SOLVING THE INTERFACE PROBLEM WITHOUT TRANSLATION: THE SAME FORMAT THESIS

BY

GABRIELE FERRETTI AND SILVANO ZIPOLI CAIANI

Abstract: In this article, we propose a new account concerning the interlock between intentions and motor representations (henceforth: MRs), showing that the interface problem is not as deep as previously proposed. Before discussing our view, in the first section we report the ideas developed in the literature by those who have tried to solve this puzzle before us. The article proceeds as follows. In Sections 2 and 3, we address the views by Butterfill and Sinigaglia, and Mylopoulos and Pacherie, respectively, and argue that both solutions entail a translation between representational formats, which both accounts aim to avoid. In Section 4, we present our brand-new claim, according to which intentions and MRs partially share the same motor format, inasmuch as executable action concepts are naturally represented in the agent's motor system together with the action's outcomes. Indeed, since intentions are constituted by executable action concepts and since there is evidence that action concepts are represented (and, thus, built) in the same motor format as action outcomes, the interlock between intentions and MRs no longer constitutes a problem. Then, in Section 5, we report empirical evidence in support of our claim, and before concluding, in Section 6 we briefly clarify our relations with two very recent accounts that criticized the proposals by Mylopoulos and Pacherie and Butterfill and Sinigaglia: Shepherd's and Burnston's. Finally, in Section 7, we offer some remarks about the philosophical idea defended here. The basic insight is that interface without translation is possible because action concepts are such stuff as MRs are made on.

1. *Introduction*

One of the most interesting issues in the contemporary philosophy of mind is determining how *intentions* relate to *motor representations* (henceforth:

Pacific Philosophical Quarterly •• (2018) ••–•• DOI: 10.1111/papq.12243

MRs). On the one hand, both intentions and MRs are mental components of action, on the other, they are built in different formats. Intentions are usually conceived as having a *propositional, sentence-like format* (e.g. Butterfill and Sinigaglia, 2014, p. 130; Bratman, 1989; Mele, 1992). For this reason, they can be featured as premises or consequences of a piece of practical reasoning. Differently, MRs are built in a *motor format* (e.g. Jeannerod, 2006; Butterfill and Sinigaglia, 2014). This is for a simple reason: MRs allow us to properly represent all the motor aspects of a specific action in a given motor situation. Only a motor format allows representing all the visuomotor, biomechanical and kinematic aspects of action that have to be satisfied in order to obtain the proper motor performance (Butterfill and Sinigaglia, 2014, p. 130; Jeannerod, 2006; Jacob and Jeannerod, 2003; Ferretti, 2016; Zipoli Caiani and Ferretti, 2017; Levy, 2017; Fridland, 2017). It is commonly assumed, indeed, that the propositional format of our intentions does not allow us to represent, with a high degree of specificity, such precise and fine-grained motor parameters that we need to specify for motor action to properly unfold (Butterfill and Sinigaglia, 2014; Shepherd, 2017; Burnston, 2017).

To this extent, standard accounts assume that a full explanation of the purposiveness of actions requires coordination between intentions and MRs, so that it is possible to proceed from the representation of the former to the representation of the latter (Bach, 1978; Searle, 1983, Mele, 1992, Pacherie, 2000; Shepherd, 2017, sect. 1; Burnston, 2017, sect. 2; Brozzo, 2017). However, the philosophical enterprise involved in offering such an explanation has to face a crucial issue: since intentions and MRs have different formats, it is not clear how we can explain the way in which they interlock. How can the motor format of MRs and the propositional format of intentions interlock? This question is at the basis of a crucial problem known as the *interface problem*, and has been recently addressed by prominent authors in the field of philosophy of mind (e.g. Butterfill and Sinigaglia, 2014; Mylopoulos and Pacherie, 2016; Shepherd, 2017; Burnston, 2017). The problem can be stated as follows:

> *Interface Problem*: how do intentions, which are built in a propositional format, and MRs, which have a motor format, interlock?

According to Butterfill and Sinigaglia (2014), one way to explain the relation – and, thus the interlocking – between intentions and MRs is by recognizing that while they have different formats, their contents interlock because the former can be partially determined by the latter. In particular, Butterfill and Sinigaglia (henceforth, B&S) propose that the interlock between intentions and MRs is explained by the fact that an intention can have constituents that refer to the action outcome by *deferring* to the MR of precisely this outcome, so the content of the intention and the content of MR may concern the motor outcome of the action (ibid., p. 120).

In a more recent paper, Mylopoulos and Pacherie (2016) (henceforth, M&P) argue that B&S do not solve the interface problem satisfactorily, and, according to their view, a full explanation of how intentions and MRs interlock should involve an appeal to *executable action concepts* and *motor schemas*. Notably, they propose that to interface with MRs, intentions must have *executable action concepts* as their constituents, and there must be *motor schemas* as the intermediary connections between the action concepts and the outcomes of the actions.

In this article, we propose a new account concerning the interlock between intentions and MRs, showing that the *interface problem* is not as deep as previously proposed. Before discussing our view, we report the ideas developed in the literature by those who have tried to solve this puzzle before us. The article proceeds as follows. In Sections 2 and 3, we address the views by B&S and M&P, respectively, and argue that both solutions entail a *translation* between representational formats, which both accounts aim to avoid. In Section 4, we present our brand-new claim, according to which intentions and MRs partially share the same motor format, inasmuch as executable action concepts are naturally represented in the agent's motor system together with the action's outcomes. Indeed, since intentions are constituted by *executable action concepts*[1] and since there is evidence that action concepts are represented (and, thus, built) in the same motor format as action outcomes, the interlock between intentions and MRs no longer constitutes a problem. Then, in Section 5, we report empirical evidence in support of our claim, and before concluding, in Section 6 we briefly clarify our relations with two very recent accounts that criticized the proposals by M&P and B&S: Shepherd's (2017) and Burnston's (2017). Finally, in Section 7, we offer some remarks about the philosophical idea defended here.

2. *The relation between intentions and motor representations*

A crucial suggestion by Butterfill and Sinigaglia (2014) is that there are *demonstrative concepts* which refer to actions by deferring to MRs; in addition, whereas intentions are constituted by these type of concepts, 'their contents are not necessarily logically independent' from the contents of MRs (Butterfill and Sinigaglia, 2014, p. 136). Instead, according to B&S, 'the contents of intentions can be partially determined by the contents of motor representations' (p. 119). This suggestion invokes a connection between intentions and MRs through a special link between demonstrative concepts and MRs so that, since intentions relate to MRs trough the *deferring function* of demonstrative concepts, the interface problem seems to be solved.

Interestingly, for B&S, the interaction between intentions and MRs is similar to the relation between two ways of representing the same route. One way may be constituted by a sentence and, therefore, is propositional, as in the case of the sentence 'follow that route'. The other way involves the use of a map and is thus cartographic (ibid., p. 133). The interlocking we can have between these two formats requires that the propositional sentence refers to the line on the map by means of the deferential function of the demonstrative phrase 'that route'. It is precisely because a demonstrative constituent of the proposition *defers* to its cartographic representation that comparing the phrasal description of the route with the map does not require translation between representational formats.

Something analogous holds concerning the coordination between intentions and MRs, since the former relate to the latter by virtue of the *deferential function* of the action concepts that constitute intentions. It is precisely because an intention deploys a demonstrative action concept that defers to a specific action outcome that it can interlock with the MR of such an outcome. Accordingly, the content of an intention, say 'do this action', would interlock with the motor representation of the related action outcome through the demonstrative locution 'this action'.[2] B&S are committed to two different theses, whose combination shapes their idea of interlocking:

> *Shared Content Thesis*: both intentions and MRs represent action outcomes.
>
> *Deference Thesis*: Intentions defer to MRs through *demonstrative concepts*.

Coupling these two theses, we have that intentions can have constituents, i.e. *demonstrative action concepts*, which refer to the action outcome by *deferring* to the MR of precisely this outcome so that the content of the intention and the content of the MR may concern the motor outcome of the action (ibid., p. 120).

