“Perceived Intention”

- Motor intention perceived as movement despite paralysis and retained insight

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Abstract

Neuroscientists since Helmholtz have debated whether movement perception relies on sensory reafference or efferent signals. Computational motor control models offer potential answers and help explain altered motor awareness in neuropsychiatric conditions.

We present the case PI, a 29-year-old lady who, following functional seizures, experiences periods of whole-body paralysis, during which she nevertheless perceives her intended movements as actually occurring. Importantly, and contrary to conditions such as anosognosia for hemiplegia, she retains full insight into both her perceived movements, and the absence of actual movement.

This presentation, which we suggest calling "perceived intention", adds a new distinction to classic motor control models. The dysfunction presumably arises after the efferent signal generation. It demonstrates dissociation between objective facts of body movement and subjective experiences of intention and movement**.** The proprioceptive qualia of movement appear to rely primarily on motor efferent signals, the explicit knowledge about movement occurrence on sensory feedback.

Previous theories postulate that a single, coherent experience of action is ensured by a comparator node integrating intended and actual movement signals, with only their discrepancy entering awareness. In contrast, PI demonstrates the possibility of simultaneous awareness of two conflicting signals about one's own action, thus indicating componential, rather than integrative motor awareness.

Key words: Movement intention, movement control, movement perception, comparator model, anosognosia for hemiplegia, phantom limb

Introduction

How do we perceive our own movements? Classically, neurophysiologists have proposed two sources: sensory reafference from the moving limb, e.g., from muscle spindle afferents, and 'efference copies' of motor commands, e.g., outflow from motor cortical areas [1, 2]. In his seminal paper on volition, Libet found that perception of movement typically occurred around 86ms prior to EMG onset [3], suggesting awareness of an efferent signal. However, the methods of such chronometric studies remain controversial [4]. Because afferent and efferent signals typically co-occur, direct evidence regarding whether efferent signals are either sufficient or necessary for movement *perception* is lacking.

Recent computational theories of motor control provide a convincing account of how efferent and afferent signals are combined for *controlling* movements. When the brain sends a descending motor command to the spinal cord, a parallel, efference copy of this motor command is used to predict the sensory consequences, notably how the limb will move (Fig. 1) [5]. Comparison of this predicted outcome to the desired outcome allows rapid and smooth adjustment of the ongoing motor command prior to movement execution, and prior to delayed reafferent feedback from the limb itself ([A] and [B] in Fig. 1) [6]. Sensory reafference provides initial information about the current state, and also feeds back the actual outcome of the movement ([B] in Fig. 1). The key role of reafference is in adaptation of future motor commands and predictions, thus contributing to learning and plasticity.

Interestingly, these models have also been applied to *motor awareness*, and can make predictions about how people *perceive* their own movements. Frith et al. suggested that motor awareness arises *after* the comparator stage, where efferent predictions and afferent feedback are integrated [7]. This theory allows a form of self-recognition for one's own movements. If afferent information about movement matches the prediction based on efference-copy, then the agent will experience a sense of agency over the movement. Alternatively, if the prediction and reafference do not match, the comparator generates a *prediction error*, and the person will not experience their movement as their own [7]. (Fig. 1)

