A Comparison of Fortunes: the Comparator and Multifactorial Weighting Models of the Sense of Agency

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Abstract

The sense of agency over bodily actions is the feeling that one is the agent of one's actions. In this paper I examine the prospects of Frith and colleagues' influential comparator account of how the sense of agency over one's bodily actions is elicited, in comparison to the multifactorial weighting model advocated by Synofzik and colleagues in response to some problems with this account. I examine two problems for the comparator model. I consider the common objection that the actual sensory consequences of action aren't needed to elicit the sense of agency with a look at the data which most strongly suggests this, namely the preserved sense of agency over phantom limb movements. I consider a problem for the comparator model in the behaviour of normal subjects placed in unusual circumstances, in particular I consider the 'wheel of fortune' studies which some take to be problematic for the comparator model. I argue that neither of these objections are devastating for the comparator model and that the comparator model plus some plausible assumptions can explain these data. However, these assumptions are not part of the original comparator model. In the end we get a version of the comparator model modified to deal with problematic cases in a manner that could be seen as somewhat ad hoc. To deal with this the multifactorial weighting model of Synofzik and colleagues is introduced. Although this model is incomplete a single version can be offered which is naturally constrained by the cases which are problematic for the comparator model. However, it is not clear what, if anything, could count as evidence against the multifactorial weighting model. Despite being generated with the data in mind it may be untestable. I conclude that currently the comparator model has stronger support than the multifactorial weighting model.

Keywords: Self Consciousness, Sense of Agency, Comparator Model, Multifactorial Weighting Model, Frith, Synofzik, Phantom Limbs, Wheel of Fortune

Introduction

The sense of agency is the feeling that one is the agent of one's bodily actions. It is to be distinguished from the sense of acting intentionally in that it is about oneself *qua* agent of action not one's mental states which seem to lead to the action. It is a non-conceptual feeling; as such some authors refer to it as the feeling of agency.

In this paper I consider two attempts to provide an account of how the sense of agency over one's bodily actions is elicited. The first of these is the comparator model proposed by Frith and colleagues (Frith et al. 2000b). Here I will defend this model from some of the objections raised against it by advocates of an alternative model, known as the multifactorial weighting model. I defend the comparator model from the common objection that the actual sensory consequences of action aren't needed to elicit the sense of agency. Although many data have been marshalled to make this argument here I consider just one of the most compelling pieces of evidence, namely the preserved sense of agency over the actions of phantom limbs. Advocates of the multifactorial weighting model also take some studies into the priming of agency judgments as evidence against the comparator model. Here I consider one of these studies known as the 'wheel of fortune'. I argue that this study is consistent with the comparator model. However, from these arguments we will see that the comparator model needs case by case adjustment to deal with problematic data. In particular several plausible assumptions about additions to the comparator model must be made. As these assumptions are not part of the original comparator model these adjustments may seem somewhat *ad hoc*. In an attempt to deal with this the multifactorial weighting model of Synofzik and colleagues is introduced. Although this model is incomplete a single version can be offered which is naturally constrained by the cases which are problematic for the comparator model. However, it is not clear what, if anything, could count as evidence against the multifactorial weighting model. Despite being generated with the data in mind it may be untestable. I conclude that currently the comparator model has stronger support than the multifactorial weighting model.

The Comparator Model of the Sense of Agency over Bodily Actions

One model of motor control which is thought to provide the resources to account for the causal history of the sense of agency over bodily action is due to Frith and colleagues (2000b). Their model of the motor control system can be understood as computations over a set of five types of representation delineated by content. These are the goal state (or the end target position for the body also called a "motor intention" or M-intention by Pacherie (2008)- i in figure 1), the motor commands [of which there are two copies iia and iib in figure 1 The copy of the motor commands that remains central is often referred to as the "corollary discharge" or "efference copy" (in e.g. Feinberg 1978; Frith et al. 2000b; Vosgerau and Newen 2007)], the predicted sensory consequences based on the copy of the motor commands that remains central (iii in figure 1), the actual sensory consequences following the movement (iv in figure 1) and an estimation of the final state of the body (v in figure 1), see figure 1 (Frith et al. 2000b p. 1773; Kawato

Article DOI: 10.5096/ASCS20096

1999; see Desmurget and Grafton 2000; Wolpert and Ghahramani 2000 for reviews).