Recently, M&P suggested that B&S faces four problems mainly related to the *Deference Thesis*: 1) there are no clear examples of demonstrative action concepts deferring to the MR of the action outcome, instead of deferring to the *mental image* of the relevant action (ibid., sect. 4.1); 2) there is no perceptual-attentional link from demonstratives to their referents, contrary to what is generally required by the demonstratives when used in utterances (ibid., sect. 4.2); 3) there is no way to explain errors in action execution if not by way of suggesting that errors depend on the fact that the demonstrative action concept defers to the wrong motor representation, but this is not clearly explained in B&S (ibid., sect. 4.3).

However, 'the most serious difficulty' (ibid., sect. 4.4) is that B&S presupposes a 'selection issue', which its authors were not able to explain. According to M&P, by demonstratively referring to something, an agent must have an 'independent grasp' of the appropriate item to be selected through such a referential process. In the case of the interlock between intentions and MRs, this means that a translation should be made to establish which motor representation is the suitable target of the deferential action concept that constitutes the intention. Indeed, if no translation is given, the motor reference of a demonstrative action concept, such as the 'that' contained in the intention of 'do that', remains undermined. Nevertheless, B&S's account is based on the fact that 'nothing at all is known about this hypothetical translation' (Butterfill and Sinigaglia, 2014, p. 133).

The solution proposed by M&P is to embrace an explanation of the problem posed by B&S that avoids the selection issue and 'does not require a translation process' (Mylopoulos and Pacherie, 2016, §5). This is possible by invoking the notion of *executable action concepts*, namely, the concepts of the movements that the agent can execute according to his/her own vocabulary of motor acts (Pacherie, 2011).[3] Notably, the executable concept of a certain action, say 'to grasp', is individuated by its relations to the representation of the motor outcome of the action related to grasping. The executability of such a class of action concepts depends on the availability of the relevant MRs, so much that they can be conceived as *functions* of the movements the agent is actually capable of executing (Pacherie, 2011, p. 69).[4]Executable action concepts are conceived as representations of types of movements that *guide the formation* of an intention, providing to the agent's intention to perform an action a constitutive relation to its motor outcome.

The possession of executable action concepts concerning an action entails that the subject has a motor schema for this type of action and allows us to explain how such motor schemas could be acquired (Mylopoulos and Pacherie, 2016, §5; see below §3). Moreover, according to M&P, executable action concepts are those that 'hook up with corresponding motor representations' (ibid.), so having an executable action concept entails having the ability to perform the action in question. However, the reader should note that, M&P offer a solution to the interface problem that follows B&S, inasmuch as M&P's account is based on the idea that intentions are composed of ('have as constituents') particular action concepts. In addition, M&P's proposal differs from the one by B&S in that M&P distinguishes between executable action concepts and demonstrative deferential concepts. Indeed, according to M&P, intentions interlock with motor representations, since intentions are composed of ('have as constituents') executable action concepts.

The solution outlined by M&P appeals to the notion of *motor schema* as an intermediate type of representation able to connect the two formats involved by the coordination of intentions and actions. Motor schemas are conceived as internal motor programs that represent the organization and structure common to a set of motor movements that are required to execute a certain pattern of action on a given occasion (Jeannerod, 1997). This motor program is defined in terms of a set of relevant parameters, such as those concerning the kinematic structure of the movement, its spatial configuration, its relative timing and its strength. When an agent is performing an action, parameter values adapt to the situation according to a system of rules that allow the agent to obtain the intended motor outcome on any given occasion. As M&P intend them, MRs that guide specific actions are nothing but instantiations of motor schemas whose parameter values are specified depending on sensory feedback.

The above reflections lead M&P to state that to have an executable action concept for a given type of action, one must have a motor schema for executing an action of that type. Indeed, since executable action concepts are conceived as *functions* of the movements the agent can execute (Pacherie, 2011), their mastery involves the representation of the related action outcomes, namely, the instantiation of a motor schema for that action. If not, that is, if executable action concepts were not accompanied by a corresponding motor schema, the agent would be unable to give course to the related action, so the executability of such concepts would be lost. It is precisely in light of this consideration that M&P assume motor schemas as mediators between the executable action concepts that are deployed in the contents of intentions and the representation of relevant motor outcomes. Therefore, M&S defend a particular thesis (Mylopoulos and Pacherie, 2016, §3):

> *Hooking-up Thesis*: to interface with MRs, intentions must have *executable action concepts* as their constituents, and there must be *motor schemas* as the intermediary connections between the action concepts and the outcomes of the actions.

In this way, MRs interlock with intentions because executable action concepts hook up with corresponding motor representations by hooking up with motor schemas.

Now, let us take stock. B&S tried to resist two temptations: first, to suppose that MRs, although significant for action execution, have no role in grounding the outcome-directedness of action and, second, to suppose that, where MRs represent action outcomes, they are intentions. B&S tried to resist these two temptations by showing that, first, MRs do represent action outcomes and, second, MRs are not built in a propositional format like intentions, although their contents bind with those of intentions (which have a propositional format). To do so, they defend the *Shared Content Thesis* and the *Deference Thesis*. By contrast, M&P suggest that the view by B&S is not reliable because the *Deference Thesis* involves a selection issue, which requires a criterion of translation between formats that is not available. Accordingly, M&P propose avoiding translation by suggesting that intentions are constituted by specific types of *executable action concepts* and that such types of concepts *hook up* with corresponding MRs by means of the motor schemas that specify the parameter values required to execute the relevant action in a given situation. This is what we called the

Hooking-up Thesis. In the next section, we offer a critical discussion of M&P, which will constitute the basis for our brand-new proposal.

3. Do motor schemas solve the interface problem?

Although we agree with M&P concerning the need to avoid a translation between intentions and MRs, we think that even the *Hooking-up Thesis* poses some problems. First, although it is suggested that executable action concepts are those that 'hook up' with corresponding MRs, is not clear how this 'hooking up' is realized. Second, although it is said that these concepts allow us to activate appropriate motor representations, it is unclear how this is possible without a translation.

The assumption that the executable action concepts 'hook up' with MRs falls short of being a possible explanation of how this 'hooking up' is possible. M&P explain the relation between MRs and executable action concepts by saying that it is a motor schema that 'bridges the gap between intentions and motor representations, ensuring proper content-preserving coordination without requiring any mysterious translation process' (2016). However, this is only a part of M&P's proposal to solve the interface problem. Indeed, the presence of a translation process lurks behind their thesis and is needed to explain the interlock. Since M&P assume that no translation is required for this hooking up, they should suggest why it is the case that the executable action concepts that constitute intentions are integrated with the action schemas that instantiate MRs. The need for such integration is not controversial.

To solve this issue, M&P suggest that the acquisition of motor schemas and the acquisition of executable action concepts share the same *Bayesian learning process*. According to the Bayesian learning approach, motor schemas are acquired through a process of 'probabilistic inductive generalization', that is, by learning regularities between initial conditions, action outcomes and motor parameter values. In the motor domain, this probabilistic inductive generalization is constrained by the presence of *motor primitives*, namely, a limited number of modules that can be combined to generate the available repertoire of actions (Wolpert *et al.*, 2011, Rizzolatti, *et al.* 1988). This set of motor primitives constrains the motor learning by making it easier to learn a motor schema for which the motor system has many primitives than one for which the motor system lacks the relevant primitives. Interestingly, M&P assume that a Bayesian generalization process allows the acquisition of the schemas that instantiate MRs, as well as the executable action concepts that constitute intentions. In other words, since to have an executable action concept is to have a motor schema for the relevant action, the gaining of the latter may be considered as a condition for the acquisition of the former.

The Bayesian framework is invoked because whereas M&P refer to evidence that action concepts and motor representations are indeed 'hooked up' (2016, sect. 3), they recognize that this evidence is not sufficient to understand how they 'get connected in the first place' (2016, sect. 5) and how the acquisition of action concepts works. The solution they propose is that motor schemas form a bridge between motor representations and the executable action concepts that are deployed in the contents of proximal intentions (§5). However, it should be noted that the Bayesian framework explains only the *bottom-up* process by which the acquisition of an executable action concept is always prompted by the acquisition of the relevant motor schema for action execution. Accordingly, the appeal to the notion of Bayesian learning says nothing about the *top-down* process that occurs when an executable action concept triggers a motor schema to give course to action execution.[5] There are two explanations for this.

