From Affordances to Abstract Words: The Flexibility of the Sensorimotor Grounding

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Abstract

Recent research has shown that the sensorimotor system plays a significant role in a variety of cognitive processes. In this paper, we will review recent studies performed in our lab (Body Action Language Lab, BALLAB) or in labs with which we collaborate, showing the involvement of the sensorimotor system at different levels. With the purpose of expounding on this aspect, we focus on studies that highlight two main characteristics of the involvement of the sensorimotor systems.

First, we concentrate on the flexibility of the sensorimotor grounding during interaction with objects. We report evidence showing how social context and current situations influence affordance activation. We then focus on the tactile and kinesthetic involvement in body-object interaction.

Second, we illustrate flexible sensorimotor grounding in word use. We review studies showing that not only concrete words, like "bottle," but also abstract words, like "freedom," "thinking," and "perhaps," are grounded in the sensorimotor system. We report evidence showing that abstract words activate sensory modalities and involve the mouth effector more than concrete words due to their privileged relationship with language, both outer and inner speech. We discuss the activation of the mouth sensorimotor system in light of studies on adults (e.g., studies employing articulatory suppression), children (e.g., studies on the effects of pacifier use on word acquisition and processing), and infants (e.g. studies on emergence of new words).

Finally, we pinpoint possible mechanisms at play in the acquisition and use of abstract concepts. We argue that with abstract concepts, we rely more on other people to learn or negotiate the meaning of words; we have called this mechanism social metacognition.Social metacognition is bidirectionally linked to our sensorimotor system. On the one hand, linguistic explanations constitute a primary source of grounding that

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may be re-enacted when retrieving a concept, for example through inner speech. On the other hand, it leads us to feel closer and be more synchronous in movement with others, who can help us understand the meaning of very complex words.

Overall, we show that the sensorimotor system provides a grounding basis not only for objects and concrete words but also for more abstract and concrete ones. We conclude by arguing that future research should address and deepen two different and interrelated aspects concerning the involvement of the sensorimotor system during object and word processing. First, the sensorimotor system is flexibly modulated by the context, as studies on affordances reveal. Second, the sensorimotor system can be involved at different levels, and its role can be integrated and flanked by that of other systems, like the linguistic one, as studies on abstract concepts clearly show. We urge future research aimed at unravelling the role of the sensorimotor system in cognition to fully explore the complexity of this intricate-and sometimes slippery-relation.

Keywords: body, action, abstract concepts, metacognition, sociality

1. Introduction

One of the aims of scientific research is to find unifying principles that hold across different systems. This paper deals with the fact that different systems, traditionally related to the so-called “low-” and “high-level” cognition, rely and build on the same system, i.e., the sensorimotor one. Theories of reuse [1,2] clearly pointed out this aspect. For example, many authors showed that language exploits and reuses structures characteristics of the most basic perception and action processes [3]. This paper reviews research conducted in our lab (currently called Body Action Language Lab, BALLAB) showing that sensorimotor grounding is a fundamental principle that concerns processes of different kinds. Specifically, we start from work pertaining to perception and action, i.e., work on affordances, all the way to work on conceptualization and language—and particularly on abstract concepts and words. In light of the evidence we present, we will advance and defend two claims. First, we argue that sensorimotor grounding can be flexibly adapted depending on the context, and we will illustrate some examples of this flexibility. Second, we illustrate how sensorimotor grounding can differ in level and role, and suggest that other experiential systems–such as the linguistic system–might complement the role of the sensorimotor system.

Let us start with the flexibility of sensorimotor grounding. As an example of flexibility, consider studies on affordances. A broad literature shows that when we observe objects and people interacting with them, we immediately activate the tendency to interact with them. Gibson [4] used the term “affordance” to name the characteristics of objects that elicit this tendency, responding to what objects offer to us. Hence, we can say that affordances engage the sensorimotor system. However, this tendency can be modulated by the local context – the presence of other objects and the presence of other people. For example, this tendency to interact with objects might be reduced when we know that objects do not belong to us [5,6]. Notably, also

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the broad context can influence affordance activation. Consider, for example, the context of the pandemics due to the spread of Covid-19. In this context, the usual affordance effect, i.e., the automatic tendency to grasp the handle of manipulable objects, might be reduced or even disappear [7]. Does this mean that no sensorimotor involvement took place? Not at all. Instead, this suggests that the sensorimotor system's involvement is influenced and strongly impacted by both the local and broad context. We believe that highlighting the flexibility that characterizes the sensorimotor system, and the contextual dependency of its engagement, is one of the most significant challenges of the years to come.