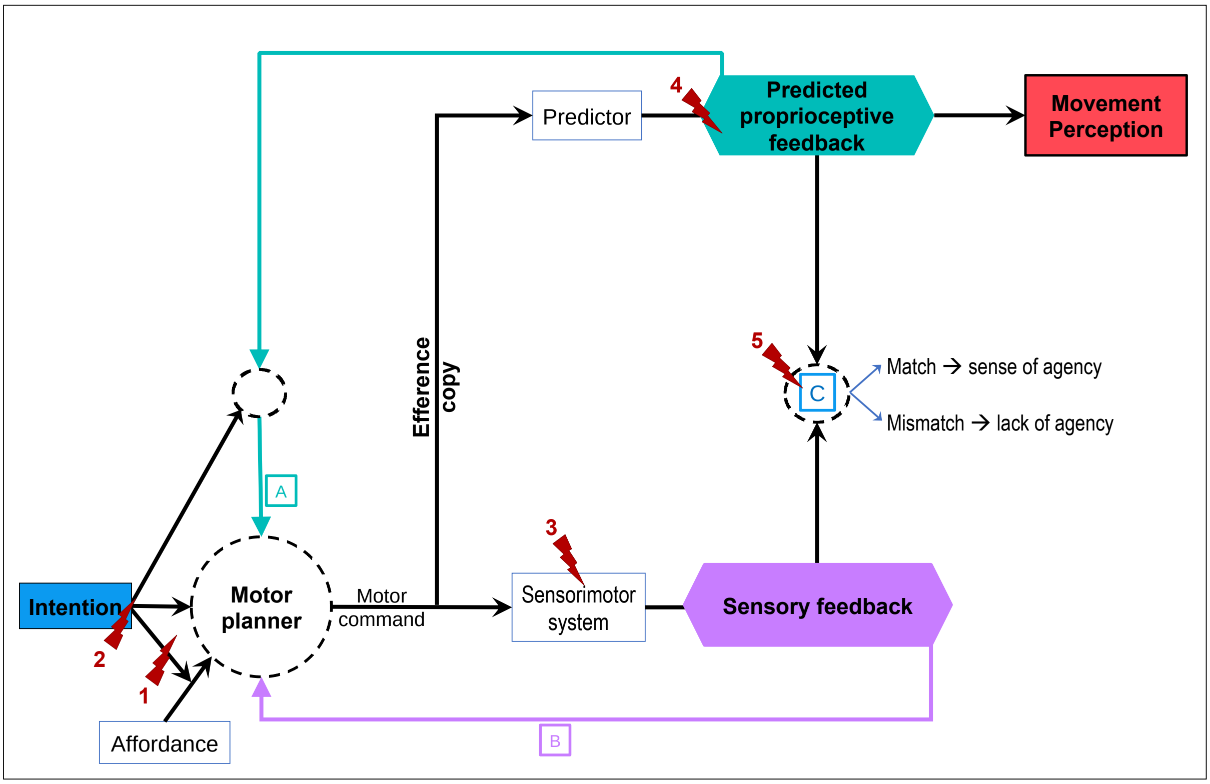

Fig. 1: Simplified schematic of the optimal motor control model, showing previously suggested lesions/dysfunctions in disorders of motor intention and perception [8]
[A] rapid, smooth motor command adjustment prior to movement execution
[B] slow, delayed sensory feedback providing information about the present state and leading to motor learning through adaptation of future motor commands
[C] Comparator integrating predicted with actual sensory feedback
Red flashes indicate lesions/dysfunctions thought to relate to established disorders of motor intention or perception[8], as follows:

1 Anarchic hand, the anterior variant of alien limb syndrome – everyday objects trigger a stereotyped motor response that is not desired or intended by the patient - retained insight
2 Utilisation behaviour - everyday objects trigger an object-oriented motor response, but patient seems unaware of mismatch between intention and action, and retrospectively confabulates a reason for the action – no insight
3 Phantom limb movement – retained insight
4 Delusion of control or passivity experience in schizophrenia – no insight
5 Anosognosia for hemiplegia – no insight

Thus, these models imply that we perceive intentions and prediction errors. In contrast, we do not perceive the normal reafference from movements themselves, because that reafference is predicted. Because our movements generally immediately and closely follow intention and prediction, this imperception is not normally noticeable. Interestingly, neurological and psychiatric conditions in which intention and actual movement are dissociated test this model, thereby providing valuable insights into normal movement awareness. Some of these insights are schematised in Fig. 1. [8].

Many people with phantom limb sensations, including phantom limb pain, also perceive movement of their phantom limb, particularly early after amputation. These perceived movements can be voluntary movements, semi-voluntary movements "*the phantom may wave good-bye, fend off a blow, break a fall or reach for the telephone*", or involuntary movements, *"the hand suddenly moving to occupy a new position or suddenly developing a clenching spasm of the fingers*" [9]. The mechanism is thought to be due to perception of the intended or predicted movement. With time, the absent sensory feedback updates the motor planner and predictor about the absence of actual movement in the phantom limb and phantom movements tend to disappear. [8]

Similarly, in anosognosia for hemiplegia (AHP) brain-damaged patients deny their hemiplegia, believing they can and indeed are moving normally. This phenomenon, arising in up to 30% of acute hemiplegic patients [10], is thought to be caused by an intact motor intention and prediction system that is sufficient to generate percepts of movement, but with damage to the comparator system. The comparator system therefore fails to integrate sensory information that the intended movement has not actually occurred [11, 12]. Crucially, the AHP patient's motor awareness is dominated by their intention, and the patient resists assimilating evidence that they failed to move by dismissing such evidence.