First, there is no reason to assume that the coordination of executable action concepts and motor schemas is a one-to-one relation, such that for any executable action concept there should be only one action schema. On the contrary, one executable action concept may be related to different action schemas, giving rise to different types of actions. For instance, we can observe that the concept of 'to open' extends to very different actions, with different kinematics and goals, for example, in cases such as opening a window and opening a box. Notably, this type of variation, also known as 'vertical variation', can be observed in several executable action concepts, for example, in the cases of 'to put' ('to *put* the cap on the pen' / 'to *put* the pen down'), 'to turn' ('to *turn* his shirt collar up/ to *turn* the paper over'), and 'to roll' ('to *roll* the shirt sleeve/to *roll* a cigarette')[6] (e.g. Moneglia *et al.*, 2014). What is important to note is that all these actions are characterized by different motor structures, different motor constraints, and different goals; therefore, they cannot but belong to different action schemas.[7]

It is precisely the consideration of the variability that characterizes executable action concepts that leads M&P to encounter a problem. Indeed, although the same Bayesian learning process underlies both the acquisition of action schemas and the acquisition of executable action concepts, you cannot univocally proceed from the latter to the former. Since there is not a univocal path from executable action concepts to motor outputs, a *selection issue* occurs, so an independent grasp is needed to select which motor representation is the appropriate one for a given action concept. In other words, since action concepts present vertical variation, it is impossible to decide which motor representation hooks up with a specific concept, unless it relies on an external selection.[8]

The second reason the notion of Bayesian learning says nothing about how an executable action concept may trigger a motor schema is that the interface problem is mainly due to a difference in the formats of representations, and it is precisely this difference in format that makes an interlocking between intentions and MRs very problematic. Indeed, M&P do not really explain how and why there is no requirement of a translation process between executable action concepts and the instantiation of a MR. Although we are sympathetic with the idea that MRs are instantiated by systems of parameterized schemas whose values concern the kinematic structure of the movement, its spatial configuration, its relative timing and its strength, it remains unclear how this sort of representation can be elicited by the propositional format of an intention. In other words, M&P seem to leave unaltered the problem of how one may inferentially proceed from action planning to action execution, given that the constituents of intentions and the instantiations of MRs have different representational formats. It should be noted that our objection to M&P's proposal concerns the top-down direction related to actions execution, and not the bottom-up learning process related to concepts acquisition. Indeed, even if we accept that action concepts are learned by means of the Bayesian process described by M&P, it remains unclear how propositional intentions can prompt non-propositional motor representations since they have different representational format.

In summary, even the introduction of a Bayesian model fails to account for the original question underlying the *Interface Problem*. The major fault by M&P is that, while they suggest that there is no translation process, they do not suggest how intentions hook up with motor schemas through executable action concepts and, thus, how it is possible to really avoid translation. This is a problem for the *Hooking-up Thesis* and is very similar to the one they attribute to the *Deference Thesis* proposed by B&S (see §2). The result is that M&P do not really solve the interface problem.

4. Resisting a further temptation

In this article, we maintain the reliability of the *Shared Content Thesis*. We also partially agree with M&P's *Hooking-up Thesis* that intentions interlock with MRs through executable action concepts. However, with respect to these two proposals, we would like to push the line even further concerning the idea that there is no need for a translation because executable action concepts and MRs are deeply, motorically related.

Our proposal aims to explain the *interface problem* by offering an account that is not plagued by the same issues afflicting the views by B&S and M&P. Accordingly, we consider a third crucial temptation not addressed by the previous proposals, namely, the temptation to assume that although MRs interlock with action concepts through the content related to the action outcome, MRs and action concepts do not interlock through their format. This article resists this temptation by showing that MRs and action concepts *mainly* interlock through their *format*, although it is maintained that they also interlock through their content (*Shared Content Thesis*). This suggests a further and more crucial way in which intentions and MRs may interlock through executable action concepts, providing an extension of the idea by M&P.

This notion is able to really explain *how* MRs and intentions interlock through action concepts, without the need for a translation process – something that cannot be obtained by B&S' *Deference Thesis* or by M&P's *Hooking-up Thesis*. Indeed, the fact that interlocking is realized through format really suggests a direct route from intentions to motor representations through action concepts. The presence of this direct route based on the format allows us to solve the interface problem without invoking any translation process.

Hence, we will show that there is no need to assume a difference in format between executable action concepts and MRs. This is the reason that, though it is maintained that intentions and MRs differ in format, this difference is bypassed through the presence of executable action concepts, which share the same motor format that characterizes MRs. This implies also that we do not need to invoke motor schemas as mediators between intentions and actions, something proposed by M&P's *Hooking-up thesis*, which presents serious problems of translation (see the previous section). Executable action concepts are indeed directly mapped on the instantiation of MRs and share with them a motor format. However, we recognize that motor schemas are crucial for the ontogenetic development of MRs (Jeannerod, 2006). Indeed, executable action concepts not only have a motor content shared with the representations built by the activity of the motor system but also share a motor format due to the proper parameters and values of the pragmatic context of the action motorically computed.[9]

Therefore, here is the claim of the article: intentions and motor representations interlock through action concepts. The argument that supports this claim is that the representation of action concepts shares – or is characterized by – the same representational format that characterizes a MR. This format is the non-propositional motor format used when we think about action through an intention and during covert or overt action performance. In other words, action concepts are the *motor mediators* between intentions and MRs since they are represented in terms of the motor representation of the relevant action outcome. We can summarize this idea through the thesis we defend:

> *Same Format Thesis*: intentions and motor representations interlock through action concepts because the representations of action concepts have the same representational, non-propositional, and motor format that MRs have.

Like the *Hooking-up Thesis* and the *Reference Thesis,* the *Same Format Thesis* holds that action concepts are crucial for MRs and intentions to interlock. Like them, the *Same Format Thesis* suggests that there is no need for a translation process. Unlike them, the *Same Format Thesis* is able to suggest why we do not need this translation process in a way that the other two theses cannot.[10]

The argument in support of the *Same Format Thesis* is based on the empirical evidence that action concepts and MRs share neural correlates, whose recruitment is crucially involved both when we think in motor terms with action concepts and when we plan or perform actions through motor representations. The activity of these neural correlates gives rise to representations that are built in a motor format. Accordingly, since action concepts and MRs share similar neural realizers, they also share the representational format of the activity subserved by these neural realizers, which is a motor one. At this point, a solution to the interface problem seems to be at hand: since action concepts and motor outcomes share the same sensorimotor representational format and since concepts figure as constituents of the intentions to act, the issue of how intentions interlock with motor representations is no longer a problem. This claim is stronger with respect to the proposal by B&S. We are saying not just that MRs and intentions share action outcomes, but also that MRs and action concepts have the same representational format. This avoids the translation process, which is still present if we invoke a relation between MRs and intentions concerning only the content, not the format.

The argument relies on three types of evidence: (1) behavioral evidence showing that the processing related to action concepts interacts with and is strictly bound to the motor processing underlying action execution; (2) neurobiological evidence showing that the processing related to action concepts recruits the same pre-motor areas as action planning; and (3) evidence showing that the activation of the motor system during action concepts processing is functional for the semantic processing of a motor intention.

This argument suggests a direct motor route from executable action concepts to MRs without the need of any translation process and without the need to explain how action concepts may select one motor schema instead of another. Thus, this article will show that the *Same Format Thesis* can solve the interface problem in a way that both M&P and B&S fail to recognize.

5. *How intentions and motor representations interlock: the sensorimotor format of action concepts*

Here we report evidence that executable action concepts and MRs share similar neural correlates. This evidence will support our argument that the representation of action concepts has the same representational format that characterizes a MR. In turn, this argument will be the basis for the claim that intentions and motor representations interlock through action concepts.

