Penultimate Draft: Published as "The Modularity of the Motor System" ***Philosophical Explorations*****, 24, 376-393.**

The Modularity of the Motor System

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Abstract: In this paper, I make a case for the modularity of the motor system. I start where many do in discussions of modularity, by considering the extent to which the motor system is cognitively penetrable, i.e., the extent to which its processing and outputs are causally influenced, in a semantically coherent way, by states of central cognition. I present some empirical findings from a range of sensorimotor adaptation studies that strongly suggest that there are limits to such influence under certain conditions. These results cry out for an explanation. In the remainder of the paper, I provide one: The motor system is cognitively penetrable, but nonetheless modular along broadly Fodorian lines, insofar as it is informationally encapsulated. This means that its access is limited to its own proprietary database in computing its function from input to output, which does not include the information stored in central cognition. I then offer a model of action control, from distal intention to action outcomes, that further helps to illustrate this picture and can accommodate the target empirical findings.

Keywords: Modularity, motor system, informational encapsulation, cognitive penetrability, action control, sensorimotor adaptation

1. Introduction

The extent to which the mind is modular, i.e., comprised of specialized sub-systems dedicated to specific computational processing tasks, is a foundational concern in cognitive science.[1] Much of this debate has centered on the degree to which input systems, i.e., sensory or perceptual systems such as vision and audition, are modular (see, e.g., Fodor [1983]; Pylyshyn [1999]; MacPherson [2012]; Firestone & Scholl [2016]; Burnston [2017a]; Mandelbaum [2018]). And some on whether the mind might even be "massively modular", such that aspects of cognition, too, can be considered to operate via dedicated modules (see, e.g., Samuels [2006]; Carruthers [2006]).

By contrast, scant attention has been paid to the question of whether, or the extent to which, our main *output* system, i.e., the motor system, is modular.[2] This is perhaps not surprising. Discussions of the modularity of perception, which are ubiquitous in cognitive science, have largely been focused on its cognitive penetrability (or 'permeability'), that is, the extent to which one's beliefs, desires, and intentions can causally influence the content or phenomenal character of one's perceptual outputs. Much of the widespread interest in this question is motivated by *epistemic* concerns—in particular regarding the rationality of beliefs formed on the basis of perception if cognitive penetrability holds. The worry goes like this: Our beliefs are often justified by way of what we perceive. For instance, my belief that the banana on the counter is ripe is justified on the grounds that I perceive it to be of a certain yellow-ish hue. If, however, my belief about the banana's colour can itself causally influence what I perceive the banana's colour to be, then it would seem that my perception of its colour cannot, in turn, justify my belief.

The sibling question of whether the motor system is modular, framed in terms of whether it is cognitively penetrable, does not invite the same types of concerns about rationality. On the contrary, in this case, what many consider to be the standard or default story (see, e.g., Davidson [1963]) of how our actions are rationalized, *assumes* a causal influence on the outputs of the motor system from the agent's beliefs, desires, and (on many recent views) intentions. On this widely accepted picture, my unpeeling the banana to eat it is a rational action because it is caused by my desire to eat it, and my belief that unpeeling it will allow me to do so. Here the cognitive penetrability of action secures its rationality, rather than undermining it.

Still, even without this epistemic thrust, I think the question is an important one to settle for a number of reasons. For one, addressing it is indispensable to the project of uncovering the mind's architecture and understanding how it is organized, as well as how the systems that comprise it share information with one another. Even though it is incontrovertible that cognition causally influences action, questions remain as to how and to what extent. Understanding how the cognition-action interface works is thus a central motivation of this project. Second, it connects directly with adjacent issues in the philosophy of action. For instance, in the literature on skill, there is much discussion of the extent to which an agent can exercise flexible cognitive control over the computations of the motor system by way of what they know (see, e.g., Pavese [2019]). We cannot hope to fully answer this question without a better understanding of the extent to which the motor system can be influenced by central cognition.

In addition to these motivations for exploring our main question, it is also important to emphasize that it has not yet been settled, nor, as the discussion to follow will illustrate, is it a trivial matter to do so. This is how the paper will proceed: I start in section 2 where many discussions of modularity do, with a focus on cognitive penetration. After articulating how I understand this notion in the context of action, I go on in section 3 to present empirical findings that suggest that there are interesting limitations to the influence of cognition on the outputs of the motor system. These results demand an explanation, as well as a closer look at the causal pathways from cognition to action that might account for them. In the remainder of the paper, I argue that the best explanation of the findings is that the motor system, while cognitively penetrable, is informationally encapsulated. In section 4, I discuss the conceptual distinction between the two notions, which are often used interchangeably in the literature. In section 5, I present an independently and empirically motivated model of action control that is consistent with the characterization of the motor system as informationally encapsulated, yet cognitively penetrable, and accounts for the results presented in section 3. My conclusion is that the motor system is informationally encapsulated, and thus modular in broadly Fodorian terms.

2. Cognitive penetration and the motor system

Cognitive penetration concerns, roughly, the extent to which a system's processing and outputs are sensitive to the information carried by, or the content of, its inputs from "central cognition". The literature abounds with purported cases of cognitive penetration—from belief, desire, and even emotion—on perception (see Firestone and Scholl [2016] for an overview and critique). For example, it is said that: desirable objects (e.g., chocolate) look closer than undesirable objects (e.g., feces) (Balcetis and Dunning 2010); having grumpy thoughts makes things look darker (Banerjee, Chatterjee, and Sinha 2012); the belief that bananas are yellow makes them appear more so (Hansen et al. 2006); and so on.

Since perception is often the phenomenon of interest in this context, and since a main concern is whether the perceptual experiences that often justify our beliefs can be cognitively penetrated by them, many characterizations of cognitive penetration focus on how things subjectively *seem* to the subject as a result of what they believe (or desire, feel, etc.) (e.g., Stokes [2013]). Our own interest is not in the effects cognition might have on perception, nor on the epistemic consequences of any such effects, but rather on the effects it has on action, how it exerts them, and what conclusions we might draw about mental architecture on that basis. So it is more relevant to focus on the effects of cognition on the *semantic contents* of the motor system's outputs, rather than on the phenomenal properties or experiences that supervene on those contents, whatever those may be.

For an articulation of cognitive penetration that respects this focus, we can draw from Pylyshyn's (1999) classic formulation. He writes, "… if a system is cognitively penetrable then the function it computes is sensitive, in a semantically coherent way, to the organism's goals and beliefs…" (343).