Our second claim argues that the sensorimotor system might be integrated and enhanced by other systems, such as those supporting processes of higher-level monitoring and control (metacognition) or language. This integration process occurs mainly for processes traditionally considered as high-level ones, such as conceptualization and language. We will show that the representation of abstract concepts involves perception and action. For example, to ground the abstract concepts of "self-" or "other-ownership," we may simulate experiences of physical controllability and agency over objects or lack thereof. Similarly, to ground the abstract concept of "justice," we might re-enact situations of discrimination or scenes in a tribunal we have directly experienced or assisted to or that someone described to us. At the same time, because the concept and the word meaning of "justice" assembles various sparse experiences, we might need to talk to ourselves to search for them and rehearse them. Inner speech can also help us prepare ourselves to ask others who are experts of justice (social metacognition, [8]). Talking to ourselves might involve, once again, sensorimotor systems, and particularly the mouth motor system. The fact of possessing a common label, such as "justice," for various elements can help us to form compact and cohesive categories. Hence, our work on abstract concepts shows the strict interaction and integration between sensorimotor, metacognitive, and linguistic systems. The linguistic system is grounded in sensorimotor systems, the latter (e.g., through the mouth involvement) foster linguistic processing, and linguistic processes enhance and modify perception.

2. The flexibility of the recruitment of the sensorimotor system: the case of affordances, and affordances and language

2.1 **Affordances among perception, action and social practices.** The notion of affordance, introduced by Gibson [4], has been re-evaluated in the last 20 years in the embodied and grounded cognition framework. The idea of Gibson that affordances are neither subjective nor objective, and they do pertain to both perception and action, clearly fits well with a paradigm that underlines the circular relationship between perception, action, and cognition. Although inspired by Gibson, seminal studies in cognitive psychology and neuroscience diverged by his externalist perspective, stressing the role of the brain. Affordances would thus be forms of reactivation in the brain of visuomotor associations: for example, we typically experience cups with a handle and associate handles with a specific kind of grip. Along these lines, highly innovative studies were performed, like early work by Ellis and Tucker [e.g., 9, 10, 11]. These studies focused on how, when we observe objects, we activate and potentiate these powerful associations, despite

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the task and the context.More recent literature has been influenced by Cisek's [12] competition model: in this view, action decisions are the product of competition in the brain of different affordances that are activated in parallel—for example, we might activate different affordances of an object depending on the context. A recent proposal [13] broadens the notion of affordances, linking them to the skills of organisms: hence, for humans, affordances are linked to sociocultural practices. In this perspective, perception would consist of a sort of "openness to affordances" [13].

A variety of studies have recently shown that different tasks contexts modulate the activation of object affordances. Research has focused both on physical and social contexts, investigating their conjunct influence on affordances activation [for an overview, see 14; for a view integrating experimental and modeling evidence on affordances and mirror neuron system, see 15]. Examples of physical contexts are the presence of other objects, scenes, and situations in which objects are embedded, and the distance of objects from the agent's body. As to social contexts, studies have considered the presence of another person [16, 17] or more people, their collaborative vs. competitive attitude, the necessity or not to perform a joint action, and the social norms establishing that an object belongs to someone else. Still, many questions remain unanswered. Among these, one is whether we only activate affordances relevant to the current context and goal, or whether instead we always activate all affordances and later operate a selection.

2.2 **Affordances and context.** Consistently with Cisek's affordance competition hypothesis but also with this broad view of affordances, in our lab and in collaboration with other labs, we have investigated the influence of both the physical and social context on affordances. One study showed that the task influences affordance activation and that affordances emerge only when deep object processing is necessary. We found an affordance effect (compatibility between the handle position and the response-key) when participants were required to process the shape of torches to determine whether they were upright or reversed. Instead, we did not find it when they had to discriminate its color [18, 19]. We also showed that physical and social context influence affordances activation. Using a behavioral, an EEG, and an eye-tracking task, we found that the presence of other objects functionally related to the target and the hand of an agent potentially interacting with them facilitates affordances processing [20, 21, 22]. In addition, we found that the part of the scene in which an object is situated evokes different grip-related affordances: for example, a corkscrew located in a drawer might evoke a power grip, whereas a corkscrew on a bottle might trigger a precision grip [23]. Affordances also vary depending on the goals of the participants, modulated by their age. In a recent study with novel and familiar objects, we found that young children respond to both novel and familiar objects in more creative ways than adolescents and adults, who respond to object affordances in more standardized ways [24, 25]. Finally, affordances activation is sensitive to our knowledge of ownership status [5, 6]. This knowledge is also grounded in the tendency to incorporate objects systematically associated with our body parts, such as rings, and consider them as part of our body [26]. An interesting case is represented by dangerous objects and their affordances. Their dangerousness is

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perceived differently and evokes different motor responses depending on their location in space and movement. Anelli et al. [27] presented neutral and dangerous objects dynamically, i.e., moving toward or away from the observer. We found slower responses when dangerous objects moved toward the participants, suggesting that they may evoke aversive affordances, reflected in response inhibition. The importance of context for dangerous affordances appears even more prominent in a recent EEG study [28]. We demonstrated that dangerous affordances are not processed automatically but based on contextual information: for example, motor inhibition with dangerous objects, detected through a frontal N2 potential, was only present in a reachability task but not in a categorization task.