First, the idea that cognition relies on the sensorimotor system is currently popular under the name 'grounded cognition' (Barsalou, 2008). According to this view, different levels of cognition, from perception to semantic processing, share the same neural substrate, all being implemented by the sensorimotor circuitries of the brain. Grounded cognition states that cognitive representations are not amodal vehicles that exist only independently of the brain's sensory and motor systems, as classically stated. Rather, cognitive representations are deeply grounded in the agent's perceptual and action systems, whereby low and higher levels of cognition end up being deeply entrenched with the agent's bodily features and possibilities of interaction. On this account, sensory and motor information acquired during real-world experience is reactivated for the sake of later conceptual processing (Barsalou, 1999; Glenberg and Kaschak, 2002; Decety and Grèzes, 2006). This means that the concepts corresponding to human motor actions and to action-related objects may be represented in areas of the brain specialized for planning and executing motor actions.

This latter aspect of grounded cognition is of prominent importance for the point at stake here. It is generally agreed, indeed, that the possession of action concepts is associated with the ability to inferentially proceed from action planning to action execution. It is precisely because intentions are constituted by concepts that they can be subject to rationality constraints and that we can judge a certain action as consistent with an intentional action plan (see, for example, Bratman, 1999; Pacherie, 2008; Searle, 1983) Hence, action concepts figure as *mediators* between propositional states, such as the agent's beliefs and desires underlying intentional action plans, and the MRs that are immediately antecedent to action execution. However, as already illustrated (§1), here is where the 'interface problem' pops out.

Since beliefs and desires are built in a propositional format, whereas the representations of motor outcomes have a different *pragmatic format*, their inferential interlock has been considered impossible through their formats, and possible only through their contents. However, neither B&S nor M&P really explains why there is no requirement of a translation between intentions and MRs (see Sections 3 and 4, respectively). They also cannot explain what really binds MRs and intentions. As a result, there are only two options available: either we show that there is a translation process – and explain the nature of such a process – or we show that executable action concepts that constitute intentions and MRs share a common motor format, and therefore that no translation is required. Notably, since the common fault of B&S and M&P is that, while they suggest that there is no translation process, they are not able to suggest how MRs are 'hooked up' by action concepts, they do not really avoid the *Interface Problem* or the *Selection Issue*. Our account follows the second option and avoids these problems by showing the direct link between intentions and MRs through action concepts that are, thanks to their shared motor format with MRs, the motor mediators between intentions and their MRs.

In light of this issue, there is today increasing interest in understanding the nature of the action concepts mediating between propositional intentions and motor representations (e.g. Fridland, 2016; Levy, 2017; Zipoli Caiani and Ferretti, 2017). To solve the interface problem, we propose that, while intentions are built in a propositional format, they can have, as constituents, action concepts that are endowed with a pragmatic nature. Since action concepts are built in a pragmatic, motor format, they can serve as a bridge between high-level cognition – mediated by the propositional attitudes that shape our intentions – and motor behavior – mediated by the MRs that shape our motor planning and execution. In other words, the challenge here is to show that the representation of action concepts has, *contra* the classical view, a pragmatic motor format. Thus, they can be motor mediators between intentions and MRs without involving a translation process, as proposed by B&S. This also suggests the presence of a direct motor route from intentions to MRs, which M&P aim but nonetheless fails to take into account.

Among the first and most influential scholars to argue that action concepts have the same pragmatic format as action outcomes, Gallese and Lakoff (2005) suggested that the sensorimotor system performs a functional role in the processing of *action concepts*. Such a functional role of the motor system can be characterized in two different ways: first, the sensorimotor system shapes the *semantic content* of action concepts in terms of the way we motorically interact with the environment and, second, it provides a *sensorimotor structure* to the information conveyed by this class of concepts.

Accordingly, the information encoded by action verbs during action planning and the information conveyed by the motor representations of action goals must share a common sensorimotor format. In other words, grounding the processing of action concepts in the sensorimotor system implies that any action concept that partially constitutes an intention to execute an action is represented with the same *sensorimotor format* that encodes the motor representation of the related action.

Now, in order to argue that MRs and action concepts may interlock through their common *format*, we provide, *step by step*, three types of evidence. First, we show that the representation of action concepts and the representation of motor outcomes, performed by motor representations, share the same substrate. This will be the first evidence supporting the hypothesis that they come from the same neural computational matrix. This hypothesis can be further supported by combining evidence showing that processing action concepts may interfere with planning or executing motor actions and that planning and executing motor actions may affect action concepts understanding. Second, we argue that action concepts are grounded in the sensorimotor system depending on the mode of execution that is proper for the type of action to which they relate. This suggests how the semantic variability of verbal instructions (e.g. grasping the glass or grasping the pen) is made possible by the different action purposes that are encoded by the intention. Third, we argue that the somatotopic activity of the motor system is a constitutive part of action concept representation. This can be done by showing that the inhibition or the arousal of somatotopic areas of the motor system induces consequences not only for action execution but also for the processing of action concepts. The following sections will be devoted to discussing such evidence.

5.1. THE PROCESSING OF ACTION CONCEPTS SHAPES ACTION EXECUTION AND VICE VERSA

The contribution of the sensorimotor system to the processing of action concepts has been under the spotlight of experimental research for almost twenty years. The aim of this section is listing a series of relevant pieces of evidence showing that conceptual processing and action execution are not independent tasks. More precisely, there is evidence that action concepts processing modulates the execution of action, and that an impairment in the motor system has functional consequences on action concepts processing abilities. In light of this, §5.2 will show that there is evidence supporting the hypothesis according to which action concepts processing and action execution share the same neural correlates.

Recently, an increasing number of articles have been published showing that performing categorization tasks concerning the use of action verbs such as grasping, pushing, and kicking, has an influence on the actual motor execution of the related actions. The importance of this type of evidence relies on the fact that they provide support to the hypothesis that action concept understanding is grounded in the functioning of the sensorimotor system by means of their common representational format.

Among the most interesting strategies adopted to support the idea that concepts processing can be grounded in the functioning of the sensorimotor apparatus there are those concerning the relation between language understanding and action execution. A paradigmatic piece of evidence of this sort is provided by Gentilucci and Gangitano (1998). Here the influence of categorization tasks on visuo-motor activity is measured by means of different kinematic components of actions consisting of reaching for and grasping a rod on whose side words such as ‘long’ or ‘short’ are printed independently of their actual size and distance from the observer. The results revealed that the peak acceleration, peak velocity, and peak deceleration of the arm were higher for actions performed on rods marked with the word ‘long’, rather than on rods marked with the word ‘short’. This result supports the hypothesis that during the initial phase of movement, subjects spontaneously categorize rods associating the meaning of words depicted on them with the distance to be covered to reach them, starting the related motor program for farther or nearer object positions.

This finding is further confirmed in another now classical experiment (Gentilucci *et al.*, 2000), as well as in the experiments performed by Glover *et al.* (2004). In the latter case, scholars employed words indirectly related to the size of the target object, such as 'apple' for a prototypically large object, or 'grape' as a prototypically small object. The authors observed the occurrence of an *interference effect* in the early phase of the grasping movements due to the concomitant processing of words printed on the objects. More precisely, the induced categorization of the target as a paradigmatically large object led the agent to adopt a larger grip aperture than that used when the agent was induced to categorize the target as a small object (see also Glover and Dixon, 2002).

