. According to this view, raised again more recently by Frith (1992), the feeling of effort gives to willed actions their specific perceptive content. If so, an interesting question is: what would occur if the sense of effort was disturbed and if, therefore, the perception of effort that normally accompanies our voluntary acts[2] was deteriorated or suddenly disappeared? Would we experience a simple feeling of loss of control of our actions, a mere impression of passivity? Or would we form, in addition, delusional beliefs as, for instance, the belief that we are controlled by external forces?

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[1] There are however a number of clinical conditions under which the distinction between voluntary and involuntary movements breaks down (Spence, 2002).

[2] At least on a preconscious level.

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Of particular concern for our purpose is the fact that many schizophrenic patients report what has been labelled as *passivity experiences*, to refer to the subjective experiences of loss of control of their own acts or thoughts. For example, a patient with schizophrenia will report:

> "When I reach my hand for the comb it is my hand and arm which move, and my fingers pick up the pen, but I don't control them." (Mellors, 1970, p. 36).

The subjective experience of lack of control *per se* should be distinguished from *delusions of alien control*. When a patient suffering from schizophrenia reports passivity experiences, in most cases her/he does not merely report a lack of agency, that is to say a simple feeling of a lack of control of her/his own acts. She/he often comes to form the firm belief, despite what everyone believes, that her/his acts are controlled by some kind of alien agent (machines, implants, aliens, religious figures, depending on her/his cultural background) rather than by her/his own intentions. For example, the patients will report:

> "The force move my lips. I began to speak." (Frith, Blakemore, & Wolpert, 2000, p. 358).
> "I am just a puppet who is manipulated by cosmic strings. When the strings are pulled my body moves and I cannot prevent it." (Mellors, 1970, p. 36).
> "My grandfather hypnotised me and now he moves my foot up and down." (Frith et al., 2000, p. 358).
> "They inserted a computer in my brain. It makes me turn to the left or right." (Frith et al., 2000, p. 358).

Do delusions of alien control, referred as *first ranks symptoms* (FRS) of schizophrenia by Schneider (1955), take their source in an altered awareness of willed actions and, more precisely, in a malfunctioning sense of effort? In the first part of this article, we will present a body of phenomenal and experimental evidence attesting that motor effort is a crucial component, available to consciousness, of willed actions. We will also address the question of the nature and of the neurocognitive basis of the sense of effort. Frith (1992), in a very authoritative work, argued in favour of a defective subjective experience of effort in schizophrenia, however without providing direct experimental evidence. In the second section, we will describe the results of a recent study by Lafargue, Franck, and Sirigu (2006), in line with this hypothesis. We will also raise the question of the link, in schizophrenia, between a presumed disrupted sense of effort and the emergence and maintenance of delusions of alien control.

2. Perceptive content of voluntary acts

2.1. Voluntary movement and sense of effort

Bain (1855), von Helmholtz (1866), Wundt (1874), Lewes (1878) or Muller (cited by Lewes, 1878) were the first to defend the hypothesis that the perception of voluntary muscular force does not result only from the activity of the muscle but also from the neural activity preceding the muscular contraction. They introduced in the scientific field notions like *sensation of innervation*, *sensation of effort* or *sensation of motor emission* by which they meant the existence of a perceptive content directly derived from volition. For instance, Johannes Muller wrote:

> "It is not certain that the idea of the force employed in a muscular contraction depends solely on a sensation. We have a very exact notion of the quantity of nerve-force starting from the brain which is necessary to produce a certain movement." [cited by Lewes, 1878, p. 24].

Before them, the French philosopher Maine de Biran (1805) regarded what he called *the feeling of effort* as the central component of the self. Maine de Biran's view is well summarised by Lewes (1878, p. 24):

> "Force is the direct revelation of Consciousness, which, when projected into the external world, appears as Cause. Independent of and antecedent to all experience, we know the degree of Force, or Effort, which a movement demands: this is a birthright of the soul."

The idea, here, is that without the subjective experience of effort there could not be any agent or action nor any feeling of agency or causality, but only mere facts of behaviour. It is the conscious experience of effort that makes our self-knowledge possible. Thus, from the beginning, the concept of *sense of effort* has been closely linked to notions such as *consciousness*, *will* and *self*. To understand well this view, one has to consider that an action is always carried out with a certain amount of effort, in the sense that each time a voluntary motor command is initiated, or even simulated, some mechanisms in the brain have to decide how big this command is. Consequently, the subjective experience of willed effort, that is the feeling of exerting a certain amount of effort in order to energise the body, is probably the key component of the *feeling of initiating an action* and an important element of the *sense of volition*. This does not mean that all our actions are carried out with the conscious feeling of exerting a certain amount of effort but that, under normal conditions, willed effort is always available to consciousness.[3]

[3] It is potentially accessible and could quickly gain access to conscious report if the agent attends to it.

The hypothesis of the very existence of a centrally originating sense of effort was primary supported by self-reports from paretic patients (see for instance Brodal, 1973; Mach, 1906; von Helmholtz, 1866; Wundt, 1892). When they attempt to move their paretic limb, these patients report that they feel as if they were producing a considerable amount of force against a resistance. The perceived force seems all the stronger as their muscular capacity is low, suggesting that they do not apprehend the intensity of the force they develop directly, via a sense of intra-muscular tension, but indirectly via the central effort necessary to produce this force. A method to confirm objectively this phenomenon is to ask to hemiparetic patients to produce a reference force with their impaired limb. Then, to evaluate its magnitude, the patients are asked to reproduce the reference force with their contralateral healthy limb. Patients with cerebellar (Angel, 1976; Gandevia & McCloskey, 1977a; Holmes, 1917; Holmes, 1922) or internal capsule damage (Rode, Rossetti, & Boisson, 1996) over-estimate the force produced by their reference hand, in accordance with the hypothesis that a voluntary force is perceived indirectly through the central effort put into the muscular contraction. Indeed, when produced with a strong muscular group a given force requires less effort than when produced with a weaker muscular group. For this reason, in order to perceive identical forces on both sides (the experimenter's instruction), the patients have to produce a greater force with their healthy muscular group than with their weakened muscular group. This phenomenon has also been observed among healthy subjects when the maximum voluntary force is reduced by fatigue (Carson, Riek, & Shahbazpour, 2002; Gandevia & McCloskey, 1978; Jones & Hunter, 1982; McCloskey, Ebeling, & Goodwin, 1974; Weerakkody, Percival, Morgan, Gregory, & Proske, 2003), by modifying the biomechanical constraints of the task (Cafarelli & Bigland-Ritchie, 1979), or by the induction of partial paralysis by the injection of a paralysing agent like curare or gallamine (Gandevia & McCloskey, 1977b; Roland & Ladegaard-Pedersen, 1977).

