So you think you can dance?

Paul M. Jenkinson and **Aikaterini (Katerina) Fotopoulou** look at an example of good intentions and poor awareness in the motor system

We usually manoeuvre through our environment so effortlessly that the complexity of voluntary movement is taken for granted. Most of the time the processes involved in running for the morning bus, flipping through the pages of a magazine, or cutting a rug on the dance floor never cross our mind… that is, unless something goes wrong. An embarrassing trip or stumble is what usually draws attention to our movements. But, even then, how much insight do we really have about what we just did? And how is it that we can normally be so oblivious, yet still move effectively? In this article we review recent experimental research in healthy individuals and patients with abnormal motor awareness, in order to explain how they can help us to better understand our own movements.

questions

Why do dancers rehearse in front of a mirror?

Does seeing oneself from the outside (i.e. from a third-person perspective) play a special role in self-awareness?

resources

Jeannerod, M. (2006). *Motor cognition: What actions tell the self.* New York: Oxford University Press.
Sensorimotor Learning Group: http://cbl.eng.cam.ac.uk/Public/Wolpert/WebHome

You sit poised in front of the television, waiting eagerly to watch your favourite celebrity perform his well-practised waltz. After months of rehearsal his time to shine has arrived at last. All eyes are on him – The Dancer – and he intends to be nothing short of dazzling. The music begins and he starts to move. You hold your breath… and stare in horror as his dance steps, far from being graceful, resemble that of a newborn deer with two left feet and the timing of a drunk.

The audience, partly sympathising but unable to look away, cannot help but ask the question: 'How can people be so deluded!?' The answer may lie in how we control and monitor our body movements, and thus our behaviour more generally.

Over the past decade or so a substantial body of research has demonstrated that our intentions to move not only determine what kind of action we are going to perform, but also influence our awareness and monitoring of the same action. Take as an example the aforementioned dancer performing his waltz. We can explain the processes involved in this action using a 'computational' model of the motor system, developed using engineering principles and adapted for use in psychology (Wolpert, 1997; Figure 1).

The process begins with the instructions (or motor commands) needed to perform each intended movement being created in the brain. Sensory information is used to ensure that these motor commands are appropriate for the intended task. For example, the visual appearance of an object affects the motor commands generated (i.e. you would not plan to lift your dance partner using the same technique you use to lift your trophy). These motor commands instruct different target muscles to contract and relax in order to produce the desired movement (e.g. a step forward). In turn, the movement is detected by sensors located in the body (e.g. the foot and leg), and these provide sensory feedback to the brain regarding the actual movement that has taken place.

Now you would be forgiven for thinking that our dancer decides whether or not he is gliding gracefully around the ballroom based solely on this sensory information, but you would be wrong. In actual fact, so long as his overall goal is met, and he makes it through the dance without a major trip, slip or fall, his appreciation of his own waltz moves would depend mostly on his prior intentions.

How does this happen? Well, the

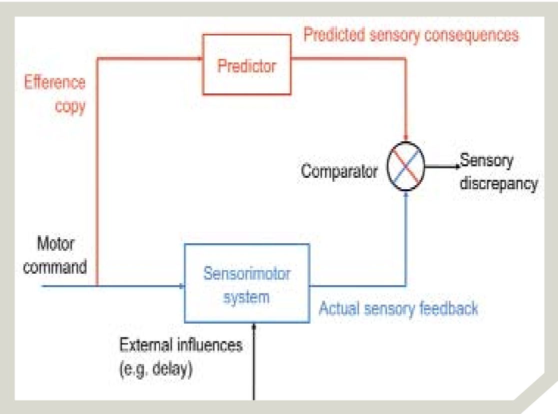

Figure 1: A simple model of the motor system (Blakemore et al., 2001, reproduced with permission)

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Frith, C.D., Blakemore, S.J. & Wolpert,

computational model of the motor system further suggests that at the time when the original instructions (or motor commands) for the intended movement are created, a duplicate of these commands or ‘efference copy’ is produced. This efference copy is used to predict the expected sensory feedback of the intended movement, and our conscious awareness relies on these predictions. By relying on intentions and predictions, we are able to perform fluent movements without the inherent delay of the sensory feedback system. We become aware of a movement error retrospectively, only when a large discrepancy is detected between the expected and actual sensory feedback. Performing such comparisons and detecting possible mismatches is an important component of action monitoring and learning (Fink et al., 1999). Consciousness is potentially called in to assist with the task; however, so long as such discrepancies are small and our initial goals are met, the system is able to make slight corrections and update its predictions without bothering the awareness system. Under these circumstances awareness simply remains loyal to the information provided by our initial motor intentions. Applying these principles to our dancer, we would normally expect him to perform each step without paying attention to the sensory feedback being received about his clumsiness, provided that on the whole his intentions continue to be met. This explains why small failures in performance remain undetected.