More direct evidence that the processing of action concepts modulates action execution is offered by Boulenger *et al.* (2006). The authors provided accurate behavioral measurements revealing the presence of a priming effect on action execution due to categorization tasks. In this case, subjects were asked to perform a reaching action concurrently or successively to lexical decision tasks concerning action verbs (e.g. to paint, to jump, and to cry) or nouns of concrete entities that cannot be manipulated (e.g. star, cliff, and meadow). The analyses of the movement parameters revealed that within 200 ms after onset, wrist acceleration peaks appeared significantly later and were smaller following the display of action verbs than during displays of the nouns of non-manipulable objects. Thus, since a wrist acceleration peak is indicative of initial muscular contractions, the measurement of longer latency and smaller amplitude suggests that processing action concepts interferes with the execution of the movement itself (see also Nazir *et al.*, 2008). In the same vein, Scorolli and Borghi (2007) and Borghi and Scorolli (2009) have convincingly shown that the presentation of nouns and verbs pairs concerning foot and hand actions modulate, respectively, the reaction times of hand and foot responses. More recently, Andres *et al.* (2015) provided evidence of the verb-effector compatibility effect, showing the interference between action concept processing and the use of compatible effectors. Moreover, Klepp *et al.* (2017) have shown that the semantic processing of high effector-specific movement verbs in German language, such as *rubbeln* (to rub) or *springen* (to jump), induces a body-parts specific facilitation effect.

Interestingly, there are behavioral results that clearly support the view that the motor apparatus is functionally involved in the processing of action concepts. For example, Fernandino *et al.* (2013a) assessed whether the disorder of the motor system that characterizes patients suffering from Parkinson Disease is associated with specific impairments in the processing of action-related sentences. Results showed that Parkinson Disease patients exhibited significantly longer reaction times when processing action-related sentences that contain action concepts, if compared to control subjects. It should be noted that, the task of the experiment relied exclusively on conceptual processing in that it did not involve pictures or video clips, and do not require to perform mental imagery. Accordingly, this pattern of evidence provides support to the claim that the motor system plays a functional role in the processing of action concepts (see also, Fernandino *et al.*, 2013b; Desai *et al.*, 2015; Bidet-Ildei *et al.*, 2017).[11]

Previous evidence supports the hypothesis that the processing of action concepts primes action preparation and execution. Nevertheless, since we assume that the processing of action concepts and the planning and execution of motor actions share the same motor resources, we expect that a priming effect also occurs in the reverse direction. This means that the execution of motor actions should interfere with the processing of the related action concepts.

Interestingly, evidence supporting this view has flourished in recent years. For example, in a classical study by Lindemann *et al.* (2006), participants were asked to make lexical decisions concerning action-related words or pseudo-words in a go/no-go task paradigm (i.e. valid word 'go' and pseudo-word 'no-go') after having prepared for a specific action that they execute only after word presentation. The results show that the response latencies were reduced if the action-related concepts expressed by the words were consistent with the previously prepared action (see also Rueschemeyer *et al.*, 2010). Moreover, van Elk *et al.* (2008) investigated the influence of motor preparation on the time course of action-related concepts comprehension, showing the presence of a facilitation effect. In the latter case, subjects were asked to prepare a meaningful action involving a target object (e.g. bringing the cup to the mouth) or a meaningless action involving the same target (e.g. bringing the cup to the eye). Then, a word meaning an action that could be either congruent or incongruent with the goal of the prepared action was presented on the screen. Participants were then required to decide whether the word described either a body part or an animal. Interestingly, the results revealed that subjects were faster responding to words for action-related body parts compared to words referring to animals (see also van Dam *et al.*, 2012).

Since the sensorimotor system plays a role in understanding the action concepts, the plasticity of the motor system should affect the processing of concepts. According to this hypothesis, the acquisition of novel motor behaviors should improve the agent's ability to recognize and classify different types of actions, even in the absence of learning processes based on probabilistic inductive generalizations (Section 3). Casile and Giese (2006) tested this prediction assessing the visual recognition of gait patterns before and after a subject was trained to learn a novel coordinated movement. The authors observed a selective improvement of the visual recognition for the learned action movement and a correlation between the levels of such improvement and the accuracy in the execution of the learned motor pattern. In accordance with this result, there is evidence that training subjects to perform new manual actions improve the processing of the related action categories. For example, Locatelli, Gatti and Tettamanti (2012) trained participants to learn new manual actions and measured their performance on a semantic judgment task after and before the motor training. The results showed that the reaction times significantly decreased after the motor training, indicating an improvement of the comprehension performance (see also Glenberg, Sato and Cattaneo, 2008).

Interestingly, from a philosophical point of view, the fact that the improvement of action categorization abilities depends on the improvement of the related action skills can be explained by means of the assumption that action categories and motor schemas share the same representational substrate. Indeed, it is because action-related concepts directly map on the representation of motor outputs that the enhancement of the agent's motor skills results in the improvement of his or her categorization ability. If executable action concepts and action schemas were encoded by different representational occurrences, there would be no reason to expect a correlation between action enhancement and semantic competences.[12]

To sum up, an explanation of the previously introduced set of behavioral evidence is obtained by assuming that both the semantic information of action concepts and the pragmatic information involved in action execution are mapped together, namely, on the same representational substrate. Indeed, it is because the representation of action concepts and the representation of motor outcomes share the same neural computational matrix that action concepts processing primes action execution and *vice versa*. Moreover, in order to strengthen our hypothesis, the following two sections provide evidence that action concepts processing and MRs not only share the same neural resources, but also that they are *somatotopically* and *functionally* related.

5.2. THE PROCESSING OF ACTION CONCEPTS SOMATOTOPICALLY ACTIVATES THE MOTOR SYSTEM

In the previous paragraphs, we showed that processing action concepts and executing motor actions are not two reciprocally independent cognitive tasks, inasmuch as they affect each other. This mutual influence can be read as evidence that the representations of action concepts and action outcomes share a common substrate. However, since our aim is to argue that action concepts are represented in the same format as motor goals (see Section 1), evidence concerning the actual role of the motor system in conceptual use and understanding is still required. Indeed, showing that using and understanding action concepts involve the activation of the motor system provides evidence for the fact that processing action concepts may involve motor information. This eventually opens the door to a subsequent analysis aiming at showing the functional role of motor information in the processing of action concepts (see §5.3).

The relationship between concept processing and sensorimotor processing is a central topic in cognitive neuroscience. According to the grounded cognition hypothesis, the semantic understanding of action concepts is represented, at least partially, in the sensorimotor system (Barsalou, 2008; Kemmerer and Gonzalez-Castillo, 2010; Martin, 2007; Pulvermüller, 2005). In accordance with this framework, several studies investigated the involvement of the motor system during the comprehension of verbs, phrases, or sentences concerning motor actions. Importantly, the well-established somatotopic organization of the human motor system has allowed for great specificity in testing the above hypotheses, providing information on how action concept representations overlap with the neural substrates for performing an action (Coello and Fischer, 2015).

Interestingly, a large number of empirical investigations has shown a systematic correlation between action concepts processing and the activation of the motor areas semantically related to such concepts (Coello and Fischer, 2015; Desai *et al.*, 2010; Desai *et al.*, 2013; Kemmerer *et al.*, 2008). At the core of this view is the evidence that motor system activation during action verbs processing is somatotopically organized, so that the processing of different action concepts functionally activate the specific motor areas involved in the execution of the related actions.

Famously, Hauk *et al.* (2004) found that passive reading of hand, foot, and mouth action verbs (e.g. to pick, to kick, and to lick) activates ventral face/mouth, lateral arm/hand, and dorsal leg/foot motor regions, respectively (see also, Boulenger, Hauk and Pulvermuller, 2009; Boulenger, Shtyrov and Pulvermüller, 2012; van Elk *et al.*, 2010). While Tettamanti *et al.* (2005) showed that the same somatotopic organization is also preserved in sentence processing. Fargier *et al.* (2012) found that subjects who have learned new action-related words show a neurophysiological sign in the motor cortex activity (suppressions of μ rhythm activity, which is related to the patterns of electrical activity involving neurons in the part of the brain that controls voluntary movement) precisely for the processing of these words after learning, whereas no such effect was seen for words concerning objects.

Furthermore, Wu *et al.* (2013), showed that this somatotopic organization of action concept representation concerns the common way agents use and understand action categories in different languages and cultures. In this experiment, processing Chinese action verbs elicited similar somatotopic representations in the motor and premotor cortex as already established for alphabetic scripts. Notably, the processing of Chinese verbs elicited a pattern of activation in the motor and premotor cortex, such that leg verbs elicited the largest activation in the dorsal leg region, whereas mouth verbs elicited the largest activation in the ventral mouth region. In line with this view, somatotopic mappings of action concepts have also been reported for sentences and verbs, in French, Italian, German, and Finnish (Pulvermüller, 2013). Recently, in accordance with previous behavioral evidence, somatotopic activation in the sensorimotor system has also been found for concepts related to objects that afford hand and mouth movements, such as 'fork', which activates hand motor regions, and food words, such as 'bread', activating face motor regions (Carota, Moseley and Pulvermüller, 2012).