The predominance of centrally originating neural signals in the perception of voluntary muscular force has been confirmed by data obtained in a deafferented subject who was able to accurately discriminate isometric forces solely on the basis of internal signals (Lafargue, Paillard, Lamarre, & Sirigu, 2003). Another experimental argument is that there is no significant difference in healthy subjects in the reproducibility of heaviness estimates of weights lifted by the digits, between non-anaesthetised and anaesthetised digits conditions (Kilbreath, Refshauge, & Gandevia, 1997). The contribution of afferent input in sensing effort must however not be dismissed. Peripheral feedback allow to modulate and calibrate the central signal of effort (Gandevia, 1982; Gandevia & McCloskey, 1978; Kilbreath et al., 1997; McCloskey et al., 1974). Visually induced expectation also influence perceived motor effort (Bridgeman, 2005).

In brief, many experimental findings support the hypothesis of the existence of a centrally generated sense of effort. This sense seems to play a central role in voluntary muscular force perception. Because of its very nature, the sense of effort may have an intimate relationship with the self-knowledge, particularly with the subjective experience of agency.

2.2. Nature and neural substratum of the sense of effort

The debate on the existence of an internal sense, the sense of effort, has been reactivated and has taken a new start in the middle of the 20th century. This followed neurophysiological evidence suggesting that the brain was able to inform itself about its own motor productions, by anticipation. It has been proposed that signals derived from the motor command, referred as corollary discharge (Sperry, 1950), efference copy (von Holst & Mittelstaedt, 1950; for a recent review see Bridgeman, 2007) or internal feedback (Miles & Evarts, 1979) are transformed into sensory information before even leaving the brain. By this mean, a central order coding for force can be transformed into sensory information—into a feeling of effort—before even leaving the brain.

A study by Carson et al. (2002) suggests that the brain takes as an indicator of motor effort magnitude a signal generated upstream of the primary motor cortex (M1). These authors asked healthy subjects to carry out inter-manual transfers of forces while the voluntary maximum force (FMV) of the arm that was equalising (the matching arm) had been reduced following the repetition of eccentric contractions. In accordance with the assumption according to which the force developed by a muscular group is perceived indirectly through the effort necessary to generate it, the participants produced weaker forces with the matching arm than with the reference arm. They feel however as if they exerted identical forces on both sides. The originality of the study was to measure cortico-motor evoked potentials during the matching task, before and after the eccentric contractions. The analysis of the results clearly emphasises that the intensity of the motor orders addressed to the weakened arm, i.e. the matching arm, was systematically greater than the intensity of the orders addressed to the reference arm. The feeling of effort, thus, does not seem to directly reflect the intensity of the cortico-motoneural order such as it could be measured by a post-M1corollary discharge. It rather reflects the degree of activity in motor centres located upstream of M1.

2.3. Distinction between intended and achieved effort awareness

In a study by Lafargue et al. (2003) it has been showed that a patient deprived of proprioception, GL, was able to make inter-manual force transfers. GL's pattern of response supported the hypothesis according to which she solved the task on the basis of her sense of effort. However, interestingly, GL reports that she is not able to feel how hard she tries when she carries out a motor task. An interpretation is that she can only perceive her *intended effort* (her *effort of will*) but not her *achieved effort*. Centrally generated signals related to the size of the motor command need to interact with sensory feedback arising from muscles, tendons or skin receptors, for *achieved effort* to be fully perceived. This hypothesis is reinforced by a

Lansing and Banzett's study (1993) in which a complete (temporary) paralysis of the whole body was induced in 4 healthy participants by intravenous injection of vecuronium.[4] If these subjects could still experience the feeling of correctly sending their motor orders towards the part of the body they wished to move, none of them ever evoked a notion as *muscular effort* to describe the feelings which accompanied their attempts to move. They rather referred to *a mental effort, a desire to move or a very light sensation*.[5]

The relevance of the notion of *intended effort awareness,* in the sense of conscious experience of willed effort, is also supported by the fact that deafferented patients are able to produce at will force impulses proportional to numerical values (Teasdale et al., 1993). Moreover, such a pattern of performance has also been observed in healthy subjects artificially paralysed in the muscles they are trying to contract (Gandevia et al., 1993). Further evidence is that healthy subjects have the ability to mentally simulate motor contractions of various intensities (Romero, Lacourse, Lawrence, Schandler, & Cohen, 2000), suggesting again that it is possible to indirectly scale muscular contractions through the monitoring of intended effort. During such a task, the e*vent-related-potentials* pattern measured at the level of the supplementary motor area (SMA) is equivalent to that measured for the same contractions really executed[6] (Romero et al., 2000). If, as proposed by Jeannerod (1994); see also McGonigle et al., 2002), there is a functional equivalence between motor imagery and motor preparation, this result suggests that the SMA plays a crucial role in the generation of the conscious experience of intending or willing a motor effort.