I will adopt this characterization with two minor adjustments, as well as some background assumptions, as follows: First, I will replace the talk of "goals", which is overly general, and might include, e.g., representations *produced by* the motor system, such as motor commands, with talk of 'intention', since it more clearly denotes states of central cognition, i.e., the system responsible for deliberation, planning, and problem-solving, which are our focus. I will assume that intentions are such states, and that the motor system takes them as inputs and has the function of outputting motor commands that, in coordination with sensory systems, result in action outcomes that correspond to them. I will also assume that intentions possess content that is discursive, i.e., sentential or propositionally formatted. Some have recently argued for views on which intentions have a dual character in that they possess content that is *both* propositionally and motorically formatted (Shepherd 2019; Ferretti and Caiani 2019). Though important to consider in its own right, I will not be evaluating this possibility here. Suffice it to say that the modularity thesis is concerned with the relationship between representational states of central cognition, traditionally construed as having exclusively propositional format, and representational states of the input/output systems, which are not construed as possessing such a format. For the purposes of engaging with that debate, I will assume the same set-up here.

Second, though Pylyshyn (1999) presents this as a merely necessary condition on cognitive penetrability, I will treat it as a sufficient condition as well. This results in the following characterization of the cognitive penetrability of the motor system:

$\text{CPT}_{\text{ACTION}}$: The motor system is cognitively penetrable just in case (i) its computations and outputs are causally influenced by the agent's beliefs, desires, and intentions, and (ii) their content semantically coheres with the content of such states.

What is meant here by "semantically coheres"? While Pylyshyn does not offer an analysis, he does elaborate on this notion in the following passage:

> We sometimes use the term "rational" in speaking of cognitive processes or cognitive influences. This term is meant to indicate that in characterizing such processes we need to refer to what the beliefs are about – to their semantics. The paradigm case of such a process is *inference,* where the semantic property *truth i*s preserved. But we also count various heuristic reasoning and decision-making strategies (e.g. satisficing, approximating, or even guessing) as rational because, however suboptimal they may be by some normative criterion, they do not transform representations in a semantically arbitrary way: they are in some sense at least quasi-logical. This is the essence of what we mean by cognitive penetration: it is an influence that is coherent or quasi-rational when the meaning of the representation is taken into account (365, fn. 3).

What is important is that the relationship between the relevant cognitive states and penetrated system's outputs not be arbitrary, but sensitive to semantic properties, such that by appeal to those properties the system's computations are seen as appropriate. I will adopt this picture as well.[3] As Pylyshyn notes, a paradigm relation of this type, in virtue of its truth-preserving nature, is that of inference. But, as he also points out, this is not the only type of relation that is semantically coherent or "quasi-rational". Dealing as we are with the relationship between the motor system and cognitive states pertaining to an agent's goals, the relation that is more relevant for us is the *means-end relation*, preserving as it does the semantic property of *satisfaction* between the means specified by the representational states of the motor system and the goals specified by cognitive states. So we can say that: Representation A semantically coheres with representation B if the content of A stands in a means-end relation to the content of B. For example, a motor representation with the content <reach forward> semantically coheres with the intention <drink from the glass in front me>, since it specifies a goal that serves as a means towards the satisfaction of the goal specified by the intention. I will also sometimes refer to the means-end character of this relationship as being, for this reason, "content-preserving".

On this characterization of cognitive penetrability, the motor system is cognitively penetrable iff its computations and outputs are causally sensitive in a means-end way to the semantic content of an agent's intentions, desires, and beliefs. But such a relation is instantiated whenever one performs a successful intentional action. So it seems that, as expected, we have a straightforward case for the cognitive penetration of the motor system. In the next section, however, I describe some empirical results that suggest that there are interesting limits to this penetration, and thus the porousness of cognition-action border, that call for an explanation.

3. Limits to the cognitive penetrability of the motor system

My aim in this section is to provide evidence for the claim that, in some cases, an agent's beliefs and intentions do not exert a semantically coherent causal influence on the processing and outputs of the motor system despite carrying information that is relevant for this processing. In order to get a better feel for what we are looking for, I will start with a study that may seem to provide evidence for this claim, but ultimately does not.

The study I have in mind was conducted by Pisella et al., who asked participants to perform a task that required them to track a moving target with a pointing gesture. On some trials (20% of them), the target would unexpectedly jump to the left or to the right. Pisella et al. (2000) were interested in testing the participants' ability to adjust or inhibit their pointing movement towards the target mid-reach on such trials. They split them up into two groups. In the "location-stop" group, participants were instructed to *interrupt* their ongoing movement in response to the target jump. In the "location-go" group, they were instructed to instead *correct* their movement in response to the target jump, i.e., to follow it to its new location.

Pisella et al. (2000) reasoned that if the participants in the "location-stop" group were strictly complying with the instructions they were given, they would either succeed in stopping their movement mid-reach, or fail to interrupt their movement. In the latter case, they would wind up pointing to the original location of the target, before it abruptly changed position. Instead, they found that, "a significant percentage of corrective movements occurred despite the 'stop' instruction in the location-stop group as well as in accordance with the 'correction' instruction in the location-go group" (730). In other words, there were those in the 'location-stop' group who made corrective movements despite intending to inhibit them. As the authors remark, "[a]fter touching the displaced target, subjects of the location-stop group were aware of their mistakes and spontaneously expressed strong frustration. Irrepressible motor corrections were thus driven toward the new target location" (ibid).

On the face of it, these results seem to offer us a case in which the processing and outputs of the motor system are not cognitively penetrated, i.e., are not causally influenced in a semantically coherent way by the inhibitory intentions of the participants in the location-stop group who made corrective movements. But this would be too quick. To see this, note that subjects (only 9% of them) made (intention-violating) corrective movements only when movement times were less than 300 ms, i.e., within extremely tight time frames. Otherwise, when their movements were of longer duration, they were able to successfully interrupt them in accordance with the instructions. This suggests that what these results reflect is simply a constraint on the time it takes for intentions to influence motor control processes, rather than any deeper reality about cognitive architecture and computation (for further discussion, see Shepherd and Mylopoulos 2021). It takes time to form an intention to interrupt an ongoing movement and for this intention to influence behaviour. But we are not here interested in failures of cognition to exert a causal influence on the motor system that are due to how long it takes neural signals to travel. We are interested in whether there is evidence for limitations to cognitive penetration due to computational or architectural constraints.

One promising place to look is empirical work that investigates sensorimotor adaptation, i.e., corrective behaviour in response to persistent movement error. Here various methods are used to introduce perturbations that alter the relationship between a movement and the resulting sensory feedback, so that the computational processes that the motor system deploys to adjust to these perturbations and calibrate its performance may be examined.

A popular paradigm involves the use of prism goggles (Held 1965; Fernandez-Ruiz and Diaz 1999; Redding, Rossetti, and Wallace 2005). When one wears prism goggles, visual feedback is displaced horizontally (or sometimes vertically) by a certain margin to the left or to the right. There are generally three phases in prism goggle experiments. In a pre-test phase, participants are asked to engage in a visuomotor task (e.g., throwing a ball at a target) to establish their baseline performance. In a second, testing phase, they are asked to put on the goggles and engage in the same task. And in a post-test phase, they perform the task without the goggles.