Aside from the influence of the external context and of object dangerousness, we have also shown that linguistic context influences affordances. Possessing a label for a novel object can facilitate learning how to grasp it for use but not how to move it. Language encodes stable properties of tools, thereby contributing to ground conceptual information–as proposed by the Label Feedback Hypothesis [29]–and plays a direct role in motor learning [30]. Reading verbs related to action and functions induces us to process affordances of objects close to our body faster than those distant from it, while reading verbs related to observation and pointing does not lead to any difference [31, 32]. Action sentences (e.g., “grasp the brush”) elicit affordance related to the grip required by objects, while this is not the case for sentences related to observation [33]. When we have to grasp an object close to us, we grasp it faster when someone says “I grasp the object”, especially if this person is not a friend of us, and can thus be conceived as a competitor for the object possession [34].

Some recent studies are testing whether also the broader context, such as the pandemic one, can impact affordance perception. Michalland et al. [7] are currently testing whether, in the current pandemic context, observing an object potentiates its affordances even if an unknown person has touched the object, thus making it potentially contaminated. Similarly, Gianelli et al. [35] are addressing the possible effects of the pandemics on language and affordances. They test whether reading sentences describing actions involving objects that are potential carriers of contagion (handle vs. toothbrush) evokes different affordances when the objects are embedded in public–hence potentially dangerous–scenarios, like the supermarket, or not.

These studies indicate that we recruit the sensorimotor system to plan and prepare our actions with objects or even simply to simulate them. Remarkably, this involvement of the sensorimotor system occurs in a highly flexible and context-dependent way. We believe that one of the next few years' challenges consists of determining with precision the elements at play in the competition for the emergence of affordances [14]. This will allow us to predict when and in which circumstances different kinds of affordances emerge. Our life takes place in the kaleidoscopic influence of many factors. Provided that the sensorimotor system is always involved, at which level is it involved? When do more stable affordances prevail, and when, instead, do the cues derived from the context prevail? In the following section, we zoom in on

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sensorimotor activation patterns of a specific modality, i.e., the sense of touch, to provide examples of its flexible and context bounded involvement.

3. The flexibility of the recruitment of the sensorimotor system: Tactile and kinesthetic modalities

During a potential or real object manipulation, sequences of actions with different goals are planned and simulated/performed. The action phases are separated by events in which we anticipate/experience different types of contact with the objects. From such sensorimotor events, somesthetic signals are generated through actual stimuli or sensorimotor simulations. These somesthetic signals can involve interoceptive, tactile, or proprioceptive signals [36, 37]. The involvement of tactile and proprioceptive modalities to detect various properties of objects such as softness, roughness, temperature or curvature, and of events such as grasping, lifting off a surface, or slipping through fingers is of primary importance and is now well-documented [38-43]. Those tactile and proprioceptive signals are involved in many human activities [44] and are thus the support of various cognitive processes involving body-environment interactions.

Indeed, tactile and kinesthetic consequences are integrated with action codes to select the effector and the force needed to perform an action [45-47], movement trajectories [48-50], and to refine the generative model used in active inference [51]. As said earlier, potential nociceptive tactile consequences deriving from object dangerousness [27-28] and the state of the body can be taken into account in the selection of action codes. For instance, presenting a picture of an injured hand compared to that of a healthy hand leads participants to produce slower responses, especially when they have to grasp a response device [52]. However, the complexity and variability of tactile and kinesthetic signals [53-54] may lead the cognitive system to introduce some flexibility in the integration of such signals. For example, Michalland et al. [55] showed that the impact of object dangerousness, object position, and body state depends on the hand used to produce a response: dominant (right) hand responses took into account all these features, while left hand responses did not take into account the body state.

The focus on the tactile and kinesthetic modalities can thus deepen our understanding of affordance flexibility and the features exploited in this body-environment bridging. The shape and spatial attributes of objects are features that may induce affordance activation [9,18], but we know little about other object features. By looking at the force exerted when facing pictures of objects varying in weight or softness, Michalland et al. [56] showed that participants modulated the exerted force when using their non-dominant (left) hand, but not with their right hand. Thus, the features of objects taken into account to perform an action may vary depending on the hand used (see also [57]). In that sense, the flexibility of affordance activation can also be related to the flexibility of the environment features selected to produce an action. This flexibility would thus bias the weight of the various sensorimotor modalities in the competition model proposed by Cisek [12].