From this model of the motor control system it is possible to generate an account of the causal history of the sense of agency. There is a set of representations the motor control system could use in order to elicit the sense of agency. On this model of the motor control system, when one performs an action without interference then the actual sensory consequences of that action match the predicted sensory consequences based on the copy of the motor commands that remain central (i.e. the efference copy/corollary discharge) (Frith et al. 1998 p. 173; Frith et al. 2000b p. 1784; Blakemore et al. 2002 p. 240; Frith et al. 2000a p. 359). However, if the movement that actually occurs is caused by some external force then there is no or a different prediction. Thus, the actual sensory consequences do not match the predicted sensory consequences. Perhaps the sense of agency arises from the capacity to detect matches between the predicted and actual sensory consequences of a movement.

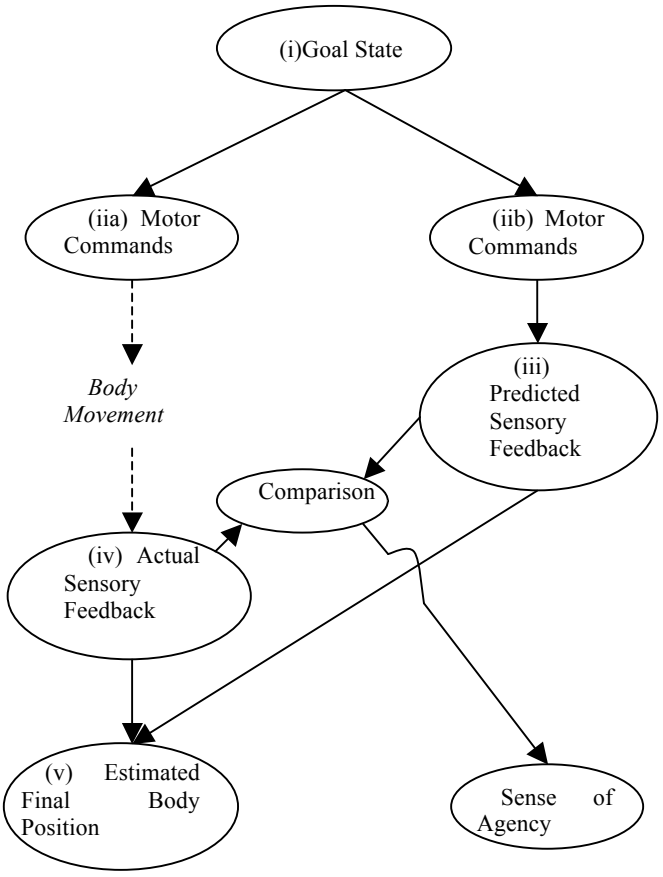

Figure 1: The comparator model, a represented match between the actual and predicted sensory feedback is used to elicit the sense of agency.

Clearly, on the comparator model actual sensory feedback is necessary for the sense of agency to be elicited. A variety of challenges have been made to the comparator model based around evidence which appears to show that the sense of agency can be elicited independently of actual sensory feedback. Next I will consider one of the most compelling versions of this argument, the argument from phantom limbs.

Is Representation of the Actual Sensory Consequences of Action Necessary for the Sense of Agency to be elicited? The case of Phantoms

A phantom limb experience is the feeling that an amputated limb is still present. Some patients who have these experiences feel that the phantom limb is voluntarily moveable. Ramachandran and Blakeslee describe a patient Tom who, after losing his left arm from just above his elbow, experienced a vivid phantom arm which he felt he was able to move. He was able to wiggle each phantom finger, reach out and grab things and perform a variety of more automatic actions, such as bracing for a fall (Ramachandran and Blakeslee 1998 pp. 21-22). He seems to have an intact sense of agency for these phantom actions. He never seems to report that the action is done by someone else or that the phantom arm does the action on its own.