The typical pattern of results in such experiments is that in the testing phase, initially one makes errors (e.g., throwing the ball to the wrong location) due to the visual feedback displacement that results from wearing the goggles. But after about 10-15 trials, the movement errors gradually and incrementally start to be corrected, as one's motor system learns to adapt to and compensate for the changes in visual feedback. Once the goggles are removed in the post-test phase, an after-effect remains, such that one's movement trajectory still displays a compensatory shift opposite the prism deviation in attempting to hit the target. Notably, such after-effects are initially resistant to the adoption of explicit cognitive strategies, i.e., intentions, to compensate for them (Martin et al. 1996). The effect is only temporary, however, with performance eventually returning to baseline, i.e., what it was prior to the visual distortion and subsequent adaptation.

What is key for our purposes is the period in the post-test phase, after the goggles have been removed, during which the after-effect persists. Here we have a scenario in which it seems that, though the agent's intention is (say) to hit the target at some location x, and the agent believes that the target is located at x, the motor system yields outputs that are not sensitive to this intention or belief on several token performances. Importantly, this is not a case where there simply is not enough time for the agent's belief and intention to exert a causal influence on the motor system—the agent may take as much time as needed to throw the ball. What the case appears to reveal is some interesting limitation to the causal reach of one's beliefs and intentions under certain conditions.

Sensorimotor adaptation studies using mirror-reversal paradigms illustrate the same point. In such paradigms, visual feedback from reaching movement is left-right reversed. A recent study by Hadjiosif, Krakauer, and Haith (2021) had participants making center-out reaching movements towards a target with their hand occluded and a computer screen providing them with visual feedback from a cursor. During the baseline condition, the visual feedback reflected their movement trajectory, but in the mirror-reversal condition, it was flipped along the y-axis. Under this perturbation, if the participant moved their arm at an angle 30 degrees clockwise from the starting position, for instance, the cursor would move 30 degrees counter-clockwise. And if they moved their arm out at a 90 degree angle, the cursor would move in the opposite direction, at a 270 degree angle. Participants were told to ignore the cursor and try to move their arm to the target. When targets were placed along the mirroring axis, at 0 degrees and 180 degrees, the participants' reaching movements would drift away from the targets. Moreover, the drift was *amplified* from trial to trial rather than corrected and reduced. This continued during the "washout" condition, under which participants received no visual feedback, reflecting clear and strong aftereffects. These aftereffects decayed slowly and only completely disappeared after veridical visual feedback was restored. As the authors note, this gradual decay of aftereffects is a signature of adaptation on the part of the motor system (often referred to as "implicit adaptation").

On the basis of their results, Hadjiosif, Krakauer, and Haith remark that the "participants never became able to compensate for the perturbation" (2758). In a follow-up experiment, The authors probed this finding further, examining whether the participants could counter the perturbation using explicit strategies, i.e., forming intentions to re-aim their movements in such a way that they could hit the target. Participants in this group had identical training to those in the first group, except that they were told to bring the cursor through the target, rather than ignore it, as the first group had been instructed to do. Once again, the participants' movements exhibited drift relative to the y-axis targets, and aftereffects in the washout condition that were consistent with the amount of adaptation present in the late trials of the perturbation condition. Hadjiosif, Krakauer, and Haith (2021) conclude that this implicit adaptation "could not be countered by the explicit system during learning even though participants were allowed to adopt a strategy" (2753). This is consistent with a picture on which the motor system is not, under such conditions, cognitively penetrated by the agent's beliefs about where the target is located and their intention to bring the cursor through it.

Further support for this picture comes from yet another type of adaptation study, this time featuring visuomotor rotation, which employs distorted feedback to create a mismatch between expected and actual sensory feedback, typically during a reaching-to-target task. In a task of this sort, participants are seated in front of a computer monitor displaying a cursor at a start position and a target at 0 degrees with their hand occluded. They are asked to make straight out-and-back movements towards the target. After a baseline condition, a perturbation in the form of an angular rotation is introduced to the feedback from the cursor. For instance, the cursor's trajectory might appear rotated 45 degrees clockwise relative to the actual trajectory of the participant's arm. In such a set-up, the motor system adapts to the perturbation, compensating by adjusting movements in the direction opposite the perturbation (in this case counter-clockwise). As in the mirror-reversal paradigm, overall amount of adaptation is measured in a "washout" trial, where participants are asked to aim straight for the target without any visual feedback in order to observe the remaining aftereffects.

In a variant of this paradigm Mazzoni and Krakauer (2006) aimed to assess the effects of explicit cognitive control strategies (e.g., aim further to the left on this trial) and implicit adaptation on the part of the motor system that is not the result of such strategies. To do so, they informed participants of the perturbation and instructed them to adopt an explicit "cheating" strategy—that is, to form intentions—to counter the perturbation. This is achieved by placing facilitating targets at 45 degree angles from the proper target (Tp), such that if participants aim to hit those neighbouring targets (Tn), the cursor will hit the Tp, thus satisfying the primary task goal. Initially, reaching errors related to the Tp are almost completely eliminated. The cursor hits the Tp as a result of the explicit strategy to hit the Tn. But as participants continue with further trials, their movements *once again* start to drift *towards* the Tn and *away* from the Tp, despite their intention to hit it.

Importantly, Mazzoni & Krakauer note that upon questioning after the experiment, "subjects were unable to characterize the nature of their errors beyond an awareness that they made progressively larger errors to the desired target" (3644). Indeed, they were surprised by such errors. Furthermore, "subjects were unaware that they became increasingly accurate to T_n" (ibid) and their verbal reports indicated that "subjects were attending to the directional error around T_p and not around T_n" (ibid). This suggests that their explicit strategy was consistently to reduce errors around Tp, rather than Tn. When participants were instructed to stop using the strategy of aiming for the Tn (in order to hit the Tp) and return their aim to the Tp "[s]ubstantial and long-lasting" (Mazzoni & Krakauer 2006, 3643) aftereffects were observed, meaning the motor system persists in aiming to reduce the difference between the visual feedback and the earlier aimed for location.

Here once again there is a limit to the cognitive penetration of the motor system by an agent's belief and intention. The agent believes that the Tp is straight ahead, they have an intention to hit the Tp, but the motor system persists in directing arm movements towards the Tn. Of course, the motor system is still being guided by one of the agent's intentions, i.e., their proximal intention to reach for the Tn. But relative to the agent's intention to hit the Tp and their belief about the location of the Tp, the motor system fails to be causally influenced in a semantically coherent way.