Good intentions and poor awareness

Experiments with healthy participants provide convincing evidence that the motor system operates in the manner described by the model above. For example, research by Gandevia and colleagues (Gandevia et al., 2006; Smith et al., 2009) has shown that motor commands (or instructions) inform body awareness. In particular, Gandevia et al. (2006) found that when sensory (i.e. proprioceptive) feedback about the position of one’s arm is blocked (by temporary anaesthesia), healthy individuals are still able to sense the position of the limb using information from motor commands.

One of the first experimental studies to directly demonstrate our limited awareness of actual movements and reliance on intentions was performed by Fourneret and Jeannerod (1998). They simply asked participants to draw a straight line between two points shown on a computer display. However, the participants could not see their movements directly because their hands were concealed beneath a table. Participants instead viewed a dot on the computer display, which represented the movement being performed. Unbeknownst to the participants, on some occasions the computer systematically shifted the direction of the dot slightly to the left or right of the actual position of the hand under the table. Therefore, in order to reach the visual target participants had to move their actual unseen hand in the direction opposite to the dot. Thus, drawing a line between the two points required participants to make hand movements that deviated between 0 and 10 degrees to the left or right of an actual straight line. Remarkably, when later asked about their performance on the task, participants had no conscious awareness that their hand movements were off target, and largely reported having drawn straight lines. Despite other sources of sensory feedback (i.e. proprioception) providing conflicting information about the actual movement being performed, awareness was dominated by visual feedback in this task. Subsequent research has replicated

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this finding, and shown that we only become aware of errors on this kind of task if the discrepancy between vision and proprioception exceeds 15 degrees, indicating a substantial deviation from our intended movement (Franck et al., 2001).

Applying these findings to our ballroom-dancing friend, we can begin to understand his failure to notice when his movements are not executed with precision. It turns out motor awareness is not simply a matter of sensory feedback, and that ignoring errors in performance is (to some extent) perfectly normal, provided that our intended goal is achieved. However, following brain injury it is possible to be unaware of even large failures in performance. It is to these brain-injured patients that we now turn, and consider how devastating motor difficulties sometimes fail to capture awareness.

Brain injury

One of the most unfortunate and easily recognisable consequences of a stroke is complete or partial paralysis on one side of the body. People are, therefore, often surprised to hear that a proportion of patients with paralysis or weakness after stroke exhibit an apparent inability to recognise or appreciate such difficulties. This curious disorder, called anosognosia for hemiplegia (AHP), means that patients may attempt to get out of their bed/wheelchair, stand or walk, despite a total inability to perform these actions. When asked about their motor ability, some AHP patients will vehemently deny the existence of any problem, and even go so far as to claim they have demonstrated their ability to move their paralysed limb (Jenkinson & Fotopoulou, 2009; for a more detailed account see Orfie et al., 2007). For example, Cocchini et al. (2002, p.2030) describe a patient with persistent AHP who, despite complete paralysis of the left half of his body, would offer to 'jump out of the car to buy the newspaper'. Similarly, Venneri and Shanks (2004) report an AHP patient who claimed she could walk, but when asked to demonstrate this ability by walking to greet visitors, would reply 'Yes, I could get up to meet them, but the doctor says it would be better if I rested' (Venneri & Shanks, 2004, p.230).

Aside from arousing general interest in clinicians, patients with AHP provide a unique opportunity to delve into the mechanisms underlying normal awareness. Of particular relevance to us here is the extent to which AHP can be utilised to evaluate the above model of the motor system, and in doing so explain how it is possible for individuals (both healthy and brain-injured) to be unaware of movement errors (see Frith et al., 2000; Berti & Pia, 2006; Berti et al., 2007). What distinguishes patients with AHP from everyone else is their apparent inability to notice even large discrepancies between their intended and actual actions. Due to their lesions, it appears that when a discrepancy occurs, the motor system of these patients continues to operate by deceiving awareness and relying exclusively on the intended movement. AHP patients therefore continue to believe they are moving normally, because they are led astray by their intentions.