We saw that at least two stages have to be distinguished in the process of effort awareness: intended and achieved effort awareness. In addition, it is important to mention that effort awareness can theoretically take place into two kinds of actions: *stimulus driven* (Milner & Goodale, 1995) or *self-generated* (Halsband, Matsuzaka, & Tanji, 1994) actions. Self-generated actions are controlled by an internal goal or a *prior intention*. Stimuli driven actions are controlled by visual affordances (Jeannerod, 1994). Nevertheless, as an action whatever its nature is always carried out with a certain amount of effort, it is likely that a healthy subject always has the possibility to attend to the willed effort she/he is furnishing; whatever the kind of action she/he is carrying out. Once again this means that awareness of willed effort—at least at an implicit preconscious level—accompanies all our actions.[7] Thus, the subjective experience of willed effort may be the core component of *the feeling of initiating an action*,[8] that is the feeling of *being about to move*.[9]

2.4. Intended effort and motor intention

The philosopher John Searle (1983a) has established a distinction between *prior intention* and *intention-in-action*. A prior intention is encoded in linguistic form. For example, one can form the prior intention to move the right wrist in a few seconds. An intention-in-action—or a *motor intention*—is an intention involving the motor brain. It is independent of any sensory afference and involves the active engagement of the subject in a particular action, which requires the activation of brain motor structures specific to a given action (Haggard & Eimer, 1999). In other words, a motor intention is the translation into neural motor codes of a prior intention, which corresponds from a functional point of view, to the motor programming of a particular gesture. As we will see, some elements of its content may reach consciousness (e.g. Blakemore & Frith, 2003).

The scientific relevance of the concept of motor intention has been highlighted by experiments in which healthy subjects are asked to mobilise a part of their body—their right hand for example—"freely" (at a moment freely chosen by themselves). To identify this moment, they have to attend at the same time, on both the moment when their intention to move is initiated and the location of a rotating spot (Libet, Gleason, Wright, & Pearl, 1983). The conscious experience of the motor intention occurs about 200 ms before the movement starts[10] (Brass & Haggard, 2007; Haggard & Eimer, 1999; Lafargue & Duffau, 2008; Lau, Rogers, Haggard, & Passingham, 2004; Libet et al., 1983; Pirio Richardson et al., 2006; Sirigu et al., 2004).

Lau et al. (2004), using fMRI, observed an increase in the dorsolateral prefrontal cortex and the pre-SMA when subjects attended to their motor intentions. Fried et al. (1991) performed direct intracranial electrical SMA stimulation in patients with intractable epilepsy. Using this method, they elicited an "urge" to perform a movement specific to the site of the stimulation: for instance an "urge to lift right elbow", an "urge to pronate right forearm, or again an "urge to move right leg inward". The "urge" to perform a given movement in the patients of the Fried et al. (1991) study may be assimilated to the subjective experience of intending to act, that is of *being about to move* in healthy subjects (Haggard, 2005). Thus, it is again likely to argue that awareness of motor intention critically involves the SMA. Sirigu et al. (2004) showed that patients with inferior parietal lesions have lost conscious access to their motor intentions, whereas they can form prior intention. Indeed, the patients of this study could normally follow the experimenter's instructions, but they became aware of their intentions to

[4] During the study, the subjects were under mechanical ventilation.

[5] They may have perceived their *intended efforts*.

[6] It is known that the amplitude and the slope of the readiness potential are influenced by movement parameters such as force (Kutas & Donchin, 1980).

[7] Note that when two objects of identical weight but different volumes are grasped and lifted, the smaller object is judged to be heavier and therefore requires more effort to lift. Since Charpentier (1891), this phenomenon, known as the size–weight illusion, has been extensively described (see for instance Flanagan & Beltzner, 2000). It suggests that effort awareness is biased by sensory information during stimulus-driven actions. Consequently, a given voluntary force is not necessarily associated with identical feelings whether it accompanies a self-generated or a stimulus-driven action.

[8] Body movements, generally, cannot be reduced to mere facts of behaviour. They are the emergent part of a goal-oriented action.

[9] This notion ("being about to move") has been introduced by HaggardPlease provide first name for Haggard in Haggard (2005). (2005). (2005).

[10] The conscious experience of intending to act is itself preceded by a readiness potential highlighted by electroencephalographic measurements on the scalp in premotor areas (Libet et al., 1983).

act only at the time they started moving.[11] All these results suggest that the SMA and the inferior parietal cortex jointly form a circuit that produce the conscious experience of intending to move.

As already mentioned, *effort* is the transverse component of willed motor acts. A willed action necessary involves at least an implicit willed effort. Even isometric contractions or imagined movements (Decety & Lindgren, 1991), which do not require any overt movements, are carried out with a certain amount of effort. For this reason and in the light of the experimental findings presented above, we think that awareness of intended effort is the central subjective component of motor intention.

3. Sense of effort in schizophrenia

3.1. Delusions of alien control, efference copy, sense of effort

According to their reports, some schizophrenic patients feel as if they were the passive observers of their own acts or thoughts which, they believe, are being controlled by external agents (Mellors, 1970; Schneider, 1955)[12]. Feinberg (1978), then Frith and Done (1989), Frith (1992), Frith et al. (2000), suggested that faulty efference-copying mechanisms are at the source of these phenomena. Initially, this assumption has been supported by a Frith and Done's experiment (1989) in which schizophrenic patients with passivity phenomena were unable to perform fast corrections in a visuo-motor tracking task. In this kind of tasks (Rabbit, 1966), healthy subjects are able to correct direction errors of their movements extremely quickly, more quickly than the minimum time necessary to react to an external stimulus. The current interpretation of this behaviour is that the brain calculates anticipated estimates of the motor orders consequences on the basis of efference copies, this in order to improve the efficiency of motor control. Such a mechanism allows to detect and correct programming errors quickly, before even the movement onset. According to Frith (1992), the schizophrenic patients' poor performances in the tasks described above and the fact that these patients believe that external causes are at the origin of their own behaviours can be accounted for by the same faulty mechanism: the mechanism that produce or compute efference copies (Frith, 1992; Frith & Done, 1989). Such an interpretation is supported, for instance, by a recent study by Lindner, Thier, Kircher, Haarmeier, and Leube (2005) in which the strength of delusions of influence, in schizophrenic patients, was correlated with a poor ability in predicting the visual consequences of eye movements. This is in accordance with the idea that a given action is perceived like having an endogenous or an exogenous origin according to the degree of discordance between its expected sensory consequences (calculated on the basis of efference copies) and its real sensory consequences.