Summarily, I have presented results from sensorimotor adaptation studies that, taken together, strongly suggest that distortions in visual feedback result in motor system processing and outputs that are not cognitively penetrated by relevant beliefs and intentions of an agent for a certain period. This is not due to the time it takes for beliefs or intentions to exert their influence on the motor system, since there is ample time in these cases. And it is not due to a failure on the agent's part to form the beliefs or intentions that are appropriate for producing the correct motor output, since participants are told explicitly to adopt such intentions and there is no reason to think that their beliefs (e.g., about the location of the target) are non-veridical. These results thus cry out for an explanation.

In the remainder of the paper, I offer one. In particular, I defend the view that though the motor system is cognitively penetrable, it is informationally encapsulated from central cognition. Fodor (1983, 71), identifies informational encapsulation as a main feature, or what he calls the "essence" of modules. If the view I present is correct, the motor system is thus modular along broadly Fodorian lines.[4]

4. Informational encapsulation vs. cognitive penetration

The aim of this section is to clearly distinguish between informational encapsulation and cognitive penetrability.[5]

Informational encapsulation concerns the *range* of information that is *available or accessible* to a module in computing the function that maps the inputs it receives to the outputs it yields. A system is informationally encapsulated to the degree that it lacks *access* to information stored in other modules or systems in the course of processing its inputs (Robbins 2009, Fodor 1983). Such systems are limited in such processing to representations in what Fodor calls their "proprietary database". Here is how Fodor (2001) suggests we think about them:

> Imagine a computational system with a proprietary… database. Imagine that this device operates to map its characteristic inputs onto its characteristic outputs… and that, in the course of doing so, its informational resources are restricted to what its proprietary database contains. That is, the system is "encapsulated" with respect to information that is not in its database. (63)

In other words, a system that is informationally encapsulated is such that, though it might take information from other systems as input, or make available information to other systems via its outputs, it cannot *compute over* information stored in other systems during the course of its processing. An informationally encapsulated system only has access to its inputs and its own store of information for computing, such as the grammar of a particular language that a language parsing module stores (Fodor 1984, 245-246), but not to information stored outside of this database (for another characterization of informational encapsulation along these same lines, see Quilty-Dunn 2020a, 337).

The notion of informational encapsulation must be understood relative to some other system or set of systems. Call a system that is informationally encapsulated relative to all other systems *strongly encapsulated*, and a system that is informationally encapsulated relative to some, but not all, other systems *weakly encapsulated*. I do not know whether any cognitive systems are strongly encapsulated. My claim here is restricted to weak encapsulation: I maintain that the best explanation of the results described in the previous section is that the motor system is weakly encapsulated relative to central cognition, but I do not claim that it is encapsulated relative to, e.g., perceptual systems. (There may be a case to be made for the strong encapsulation of the motor system that proceeds along the same lines that Clarke 2020 pursues in defense of the strong encapsulation of perceptual systems, but I leave examination of this issue for another time.)

The notions of informational encapsulation (relative to central cognition) and cognitive impenetrability are often used interchangeably. Some suppose that cognitive impenetrability refers simply to cases of informational encapsulation from central cognition. By contrast, I hold that informational encapsulation is *not* the same as, nor does it entail, cognitive impenetrability. A system might be such that its computations and outputs are causally influenced, in a semantically coherent way, by the contents of states of some system S—perhaps because it takes such states as inputs—but nonetheless not have access to states of S and their contents during the course of its computations. I take the motor system to be just such a system.

In sum: Cognitive impenetrability concerns the *causal reach and semantic influence* of semantic content carried by cognitive states with respect to the outputs of other systems. Informational encapsulation, on the other hand, concerns the *access* (both in terms of what is accessible and what is actually accessed) that a system has to information for computing a function that maps its input to its output. We can allow, as I do, that content carried by one's proximal intention gets propagated through the motor system in a way that results in the outputs of the motor system being causally influenced and semantically related to it in a coherent way. We can also allow that this is, at least in part, the result of proximal intentions being taken as *inputs* to the motor system. But this does not entail that in computing its function from these inputs to its outputs, the motor system *accesses or has access to* information stored in central cognition.

As will become even clearer in the remainder of the discussion, I take myself to be defending a version of what Burnston (2017a) describes (in the context of perception) as an 'external effect view' of the influence of cognition on motor control, according to which "cognition can and does exert diverse causal influences" (3636) on motor control "without affecting its computations", but instead by biasing which computational processes will occur.

In the next section, I present a model of action control that is consistent with this picture and the claim that the motor system is cognitively penetrable, yet informationally encapsulated, and helps to further clarify this distinction. I also explain how the model can account for the target results discussed in the previous section.

5. From Intention to Action Outcome: A Model of Action Control

The model of action control I present in this section is a direct descendant of the dynamic hierarchical model of intention proposed by Pacherie (2006, 2008) (see also Mylopoulos and Pacherie [2017], [2019]; Fridland [2019]). The core idea is that actions are controlled by way of hierarchically arranged goal representations and processes. The levels of the hierarchy are organised in a means-end structure, so that goal representations on a given level specify means of implementing the goal representations on the level(s) above them, if any. They are also hierarchical in terms of the degree of specificity of these representations. The further down the hierarchy one goes, the less abstract and more detailed are the action representations involved. Finally, the hierarchy is causally structured, with the representations on higher levels causally influencing those on lower levels.[6]

To get a feel for the model, it may help to consider the following vignette. Suppose I am out playing darts with a friend at a bar. While my friend takes their turn, I contemplate what my strategy should be for hitting the bullseye on my next turn. I am aware that I have had a beer to drink, and when I have had a beer to drink, my dart throws tend to skew slightly to the right. I decide to aim further to the left on my next turn in order to compensate for this bias. My turn arrives. I pick up my dart, position myself in front of the dartboard, and focus to the left of the bullseye. I decide to throw the dart. I grip it in the right spot, swing my arm back, then accelerate it forward, and release. Since this is my story, I hit the bullseye.

The action control model I present here accounts for key junctures in this vignette as follows. First, the outcome of my deliberation regarding strategy at the outset is a decision that results in a *distal intention* to aim further to the left than I normally would on my next turn. Distal intentions are intentions for the future. Among other things, they are terminators of practical reasoning about what to do, and sometimes initiators of practical reasoning about how to do it (Pacherie 2008; Bratman 1984). My distal intention marks the end of my deliberation process and sets a goal for me. Next, I perform actions in the service of that distal intention, i.e., picking up my dart, positioning myself, and focusing my attention just to the left of the bullseye. My decision to initiate my throw culminates in a proximal intention, i.e., an intention to do something now. The function of this intention is to structure action and aid in its initiation and guidance by way of coordination with the motor system, attentional processes, and multi-modal perceptual feedback (Mele 1992; Pacherie 2008; Fridland 2019).