In other conditions, however, intentions are not correctly perceived. In delusions of control or passivity experiences in schizophrenia, intentional actions are perceived as externally-generated rather than self-generated. The deficit is suggested to lie in an impaired efference copy mechanism. As a result, there is a mismatch between predicted and actual feedback, and the patient has no sense of agency with respect to the sensory signals generated by their own actions [8]. Thus, AHP and delusions of control can be seen as complementary deficits within a comparator model. AHP patients fail to register signals in the reafferent 'arm' of the comparator, and their motor awareness is accordingly dominated by intention. Patients with delusions of control fail to register signals in the efference copy/predictive 'arm' of the comparator, and their motor awareness is accordingly dominated by prediction errors generated by reafferent feedback.

Methods & Results: Case presentation

We present the case of patient PI, a 29-year-old lady with a background of asthma, childhood sexual abuse, depression, anxiety and obesity. She gave written, informed consent for the publication of her case. She has a 3.5-year history of 2-10 functional seizures (aka non-epileptic attack disorder) a month, during which she experiences involuntary whole-body trembling, with retained consciousness. These seizures are followed by an inability to move or speak for several minutes, occasionally up to 90 minutes. During her initial neurological consultation, she spontaneously stated that *it sounded crazy, but* that during this period of post-functional seizure paralysis, she has intentions to move, and feels herself to be moving in the way intended, since she can feel the corresponding limb and joint movements. Yet she is simultaneously fully aware that there is no actual movement, either because she can see that her limb is not moving, or because she does not feel the external consequences that would accompany any actual movement, e.g. tactile pressure when squeezing someone´s hand, or the gravitational force acting on her leg when she lifts it. "*I felt that it [the hand] was moving, but I could see that the hand wasn´t moving […] I´m moving my leg, in my head it´s happening, but I can´t feel the weight / gravity changing*." When asked whether she would think the movement had happened had her eyes been closed, she answered with a clear "*yes"*, adding: "*I can feel everything happening as if it was happening – I cannot feel the outside consequences of the movement, but I can feel the arm/leg and joints movements.*" It makes her feel *"angry, frustrated, I´m talking to you* [the unresponsive limb] *why are you not listening. Makes me feel as if I made it all up. Just stand up and get on with it!"*.

Interestingly, the perception of intended but unexecuted movements is not paralleled in speech. She reports her inner voice telling her to speak but being unable to do so. Strict comparability with bodily motor movements would have implied that she at least experiences the orofacial movements of speech.

These unusual experiences of bodily movement occur after approximately 90% of her functional seizures, but never outside of these. In between episodes her movements and their perception are entirely normal. Her commentary implies that she perceives her intended movements with a phenomenology that resembles actual movements, while at the same time she recognises that these perceptions are false. She clearly processes the fact that no movement occurs and experience a logical affective response of frustration.

Discussion

This case differs from previously described cases of altered movement perception, and therefore adds information about the mechanisms of motor awareness in health and disease. The patient forms intentions to act and is fully aware of her intentions. She also experiences that these movements actually occur. The proprioceptive sensations that she reports cannot be based on actual sensory reafference, since the patient is functionally paralysed, and no movement occurs. Instead, we suggest that the patient experiences proprioceptive sensory predictions about limb movements generated by a sensorimotor forward model that generates sensory predictions from efference copies. This stands in contrast to classic comparator models suggesting that such sensory predictions of movement are not perceived and do not enter motor awareness. Classically, only prediction errors should be perceived. However, more recent work suggests an important perceptual role for sensory predictions [13]. For example, perception of sensory predictions may explain the experiences of patients with phantom limb movements, or with AHP.

The distinctive feature of this case is the combination of movement phenomenology and wider understanding. Paradoxically, while the patient experiences the movement that she intends to make, she *also* knows, on the basis of specific sensory evidence, that the limb does not actually move: she sees that it is not moving and/or she does not perceive the external sensory consequences of the movement. Thus, she experiences movement, but simultaneously knows that there is no movement. This dual aspect of her motor awareness presentation shows that she can detect intersensory conflicts, by comparing proprioceptive sensory predictions with the actual consequences of movement intentions – which in this case are a lack of movement.