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The differential involvement of tactile and kinesthetic features in physical body-object interaction underscores the flexibility of sensorimotor grounding of cognitive processes. Just as the various dimensions of tactile and kinesthetic modalities can varyingly be involved in body-object interactions, different bodily and sensorimotor features can be involved in language processing—as a particular word or concept recruits sensorimotor grounding sources through its referent and/or through the actions of talking and listening [58-60]. In the following, we show how these bodily components are responsively co-opted not only for object concepts but also for more complex and abstract concepts.

4. Different level of involvement of the sensorimotor system, and the integration with the linguistic system: the case of abstract concepts

4.1 **Grounding of abstract concepts in the sensorimotor system.** While the role of sensorimotor aspects involved in the processing of objects, actions, and object concepts is now well-established, only recently has the scientific community started to acknowledge the importance of sensorimotor components in the representation of more abstract entities. Traditionally, concepts were divided into two general classes, i.e., concrete and abstract concepts. Concrete concepts refer to physical and perceivable entities in the world (e.g., *hammer*). Converging evidence showed that concrete concepts are acquired earlier [61], and processed and remembered faster [62]. Conversely, abstract concepts (e.g., *justice*), i.e., concepts referring to ideas or entities which are not experienced through the five senses, have a general disadvantage in response times and are acquired later in life (see [63]). Research focusing on concrete concepts has widely documented the entanglement between conceptual processing and systems devoted to perception and action (see [64, 65]), as well as the role of sensorimotor features in language comprehension [66-70]. On top of that, concrete concepts are said to be acquired primarily through physical interaction with their referents, while abstract concepts are generally acquired and represented via linguistic associations (e.g., explanations or examples;[71-73]). While most studies focus on children and adults, recent results on word comprehension in infants confirm that abstract words are learned later and often in conjunction with the acquisition of critical social abilities, such as joint action [74]. Furthermore, studies on word production of infants suggest that possessing abstract words in early vocabulary can enhance later language acquisition [75, 76]. The importance of linguistic associations for abstract concepts is also testified by research on the elderly, especially by evidence showing that, likely because they rely on language, abstract concepts deteriorate less than concrete concepts with age [for a review, 77].

4.1.1 ***Different abstract concepts are couched in different modalities.*** Although most of the evidence in favoring a causal role of sensorimotor simulations in conceptual processing comes from studies dealing with concrete concepts, there is nowadays a growing interest in assessing sensorimotor components engaged in abstract knowledge as well. Mathematical knowledge, for example, has been the remit of several studies documenting the activation of specialized neural correlates(especially for concepts denoting

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numerosity, see[78, 79]). Along these lines, proponents of embodied cognition posit that numerical and mathematical knowledge is grounded in motor processes related to the habit of finger counting and spatial associations [80-82]. For example, in various behavioral and kinematics studies, we found that participants compute more additions than subtractions when performing an ascensional movement, moving rightward, and moving in a circular clockwise way [83-85]. We also found that object affordances and task-irrelevant hand actions enhanced the sensitivity to the numerical magnitude and that numerical magnitude modulates grasping [86, 87]. These results document the strict relationship between the processing of abstract concepts (numbers) and their sensorimotor basis. Emotional concepts were also found to activate a widespread network of brain areas, mostly related to emotion processing (e.g., fronto-parietal regions) together with motor and pre-motor areas [see 88]. For instance, Moseley and collaborators [89] found in an fMRI study that even abstract emotional words with low scores on ratings of sensorimotor activation (e.g., *hate*, *gibe*) activated the precentral cortex, overlapping with areas activated by arm and face related verbs.More recently, in a meta-analysis comparing patterns of neural activation for different kinds of abstract concepts, Desai, Reilly and van Dam [90] found that the representation of emotional, numerical, moral concepts and concepts referring to Theory of Mind (TOM) was spanned over different brain regions. Nonetheless, each subcategory was associated with uniquely identifying areas. The specificity of modality-specific brain regions co-opted in the elaboration of abstract concepts is also illustrated in an fMRI study comparing patterns of activation of 64 abstract concepts, distinguished according to their specific features [motor, e.g., *fitness* vs.visual, e.g., *beauty*; 91] in a lexical decision task. The results show that processing motor abstract concepts activated areas usually found active in the execution of hand movements (left precentral and postcentral gyrus), whereas visual abstract concepts triggered the activation of lingual and fusiform gyrus—often reported during the observation of object scenes. Finally, despite the fact that the abstract domain of object ownership has been proposed as the hallmark of disembodiment [92], recent studies have shown that explicit knowledge of the ownership status of objects interacts with multisensory and motor processes in surprisingly direct ways. As suggested above, it has been shown that knowing whether a graspable object (e.g., a cup) is “mine” or not differentially modulates the automatic potentiation of actions towards it [affordance activation; 5]. In a simple grasp-to-lift task, such knowledge can alter the kinematic profile of movements in ways that suggest an automatic resistance to interact with objects owned by others [5]. Knowledge of the ownership status of objects can also influences the linguistic choice of spatial demonstratives like ‘‘this’’ and ‘‘that’’ in subtle and unconscious ways [93]: participants tend to use ‘‘this’’ more often to refer to objects that they own than to objects owned by someone else. Intriguingly, a recent study has also provided initial evidence that the ownership status of an object can also affect the multisensory representation of the space around the body [the peripersonal space; 94], as measured by the enhancement of visuotactile interaction effects when manipulating objects that belong to the participant but not with objects belonging to someone else. Finally, intriguing evidence from a somatoparaphrenic patient denying ownership of her left hand revealed that she also displayed selective disownership of objects typically associated with it [e.g., a wedding ring, a garnet ring, a watch etc.; 95, 26]. Taken together, these