Remarkably, the location and the strength of activity in the sensorimotor system vary according to different variables associated with the word meaning. For example, the activation of the motor system due to the processing of an action concept can be lateralized depending on the way the related action is usually executed (mono-manual versus bi-manual actions, see Hauk, 2011). Additionally, it has been suggested that the agent's hand preference and his or her motor ability modulate the activations in the motor system induced by semantic processing (Beilock *et al.*, 2008).

In accordance with previously introduced behavioral evidence (e.g. Casile and Giese 2006; Locatelli, Gatti and Tettamanti, 2012), several studies have shown that the acquisition of new motor experience can facilitate action concept understanding by enhancing the actual involvement of the brain motor regions in intentional planning. For example, Beilock *et al.* (2008) investigated how motor expertise modulates brain activity during action concept understanding. In this experiment, ice hockey players with strong experience in playing and observing hockey games, together with a group of novices, were scanned when listening to a series of sentences concerning hockey actions. The results showed that subjects with hockey experience were facilitated in the comprehension of hockey sentences by increasing the activity in the left dorsal premotor cortex and decreasing the activity in bilateral sensorimotor cortex (Lyons *et al.*, 2010). More recently, Tomasino *et al.* (2013) compared the functional neuroimaging data of expert volleyball players and novice individuals who were presented with a series of sentences describing possible technical volleyball-specific motor acts. Even in this case, the authors found that the somatotopic activity within the sensorimotor areas induced by action concept processing was a function of the action feasibility and agent's expertise.

This section has shown that action concepts are grounded in the sensorimotor system depending *on the mode of execution* that is proper for the type of action to which they relate. Thus, it is the case that semantic variability of verbal instructions (e.g. grasping the glass or grasping the pen) is made possible by the different action purposes that are encoded by the intention. We can now move to the third empirical point in support of our argument.

5.3. THE REPRESENTATION OF ACTION CONCEPTS IS PART OF THE ACTIVITY OF THE MOTOR SYSTEM

In the previous section, we showed that action concepts are somatotopically represented in the agent's motor system according to the related type of action, as well as the way in which and the proficiency with which it is executed. However, the activation of a brain area could be a simple collateral consequence of the task at hand and does not guarantee that this area is functionally involved in the performance. Importantly, since we argue that action concept representations and action outcome representations interact because they share a common motor substrate and format, it is relevant that their representational overlapping over the motor system also has functional consequences. It is therefore essential to confirm that the role of the motor system has actual relevance in action concept processing, or whether it is a mere epiphenomenal effect (Leshinskaya and Caramazza, 2014; Mahon and Caramazza, 2008). The transcranial magnetic stimulation technique (TMS) provides evidence of a functional link between the activity in a cortical area and the execution of a certain task, making it possible to test the consequences of either the stimulation or the inhibition of such an area on the action performance.

Within this methodological framework, Buccino *et al.* (2005) used single pulse TMS addressing the hand motor area to assess whether listening to action-related sentences modulates the activity of the motor system. The results showed that motor evoked potentials (MEPs) recorded from hand muscles were specifically modulated by listening to sentences concerning hand-related actions, whereas MEPs recorded from foot muscles were modulated by listening to sentences concerning foot-related actions. Moreover, Pulvermüller *et al.* (2005) used a single pulse TMS to assess the role of the motor system in action concept recognition. Even in this case, the results confirmed that when the stimulus was addressed to the somatotopic hand area, reaction times were lower for hand-related action words compared to leg-related ones. More recently, Innocenti *et al.* (2014) verified an analogous result using TMS to cause MEPs from right-hand muscles while participants were asked to express judgments related to hand-related action words (compared to abstract words). The authors found that verbs describing motor actions rather than abstract concepts modulated the primary motor cortex excitability. Evidence such as this points to the direction of an active role of the sensorimotor cortex in the semantic processing of action concepts, enhancing the motor performance when the relevant area is stimulated (see also Shebani and Pulvermüller, 2013; Willems *et al.*, 2011).

Although previous studies clearly show that motor areas of the brain are activated when people are required to process action concepts, it remains to be established whether such activation is necessary for concept understanding. Indeed, since action concepts share the same neural substrate and representational format as action outcomes, impairment to specific somatotopic areas of the motor system should have effects on action execution, as well as on the use and comprehension of related concepts.

In this regard, understanding whether lesions to the motor system may cause a deficit in processing action concepts is a matter of debate (see, for example, Arévalo, Baldo and Dronkers, 2012). However, it can hardly be denied that patients with lesions in their motor system, such as victims of injuries, strokes, motor neurons disease and Parkinson's Disease, show specific motor cognition deficits, involving an impairment in the processing of action concepts. For example, Ibáñez *et al.* (2013) assessed the influence of action concept processing over action execution on Parkinson's Disease patients, showing a much-diminished influence relative to non-patient volunteers. This result confirms that the processing of action concepts requires a preserved functionality of the agent's motor repertoire. Indeed, the measured reduction of the action-sentence compatibility effect in Parkinson's disease patients is unrelated to other cognitive domains and can be caused by an impairment of the basal ganglia, which connects with the motor, premotor and prefrontal cortices, where the motor ability of the agent is actually represented.

Desai *et al.* (2015) tested stroke patients to examine the relationship between the loss of manual abilities and action-related conceptual abilities. Interestingly, the authors found that the degree of impairment in reaching performance, due to a lesion in the hand/arm motor areas, allows us to predict the degree of selective impairment for processing action words concerning reaching actions assessed through a semantic similarity judgment task and lexical decision task. Moreover, Kemmerer *et al.* (2012) explored the behavioral patterns of several brain-damaged patients, all of whom received a battery of tasks aiming to probe their ability to understand action concepts in a variety of verbal and non-verbal ways. The authors found a correlation between the presence of lesions on somatotopic related areas of the motor system and the inability to process action concepts (see also Bak and Chandran, 2012).

In support of the *Same Format Thesis*, this third set of evidence suggests that the somatotopic activity of the motor system is not a mere causal consequence of action concepts processing but rather a constitutive part of our conceptual representation of executable actions. Indeed, if the recruitment of motor information were only a consequence of the processing of the executable action concepts involved in our intentions, there would be no reason to hypothesize that an impairment of the agent's motor repertoire also compromises the ability to use and understand executable action concepts. It is because the representation of our executable action concepts is mapped directly on the representation of executable actions that impairment in the processing of the latter involves impairment in the processing of the former.

Someone might argue that the evidence we report suggests a solution to the interface problem because the data that we are discussing simply show that there are close causal relationships between different types of states: those involved in action concept processing and action execution. However, it is important to note that the hypothesis that action concepts are encoded in a motoric format *explains the available evidence better* than the hypothesis according to which action concepts and motor schemas rely on separate representations and formats that have to then be translated in a common code. Indeed, if the executable action concepts and the action schemas were encoded by two different representational formats, there would be no reason to expect that an impairment of the agent's motor system would affect his or her ability to use and understand action categories.

At this point, we have reported all the sets of evidence in support of our argument: the representation of action concepts has the same representational format as MRs. Thus, the claim of the article that intentions and motor representations interlock through action concepts seems to be reliable.