A question is now to know if the sense of effort is at fault in schizophrenic patients with passivity phenomena. As already mentioned, the feeling of effort and the feeling of initiating a voluntary action (the feeling of being about to move) seem closely linked. Moreover, the sense of effort is supposed to use efference-copying mechanisms (for a review, see Gandevia, 1987; Jones, 1986; Lafargue & Sirigu, 2006). The relevance of this issue in the current scientific context is also supported by the fact that Frith (1992) himself, in his first model of delusions of control, used the notion of *sensation of effort* to characterise the subjective experience normally associated to willed actions. According to him, in line with the view of Maine de Biran (1805), *effort* is the landmark of the exercise of the will. If our actions, and even our thoughts, were not accompanied any more by the feeling of exerting a certain amount of effort, they could be apprehended like involuntary actions caused by external forces. Frith (1992, p. 81) wrote:

> "Thinking, like all our actions, is normally accompanied by a sense of effort and deliberate choice as we move from one thought to the next. If we found ourselves thinking without any awareness of the sense of effort that reflects central monitoring, we might well experience these thoughts as alien and, thus, being inserted into our minds."

As this author explicitly stated that the sense of effort should be disrupted in schizophrenic patients suffering from passivity phenomena (Frith, 1992), one can wonder why this hypothesis has never been directly tested, i.e. quantitatively. According to us, the reason is that the concept of *sensation of effort*, when it is used by the authors who established a link between the *sense of effort* and *the senses of agency* or *volition* (Frith, 1992; Maine de Biran, 1805), is used in a purely qualitative meaning. These authors did not seem to consider that the feeling of effort was emanating from an internal sense of willed motor effort, intrinsically linked to the size of the motor command of force. Frith (1992) was probably rather referring to the more mysterious—at first glance—*effort of will* of von Helmholtz (1866), which could appear beyond empirical investigation. Helmholtz referred to the effort made by patients with paralysis of the muscles controlling the position of the eyes when they were asked to look in the direction that they could not. But even in such a view, the *effort* is an intended motor effort, in the sense that it should involve the motor brain.

Referring to the concept of *sense of effort* in the meaning of *sense of motor effort* does not totally abolish the ambiguity. The sensation of effort can indeed refer to various perceptive consequences of the descending motor command of force coming from the volitional system (Gandevia & Burke, 1992). One could thus support that the *sensation of effort*, in Frith's terminology (1992), is a cognitive phenomenon of a higher hierarchical level than the feeling of effort explored in the tasks

[11] And not, like healthy subjects, roughly about 200 hundred milliseconds before.

[12] This pathological condition means that humans are not immune to agency disorders. A neurocognitive mechanism aims at recognising oneself as the agent of one's own acts. This mechanism, like any mechanisms, can break down.

investigating the perception of muscular force. This claim does not appear founded because Frith himself (Frith & Done, 1989; Frith, 1992), in his original account of alien control experiences, hypothesised that a dysfunction at the level of motor control be responsible for the passivity phenomena observed in schizophrenia. Moreover, one of the criticisms often addressed to this first Frith's model of passivity phenomena (1992), by Georgieff and Jeannerod (1998) for example, is precisely to put the focus on low-level motor signals, which are supposed to operate on an automatic and nonconscious mode to account for a high cognitive disorder as an agency disorder. Hence, the assumption according to which the passivity experiences, in schizophrenia, can be explained by a malfunction at the level of neural signals involved in some automatic and nonconscious components of motor control is not satisfactory, as assumed by Frith himself later (see for instance Frith, 2005). In his more recent formulation of the neurocognitive disorder underlying delusions of control, Frith gave up the hypothesis of an abnormal awareness of effort. He put rather the focus on the fact that, firstly, the patients are abnormally aware of the sensory consequences of their movements (Blakemore, Smith, Steel, Johnstone, & Frith, 2000; Shergill, Samson, Bays, Frith, & Wolpert, 2005); secondly, they cannot accurately predict the consequences of their movements (Frith & Done, 1989) and thirdly, they may have an exaggerated sense of agency (Haggard, Martin, Taylor-Clarke, Jeannerod, & Franck, 2003).

3.2. Production and perception of voluntary forces in schizophrenia

A recent study by Lafargue et al. (2006) has reintroduced the Frith's hypothesis (1992) of a disrupted sense of effort in schizophrenia. As far as we know, before this study, the sense of effort had never been experimentally investigated in schizophrenic patients. However, if one considers that a function of the sense of effort is to estimate the intensity of voluntary muscular force (Carson et al., 2002; Jones, 2003; McCloskey et al., 1974), it is easy to test its efficiency. This was often carried out in healthy subjects (Cafarelli & Bigland-Ritchie, 1979; Jones, 2003; Jones & Hunter, 1982), patients with strokes (Gandevia, 1982) or degenerative diseases (Lafargue & Sirigu, 2002; Lafargue, D'Amico, Thobois, Broussolle, & Sirigu, 2008).

The general assumption of the Lafargue et al. study (2006) was that if the sense of effort is at fault in schizophrenic patients with passivity experiences, these patients should encounter difficulties when monitoring intended effort or when appreciating achieved effort. In the second task of this study, the subjects were asked to produce muscular contractions of different intensities in response to numerical values (1, 3, 5, 7 or 9 on a 10-points scale, "0": no effort; "10": maximum effort) given by the experimenter. The muscular contractions had to be produced quickly, i.e. according to an open loop mode of control. All the patients and control subjects were able to maintain a linear and statistically significant relationship between the numerical values given by the experimenter and the exerted forces. On the other hand, the strength of this relationship was much weaker, on average, for both groups of schizophrenic patients. It was particularly poor for the group with SPR.

In the first task of the same study, the participants had to reach and maintain preselected forces with one hand, the reference hand, with the assistance of visual feedback. After a 3-s delay, the reference forces had to be reproduced by the other hand, the matching hand, which worked without any visual feedback. In this task, the performance of individuals with schizophrenia, with and without passivity experiences, was not statistically different from that of healthy subjects. The authors then concluded that at least one aspect of the sense of effort, namely its involvement in achieved effort awareness, was preserved in schizophrenic patients, regardless of their symptomatologic profile.