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studies strongly suggest that the abstract conceptual domain of ownership may in fact be, at least partially, grounded and profoundly shaped by our sensorimotor experiences [96]. These findings support the idea that the representation of abstract concepts–similarly to that of concrete concepts–also recruits sensorimotor neural areas, while at the same time pointing to the composite and heterogeneous character of the category of abstract concepts.

Behavioral and linguistic results also advocate for a more fine-grained perspective on abstract concepts. Methods typically used to identify underlying features of conceptual representation (e.g., feature listing, ratings, typicality judgments) have highlighted how different aspects (e.g., internal, perceptual, social) concur in the representation of abstract concepts, sometimes overlapping with more concrete features. To illustrate, Connell and Lynott [97] found that, across more than 500 English words, ratings of concreteness and perceptual strength (i.e., the extent to which a concept is experienced through one of the five senses) did not always align. Specifically, concepts related to taste (e.g., *bitter*) or sound (e.g., *noisy*) experiences were found to have strong perceptual components while being highly abstract. Importantly, the authors also showed that scores of perceptual strength outperformed traditional psycholinguistic measures such as concreteness and imageability in lexical decision and word-naming tasks. Along the same lines, Troche and colleagues [98, 99], in two large rating studies reported that abstract concepts were characterized mainly by affective, social, and moral aspects. However, concepts with higher affective-emotional components (e.g., *chocolate, trust*) tended to cluster together irrespectively of their abstractness level, further suggesting that the distinction into abstract and concrete classes of concepts alone might not suffice to capture all grounding sources efficiently. In addition, a recent study [100] shed further light on other modality-specific grounding mechanisms for abstract concepts, showing a predominant role of interoception in abstract conceptual representation and processing. Internal grounding was also found to be one of the latent factors explaining abstract concepts' representation in a large rating on Italian abstract words [101]; interestingly, the 'Inner grounding-social' factor included the relation of abstract meanings with the mouth effector, together with emotions, metacognition, and interoception [see also 102]. Crucially, the role of sensorimotor grounding varies also within abstract concepts. Villani et al. [101] showed that the latent sensorimotor factor characterized primarily physical, spatio-temporal, and quantitative (PSTQ) abstract concepts (e.g., *reflex*). The inner grounding factor played a more critical role for self-sociality (SS) (e.g., *politeness*), and emotive/inner states concepts (EM) (e.g., *anger*). Philosophical-spiritual (PS) concepts (e.g., *value*) qualified as more abstract than the other concepts. In addition, recent studies revealed that the expertise of participants and the culture might influence the perceived role of sensorimotor features. In a rating study, law experts judged institutional concepts as involving more the emotional dimension and the sense of touch than a control group; since touch is typically associated with concrete concepts, these results suggest that expertise might contribute to render abstract concepts more concrete [103].