Some rather different reports come from a patient who suffered from a congenital lack of limbs; she was missing both arms from above the elbow. She seems to experience her phantom arms as moving on their own when she says:

> … as I'm talking to you, they are gesticulating. They point to objects when I point to things, just like your arms and hands (Ramachandran and Blakeslee 1998 p. 41).
>
> When I walk, doctor, my phantom arms don't swing like normal arms, like your arms. They stay frozen on the side… But when I talk…my phantoms gesticulate. In fact, they're moving now as I speak (Ramachandran and Blakeslee 1998 p. 41).

Here the subject seems to be describing the gestures her phantom arms perform as automatic. Perhaps she is going as far as to deny that she is the agent of these actions, but this is not necessarily the case. However, despite these reports this patient also experiences her phantoms as voluntarily controllable (Ramachandran and Blakeslee 1998 p. 42).

These reports are problematic for the comparator model. There is no actual sensory feedback from the phantom arm, either visual or non-visual, that could be compared to predicted sensory feedback or goal state and used to elicit the sense of agency. Yet these patients don't necessarily deny that they are the agents of their phantom actions. The reports of phantom arms moving on their own when gesticulating seem more consistent with the comparator model. However, these reports seem to be the exception, with even the patients who have these experiences at other

times reporting that they voluntarily control their phantom movements.

In addition to this Synofzik and colleagues (2008) raise a problem that arises from a consideration of cases of paralysed phantoms. Some patients experience their phantom limbs as paralysed. However, they can come to experience their phantom as moveable using a simple visual illusion. To experience this illusion the patient is asked to place their real arm and their phantom arm into a box on either side of a mirror. They are then asked to look at the reflected image of their real arm and move it until it seems to be superimposed on their phantom arm. They are then asked to attempt to move both arms. On seeing the reflected image move they can feel as though their phantom arm is now moving (Ramachandran and Blakeslee 1998 pp. 48, 52-53). As with the patients described above these patients seem to feel that they are the agents of these actions. They do not attribute the action to someone else, nor do they claim that the phantom moves on its own. There is a possible comparator explanation here of the sense of agency over these actions in terms of the visual feedback from the mirror. However, as Synofzik and colleagues point out this requires that visual feedback from the limb is still being predicted long after the amputation (Synofzik et al. 2008 p. 225). It seems that the motor control system should be able to learn not to predict visual feedback when such feedback is permanently lost. Indeed one proposed role of the comparison between actual and predicted sensory feedback is to teach the motor control system to generate more accurate predictions (Frith et al. 2000b p. 225; Synofzik et al. 2008). As such this potential explanation just raises a further problem of why the motor system is no longer updating its ability to predicted sensory feedback in this case. Furthermore, such an explanation is not applicable to those cases where phantoms are felt to be voluntarily moveable without using the mirror.

However, there is data from these reports that offers a way out of the problem. The feelings of position, touch, pain and kinaesthetics that these patients experience all seem to the patient to be real sensory feedback. The touch seems to be touch; the pain seems to be pain. All of these representations of the phantom are misrepresentations, their false content is that they are real feedback from a real limb; this is even the case for visual feedback, at least in the case of Ramachandran's box. If these representations have this false content consciously, there seems to be no reason to think they don't have this false content unconsciously. That is representations of the phantom limb have the false content that they are actual sensory feedback from a real limb and entered into the comparator as such. Given this the sense of agency could still be elicited in the case of phantom limbs. Furthermore, as the comparator is consistently receiving representations of actual sensory feedback it would continue to generate a learning signal for the formation of predictions consistent with there being real feedback. As such the motor control system ought to continue to predict the formation of actual sensory feedback.