In our opinion, the dissociation observed in the study by Lafargue et al. (2006) between an impaired ability to grade self-initiated force impulses and a preserved ability to estimate, online, the intensity of muscular force, in individuals with schizophrenia, leads to modifications in the sense of effort theory, in healthy controls. Indeed, such a finding suggests that the process underlying the production of effort could be at least divided into two main stages, one for intended effort and another for achieved effort. Moreover, the conscious experience of effort seems to be possible and specific at each stage of this process. In sum, the schizophrenic patients of the study by Lafargue et al. (2006) had difficulties to accurately scale muscular forces on an open loop mode, whereas they were normally able to estimate the intensity of the same force once it was produced.

Such a pattern of performance is in agreement with the hypothesis that individuals with schizophrenia in general, but more particularly those with passivity phenomena, have difficulties in consciously monitoring central signals coding for force in the situations where these signals do not interact with proprioceptive signals. Their difficulties could be accounted for by a lack of awareness of willing to act; an assumption supported by the fact that schizophrenic patients are also impaired in motor imagery tasks (Danckert, Rossetti, D'amato, Dalery, & Saoud, 2002; Maruff, Wilson, & Currie, 2003), that is in conditions where centrally originating motor signals do not interact with peripherally originating signals. This view is again supported by preliminary data obtained in 6 patients with schizophrenia in a study by Pirio Richardson et al. (2006). The authors showed that their patients, when tested with the temporal judgement task developed by Benjamin Libet, reported time W[13] shifted after movement onset (mean: +10.4 ms; SEM: 75.8 ms). In other words, schizophrenic patients seem to experience the will to move shortly after moving and not, as healthy subjects, before moving (mean: −121.6 ms; SEM: 45.6 ms, in the same study).

The hypothesised abnormal awareness of willed effort, in schizophrenia, fits well with the following phenomenological description of delusions of control given by Frith et al. (2000):

[13] W: conscious experience of the will to move.

> "What it is like to experience delusions of control? A useful analogy can be found by considering the artificial control systems with which we all interact. For example, the veteran conference goer knows that slide projectors will undoubtedly fail at the worst moment and in the most unexpected way. Consider,... this... case: You are speaking immediately after a rather old-fashioned Scandinavian lecturer who has studiously ignored the control box on the lectern and called out 'next slide, please' instead. You decide to operate the projector yourself, but each time you are about to press the forward button the projector moves on by itself. The projector is doing what you want, but it is not being controlled by you. What do you conclude? That someone in the projection box is anticipating your actions and advancing the projector for you. This is what it is like to have delusions of control." (Frith et al., 2000, p. 362).

In this example, firstly, it is well illustrated that schizophrenic patients with delusions of control are normally able to act according to their prior intentions. They indeed can form prior intentions, as demonstrated for instance by the fact that they can normally follow the experimenter's instructions when they participate to experimental studies. Secondly, it is also correctly stated in the Frith's illustration that schizophrenic patients can normally translate their prior intentions into motor intentions and motor acts. Thirdly, in accordance with our hypothesised lack of intended effort awareness in schizophrenia and with our hypothesis that the sense of effort is the core component of the feeling of initiating an action, Frith suggests that these patients fail to consider themselves as the initiators of their action.

However, it could be objected against Frith et al. (2000) analysis and ours that, in every day life, healthy subjects perform much of their actions in the lack of awareness, automatically and effortlessly, without experiencing passivity phenomena. This could suggest that intended effort awareness cannot be the criterion of *the sense of initiating an action* (see for instance Campbell, 1998). In response to this objection let us emphasise that the lack of awareness, during most of our actions, includes a lack of awareness of *initiating an action* or of *being in control*. Moreover, it can be argued that passivity phenomena, in schizophrenia, are never associated with all movements and are not present continuously. They occur only under certain circumstances. A possibility is that the first-order abnormal phenomenal experience which leads to delusions of alien controls only occurs, firstly, when intended effort awareness is disrupted below a certain threshold and, secondly, when the patients attend to their motor intentions. What would be impaired might be the ability to attend to motor intentions. However, note also that in most studies they participate in, schizophrenic patients do not experience passivity phenomena. As other symptoms of schizophrenia, the degree of abnormality of intended effort awareness might fluctuate over time.[14]

Recently, Frith (2005) has suggested that the sense of being in control derives from the awareness of the sensory consequences of actions. He wrote:

> "patients with delusions of controls are abnormally aware of the sensory consequences of an action and cannot accurately predict the consequences of their movements. This leads to a feeling of not being fully in control of their actions" (Frith, 2005, p. 766).

On the basis of this suggestion we might expect that passivity phenomena should be more likely to occur when an action causes an effect rather than when an action is not followed by an effect. If effort awareness is also a component of the feeling of being in control,[15] and if it is disrupted in schizophrenic patients, passivity phenomena should occur in both kinds of actions.

3.3. Distinction between the level of action regulation and the level of action awareness

Do the data of Lafargue et al. (2006) and Pirio Richardson et al. (2006)—presented above—favour the assumption of a deterioration at the level of efference copy processing (Frith, 1992; Frith & Done, 1989; Frith et al., 2000) in schizophrenia? Efference copies are probably generated at various hierarchical levels of motor control (Jeannerod, 1995). The corollary discharges that play a role in the fast and automatic motor corrections and those that could be involved in the sense of effort might take their source at various hierarchical levels of this control. The former might arise from the level called by Jeannerod (2003) *level of action regulation*; the later from the level he called *level of action awareness*. Contrary to the corollary discharges involved in the feeling of effort, the corollary discharges involved in action regulation would be processed nonconsciously and automatically (Blakemore, Goodbody, & Wolpert, 1998; Flanagan, Tresilian, & Wing, 1993). The key structure of this latter processing level is supposed to be the cerebellum (Blakemore, Frith, & Wolpert, 2001; Miall, Weir, & Stein, 1993). When patients with cerebellar lesions handle an object and when predictable disturbances (on the basis of corollary discharges) occur, these patients have difficulties to normally adapt the force of their affected hand (Serrien & Wiesendanger, 1999). Moreover, it is of interest to note that cerebellar lesions do not abolish the feeling of effort and the ability to accurately discriminate weights remains relatively well preserved after this structure is damaged (Gandevia & McCloskey, 1977a; Holmes, 1917; Holmes, 1922). This claim reinforces the assumption according to which corollary discharges are generated at various levels of the motor control. The corollary discharges used in the regulation of action might be issued from collateral of cortico-spinal tract projecting on the cerebellum. In accordance with the already quoted study by Romero et al. (2000), the corollary discharges used by the sense of effort might take their source upstream of M1, in the SMA, and might project to the parietal cortex.