Here I will also adopt the view that Mylopoulos & Pacherie (2017, 2019) defend, on which proximal intentions have as part of their content specialized action concepts. Some action concepts are formed on the basis of multiple observations of other agents performing instances of some action type. Thus, by watching enough gymnastics competitions, I may form concepts of backflips, cartwheels, handstands, and so on. These concepts help me to categorize and think about these various action types, whether or not I have ever performed them myself, or have the ability to perform them. They are *observational action concepts*. By contrast, the action concepts that are constituents of the content of proximal intentions are not acquired on the basis of observing others perform actions, but on the basis of performing those actions oneself. These are *executable action concepts*. If I do not know how to perform a cartwheel, or do a backflip, then I do not possess an executable action concept corresponding to either of these action types, though I may possess observational action concepts for them. In short: If I have an executable action concept of Φ-ing, then I know how or am able to Φ.

The reason that executable action concepts are linked to an agent's abilities is that they are linked to the motor system's processing, and in particular the information it computes over.[7] Some evidence for this comes from results that suggest a bidirectional link between the processing of linguistic concepts of action types and the activation of corresponding motor representations (e.g., reading action verbs like 'kick' activates areas of the motor cortex responsible for kicking). But how are EACs linked to the motor system? Though the literature is rife with proposals, no completely worked out account yet exists, and I will not attempt to provide one here, nor wade into the debate.[8] But a proposal recently put forth by Quilty-Dunn (2021) of how concepts work more generally is intriguing, and may serve to fill in this part of the model for our present discussion.

On Quilty-Dunn's (2021) view, concepts are *pointers* to representations stored in long term memory. In particular, they are atomic (non-structured) representations that contain addresses of memory locations where an array of informational structures corresponding to that concept are stored (Gallistel and King 2010). As Quilty-Dunn (2021) highlights, a pointer architecture such as this has the benefit that one can compute over a pointer without computing over the body of information to which it points. For instance, one can think the thought that <most dogs are friendly> without having to compute over all the informational structures associated with the concepts of DOG and FRIENDLY. Applied to proximal intentions, pointer EACs can enter into logical inferences, and be the products of practical reasoning, without one having to also take into account all of the information that they point to. My tentative suggestion here is that EACs point to, and thereby heavily bias the selection of, informational structures stored in long term memory that pertain to motoric processing.[9]

What exactly are these information structures? Following an influential theory in the motor control literature, we can view at least some of these structures as *motor schemas* (Schmidt 1975, 2003; Schmidt and Lee 2014). According to this theory, a schema is a "knowledge structure that can be instantiated in different ways depending on the values of its underlying variables or parameters" (Rosenbaum 2009, 103). More specifically, this view holds that a schema is a representation that stores information in long-term memory about the general form of an action type. It does so by representing its invariant features, i.e., those that remain the same—or with negligible differences—across several token performances of an action. These include such features as an action's spatiotemporal organization and sequence, as well as its being directed (or not) towards a target object. Thus, my proximal intention to throw the dart would point to, and thereby bias the selection of, a motor schema stored in LTM corresponding to the action type of throwing a dart. This schema would store information on the specific sequence of steps in terms of their spatiotemporal properties (e.g., swing arm back, accelerate it forward, release, etc.) as well as the type of object (i.e., the dart board) the action sequence is directed towards.

In addition to representing these invariant features, motor schemas also represent open *parameters*. These correspond to those features of an action type that vary across token performances of it. Filling in, or specifying, these parameters "online", during action execution, allows the action to be tailored to the agent's present context. In my case of throwing the dart, these parameters might correspond to features such as the location and distance of the dartboard, the force with which I throw the dart, the speed, the direction, and even which hand I use.

The initial setting and adjustment of these parameters as the movement unfolds is subserved by way of attentional processes as well as further stored mappings (sometimes referred to as 'recall' and 'recognition' schemas) of the relationships among initial conditions of the body and the agent's environment, parameter values, sensory feedback from resultant behaviour, and action outcomes. The filling in of values of the motor schema's parameters (what some might refer to as the 'control policy') given the features of the present context and this stored information results in the output of *motor commands*, which (when successful) cause the relevant action outcome, in this case, throwing the dart and hitting the bullseye.

Thus we have a hierarchical control structure that takes us—by virtue of causal pathways—from the input of distal intention to the formation of proximal intention and on to motor schemas, motor commands, and subsequent behaviour. Key for our purposes are the proximal intentions that have as their constituents EACs. These concepts serve as pointers to locations in long term memory where motor schemas (and their recall and recognition schemas) are stored. By way of filling in their open parameters with appropriate values, motor schemas are scaled to the present context with the help of current perception, attention, as well as stored recall and recognition schemas. This results in detailed motor commands being outputted in the final stage of computation, yielding corresponding action outcomes. The point to emphasize here is this: what this model describes is a way for semantic content to get propagated through the action production system—in a semantically coherent way—all the way to behaviour. When things are going well, the model indicates there will be cognitive penetration all the way through the system.

If the model is correct, in implementing the goals that are set by the agent's intentions, the motor system makes use of its own stores of information in its computations, as well as the deployment of attention and sensory feedback, but does not access information stored in central cognition (e.g., that the target is located straight ahead). Codified in the model is a view of the motor system as informationally encapsulated, despite being cognitively penetrable.

For a clear illustration of this main point, we can look more closely at the role of selective attention in propagating the content of intention in a way that causally influences the processing and output of the motor system—in particular the parameterization of motor schemas—but does not violate informational encapsulation. Across both philosophy and cognitive science, it is increasingly recognized that intentions exert causal influence on the motor system in part via the guidance or biasing of attention (Wu 2016, Fridland 2014; Hayhoe and Rothkopf 2011; Buehler 2019). As Wu (2016) articulates the point:

> … intentions influence attention. We do not attend willy-nilly, but attention is coordinated with intention. […] The idea is that in setting intention, one sets the weights that bias which selections are made in action […]. So, if one intends to act on X, then X is selected for action; if on Y, then Y is selected. This is part of intention's causal role, one that is driven by the content of intention (110).

The idea here is this: my intention to reach for, say, the milk carton in the fridge guides attention to prioritize and select perceptual information regarding the milk carton and its spatial location, as well as its action-relevant features (e.g., shape, size). This process makes available information about the milk carton in order for the motor system to program an appropriate reaching and grasping response directed towards it. Put in terms of our model, the object parameter of one's motor schema for reaching and grasping is filled in with information about the milk carton extracted with the help of selective attention.