6. The relation of our proposal with recent accounts of the problem

We need now to address and briefly discuss two very recent accounts that criticize the proposals by M&P and B&S in a very similar way we do, and try to tackle the interface problem in a new way. We do not focus on the criticism. Rather, we just highlight the proposals to suggest their compatibility with our account while, nonetheless, pointing out the respective differences. The first one is by Shepherd (2017). Shepherd has suggested that:

> The solution to the interface problem is that intentions lead a double life. Intentions can take propositionally formatted contents that enable their integration with propositional thought. And intentions have motorically formatted contents that communicate in a fairly direct way with the operations of motoric-level action implementation. The interface problem is a problem about how the outcomes specified in intentions could guide and constrain the outcomes specified in motor representations. The answer is that intentions specify outcomes both propositionally and motorically. This is not, of course, to say that intentions specify outcomes at the finest possible grain. There is clearly room for the independent operation of sensorimotor adaptation processes. What we need to understand, however, is how intentions could provide guidance sufficient to render our common action successes non-accidental. Intentions do this by specifying outcomes that motoric-level action implementation processes take on board directly (p. 10).

Very relevant for our point, he also suggests that:

> If an action concept such as GRASPING MY COFFEE MUG becomes linked with the relevant motor schemata via repeated tokening within very similar intentions, there may come a

> time when all I need to grasp my coffee mug successfully is the tokening of an abstract, propositionally represented intention (e.g. GRASP MY MUG!), which then defers successfully to the associated motor schemata. In such a case, the learning process that links the action concept with the motor schemata will explain the non-accidental nature of the link. My proposal is simply that in virtue of an agent's cognitive combinatorial capacities, an intention can take both propositional and motoric contents (ibid.).

Like Shepherd, we think that intentions can have a double life. However, the difference is the following. Shepherd claims that intentions are not exclusively propositional, as endorsed by B&S (p. 9). We do not propose such a claim on intentions. Rather, we claim that a component of the propositional structure of an intention, such an action concept, can be a representation with a motor format. This move allows us to maintain that intentions are mental objects with propositional format which, nonetheless, have within their constituents mental objects that are represented in a motor format (see also note 10). Given their format, motor concepts contained in an intention can be related to motor representations, with which they share the same format. Accordingly, since a motor concept recruits the same motor resources activated by a motor representation, unlike Shepherd's view, our proposal does not need any translation process: a motor concept recruits the same motor resources activated by a motor representation. This is the 'motor bridge' between intentions and MRs: action concepts are 'motor mediators'. However, we remain in line with Shepherd by suggesting (§4) that intentions and MRs partially share the same motor format, inasmuch executable action concepts are naturally represented in the agent's motor system together with the action's outcomes. Remarkably, our proposal individuates the specific motor mediators at the basis of this 'double life': action concepts.

The second proposal we need to address comes from Burnston (2017), who proposed that intentions *bias* towards certain types of actions, rather than determining the contents of MRs (p. 248). This is because, according to Burnston, there is not a one-to-one relation between intentions and motor representations, but there are multiple MRs that correspond to the same intention. Therefore, it cannot be the content of the intention that determines the content of the MR (p. 246). Interestingly, Burnston also analyzes the case of motor concepts:

> 'Kick' corresponds to roundhouse kicks, sweep kicks, nudges with the foot, etc. Even within each of these different types, motor kinematics will vary depending on the properties and positions of the objects being kicked. So, even once I've decided to kick someone, I still need to select a particular subtype of that action and execute the kick appropriately depending on the properties of the target (how tall or short they are, their current posture, etc.). These parameters of the action must be specified by the motor representation for the action to be carried out. The worry is that, given that propositional content doesn't have the same structure as motor representations, it doesn't have the resources to determine these particulars (p. 247).

However, this is not a problem for a *biasing view*, but only for a *determination view*. Indeed, reporting several experimental results (sect. 3) Burnston suggests that, though concepts contained in propositional structured intentions cannot '*determine*' the specific motor representational instructions that allow us to act, they play an important role in '*biasing*' us to a specific motoric 'value' that is very close to the act recalled by the concept. This priming is important in defining the range of motoric values related to the context (p. 251). The peculiar adjustments related to the very specific motor context are then due to the relation between perception and motor representations (ibid.).

As Burnston, we think that propositional states cannot fully determine motor parameters and therefore we find his '*biasing view*' very interesting. However, we think that the relation between intentions and MRs are deeper, and so we push the line even further. More precisely, we argue that action concepts and MRs share the same substrate and format as suggested by the sets of evidence we reviewed, which show a specific relation between action concepts and MRs. First, the motor system activation during action verbs processing is somatotopically organized so that different action concepts activate the specific motor areas involved in the execution of the related actions: both the semantic information of action concepts and the pragmatic information involved in action execution are mapped together, namely, on the same representational substrate (§5.1). Second, action concepts activate cortical regions that encode very specific actions related to very specific effectors. (§5.2). Third, crucially, processing of action concepts requires a preserved functionality of the agent's motor repertoire, and *vice versa* (§5.3). All this suggests the presence of a deep somatotopic relation between the processing of specific action concepts and the specific actions recalled by such concepts. Importantly, this somatotopic relation not only provides evidence that the match between action concepts and MRs is non-accidental, it also suggests that this match has a very specific functional role.

With respect to Burnston, we admit a more direct relationship between an action concept and a MR. This relationship is not only based on behavioral evidence, but also on the way the motor brain somatotopically organizes actions and their related concepts. However, we share his idea that both the perceptual and the motor context might shape the very specific way in which motor parameters are adjusted. This is not a trivial point. Most of the literature focuses on the fact that what remains undetermined is the link between the intention and the MR, but we should also focus on the fact a MR underling the execution of an action is not fixed once and for all. Indeed, since we need to continuously adjust our behavior in a motor context (Pacherie, 2000; Ferretti, 2016; Jeannerod, 2006; Zipoli Caiani and Ferretti, 2017) a fixed intention cannot express the entire complexity of the motor coordination. Accordingly, (even when an intention does not vary during the action) a MR needs a continuous refinement. This frees us from the anxiety concerning the determination problem. Our view that MRs are linked to intentions through the motor format of actions concepts explains how two mental processes with different format can interlock. This is the most important issue when confronting the interface problem. The presence of this special motor route (which constitutes a *motor mediation*) from the action concept to a MR solves the interface problem: even general action concepts are motorically related to specific MRs. At this point, the fact that every context forces us to select a specific MR does not depend on the way intentions and MRs interlock. Rather, it depends on the way the specific parameters characterizing the specific situation are filled in by way of forming the relevant motor representations, which are indeed motorically recalled by the action concept.

7. *Conclusions: a solution to the interface problem*

We saw that B&S proposed the *Deference Thesis* and the *Shared content Thesis* to solve the *Interface Problem*. In accordance with the *Deference Thesis* by B&S, M&P agreed that the intentions have as their components specific types of action concepts that relate to the representation of the relevant motor outcome. However, contrary to the *Deference Thesis*, they disagreed that these concepts should be demonstrative deferential concepts. Thus, they proposed the *Hooking-up Thesis*, based on the notion of motor schemas and executable action concepts. Although we agree with M&P that we need to avoid a translation between intentions and MRs, we reported several problems afflicting the *Hooking-up Thesis*. Among them is the fact that M&P do not consider the vertical variation that characterizes the motor representation of action concepts. Indeed, since the action concepts expressed by action verbs may have several motor meanings, the interlocking between action concepts and motor representations implies a *selection issue*.

Since for M&P the sharing of content is not sufficient to solve the interface problem, we have two possibilities: either we accept that there is a translation process between intentions and MRs or we argue that this translation process is not required because intentions and MRs interlock not only through their content but also through their format. Our account suggests that we should pursue the second way to avoid the translation and the selection issues faced by M&P and B&S. This also explains how intentions and MRs really and precisely interlock. Accordingly, we reported a third crucial temptation, not addressed by B&S or M&P, namely, the temptation to assume that since MRs interlock with action concepts through the content related to the action outcome, MRs and action concepts cannot interlock through their format.

To address this temptation, and to solve the interface problem, we proposed *The Same Format Thesis*, arguing that intentions and motor representations interlock through action concepts. This view states that the representation of action concepts shares the same representational format that pertains to MRs. This amounts to saying that action concepts and MRs have the same representational format, which is the non-propositional, motor format used both when we think about actions through an intention and during covert or overt action performance.