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Feature listing tasks also offered hints into perceptual and sensorimotor components of abstract concepts [for a review, see 104]. For instance, Harpaintner, Trumpp and Kiefer [105] asked participants to generate features for 296 abstract concepts, and found that while internal, emotional, and social aspects were especially relevant, sensorimotor features were also present. Aside from the results obtained with more classic ratings and feature production tasks, recent studies using novel, interactive methods reached similar conclusions. Villani, Orsoni, et al., [106, 107] asked participants to respond to a sentence containing an abstract or concrete concept as if they were engaging in a conversation. Compared to concrete sentences, abstract sentences evoked primarily inner properties, but they also yielded sensorimotor ones; specifically, physical, spatio-temporal, and quantitative (PSTQ) abstract concepts yielded more sensorimotor features than the other abstract concepts. Notably, abstract sentences also led to more interactive exchanges, characterized by more questions to the fictitious interlocutor [106]. Further studies carried out in our lab confirm this interactive component of abstract concepts. In the first study participants start from different kinds of concrete and abstract concepts to create a post for Facebook and for Twitter [108]; in the second study, we investigated mind wandering and reporting of it in children and adolescents who received concrete and abstract words as cues [109]. Preliminary results indicate that more abstract concepts evoke more questions and interactive exchanges than concrete ones.

4.1.2 ***Culture and language shape bodily components of abstract concepts.*** The variable integration between sensorimotor components and abstract concepts is well expressed in cross-cultural studies. The cultural background represents the natural scaffolding where the relation between language and body is flexibly shaped [110]. Evidence coming from our and associated labs also confirms how flexibly sensorimotor and perceptual components are incorporated in abstract concepts, depending on specific experiences or cultural settings. In a recent study, we asked Italian and Iranian participants to process concrete and abstract sentences while observing a video and imitating a motor task, and we found facilitation in the Italian group and interference in the Iranian group, likely due to the higher integration of language and gestures in the Italian language [111]. The results suggest that the culturally acquired habits might strongly influence concrete and abstract language grounding in the sensorimotor system. Studies on sign languages confirm that different relationships between abstract concepts and body parts might be salient depending on the considered culture and signed language [112]. Similarly, a concept such as *gender*, which cannot be considered neither strictly abstract, nor concrete, displays differing characterizing features as a function of participants' previous experiences and cultures. To illustrate, Mazzuca et al. [113] asked a sample of Italian “normative” (i.e., monosexual, cis-gender) and “non-normative” (i.e., plurisexual, gender-diverse) participants to provide free associations to the word *genere*(“gender”). We found that, while “normative” participants mainly stressed aspects related to a binary, more concrete conception of gender (e.g., *woman* and *man*; *female* and *male*), “non-normative” participants mostly produced sociocultural, more abstract features (e.g., *construction, queer, fluidity*). Preliminary results [113] also

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indicate that more abstract or more concrete features of *gender* might be differentially relevant depending on cultural and social aspects. For instance, when asked to list words referring to *gender*, Dutch participants more frequently mentioned words linked to bodily and perceptual components of the concept—e.g., *breasts, vagina, penis, hormones*. Conversely, Italian participants focused more on aspects mediated by sociality and culture, mentioning more frequently words like *discrimination, construct, patriarchy*. Results from a following rating study in which participants were asked to rate a set of abstract and concrete words in terms of how much they were related to *gender* support the idea of different levels of abstractness in the conceptualization of *gender* between Dutch and Italian speakers. In fact, Dutch participants rated more concrete words as more related to gender, whereas Italian participants showed the opposite pattern. Finally, recent studies indicate that, likely because of their more substantial reliance on the linguistic than on the sensorimotor system, abstract concepts vary across languages more than concrete ones [for a review, see 114]. We recently asked Italian, Iranian, and Israeli participants to sort concrete and abstract nouns into groups and name each group [115]. The results revealed a higher variability of abstract compared to concrete concepts both within individuals of the same culture and across cultures and languages.

To summarize, abstract concepts seem to be primarily characterized by dimensions such as affect, internal states, and social components; perceptual and sensorimotor features are also implicated in their grounding. Significantly, however, the role of internal and external grounding is flexibly modulated by the context - the language, the culture, and the current situation, as a recent study on the impact of the Covid-19 pandemics on conceptual organization, indicates [116].

4.2 **Grounding of Abstract Concepts in Metacognition.** Besides internal domains like affect and interoception, abstract concepts might also be grounded on metacognitive processes in which higher-level systems monitor and control other object-level mental states and processes like perception, memory, learning, reasoning, etc. [72]. Although often mentioned so far, the role of metacognition in grounding abstract concepts has not been so far systematically explored— and discussions on its involvement have typically been limited to conceptual domains with explicit meta-level content like mental states concepts. Moreover, its integration with the sensorimotor systems has been mostly neglected. However, consider again how a basic understanding of "mine," "yours," and other concepts of property ownership might develop. We have already illustrated recent evidence of a direct grounding of this abstract knowledge domain on the sensorimotor system. Despite this connection, it has been argued that the semantic core of ownership is ultimately related to the unobservable and thereby abstract notion of "control" [6]. Tracing a plausible cognitive development of this control-based view, it has been hypothesized that concepts of possession and ownership develop as a byproduct of the intrinsic motivation of children to effectively interact with the environment and the need of infants, during their first two years of life, to identify the objects in their environment that occasion feelings of efficacy and personal control to keep them apart from those that instead thwart such feelings [117]. From the child's perspective, the former class of controllable