Compared to established disorders of higher motor control (schematised in Fig. 1.), our case of intended movement is quite distinct, since the movement is not executed, but is nevertheless perceived as executed, while insight is retained. Indeed, this case appears to be the converse of two other conditions which involve execution of unintended movements, namely anarchic/alien hand and utilisation behaviour. In utilisation behaviour, everyday objects trigger an unintended, object-oriented motor response. Although this response is recognised as self-related, the patient lacks insight into the source of the action, and retrospectively confabulates an explanation for what they have done. In anarchic hand, commonly regarded as an anterior variant of alien limb syndrome, insight is retained with the unintended but executed action not being perceived as self-generated.

Our case has strong similarities to anosognosia for hemiplegia or phantom limb movement, notably because of the absence of actual movement. However, there are important differences. Crucially, unlike patients with AHP, our patient has full insight into the fact that there is no actual movement corresponding to her perceived intention. In contrast to phantom limb movements which tend to disappear over time [9], our patient reports repeated altered motor awareness across three years. We speculate that this may reflect the frequency of mismatch signals updating the motor prediction model. In phantom limb, every intention to move the limb is accompanied by evidence that movement has not occurred. In our patient, altered motor awareness only occurs for periods of minutes following her functional seizures, and motor control is otherwise normal. The only occasional nature of the mismatch between perceived intention and lack of movement in our patient may explain why the predictions made by the forward model are not updated, and so the illusion of making intentional movements does not extinguish.

Functional neurological disorder represents a dysfunction of the central and not the peripheral nervous system; attention for example, is known to play a central role in this condition [14]. The deficit in the current case is thus hypothesised to lie within the central, and not the peripheral nervous system, in contrast to phantom limb which begins with peripheral trauma (amputation). Our patient has intentions, efference copies and sensory predictions that appear to be unaffected. Furthermore, her insight is fully preserved in that she perceives both the movement she intended and the fact that no movement actually occurred. Further, she also perceives the discrepancy between the two. The intended motor command is clearly not executed, since there is no actual movement. Taking all of this into account, we hypothesise that the deficit arises in the processing of the motor command in the central nervous system, but after the generation of the efference copy (see Fig. 2).