Ramachandran offers an explanation of this phenomenon for the modality of touch in terms of current body representations and neuroanatomy. He suggests that this occurs due to cross wiring in the 'Penfield Homunculus' (Ramachandran 2003 pp. 11-14). The Penfield Homunculus is an area of the somatosensory cortex, which is responsible for representations of body surface. Different regions of the cortex are responsible for representations of different parts of the body surface. The regions of the cortex that generate representations of the face and the hands are anatomically adjacent. Perhaps when one region (say the hand region) loses input (due to amputation), signals from adjacent regions (e.g. the face region) spread into the now inactive area (Ramachandran 2003 p. 14). Since this region is still responsible for representations of the hand, the signals from the face are misrepresented as coming from the hand. To date no hypothesis exists as to how this may work for other modalities, such as proprioception.

In this section I have examined the argument from phantom limbs to the claim that the sense of agency does not depend on a representation of the actual sensory consequences of an action. This argument has not been able to establish this conclusion, as the experience of the phantom itself suggests that these patients form misrepresentations of the phantom that seem to be actual sensory feedback from the amputated limb. In the next section I will consider an alternative argument against the comparator model from the wheel of fortune task.

The Wheel of Fortune Task

Aarts and colleagues (2005) 'wheel of fortune' task examines the effects of spatial primes and conscious intentions (that are not acted on) on the sense of agency. In this study subjects sat facing a computer screen showing eight white tiles. Two grey squares moved around these tiles. One square moved anticlockwise and was controlled by the subject pressing and holding the 's' key. The other grey square moved clockwise and was controlled by the computer. After some time (8-10 rotations) the subject received a cue to stop movement by pressing the 'enter' key. At the point the stop cue appeared the grey squares disappeared, after the subject pressed the 'enter' key one of the white tiles turned black. The subject was told that this black tile represented the location of either their grey square or the computer's at the point the 'enter' key was pressed. Subjects where then asked to rate (on a 1-10 scale) the extent they felt they had controlled the stop point (Aarts et al. 2005 pp. 443, 445, 446). In the conditions I am interested in here subjects did not control the point where the black square appeared, instead it always appeared 4 spaces ahead of where the subjects' grey square was when the stop cue appeared, i.e. 4 spaces ahead of the final seen location of the subjects' grey square. Due to the rate of rotation the subjects' square would have stopped at the location of the black square if they pressed the 'enter' key 0.480s after the stop cue appeared (Aarts et al. 2005 p. 447).

In the experiments of interest here (experiments 1 and 2) four conditions were compared. In experiment 1 these were 1) a subliminal prime task where the location of the black square was to appear flashed black for 0.034s 0.046s before the stop cue appeared, 2) the 'conscious goal task' where subjects were told to try to stop their square on the tile that would turn black and 3) a baseline task where no prime or instruction was given. Importantly in the conscious goal condition (as with the other conditions), subjects were instructed to press the 'enter' key as soon as possible after the stop cue appeared. If subjects adhered to this instruction then their 'goal' to stop at a particular location should not have influenced their action. There is some reason to suppose that subjects did follow this instruction as there was no difference between reaction times for the prime and goal conditions (although both were longer than baseline), suggesting subjects did not adjust their reactions in order to hit the goal square (Aarts et al. 2005 p. 448). These were presented in 2 blocks, 8 baseline trials then 8 trials from either the subliminal prime or conscious goal conditions with each subject receiving only 1 of the 2 test conditions. In experiment 2 the conscious goal condition was replaced by 4) a supraliminal prime condition, where the square which would turn black flashed black for 0.068s 0.012s prior to the stop signal appearing (Aarts et al. 2005 p. 450).

Subjects gave higher ratings for their sense of agency over the position of the black square for subliminal prime, supraliminal prime and conscious goal conditions than for baseline (Aarts et al. 2005 pp. 447, 450). There was no difference in the ratings given for either prime condition or the conscious goal condition (Aarts et al. 2005 pp. 447, 450). This result is especially interesting as it was less likely that participants stopped their square on the tile that turned black in these conditions due to their increased reaction times from baseline (Aarts et al. 2005 p. 448). Thus it seems it is possible to increase subjects' sense of agency over an action when it is, in fact, less likely that they controlled the action. However, exactly what this method probes is called into doubt by a recent replication which suggests the effect of priming is specific to women (Jones et al. 2008).