What is especially important to note is that intention-guided attentional selection that prioritizes information in the perceiver's environment in a way that influences the motor system's computation from its inputs to its outputs is not a violation of informational encapsulation relative to central cognition. And this is because it is not a case of the motor system *accessing* information carried by the states of central cognition in the course of its computations. Instead, what the motor system accesses (in addition to stored motor schemas) is the *sensory* information prioritized and selected for by attention, e.g., the spatial location of the target object and its shape and size. But this is not a problem for the view I am proposing.[10]

On the model of action control with which we are working, intention biases the selection of motor schemas by way of executable action concepts deployed in its content. Consider the following line of reasoning against the view I am defending, presented by Wu (2013, 660):

> Intentions as stored plans constitute an action database. Is this database proprietary to the motor system or not? Assume that it is not: intentions are plausibly a database of plans proprietary to the practical reasoning (cognitive) system. Then the motor system is not informationally encapsulated from intention since motor computation is clearly sensitive to intention: which perceptual-motor computations are performed depends on what is intended. So, the motor system is not informationally encapsulated from the practical reasoning system.

My issue with this reasoning is precisely that it does not distinguish between cognitive penetration, which involves sensitivity to semantic content, and informational encapsulation, which concerns the information accessed during the course of computation. One cannot make a valid inference from the cognitive penetrability of a system relative to some other system, to its informational encapsulation from that system.

One might argue here that the motor system does access intention insofar as, on the model I have proposed, intentions are responsible for activating motor schemas stored in LTM, and these are part of the proprietary database of the motor system. But this form of top-down influence is not a case of the motor system accessing intention in a way that violates informational encapsulation. First off, it does not take place during the course of its computations. I have allowed that intentions are the inputs to the motor system, but what we are interested in is the nature of the computation that takes the motor system from its input to its outputs. And this does not involve access to states of central cognition, as the empirical results from Section 3 strongly suggest. Second, there is a difference between claiming that the only information the motor system has access to during the course of its computations is its proprietary database and claiming that only the motor system has access to its proprietary database.[11] I am only claiming the former here. We can allow that intentions access motor schemas by way of activating them using semantic pointers. But this does not entail a rejection of the claim that the only information the motor system accesses in its computations is from that database.

If the foregoing is correct, it suggests an important result, which is that the motor system is cognitively penetrable, but nonetheless informationally encapsulated, and thus modular in broadly Fodorian terms.

This is consistent with the model of action control presented in the previous section. On that model, proximal intentions causally influence the processing and outputs of the motor system in two ways: (i) via the pointer relation between EACs deployed in the content of proximal intention and appropriate motor schemas, and (ii) via the guidance of attention to help parameterize motor schemas. Neither of these ways constitutes the motor system's direct access to the content of intention via the course of its computations. The intention, via its EACs and attentional guidance, serves as *input that biases or shapes* the motor system's processing—it usefully constrains the information that it computes over (for an illuminating discussion of such biasing that I take to be consistent with the way I present it here, see Burnston 2017 and 2020). But it and other states of central cognition are not directly available to the motor system during the course of its computations as part of its proprietary store.

The model offered here makes available a tidy explanation for what happens in the sensorimotor adaptation studies, wherein the information the motor system uses to compute its outputs is systematically altered. In these cases, the stored mappings between parameter values, sensory feedback, and action outcomes that the motor system uses in its computations cannot be successfully used to fill in the parameters of the currently activated motor schema (they result in error), and must be recalibrated to adjust for the distortion in visual feedback. This the motor system eventually does through gradual and incremental recalibration. Once the distortion has been removed in the "washout" condition, a secondary recalibration must take place restoring the original mappings so that they can be used for appropriate computations.

Note that we can accept this conclusion while still maintaining that the adaptation and learning that the motor system exhibits is still strongly influenced by intention. Shepherd (2018) convincingly argues this point by appeal to a visuomotor adaptation study by Day et al. (2016), which suggests that the amount of implicit learning that the motor system exhibits in such settings is sensitive to where the participants intend to reach (or throw), and not (just) where visual feedback indicates they reach, or where they actually reach, which is presumably reflected in proprioceptive feedback. As Shepherd remarks, this suggests that "sensorimotor adaptation processes take on board elements of an intention's content in performing their characteristic functions" (2-13). The pressing question is then how to unpack this "taking on board", which I have attempted to answer in this discussion.

6. Conclusion

In this paper, I have presented a case for the modularity of the motor system. The case rests not on its cognitive impenetrability, but on its informational encapsulation. I hope this discussion to be of interest to those concerned with the mental architecture of the mind and the relationship between cognition and action. It may also be of interest to those involved in neighbouring debates regarding how to delineate the boundaries or borders between different cognitive systems. Recently, this has been a topic of much interest regarding the cognition-perception border (Burnston 2017a; Beck 2018; Green 2020; Mandelbaum 2018; Phillips 2019; Quilty-Dunn 2020b; Block forthcoming;). The same questions can be raised regarding the cognition-action border. If the view I have defended here is correct, we may have reason to adopt an architectural approach to drawing the cognition-action border, according to which there are constraints with respect to the range of information within cognition that can influence the motor system during the processing of its inputs becomes quite attractive (see, Green 2020, for a defense of this approach with respect to drawing the cognition-perception border). This is a question for another time, though (see Christensen 2020 for a rich discussion of it).

Acknowledgements

For valuable comments and feedback, I'm grateful to Denis Buehler, Sam Clarke, Thor Grünbaum, Elisabeth Pacherie, Joshua Shepherd, Hong Yu Wong, Wayne Wu, Laurenz Casser and participants at the MindWork – UT Austin session, as well as two anonymous referees.

This work is supported by funding from the Social Sciences and Humanities Research Council of Canada (Grant No. 430-2017-00811).