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objects becomes the category of objects that are understood as “mine”, while the latter one includes those that are not. Casting this proposal in contemporary computational frameworks of reinforcement learning might reveal that such a curiosity-based exploration of new skills relies on monitoring one’s competence improvement (or lack thereof), which is a fundamentally metacognitive learning signal [118, 119]. Thus, in principle, even metacognitive processes that monitor and control lower level sensorimotor ones can provide the kind of information that can be used to develop and ground higher-level abstract concepts.

4.3 **Abstract concepts, language, and their relation with mouth motor areas.** Beside these more interactive experiences, abstract concepts tend to be acquired mainly through linguistic inputs [120], so according to multiple representation proposals their representation should massively rely on the linguistic system [8, 121-123]. The specific recruitment of linguistic information in the representation of abstract concepts is confirmed by rating studies showing that abstract concepts are judged to be more associated with the mouth effector compared to concrete concepts, which in turn are more associated with hands or other effectors eliciting action patterns [102; see also 101]. Ratings and behavioral studies further suggested that this association with the mouth is particularly marked with some kinds of abstract concepts, such as mental states and institutional concepts [102, 103].

Behavioral studies performed in our and other labs in which participants were asked to use the hand or the mouth to deliver responses support the connection between mouth activation and abstract concepts [for reviews 8, 123]. Both in Borghi et al. [124] and Granito et al. [125], we implemented novel paradigms to investigate how we form new conceptual categories from elements, i.e., geometric shapes or names, never experienced before. In Borghi et al. [124], after having manipulated or interacted with new objects and then formed conceptual categories, participants were submitted to a property verification task in which they were required to indicate whether a feature belonged to a specific learned concept. Participants were faster with abstract concepts when using a microphone to respond and with concrete concepts when pressing a button on the keyboard. Similarly, in Granito et al. [125], participants were submitted to a categorical recognition task after learning verbal categories from new objects and names. Results indicate that responses were faster when the words were abstract, and the answer was delivered with the microphone for participants who have benefited from linguistic training. The advantage of using the microphone over the hand when processing abstract concepts was found for the first time with real words and sentences by Borghi&Zarcone [126]; in this study participants had to decide whether a concrete or abstract word matched with a definition. Finally, Mazzuca et al. [127] confirmed the same effect in a word recognition task but not in a lexical decision task. This latter probably failed to replicate the results because it was too shallow. Other studies have outlined interference effects, which emerged when the mouth was occupied while performing the task as in Villanie et al. [128]. Here, participants were asked to chew gum while evaluating words’ difficulty, and such manipulation resulted in an increase in the perceived difficulty of concrete but not abstract concepts.

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Neural evidence encompassing TMS and fMRI studies further outlined the role of mouth-motor areas in processing abstract meanings. In a TMS study, Scorolli et al. [129] had participants process sentences composed by abstract and concrete nouns and verbs. The early activation of hand-related areas with concrete concepts and delayed activation of the same areas with abstract verbs was likely due to a cascade effect of early activation of the topologically contiguous mouth motor areas. As to fMRI studies, Sakreida et al. [130] compared concrete and abstract expressions and found that abstract sentences consistently activated the anterior part of the left middle temporal gyrus, one of the language system nodes. While specific patterns of activation of mouth-related areas were already reported for emotional words [131, 132], Dreyer and Pulvermüller [88] extended previous findings to mental abstract words (e.g., *logic*). Scanning hemodynamic activity within the motor system during a passive reading task, they found a stronger activation of face motor areas for mental abstract words compared to emotional abstract words, which instead activated different foci of motor areas (e.g., hand, leg, mouth) to the same extent. Together, such evidence corroborates the hypothesis that acquiring and processing abstract concepts might request a more substantial linguistic contribution compared to concrete concepts, expressed by the facilitating or interfering effect of mouth motor areas activation observed in various experimental conditions. While the studies discussed so far attest to this entanglement in the context of online language processing or in tasks mirroring processes of conceptual acquisition, they do not directly target abstract concepts acquisition. One way to address the role of linguistic motoric components in abstract conceptual knowledge emergence is to look at the developmental pathway of this connection. In the following section, we report studies that we conducted that might offer key insights into this undertaking.