This argument has been supported step by step by three sets of evidence showing that that action concepts and MRs share similar neural correlates, and a similar motor format, whose recruitment is crucially involved both when we think in motor terms with action concepts and when we plan or perform actions through motor representations. The activity of these neural correlates gives raise to representations that are built in a motor format. The conclusion is that action concepts are the *motor mediators* between intentions and MRs.

Like the *Hooking-up Thesis* and the *Reference Thesis,* the *Same Format Thesis* holds that action concepts are crucial for MRs and intentions to interlock. Like them, the *Same Format Thesis* suggests that there is no need for a translation process. Unlike them, the *Same Format Thesis* is able to really suggest why we do not need this translation process in a way that the other two theses cannot do. Our proposal explains the *interface problem* by offering an account that is not afflicted by the same issues bothering the views by B&S and M&P. Our proposal is well supported by empirical evidence and is much simpler and more complete than those of M&P and B&S: *interface without translation* is possible because *action concepts are such stuff as MRs are made on*. This 'stuff' is the motor format.[13]

Dipartimento di Lettere e Filosofia
Università degli Studi di Firenze

NOTES

[1] It should be noted that concepts are here considered as psychological entities with a representational function, but also as basic components of propositions. Accordingly, for the sake of our argument, we assume that action concepts are symbolic items embedded in propositional intentions, which refer to the planning or execution of a goal-directed motor plan.

[2] The idea of linking MRs to action concepts is not new in the literature. Different attempts have suggested the link between MRs and demonstrative and deferential action concepts (ibid.), causal indexical concepts (Jacob and Jeannerod, 2003, sect. 8.2; Pacherie, 2000) and demonstrative concepts of movement (Pacherie, 2011).

[3] M&P distinguish between two different types of action concept. First, there are those that do not hook up with the corresponding motor representations. These concepts, like observational concepts more generally, allow us to accurately categorize instances of action that fall under them, even without being able to perform the action ourselves. As they specify: 'However, a second class of action concepts does more than this. These concepts allow us to activate appropriate motor representations, in part because they are formed on the basis of such

representations, rather than third-personal perceptual information' (p. 329). Hence, typically, having the possibility to perform an action entails forming the appropriate action concept related to the action we are able to perform. Following Pacherie (2011) and M&P, we call these concepts 'executable action concepts'.

[4] It should be noted that the most relevant distinction between *executable action concepts* and *demonstrative deferential concepts* is that having the former kind of concepts entails being able to perform the related action, whereas this is not true for the latter. The latter refers only to the appropriate motor representation and is not peculiarly related to action. It expresses only deference. Conversely, the former is strictly related to the specific motor representation, which is, indeed, hooked up by the concept. This is due to the co-development of both in the individual; see endnote 2 and (§3).

[5] Note also that, *describing that* a process P1 (e.g. acquisition of an executable action concept) is always preceded by a process P2 (e.g. the acquisition of the relevant motor schema for action execution) is not an *explanation of how* P1 might involve P2. Our account will be able to *explain how* motor representations interlock with the action concepts of which the intentions are constituted. The fact that we can describe that there is a link between them is precisely where the *Interface Problem* starts and what we have to *explain*.

[6] It should be noted that, the vertical variation that characterizes many action verbs cannot be equated to a case of homonymy. Cases of homonymy are those in which two identical strings of symbols may denote different concepts in different contexts, as it happens for the word '*stalk*' which can be used to denote a part of a plant or the stealthy approach of a predator, or in the case of the word '*bank*' which can be used to denote a sloping raised land near a river or a financial institution. However, it is important to consider that action verbs are employed to categorize types of actions. Accordingly, it seems reasonable to assume that if two sentences use the same action verb, they categorize the actions in the same way. Notably, English speakers are used to categorize certain actions towards boxes and windows by means of the same action verb 'to open'. Therefore, since the action verb 'to open' is the same in 'to open the box' and in 'to open the window' there are reasons to assume that the action concept involved in the two cases is the same as well. Importantly, there is not any argument in linguistics that provides reasons to doubt that the occurrences of the verb *to open* in 'to open the box' and in 'to open the window' are two instances of the same verb. Moreover, the vertical variation that characterizes the English verb 'to open' can be found in different languages like in the case of the Italian verb 'aprire' (e.g. 'aprire la scatola', 'aprire la finestra') and the French verb 'ouvrir' (e.g. 'ouvrir la boîte' 'ouvrir la fenêtre'). This fact reveals that there is a common way to categorize actions with different kinematics by means of the same action concept. Differently, the homonymy that characterizes the uses of words like 'stalk' and 'bank' has not correspondence in Italian and French.

[7] There are also 'horizontal variations' according to which different occurrences of the same executable action concept can be applied to the same action schema, but with different parameter values, as in the case of 'John turns the card over' and 'John turns the mug over' (Moneglia *et al.*, 2014).

[8] Interestingly, Burnston (2017) uses a similar argument (see Section 6 below).

[9] We are not defending a radical embodied view of concepts, according to which all concepts are characterized by a non-propositional embodied format. Here, we are just focusing on *action* concepts. However, the view that the many high-order cognitive abilities are grounded in the activity of the sensory-motor system is largely shared in the neuroscientific literature (for recent reviews see Craighero, 2014; Ferretti 2016; Zipoli Caiani and Ferretti, 2017). We will use this idea to regiment and defend a philosophical claim.

[10] Someone may ask whether the *Same Format Thesis* leaves the interface problem at the junction between intentions and action concepts. However, we maintain that, despite intentions have a propositional format and action concepts have a non-propositional format, there is not any interface problem in assuming that propositional intentions are *composed by* non-propositional action concepts. An analogy with language processing can be helpful in this case. It is a matter of fact that a sentence can have a propositional format even if its

components, like nouns, verbs or adverbs, cannot have a propositional format. In the same way, we conceive an intention underlying an action as a proposition even if its conceptual components do not share a propositional nature. Accordingly, an intention that contains an action concept as its part can have a propositional format even though this action concept has a motoric format.

[11] It should be noted that the best explanation of the abovementioned behavioral evidence is that the processing of action concepts relies on the functioning of the motor system at the neural level, and therefore that action concepts are motorically formatted. This interpretation is motivated by two considerations: (1) the priming effect is usually measured within 200 ms after the stimulus onset. This evidence is not compatible with the hypothesis that the agent is imagining the action or that he/she is performing some instance of indirect inferential processing; (2) our interpretation is compatible with the evidence that action concepts processing somatotopically and functionally activates the motor system (see Section 5.2). Since this is a crucial point, we might need to go slowly on this. The best candidate to be considered as the neural correlate for MRs is represented by the hodological pathway that goes from the early stage of the dorsal stream (the posterior parietal cortex), through the premotor areas, to the motor areas (Ferretti, 2016; Nanay, 2013; Pacherie, 2000; Butterfill and Sinigaglia, 2014). In this respect, also action concepts are subserved by the premotor and motor cortices. If so, it is reasonable to infer that the representation of action concepts comes in a motor format. Moreover, concerning the activation of the motor system during the processing of action concepts, we discussed evidence that the motor system gets activated within 200 ms after the onset. This timing does not allow any inferential process based on propositional computing. Thus, it seems unlikely that action concepts are not built in a motor format. This is also in line with the evidence that the magnocellular advantage that characterizes the activation of dorsal and premotor areas makes the activation of such neural correlates so fast that any mental process in a format other than the motor one is doomed to arrive only after the motor activation.

[12] It should be noted that this claim differs from M&P's assumption that motor schemas are acquired through processes of probabilistic inductive generalization. Indeed, whereas M&P state that improving action skills influences the acquisition of action schemas linking action concepts to MRs, we interpret the evidence as supporting the view that the improvement of action abilities facilitates the acquisition of related conceptual competence.

[13] The authors are listed in alphabetical order and contributed equally to the article. The authors would like to thank Bence Nanay, Joshua Shepherd, Chiara Brozzo, Alessandro Panunzi and the audience at the Conference of the Italian Association for Cognitive Science (AISC) in December 2017 for their very insightful comments on previous versions of this article as well as two anonymous referees, whose comments have proven very fruitful in improving the paper.

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