Notes

[1] Here I follow Butterfill (2007) in holding that at the heart of modularity is the idea that modules are computational systems, understood in the familiar way as those that yield outputs by performing content-respecting causal operations on mental symbols—and that this helps to explain core features of modularity, such as informational encapsulation and domain specificity.
[2] This is not to say that this question has gone completely unacknowledged. For instance, Christensen (2020) presents a model of action control that has important implications for the cognition-action interface and how to understand the modularity of the motor system. (I devote a separate discussion to Christensen's model in Mylopoulos ms). And even in *Modularity of Mind*, his classic essay that set the terms for this debate, Fodor (1983) writes: "It would please me if the kinds of arguments that I shall give for the modularity of input systems proved to have application to motor systems as well" (42). But Fodor goes on to say that he doesn't "propose to investigate that possibility here" (ibid).
[3] For discussion of other available interpretations of Pylyshyn's condition, see Stokes 2013.
[4] I will not make the case here, but I think that there is also good reason to view the motor system as possessing other key features of modularity that Fodor (1983) highlights, such as domain specificity, automaticity, and speed.
[5] I take what I say here to be very much in line with what some other theorists have proposed in the context of the cognitive penetration of perception. For instance, Burnston (2017a) draws a distinction between what he calls a "computational condition" and a "semantic coherence" condition on cognitive penetration. I use 'informational encapsulation' where the former is concerned, and 'cognitive penetration' where the latter is concerned. And Quilty-Dunn (2020a) characterizes informational encapsulation as a "formal, architectural" notion and cognitive penetration as a "semantic" notion, and holds, as I do, that "[c]ognitive penetration (qua semantic notion) thus does not entail a violation of encapsulation (qua formal notion)" (341). Finally, Clarke (2020) argues for a distinction between cognitive penetration and informational encapsulation on similar lines, and defends the view that cognitive penetration "need not have any straightforward bearing" on whether a system is informationally encapsulated.
[6] Note that this does not rule out reciprocal, feedback-based, connections across levels of the hierarchy. Sometimes a goal representation lower down in the hierarchy may ultimately lead to effects on goal representations at levels higher up. This does not take away from the top-down organization of the hierarchy in terms of levels of abstraction and means-end relations (cf. Uithol et al. 2012).
[7] Note that EACs in Mylopoulos and Pacherie's (2017) sense differ from Ferretti & Caiani's (2018) view of such concepts in that they deny that they are motorically formatted and realized in the same neural substrate as motor schemas.
[8] See, e.g., Butterfill & Sinigaglia 2014, Pacherie & Mylopoulos 2017, Burnston 2017b, Ferretti & Caiani 2018, Shepherd 2019, Fridland 2019, Christensen 2020.
[9] As a reviewer notes, it may be that sometimes distal intentions, too, deploy EACs in their content that point to motor schemas. For instance, if I intend to wash my windows next week, perhaps the relevant motor schemas for window-washing become activated in just the way they would if that EAC were deployed in the content of a proximal intention.
[10] I do not here need to take a stand on the heavily debated question of whether attentional effects constitute a violation of informational encapsulation of vision. (For proponents of this view, see, e.g., Mole 2015, Wu 2017. For a recent opponent, see Quilty-Dunn 2020a.) Even if it is true that they do, this does not entail a violation of the informational encapsulation of motoric processing relative to central cognition, which is the issue I am focused on.
[11] I thank Elisabeth Pacherie for helpful discussion of this point.

Bio Notes

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References

Balcetis, E., and D. Dunning. 2010. "Wishful Seeing: More Desired Objects Are Seen as Closer." *Psychological Science* 21:147–52.

Banerjee, P., P. Chatterjee, P., and J. Sinha, J. 2012. "Is it Light or Dark? Recalling Moral

Behavior Changes Perception of Brightness." *Psychological Science* 23:407–409.

Beck, J. 2018. "Marking the Perception-Cognition Boundary: The Criterion of Stimulus-Dependence." *Australasian Journal of Philosophy* 96 (2): 319-34.

Block, N. Forthcoming. *The Border between Seeing and Thinking*. Cambridge, MA: MIT Press.

Bratman, M. E. 1987. *Intention, Plans, and Practical Reason*. Cambridge, MA: Harvard University Press.

Buehler, D. 2019. "Flexible Occurrent Control." *Philosophical Studies* 176, 2119–2137.

Burnston, D. C. 2017a. "Cognitive Penetration and the Cognition-Perception Interface." *Synthese* 194 (9): 3645–68.

Burnston, D. C. 2017b. "Interface Problems in the Explanation of Action." *Philosophical Explorations* 20(2): 242-258.

Burnston, D. C. 2020. "Anti-Intellectualism for the Learning and Employment of Skill." *Review of Philosophy and Psychology* doi: https://doi.org/10.1007/s13164-020-00506-5

Butterfill, S. 2007. "What Are Modules and What Is Their Role in Development? *Mind and Language* 22 (4): 450-473.

Butterfill, S.A., and C. Sinigaglia, C. 2014. "Intention and Motor Representation in Purposive Action." *Philosophy and Phenomenological Research* 88 (1): 119-145.

Christensen, W. 2020. "The Skill of Translating Thought into Action: Framing The Problem." *Review of Philosophy and Psychology* doi: https://doi.org/10.1007/s13164-020-00517-2

Christensen, W., J. Sutton, and D. J. McIlwain. 2016. "Cognition in Skilled Action: Meshed Control and the Varieties of Skill Experience." *Mind and Language* 31 (1): 37–66.

Clarke, S. 2020. "Cognitive Penetration and Informational Encapsulation: Have We been Failing the Module?" *Philosophical Studies*. doi: https://doi.org/10.1007/s11098-020-01565-1

Day, K. A., R. T., Roemmich, J. A. Taylor, and A. J. Bastian. 2016. "Visuomotor Learning Generalizes Around the Intended Movement." *eNeuro* doi: https://doi.org/10.1523/eneuro.0005-16.2016.

Fernández-Ruiz J., and R. Díaz. 1999. "Prism Adaptation and Aftereffect: Specifying the Properties of a Procedural Memory System." *Learning and Memory* 6 (1): 47-53.

Ferretti, G., and S. Z. Caiani. 2018. "Solving the Interface Problem Without Translation: The Same Format Thesis." *Pacific Philosophical Quarterly* doi: 10.1111/papq.12243

Firestone, C., and B. J. Scholl. 2016. "Cognition Does Not Affect Perception: Evaluating the Evidence for "Top-Down" Effects." *Behavioral and Brain Sciences* 39: 1–72.

Fodor, J. 1983. *The Modularity of Mind: An Essay on Faculty Psychology*. Cambridge, MA: The MIT Press.

Fodor, J. 2001. *The Mind Doesn't Work That Way: The Scope and Limits of Computational Psychology*. Cambridge, MA: The MIT Press.

Frankfurt, H. 1978. "The Problem of Action." *American Philosophical Quarterly* 15 (2): 157-162.

Fridland, E. 2014. "They've Lost Control: Reflections on Skill." *Synthese* 91 (12): 2729–2750.

Fridland, E. 2017. "Skill and Motor Control: Intelligence All the Way Down." *Philosophical Studies* 174 (6): 1539-1560.

Fridland, E. 2019. "Intentions at the Interface." *Review of Philosophy and Psychology* doi: https://doi.org/10.1007/s13164-019-00452-x.

Gallistel, C. R., and A. P. King. 2010. *Memory and the Computational Brain: How Cognitive Science Will Transform Neuroscience*. Oxford, UK: Wiley-Blackwell.

Green, E. J. 2020. "The Perception-Cognition Border: A Case for Architectural Division." *Philosophical Review* 129 (3): 323-393.