> "a tendency to ignore small performance errors is perfectly normal"

This process can be easily understood if we consider similar examples from our everyday behaviour – think about how many times you intended to do something, were sure you had done it, and later discovered that you did not? It is a scenario familiar to us all: for example, you believe you sent that e-mail to your boss on Friday night as you intended, but find out on Monday morning that you did not. Likewise, patients with AHP believe the movement they planned and intended to make has been completed successfully, but unlike people without AHP, they fail to discover that their initial belief was false.

Unfortunately, few experimental studies have attempted to evaluate this explanation of AHP; that is, until recently. As we've seen, AHP may occur because patients retain the capacity to plan intended movements, and mistake these for actual movement. Because the planning, initiation, execution and monitoring of voluntary movement involves various different stages and brain regions (Grèzes & Decety, 2001), it is possible for patients with paralysis to be

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able to plan movements that are actually impossible for them to execute (Johnson, 2000; Johnson et al., 2002). However, the question of whether patients with AHP also retain this crucial ability was only examined recently by Jenkinson et al. (2009). They performed the first study to examine whether AHP patients are capable of planning (i.e. creating an internal representation or simulating) movements that they cannot perform, using a measurement of motor representations (Johnson, 2000) involving patients first being asked to say how they would (hypothetically) grasp an object (e.g. a door-handle) with their paralysed arm, and then being asked to actually perform the same action with their unaffected hand. The accuracy of a patient's ability to simulate/plan movements can be determined by calculating the degree of consistency between these two sources of information.

The results showed that AHP patients retain the ability to generate relatively accurate simulations of their intended movements, even those that are impossible to perform (i.e. those involving the paralysed arm). This ability did not differ from that of hemiplegic control patients without anosognosia, ruling out the possibility that impaired motor planning might directly account for AHP. However, this finding supports the idea that the ability to mentally represent an intended movement is possible in patients with AHP.

So is this representation of intended movements key to the illusory sense of movement in AHP? Based on the above model of the motor system, Fotopoulou and colleagues (2008) reasoned that the false sensation of having moved the paralysed limb would be related to whether or not AHP patients intended to move. That is, patients should only believe they have moved their arm when they had the intention to do so, and observing movement of the limb without this accompanying intention should not result in a false sense of movement.

The researchers substituted a prosthetic hand for the patient's own paralysed hand in order to provide false visual feedback of the paralysed limb moving (or not) without affecting the patient's sense of touch. Thus, patients believed that they were looking at their own hand, when in fact they were seeing a lifelike prosthetic. At the same time patients were asked to voluntarily move their hand (intention present), not move their hand (intention absent), or the prosthetic hand was moved passively by a second experimenter (intention absent). The remarkable finding of this experiment was that the AHP patients only believed they had moved their hand when the intention to do so was present, and ignored the motionless hand they could see. In other words, despite watching a left hand they thought was their own remain still, patients believed they were moving! These false claims were not made in trials when the intention to move was absent (i.e. when expecting the experimenter to move their arm or for no movement to occur), with AHP patients freely admitting that 'their hand' had not moved in such instances. Furthermore, a group of control hemiplegic patients without AHP did not experience this same illusory sense of movement even when they intended to move.

These findings support the suggestion that intended motor representations play a crucial role in producing the illusory sense of movement experienced by patients with AHP. Furthermore, the combined findings of Fotopoulou et al (2008) and Jenkinson et al (2009) have implications for our understanding of everyday motor awareness in healthy individuals.

Conclusion

To come full circle, we can use all of what we have learnt so far to try and better understand our good-intentioned, celebrity dancer. By looking at the normal motor system we have established that awareness is usually based on what we intend to do, rather than what we have actually done. A tendency to ignore small performance errors is perfectly normal (Fourneret & Jeannerod, 1998; Wolpert, 1997). It should therefore come as no surprise that our dancer fails to notice minor errors in his performance.

We can further explain a failure to detect larger errors in movement by drawing on the extreme example of AHP. This pathology of awareness has confirmed that motor representations and intentions exert considerable influence over awareness (Fotopoulou et al., 2008; Jenkinson et al., 2009), and that the motor system can deceive us into believing we have executed our intended actions correctly, even when there is overwhelming evidence to the contrary. What we observe in our apparently self-deluded dancer may, in fact, be a mild version of this faulty mechanism of awareness.

Of course, the similarities we have drawn between AHP and our hypothetical dancer are exaggerated, but the underlying principles remain faithful to the usual operation of the motor system, and allow us to demonstrate how studying individuals with brain-injury can reveal the workings of a healthy mind (see Ellis & Young, 1996; Rapp, 2001). Thus, through no fault of his own, our dancer friend may be completely oblivious and unable to possess knowledge about his awful performance. After all, he had all of the right intentions!

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