This experiment and others measuring the effects of auditory primes on the sense of agency have been used to argue that the comparator model cannot explain how the sense of agency is elicited (Synofzik et al. 2008 p. 226). Whilst the conscious goal condition seems easy to understand on the comparator model (the subject produces a prediction from the goal), the priming cases seem harder to understand. Why should priming a location influence the sense of agency? There is a way that studies such as the wheel of fortune could be understood using the comparator model. As with phantom limbs, one possibility is that subjects misrepresent some information they receive as coming from one source when in fact it comes from another. In the phantom limb case it was proposed that patients misrepresent internally produced body representations as actual sensory feedback, in the wheel of fortune task subjects may misrepresent external cues (the primes) as internally produced predictions.

We want to understand how priming the stopping place of a square can cause one to feel one is, to some extent, the agent of an action that one doesn't control. Jones and colleagues (2008) suggest that the primes may act as a kind of "proxy predicted state" (Jones et al. 2008 p. 578 although note that Jones et al are not advocates of the comparator model). I take it that their proposal is that the prime stimulus is somehow misrepresented as a prediction of what is about to happen based on the motor commands and compared to actual sensory feedback causing an erroneous sense of agency to be elicited when they match. If such a model turns out to be correct then the comparator model can explain these data. Future work could focus on whether and how such representations could be misused.

It appears that a modified comparator model can explain the wheel of fortune data. As with phantom limbs, it is possible to explain these experiences by building in some additional assumptions about the misuse of certain representations. However, this could seem like a rather large assumption and as it is not predicted by the initial presentation of the comparator model it may seem somewhat *ad hoc*. Under what conditions might subjects mistake external cues for predictions? No answer currently exists to this question. This gives us reason to look elsewhere for an explanation for the sense of agency. In the next section I consider the multifactorial weighting model advocated by Synofzik and colleagues. I argue that even though this model is more naturally constrained by the data than the comparator model it seems to be unfalsifiable, hence the comparator model is to be preferred.

Multifactorial Weighting

In this paper I have been examining the possibility that the comparator, suitably constrained by the data, can provide a viable account of the sense of agency. Here I have considered data that suggest the comparator sometimes misuses visual primes as predictions and internally generated body representations as actual sensory feedback need to be built into the model. In describing the approach to the comparator model above Synofzik et al state:

> The strategy he [GC] uses is to show that each particular case we discussed can very well be explained with a somewhat adjusted [comparator model]. This strategy of adjustment is, we are ready to admit, a possible strategy. The crucial point is, however, that is such adjustments are necessary for *each* case (Synofzik et al. 2009 p. 522)

It is important to note that the account of the comparator model presented above does indeed follow this strategy. In the cases considered here the specific strategy has been to build in additional hypotheses as to the use of misrepresentations by the comparator. The problem specific to this data is that there is no argument as to why these misrepresentations would be used in such a way, beyond the fact that it helps generate a more constrained version of the comparator model. How might phantom limb patients form

misrepresentations of actual sensory feedback for modalities other than touch? Could these be entered into the comparator? Why might the comparator mistake visual experiences for motor predictions? There are no obvious answers to these questions at this stage.

To solve this kind of problem Synofzik and colleagues introduce the notion of a multifactorial weighting process. They suggest that the inputs to the mechanism that elicits the sense of agency are weighted for importance in each case. The inputs include, but are not limited to the comparison of actual sensory feedback to predicted sensory feedback. There are other "agency cues" such as predicted visual consequences, actual visual consequences, their comparison and predicted non-visual sensory consequences all of which could contribute to the sense of agency being elicited. In the case of the wheel of fortune the prime itself is given an inappropriate weight of greater than zero as an agency cue. Like the modified comparator model discussed here this is in essence a case of misuse of the visual prime. However, unlike the comparator model it is not proposed that the prime is entered into a comparator; rather it is entered along with the output of the comparator into an additional process. The sense of agency over phantom limbs could be explained by high weights being given to an intention or effort to move and the internally generated body representations. A low weight would also need to be given to mismatches at the comparator and the absence of proprioceptive and tactile feedback from the limb. Although there is still much to discover about how such a weighting process works (e.g. how weights are assigned) this notion seems to offer a powerful amendment to the comparator model.