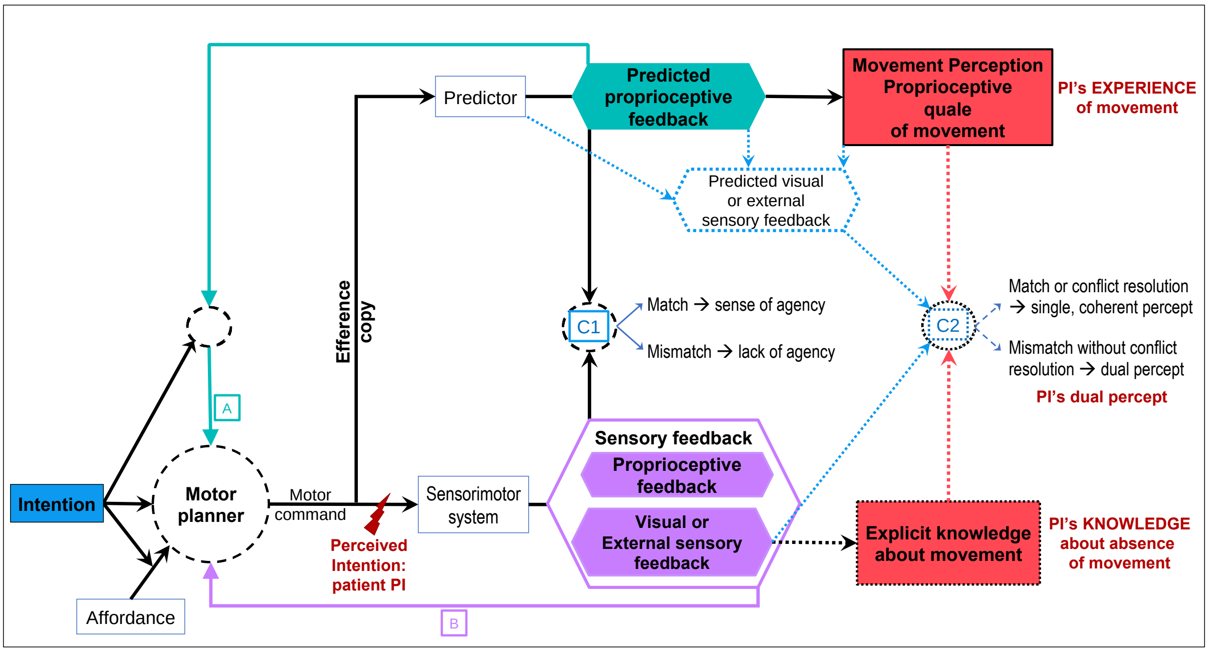

Fig. 2: Suggested extension of the optimal motor control model, with the new suggested entity of "perceived intention", and distinct endpoints for movement perception and knowledge about movement.
The dotted elements represent additions to the classic motor control model, as suggested by patient PI.
[A] and [B] same as in Fig. 1
[C1] Comparator 1, integrating predicted with actual sensory feedback
[C2] Comparator 2, comparing the proprioceptive feeling of movement with explicit knowledge about the movement (red dotted arrows). In case of a mismatch, C2 either enforces a single coherent percept by suppressing one input or, as in PI's case, permits perception of two conflicting signals about movement to enter awareness. C2 may also receive its input from other sources indicated by the blue dotted arrows.
The red flash indicates the suggested dysfunction in the present case PI.

The present case represents a novel entity which we suggest might be termed "perceived intention". We use this term to indicate that the patient's perception of movement is driven by the efferent arm of the motor control circuit, rather than by sensory feedback. We assume that sensory feedback from the (non-moving) limb underlies her knowledge that the limb is paralysed and does not move to command. Interestingly, this knowledge coexists with the perception of actual movement, and there is no apparent resolution of the resulting conflict. (Fig. 2)

An obvious limitation of this suggested new entity is that it is so far limited to a single case requiring replication. We hypothesise that a similar experience may occur not only following functional, but also epileptic seizures, during the period of Todd´s paralysis. However, unless the epileptic seizure was focal, this may be hard to ascertain due to typical post-ictal confusion. Furthermore, depending on the extent of a simple motor seizure, the crucial components of the prediction system and comparators may also be affected, hence failing to generate this experience.

Another limitation is that PI's experience could be seen as an unexplainable, strange experience in the context of a functional neurological disorder. Functional symptoms are very varied and at times appear to defy logic, bringing some to question the wider implications on brain functioning that can be validly drawn from such experiences. Typical examples are sensory loss not following any anatomical distribution or tunnel vision, in which a person´s visual field diameter remains identical, regardless of the viewing distance. While such symptoms might be expected by a lay person, they defy the known anatomy or in the case of tunnel vision the basic laws of physics. Yet rather than branding such symptoms as impossible, these commonly observed symptoms may reflect a normal brain mechanism, in these two examples notably that perception is shaped by beliefs or prior expectations. Furthermore, however strange such experiences may appear, they clearly require a brain-based explanation. Indeed, understanding such experiences may help provide further insight into brain mechanisms in health and disease.

The present case highlights a distinction that goes beyond previous cases and models. Studies based on the comparator model suggested that the key signal for motor awareness is the difference between intention and sensory feedback. Furthermore, in many conditions of altered intention or movement perception, awareness is dominated by one input, with the other input being blocked or unavailable to consciousness. Thus, in anosognosia for hemiplegia awareness is dominated by the intention to move, and the absence of actual movement is ignored. In delusions of control, awareness is dominated by sensory inputs, and the fact that these are intended is ignored. Such cases are normally treated as evidence for the need to produce a single, coherent content of awareness by suppressing conflicting signals. The integration of efferent predictions and afferent feedback at the comparator would be the key process in producing awareness. In contrast, the present case suggests that one can be conscious of both proprioceptive predictions based on intention and efference copy, and also of sensory feedback signals such as vision and touch, and one can indeed additionally be conscious of the fact that these different signals do not match. The movement intention appears to lead to a proprioceptive *quale* of movement, whereas other sensory feedback signals contribute to "knowing" that movement is absent (Fig. 2). In other words, this case indicates that it is possible to entertain within awareness that there are conflicting efferent-based and afferent-based signals about one's own action. It suggests a componential, rather than an integrative view of motor awareness.

Statements and Declarations

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Ethical standards

Our patient gave informed consent for the publication of her case, received the initially submitted article and signed the Springer Nature consent form for publication. This publication complies with the ethical requirements of Cambridge University Hospitals NHS Foundation trust.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Supplementary material

None

Authorship

Anne-Catherine Huys conceptualised this article following clinical contact with the patient, and wrote the first draft and subsequent versions. Patrick Haggard critically reviewed and edited the paper.

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