[14] If our hypothesis is correct, further studies should attempt to identify the circumstances leading to such fluctuation.

[15] As already suggested by Frith in its first model of delusions of control (1992).

It is also important to note that empirical results in line with the hypothesis of a deterioration at the level of action regulation, in schizophrenia, are rare (Frith & Done, 1989). On the contrary, some studies suggest that this level of control is intact in schizophrenia, independently of the patients' symptomatology (Fourneret, Franck, Slachevsky, & Jeannerod, 2001; Pitblado, Shapiro, & Petrides, 1980). On the other hand, cognitive conscious processes such as recognition of actions (Franck et al., 2001), motor imagery (Danckert, Rossetti, D'amato, Dalery, & Saoud, 2002; Maruff et al., 2003) or perception of the sensory consequences of one's own movements seem to be disrupted (Blakemore et al., 2000; Shergill et al., 2005).

To solve the question of a defect of action regulation *versus* a defect of action awareness, in individuals with schizophrenia, further studies should directly assess and compare the performances of the same sample of patients in *forward modelling* and *internal monitoring* tasks. To our knowledge, such studies have never been made.

3.4. Possible neurocognitive basis of the perceptual aberration leading to delusions of alien control

If confirmed, a lack of awareness of intended effort, in schizophrenic patients with delusions of control, would be only one aspect of a more global abnormality in the awareness of self-generated actions. Indeed, the normal attenuation of self-produced tactile stimulation (Weiskrantz, Elliot, & Darlington, 1971) is not observed in these patients (Blakemore et al., 2000). Moreover, they do not show the attenuation of self-applied force (Shergill et al., 2005) normally observed in healthy subjects (Shergill, Bays, Frith, & Wolpert, 2003).

Hence, schizophrenic patients with somatic passivity experiences would be excessively aware of the proprioceptive feedback and insufficiently aware of efferent signals during self-generated actions (for a review see Farrer & Franck, 2007). As it has been suggested that the supplementary motor area provides an efferent signal for sensory attenuation (Haggard & Whitford, 2004), it seems likely to postulate that intended effort awareness and attenuation of self-induced sensory feedback are related. A corollary of the motor signal involved in intended effort, in the SMA, could be sent to attenuate parietal activity due to proprioceptive feedback during active and so effortful movements. The balance between both phenomena might be abnormal in schizophrenia.

At the moment schizophrenic patients are experiencing a movement as being controlled by an alien force, Spence et al. (1997), using positron emission tomography, have recorded hyperactivation in the inferior parietal cortex; a result that has been recently replicated with fMRI by Ganesan, Hunter, and Spence (2005). This can be interpreted as a failure to attenuate sensory feedback during voluntary movements, in agreement with the fact that a similar pattern of activation has been observed during an illusory passive movement performed under hypnosis (Blakemore & Frith, 2003). According to Spence, Hirsch, Brooks, and Grasby (1998), the increasing activity observed in the parietal cortex of schizophrenic patients with delusions of alien control does not originate in this region but is the result of abnormal input signals from the prefrontal cortex, the source of willed action. Interestingly, Farrer and Frith (2002) have asked healthy subjects to decide whether they or another person have performed an ambiguous movement. Using fMRI, they observed that the right inferior parietal cortex was engaging in "nonself" attribution while the right anterior insula was activated when the subjects made self-attribution. Farrer et al. (2003) have also showed that the less a subject feel in control of the movements of a virtual hand, the higher the level of activation in her/his inferior parietal lobe is. Increased activity in the right inferior parietal cortex as also been observed when healthy subjects imitate actions performed by somebody else (Decety, Chaminade, Grezes, & Meltzoff, 2002).

Altogether the data presented here suggest that increasing activity of the parietal cortex contributes to the experience that active movements are externally controlled in delusions of alien control. Interestingly, this pattern is not common to all forms of delusions but specific to delusions of alien control (Spence et al., 1997), suggesting that delusions are not "empty speech acts", as proposed for instance by Berrios (1991), but rather behaviours reducible and understandable in terms of more elementary neurocognitive deficits. To explain delusions of alien control, Frith (2005) has established an interesting distinction between *the feeling of being in control* and *the feeling of agency*. This idea is supported by the data of a study by Haggard et al. (2003) in which schizophrenic patients, independently of their symptomatologic profile, showed an unusually strong temporal binding effect between an intended action (a button press) and its consequence (a tone). The binding effect—the fact that the time at which an act is initiated is perceived later and the time at which its effect occurs is perceived as earlier than it is actually the case—has been considered as a behavioural marker of the experience of agency (Franck, Posada, Pichon, & Haggard, 2005; Frith, 2005; Haggard, Clark, & Kalogeras, 2002; Haggard et al., 2003). Thus, an exaggerated feeling of agency might be a general characteristic of schizophrenia. According to Frith (2005), delusions of alien control might result from the combination at the same time of two feelings, the feeling of not being in control of one's own action with the feeling that there is an agent causing this action.

3.5. Formation and maintenance of delusions of alien control

The fact that patients with schizophrenia have difficulty to accurately produce force impulses proportional to their prior intention (Lafargue et al., 2006) provides a preliminary experimental claim consistent with the hypothesis of an abnormal subjective experience of the will to act in this pathology. More specifically, this finding is in agreement with the hypothesis of an abnormal awareness of willed effort (AAWE) and, consequently, with the hypothesis of a subjective experience of a lack of control of one's own acts in schizophrenia. As the patients prone to passivity experiences were particularly affected in this task, AAWE below a certain degree may be at least a marker of vulnerability of such symptoms. However, as already mentioned, in most of the experimental studies in which they participated in, schizophrenic patients did not report a feeling of passivity during the tasks, nor do they exhibit delusions of controls. This could be due to the fact that AAWE as well as other abnormalities in the awareness of action, in schizophrenia, are very subtle deficits only detectable with laboratory tasks. For instance it has been reported that schizophrenic patients do not show the normal attenuation of self-applied tactile stimulation (Blakemore et al., 2000; Shergill et al., 2005). But to our best knowledge this deficit is rarely reported at a clinical level.