Synofzik and colleagues seem to offer a more parsimonious explanation of the sense of agency based on a multifactorial weighting process. Once it is fully understood multifactorial weighting of agency cues might offer a plausible way to understand how the sense of agency is elicited. But then, as Synofzik and colleagues note "The weighting process takes the entire explanatory burden as soon as we wish to explain different cases with *one and the same* model" (Synofzik et al. 2009 p. 522). The upshot of this is that in attempting to solve problems for the comparator model we end up seeing that Synofzik and colleague's model is more parsimonious. Crucially a Multifactorial weighting model is more naturally constrained by the findings discussed here than a comparator model could be.

However, this strength of the model also seems to give rise to a serious problem. It is not clear what, if anything, could falsify the multifactorial weighting model. In the case of the comparator model all we need to falsify it is a case of the sense of agency over one's body being elicited when no representations of actual sensory consequences or predicted sensory consequences are present or when no comparison between these representations is possible. As we have seen, some take the case of the sense of agency over phantom limbs to be exactly such evidence. As it turns out these cases haven't provided such evidence, but it is always possible that such evidence could arise. The comparator model is an unfalsified, but highly falsifiable model. In contrast it seems that no such evidence could be, in principle, marshalled against the multifactorial weighting model. On this model, if the sense of agency is elicited when one or other agency cue (say a representation of actual sensory feedback) is absent it can always be proposed that the errant cue is given a weight of zero, with the remaining cues (predicted sensory feedback, motor intentions and their comparison) being more highly weighted so as to elicited the sense of agency. What else could falsify this model? Perhaps a case of the sense of agency being elicited in the absence of all the proposed agency cues will suffice? However, in that case another cue could always be proposed and given a weight of one. More strongly if no representations of actual sensory feedback, predicted sensory feedback, motor intentions, their various comparisons or any other proposed agency cue are possible, then it would be surprising if any bodily action had taken place and such a case would surely falsify any proposed model of the sense of agency. At the very least it would *also* falsify the comparator model.

The price of having a model easily constrained by the current data seems very high indeed. It is not clear what could, in principle, falsify the multifactorial weighting model. In order to argue for this model Synofzik and colleagues need to predict what could falsify their model and test the model against this prediction. Such a prediction would likely need a specific hypothesis as to how weights are assigned. Preferably this would be something that would not also falsify the comparator model. However, given the nature of these models that may not be possible.

Conclusion

In this paper I have considered problems for the comparator model. Although not devastating these problems do tend to push us in the direction of a more general model. In response to this I have considered the multifactorial weighting model advocated by Synofzik and colleagues. This model seems to be more naturally constrained by the findings discussed in this paper than the comparator model. However, this comes at the price of apparent unfalsifiability.

Acknowledgments

This work is taken from two chapters of my PhD thesis written across spells at Adelaide University and Macquarie University. I thank John Sutton, Max Coltheart (Macquarie), Gerard O'Brien and Philip Gerrans (Adelaide) for their work in supervising this project. I also wish to thank Matthis Synofzik and Gottfried Vosgerau for many helpful discussions related to this material. My attendance at ASCS 2009 was made possible by funding from the Macquarie Centre for Cognitive Science.

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Citation details for this article:

Carruthers, G. (2010). A Comparison of Fortunes: the Comparator and Multifactorial Weighting Models of the Sense of Agency. In W. Christensen, E. Schier, and J. Sutton (Eds.), *ASCS09: Proceedings of the 9th Conference of the Australasian Society for Cognitive Science* (pp. 35-40). Sydney: Macquarie Centre for Cognitive Science.
DOI: 10.5096/ASCS20096
URL:
http://www.maccs.mq.edu.au/news/conferences/2009/ASCS2009/html/carruthers.html