Hadjiosif, A.M., J. W. Krakauer, and A. M. Haith. (2021). "Did We Get Sensorimotor Adaptation Wrong? Implicit Adaptation as Direct Policy Updating Rather than Forward-Model-Based Learning." *Journal of Neuroscience* 41 (12): 2747-2761.

Hansen, T., M. Olkkonen, S. Walter, and K. R. Gegenfurtner. 2006. "Memory Modulates Color Appearance." *Nature Neuroscience* 9(11):1367–68.

Hayhoe, M.M., and C.A. Rothkopf. 2011. "Vision in the Natural World." *Wiley Interdisciplinary Reviews: Cognitive Science* 2 (2): 158–66.

Held, R. 1965. "Plasticity in Sensory-Motor Systems." *Scientific American* 213 (5): 84-94.

James, W. 1890. *The Principles of Psychology* (Vol. I). New York: Holt.

Krakauer J. W. 2009. "Motor Learning and Consolidation: The Case of Visuomotor Rotation. *Advances in Experimental Medicine and Biology* 629: 405-21.

Levy, N. 2017. "Embodied Savoir-Faire: Knowledge-How Requires Motor Representations." *Synthese* 194 (2): 511- 530.

Martin, T.A., J.G. Keating, H.P. Goodkin, A.J. Bastian, and W. T. Thach. 1996. "Throwing While Looking Through Prisms. II. Specificity and Storage of Multiple Gaze-Throw Calibrations." *Brain* 119: 1199–1211.

Mazzoni, P., and J. W. Krakauer. 2006. "An Implicit Plan Overrides an Explicit Strategy During Visuomotor Adaptation." *The Journal of Neuroscience*, 26 (14): 3642- 3645.

MacPherson, F. 2012. "Cognitive Penetration of Colour Experience: Rethinking the Debate in Light of an Indirect Mechanism." *Philosophy and Phenomenological Research* 84 (1): 24-62.

Mandelbaum, E. 2018. "Seeing and Conceptualizing: Modularity and the Shallow Contents of Perception." *Philosophy and Phenomenological Research* 97(2), 267-283.

Mole, C. 2015. "Attention and Cognitive Penetration. In *The Cogniive Penetrability of Perception: New Philosophical Perspectives*, edited by J. Zeimbekis and A. Raftopoulos, 218–38. Oxford: Oxford University Press.

Mylopoulos, M. (ms). How to think about the cognition-action border: An architectural approach.

Mylopoulos, M., and E. Pacherie. 2017. "Intentions and Motor Representations: The Interface Challenge." *Review of Philosophy and Psychology* 8 (2): 317–336.

Mylopoulos, M., and E. Pacherie. 2019. "Intentions: The Dynamic Hierarchical Model Revisited." *Wiley Interdisciplinary Reviews: Cognitive Science* 10 (2): e1481.

Mylopoulos, M. (2020). The intelligence of motor control. In *The Routledge Handbook of Philosophy of Skill and Expertise*, edited by C. Pavese and E. Fridland, 258-268. New York: Routledge Press.

Pacherie, E. 2006. "Towards a Dynamic Theory of Intentions." In *Does consciousness cause behavior? An Investigation of the Nature of Volition*, edited by S. Pockett, W. P. Banks, & S. Gallagher, 145–167. Cambridge, MA: MIT Press.

Pacherie, E. 2008. "The Phenomenology of Action: A Conceptual Framework." *Cognition* 107, 179–217.

Pacherie, E. & Mylopoulos, M. 2020. "Beyond Automaticity: The Psychological Complexity of Skill". *Topoi* doi: https://doi.org/10.1007/s11245-020-09715-0

Pavese, C. 2019. "The Psychological Reality of Practical Representation." *Philosophical Psychology* 32(5): 784-821.

Phillips, B. 2019. "The Shifting Border between Perception and Cognition." *Noûs* 53 (2): 316-346.

Pisella, L., Gréa, H., Tilikete, C., Vighetto, A., Desmurget, M., Rode, G., Boisson, D., & Rossetti, Y. 2000. "An 'Automatic Pilot' for the Hand in Human Posterior Parietal Cortex: Toward Reinterpreting Optic Ataxia." *Nature Neuroscience* 3 (7): 729-736.

Quilty-Dunn, J. 2021. "Polysemy and Thought: Toward a Generative Theory of Concepts." *Mind and Language* 36 (1): 158-185.

Quilty-Dunn, J. 2020b. "Attention and Encapsulation." *Mind & Language* 35 (3): 335-349.

Quilty-Dunn, J. 2020b. "Perceptual Pluralism." *Noûs* 54(4): 807-838

Redding, G.M., Y. Rossetti, and B. Wallace. 2005. "Applications of Prism Adaptation: A Tutorial in Theory and Method." *Neuroscience and Biobehaviour Review* 29 (3): 431-44.

Rosenbaum, D. 2009. *Human Motor Control, Second Edition*. Imprint Academic Press.

Schmidt, R. A. 1975. "A Schema Theory of Discrete Motor Skill Learning." *Psychological Review* 82 (4), 225-260.

Schmidt, R. A. 2003. "Motor Schema Theory After 27 Years: Reflections and Implications For a New Theory." *Research Quarterly for Exercise and Sport* 74 (4): 366–375.

Schmidt, R., and T. Lee. 2014. *Motor Learning and Performance, 5th Edition. With Web Study Guide: From Principles to Application*, Champaign, IL: Human Kinetics.

Shepherd, J. 2018. "Intelligent Action Guidance and the Use of Mixed Representational Formats." *Synthese* doi: https://doi.org/10.1007/s11229-018-1892-7

Shepherd, J. 2019. "Skilled Action and the Double Life of Intention." *Philosophy and Phenomenological Research* 98(2): 286-305.

Shepherd, J., and M. Mylopoulos. 2021. "Unconscious Perception and Central Coordinating Agency." *Philosophical Studies* doi: https://doi.org/10.1007/s11098-021-01629-w

Stokes, D. 2013. "The Cognitive Penetration of Perception." *Philosophy Compass* 8: 646–663.

Wu, W. 2016. "Experts and Deviants: The Story of Agentive Control". *Philosophy and Phenomenological Research* 93(1): 101-126.

Wu, W. 2017. "Shaking Up the Mind's Ground Floor: The Cognitive Penetration of Visual Attention." *Journal of Philosophy* 114(1): 5–32.

Taylor, J.A. and R. B. Ivry. 2011. "Flexible Cognitive Strategies During Motor Learning." *PLoS Computational Biology* 7 (3): p.e1001096.

Uithol S., I. van Rooij, H. Bekkering H., and P. Haselager. 2012. "Hierarchies in Action and Motor Control." *Journal of Cognitive Neuroscience* 24(5): 1077-86.