As other symptoms of schizophrenia, it is likely that the degree of AAWE fluctuates over time. It is then possible to distinguish at least two possibilities. First, AAWE does not lead alone to delusions of controls but only when it is below a certain threshold and when it is coupled with additional higher-order cognitive factors. According to this view (see for instance Langdon & Coltheart, 2000), a disturbance of the processes mediating the formation and maintenance of normal beliefs would also be present in deluded individuals. The misattribution of agency would result from mistaken inferences, at a second-order introspective level, of an abnormal experience at the level of first-order phenomenal consciousness. The second possibility, discussed below, is that AAWE (Lafargue et al., 2006) and exaggerated awareness of the sensory consequences of action (Blakemore et al., 2000; Shergill et al., 2005), at a certain threshold, are intrinsically linked with delusions of alien control. They would be a subjective counterpart of neurological anomalies in the frontal and parietal lobes. Following such anomalies the global behaviour of the schizophrenic patients neural "who system" (the terminology has been introduced by Georgieff & Jeannerod, 1998) might be less stable compared to healthy subjects. Under certain conditions, it might move to the state coding for "I intend to act" toward the state coding for "someone else intends to act", too easily, even without the presence of another agent. According to this second possibility, in delusions of alien controls, the patients would just report what they actually experience.

In favour of the first possibility one could argue that AAWE, in the worst-case scenario, should lead the patients to experience a loss of control of their actions, which would be performed effortlessly (Campbell, 1998; Gallagher, 2004). But the patients should not misattribute the control of their actions to external entities. When a patient suffering from Tourette disease hears herself blurt out obscenities (Baron-Cohen, Cross, Crowson, & Robertson, 1994), when the affected limb of a patient with anarchic hand syndrome carries out acts that may be against the individual's own intentions (Marchetti & Della Sala, 1998), or when a patient with a lesion of the angular gyrus reports the impression being detached from his own body (Sirigu et al., 2004), all seem to be the passive observers or executors of their own acts; they have lost the feeling of initiating some of their actions. Nevertheless, in general, none exhibits delusions of control. They rather affirm that their illness is responsible for their aberrant experience. The question is then to understand why in most cases, when schizophrenic patients exhibit what have been called "experiences of somatic passivity", they call upon an external agency[16]. According to the two-stage models of delusions (Davies, Coltheart, Langdon, & Breen, 2001; Langdon & Coltheart, 2000), a perceptual disorder (the first factor) must be coupled with a thinking disorder (the second factor) to lead to delusions. Davies et al. (2001) have described the second factor[17] as "a loss of the ability to reject a candidate for belief on the grounds of its implausibility and its inconsistency with everything else that the patient knows". Then it could be argued that to lead to delusions of alien control, an abnormal awareness of willed action (including a sense of effort disorder) should be augmented by additional factors that constraint the processes mediating the formation and maintenance of normal beliefs. The limited cognitive resources due to attentional (Gouzoulis-Mayfrank et al., 2007) and memory (Walter, Vasic, Hose, Spitzer, & Wolf, 2007) deficits, during a psychotic episode, could limit the patients' ability to focus on alternative explanations. The patients could fail to inhibit what Davies et al. (2001) called the *pre-ponent doxatic response.* Delusions of alien control would then be regarded as an attempt (operating at a subpersonal or/and at a personal level[18] to give meaning to an unusual experience of the feeling of being in control. Because of altered prefrontal functions in schizophrenia, this attempt would lead to the false belief of an external control. As some of their actions are carried out effortlessly, the patients might come to form the belief that they are energised (or initiated) by a force external to them.

In our opinion, the two-stage models of delusions of somatic passivity do not fit well with the fact that these symptoms, in schizophrenia, are associated with an abnormally high activity in the right inferior parietal cortex (Ganesan et al., 2005; Spence et al., 1997), a structure which is also involved in the production of the sense of another's agency (nonself attribution) in healthy subjects (Farrer & Frith, 2002; Farrer et al., 2008); and that such an inappropriate activation seems to be related to a structural anomaly of the parietal cortex.[19] Indeed, the normal left-greater-than-right inferior parietal volume asymmetry seems to be reversed in schizophrenic patients (Buchanan et al., 2004; Nierenberg et al., 2005; Niznikiewicz et al., 2000). In this context, we agree with Gallagher (2004) that "the attribution of agency to another is not the result of a misinterpretation or cognitive accounting that would force the subject to infer that since he is not the agent, someone else must be, or a supplemental account generated by introspection, the odd result of a productive narrative; rather, it is a genuine report of what is truly experienced".

Such a view is also supported by the facts that (i) schizophrenic subjects would have significantly smaller volumes of left pre-SMA compared with control subjects (Exner, Weniger, Schmidt-Samoa, & Irle, 2006); (ii) a lack of self-control,[20] in schizotypal people, would also be related to volumetric differences in SMAs (Matsui et al., 2002). As already stated, the

[16] See for instance the cases reported by Mellors or Frith at the beginning of this paper.

[17] This second factor would be what all form of delusions have in common (Halligan & Davis, 2001).

[18] Semantic processes can occur unconsciously (see for instance Dehaene et al., 1998).

[19] von Angyal (1934) was probably the first author to report IPL structural abnormalities in schizophrenic patients. His opinion was based on histological studies conducted by Miskolczy (1933) (see Torrey, 2007).

