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Research report

Volitional action as perceptual detection: Predictors of conscious intention in adolescents with tic disorders

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ABSTRACT

Voluntary actions are accompanied by a distinctive subjective experience, so that they feel quite different from physically similar involuntary movements. However, the nature and origin of this experience of volition remain unclear. Voluntary actions emerge during early childhood, in parallel with reduction of involuntary movements. However, the available markers of the experience of volition, notably Libet's mental chronometry of intention, cannot readily be used in young children. In Gilles de la Tourette syndrome (GTS), however, involuntary tic movements may coexist with voluntary control into adulthood. Therefore, adolescents with GTS could potentially confuse the two classes of movement. We have measured the temporal experience of voluntary action in a well-characterised group of adolescents with GTS, and age-matched controls. We replicated previous reports of a conscious intention occurring a few hundred milliseconds prior to voluntary keypress actions. Multiple regression across 25 patients' results showed that age and trait tic severity did not influence the experience of conscious intention. However, patients with stronger premonitory urges prior to tics showed significantly later conscious intentions, suggesting that the anticipatory experience of one's own volition involves a perceptual discrimination between potentially competing pre-movement signals. Patients who were more able to voluntarily suppress their tics showed significantly earlier conscious intention, suggesting that the perceptual discrimination between different action classes may also contribute to voluntary control of tics. We suggest that the brain learns voluntary control by perceptually discriminating a special class of internal 'intentional' signals, allowing them to emerge from motor noise.

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1. Introduction

Human societies assume that individuals voluntarily control their actions, yet the neurobiological basis of volitional control is hardly understood. Voluntary control emerges gradually with the development and maturation of cortical motor structures: newborn infants move continually, but seem to have little voluntary control over their movements (Piaget, 1952). Societies recognise this progressive development of voluntary control by defining ages of criminal responsibility, although the specific age point shows notable cultural variations. These biological and social notions of volition are based not only on physiological facts about the motor system, but also on descriptions of the *subjective experience* of voluntary action. The mental life of healthy adults includes a continuous and coherent experience of agency related to future, present and past actions (James, 1890). This sense of voluntary control over one's actions is essential in order to accept responsibility. In contrast, involuntary movements (reflexes, spasms) are classed as "automatisms" that are not under an individual's voluntary control.

The developmental trajectory from unstructured, involuntary motor acts to dominance of volitional actions and conscious self-control has been described by developmental psychologists (Piaget, 1952). However, experimental data are scarce, because the critical changes occur in early life, before formal testing and subjective report are possible. Acquiring voluntary control over one's own bodily actions presumably involves a form of instrumental learning. Experiences of volition and motivation are repeatedly paired with goal-directed body movements, and with rewarding outcomes (Balleine, 2011; Fetz, 1969, 2007). In contrast, other, involuntary movements simply occur, without any associated experience of volition. Learning associations between a feeling of volition, a body movement, and a subsequent external event would allow one to learn to be voluntary (Haggard, Clark, & Kalogeras, 2002).

In developmental tic disorders, however, this progressive dominance of voluntary action over involuntary movement is altered. Gilles de la Tourette's syndrome (GTS), for example, affects approximately 1% of children and adolescents (Robertson, Eapen, & Cavanna, 2009). It is characterised by tics, involuntary, patterned and repetitive exaggerated movements and vocalisations misplaced in context and time with a mean onset around the age of 7 years (Robertson et al., 2009). This disorder provides a valuable opportunity for studying the emergence of volition at a critical stage. In GTS, movements that may be behaviourally similar become classified as voluntary actions, or as involuntary tics. The main evidence for this classification is often a parent or caregiver's judgement regarding whether a movement is 'appropriate' (inappropriate implies involuntary) and how often it is repeated (voluntary actions are often quite sporadic, while involuntary movements are often repetitive). Since children appear to lack a strong phenomenal awareness of all their actions, both voluntary and involuntary, this classification is generally third-person rather than first-person in origin.

Indeed, tics in GTS have features of both volitional and involuntary movements: they are generated by the brain's voluntary motor pathways (Bohlhalter et al., 2006), yet they are experienced as involuntary or unwanted. We hypothesised that the presence of tics might lead to blurring of the normal boundaries between voluntary and involuntary movement, and an impaired perception of the different subjective experiences accompanying these two distinct kinds of action. For example, many GTS patients are able to suppress their tics voluntarily, yet report the tic itself as involuntary or imposed (Ganos et al., 2012). GTS patients often report "premonitory urges" prior to tics. These may resemble somatic sensations such as itches (Jackson, Parkinson, Kim, Schüermann, & Eickhoff, 2011), but may also resemble the experience before voluntary action – for example they may be accompanied by Readiness Potentials (Karp, Porter, Toro, & Hallett, 1996; van der Salm, Tijssen, Koelman, & van Rootselaar, 2012). These features set tics apart from other extra movements in children, e.g., transient postural chorea, that are perceived as completely automatic and uncontrollable. Tics are thus located in the borderland between voluntary and involuntary action. Patients often report partial control for some time until urges become irresistible and they are forced to tic. One recent study offers some direct support for the hypothesis that tics might mask normal volition. Moretto et al. showed that adults with GTS have an altered experience of their own volition (Moretto, Schwingenschuh, Katschnig, Bhatia, & Haggard, 2011), using Libet's paradigm for reporting "W judgements" – the perceived time of intentions preceding voluntary action (Libet, Wright, & Gleason, 1983).

The relation between voluntary and involuntary movement in GTS could also clarify the bases of "conscious free will" in the healthy brain. On one view, intention to act is a perception-like experience that occurs when activity within frontal motor networks exceeds a threshold level (Fried, Mukamel, & Kreiman, 2011; Hallett, 2007; Matsuhashi & Hallett, 2008). On this view, the increased level of "motor noise" in GTS might require a more conservative threshold for detecting volition, in order to avoid excessive sensitivity to noise. This increased threshold would in turn produce delays in the perceived urge to move (Hallett, 2007) (see Fig. 1). This view therefore predicts that tic parameters should correlate with mean W judgement.

Studies of developmental tic disorders could therefore potentially clarify the processes whereby voluntary control emerges from the wider noise of involuntary sensorimotor activity, and becomes a characteristic cognitive and phenomenological event. In particular, we speculated that the experience of volition in GTS could resemble a perception-like signal detection process, rather than a post hoc explanation of actions. Investigating this hypothesis would also provide an important window into the learning process assumed to underlie the normal development of capacity for voluntary action. We therefore tested the experience of volition in 27 adolescents with GTS, and 30 healthy volunteers, using a cross-sectional design. We hypothesised that high levels of tics would be associated with delays in the normal experience of volition, because the characteristic neural activities that signal one's own volition would be lost in motor noise, delaying awareness of one's own intentions. As a control for non-specific features of the task unrelated to volition, patients and controls also judged the perceived time of the keypress action itself.