[20] As assessed by the schizophrenia-related personality subscale scores from the Minnesota Multiphasic Personality Inventory (MMPI).

pre-SMA (Lau et al., 2004) and the inferior parietal lobule (Sirigu et al., 2004) are precisely the brain structures which are likely to play a key role in producing a conscious experience of intending to act, that is a conscious experience of willed effort. Thus, a parsimonious explanation of delusions of alien control is that patients' perceptual experience comprises the very content of delusions, the subjects simply reporting what they perceive[21] (Maher, 1974; for a review, see Pacherie, Green, & Bayne, 2006). In the context of schizophrenia, according to such a view, an AAWE combined with the experience of another's agency would merely be a subjective counterpart of an abnormal pattern of neural activity for intended actions.[22] However, a question remains: why AAWE, in schizophrenia, would be always linked to the subjective experience of another agency? Why don't patients—at least sometimes—experience a simple feeling of loss of control of their actions, a mere impression of involuntariness following their hypothesised AAWE?

Recent neuroimaging studies have showed that part of the neural network which is activated when a subject performs an action is also activated when she/he imagines the same action or even when she/he observes the action of another (Rizzolatti & Craighero, 2004). This is generally interpreted as the fact that the brain represents other's action in the same way as it represents one's own. A neural "who system" (Georgieff & Jeannerod, 1998) would map onto the same brain areas an overlap of functions coding for different representations. The discrimination between self and nonself would occur on the basis of non-overlapping areas. As a consequence of this idea, Jeannerod (2003) has suggested that in certain pathological conditions, as schizophrenia, "changes in the pattern of cortical connectivity could alter the shape of the networks corresponding to [these] different representations, or the relative intensity of activation in the areas composing these networks". In our opinion, it is then helpful to interpret delusions of alien controls into the framework of dynamical systems (Loh, Rolls, & Deco, 2007), by considering the different representations coded by the "who" system as different attractor states. Because of the fronto-parietal abnormalities mentioned earlier, the global behaviour of the network might be less stable in schizophrenia compared to healthy subjects, tending to move to one attractor to another attractor easily, even without a stimulus. For instance, during an intended act our own movements should be experienced as initiated by someone else if the behaviour of this "who network" was jumping to the state coding for *I move* toward the state coding for *someone else move*, even without the presence of another agent.

At the level of the phenomenal consciousness, such switches between attractor states, could lead schizophrenic patients to experience at the same time a lack of control of some of their actions (including a lack of awareness of willed effort) with an intense feeling of agency for these actions (see above), thus creating the conditions for the emergence of the so-called delusions of controls. The hypothesised instability of the "who network" and its subjective counterpart, in schizophrenia, might result from abnormal SMA and parietal activity.

This latter view of delusions of alien control seems in line with the Maher (1974) one-stage model of delusions according to which delusions arise as the result not from a thinking disorder but from a perceptual disorder. Maher (1974, p. 99) argued that "where the patient may differ from a normal observer is not in the manner of drawing inference from evidence but in the kind of perceptual experience that provide the evidence from which the inference is to be drawn". 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". The perceptual anomaly of deluded patients could be extremely distressing and cognitively intractable (Gerrans, 2001), explaining why the errors in action attribution are difficult to correct with the passage of time and the existence of disconfirming evidence. Such a view fits also well with Maine de Biran's (1805) intuition that the feeling of effort—in the sense of intended effort—is the direct expression of the causality of consciousness, the core component of the self-experience. If this is true, the experience of an intended effort should immunise against experiences of external control such as those encountered in schizophrenia. It would be a subjective counterpart of the "who system" being in the state *I intend to act* or *I'm initiating a willed effort*. And if *I*'m doing the effort, *I* cannot attribute it to an external agent.

4. Conclusion

Awareness of willed effort, at least on a preconscious level, accompanies all our actions. Moreover, this seems to be the core component of motor intentions awareness and of *the feeling of initiating an action*. Here, we have presented a body of evidence suggesting that patients with schizophrenia have an abnormal awareness of voluntary action. Experimental data suggest that this abnormality includes an altered awareness of efferent neural information (Lafargue et al., 2006; Pirio Richardson et al., 2006) and an exaggerated awareness of afferent neural information[23] (Blakemore et al., 2000; Shergill et al., 2005). On this basis, under some conditions which will have to be determined, the patients would experience a loss of control

[21] Note that it would be possible to argue, on the basis of the current literature, that there is nothing specific about the parietal disturbance seen in passivity phenomena and the parietal disturbance seen in other disorders as anorexia nervosa or somatic hallucinations (for such an alternative perspective, see Spence, 2006).

[22] It is indeed difficult to conceive how such a mental state could have a causal role distinct from the intrinsic neural properties of the subject.

[23] Once again, it is important to note that the idea of a lack of awareness of willed effort, in schizophrenia, is based on scarce experimental evidence. The work of Pirio Richardson et al. (2006) has been done on 6 patients only. Moreover, in the study by Lafargue et al. (2006), this hypothesis is tested indirectly: in their second task, the production of grip force was recorded but not the awareness of willed action. The hypothesis of an exaggerated awareness of afferent neural information, in schizophrenia, is also based on scarce experimental evidence and regardless of the former hypothesis. Therefore, further studies should directly address the hypothesis of a lack of awareness of willed effort associated with an exaggerated awareness of afferent neural information, in the same sample of schizophrenia patients.

of intended actions, associated with the strong feeling that these actions are intentional (Frith, 2005), leaving the door open to delusions of alien control. Thus, the perceptual anomaly would include the very content of the delusion[24] explaining why delusions of control are difficult to correct. This view has implications for the development of rehabilitative interventions in schizophrenia, suggesting that any improvement in the behavioural stability of the neural network underpinning the awareness of willed actions can potentially influence the formation and maintenance of delusions. Moreover, our position in the current article seems in line with that of Maher (1974) but also with that of de Clérambault (1942) and Lacan (1980) who was his disciple. A perspective that appears to be shared by these authors is that hallucinations are at the source of delusions. Contemporary scientific research suggests that what was at the time of the three authors only an almost abstract view can now be supported by data of observation. Indeed, as well for hallucinations as for passivity experiences (the subject of this article), one can now describe the mechanisms involved in the production of the abnormal subjective experiences on which delusions are built.

Statement of conflict of interest

The authors declare that they have no conflict of interest.

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[24] Depending of her/his cultural background the patients would add superficial elements.

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