4.3.1***Mouth engagement and abstract concepts in a developmental perspective.***Behavioural data collected with adults responding to abstract stimuli indicate that the mouth motor system is consistently involved in the processing of abstract concepts. In addition, as already mentioned, abstract concepts are mainly acquired through linguistic inputs and social interactions [120, 8]. Given the significance of linguistic simulations occurring in the mouth motor area for abstract concepts acquisition and processing, one might wonder whether consistently inhibiting such processes could lead to a selective impairment with abstract concepts. Along these lines, Barca et al. [133, 134] designed two different studies in which they tested the relation between the extensive use of an oral device (i.e., the pacifier) and abstract conceptual knowledge in children. While some studies [e.g., 135, 136] found evidence for an impairment in emotional competence (e.g., expression and recognition of emotions in faces) as a consequence of an extensive use of pacifiers, the link between the latter and abstract concepts was still unexplored. In a first study [133] children aged 6-7 years with different histories of pacifier use (ranging from never to three years of use) were asked to produce oral definitions for abstract, emotional, and concrete concepts. The definitions were then coded both for accuracy and for the conceptual relations they were composed of. We found no differences in accuracy, but reported some interesting qualitative differences among children depending on their use of the pacifier. Specifically, children who overused the pacifier (i.e., for more than three years) tended to use overall more examples and functional associations and less experiential and free-associations

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to describe concepts than the other children. More importantly, their definitions of abstract and emotional concepts were less sharply diversified from their definitions of concrete concepts compared to the other groups. This pattern was further confirmed by the second study [134], in which children (7-8 years old) with differing histories of pacifier use completed a semantic categorization task that included in the target stimuli abstract, emotional, and concrete concepts. The results show that children who made an extensive use of the pacifier during infancy were also slower in the categorization task, and this held especially with abstract concepts. Overall, these results suggest that limiting the mobility of speech motor acts by forcing mouth muscles into a static position for a long time during language acquisition might interfere with the subsequent ability to master abstract concepts.

4.4 **Abstract concepts and Inner Speech.** Whether the mouth sensorimotor system is interfering or facilitating the processing of abstract concepts and words, its involvement is undoubtedly marked. In the context of searching unifying principles to explain different phenomena, this bears the question of which kind of mechanism might underlie the mouth motor activation during the processing of abstract concepts. One reliable hypothesis proposes that the mouth motor activation might be related to Inner Speech (IS), which could represent the neuropsychological function contributing to the processing of complex and abstract meaning. Over time, IS has been defined differently [for a review, see 137]. Some defined it as an initial outer speech, internalized during cognitive development [Vygotsky's 138]; others described it as an active rehearsal mechanism, using offline speech to plan overt speech or action [139]. Recently, it has been proposed that IS might represent a simulation of articulatory actions recreating auditory percepts fulfilling a self-regulatory behavioral goal [140; for reviews, see 141-143]. In keeping with the “embodied simulation” theories [e.g., 144], IS and overt speech seem to overlap partially, and IS might be considered as the internal preparation for specific (linguistic) motor acts [137]. Behavioral evidence supports such a view. It has been shown that silent reading entails the covert articulation of the speech gesture arranged to produce a particular sound [145, 146]. Overall, the literature converges in showing the critical role inner speech might play in improving cognitive processes. For example, recent computational work with a model reproducing the effects of the Wisconsin Card Sorting test showed that inner speech strongly enhances cognitive flexibility [147]. Consistently, the reduced use of IS can explain some impairments in children and elderly autistic people [148].

In keeping with the Words as Social Tools (WAT) theory [63, 14, 8], abstract concepts acquisition takes place within the social context through linguistic exchanges. One of the pillars of this theoretical proposal is the social metacognition hypothesis [14, 8], according to which the more abstract and complex concepts are, the more we would develop the metacognitive awareness of the limits of our knowledge [149]. Therefore, we would need to use inner speech to retrieve and re-explain to ourselves the word meaning or prepare ourselves to ask the meaning of words to other social actors [14]. Because of the higher uncertainty of word meaning, IS might be more likely to be utilized in the semantic search of abstract words compared to concrete words, helping us to put sparse information together in an ordered way to determine what the

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word really means [150-152]. IS might, thus, represent the gateway to access complex semantic meanings, which cannot be fully experienced through the five senses. Many studies have testified [review in 142] that IS requires articulation. If abstract more than concrete concepts require IS for their processing and IS has an articulatory component, then interfering with the latter might be more detrimental for abstract than concrete concepts. We addressed this question in a recent study [150] where we disrupted the phonological loop–formed by IS and the articulatory system [see 153]–during a semantic categorization task of abstract and concrete words. We took advantage of articulatory suppression, i.e., number, word, or syllable repetition, which has been widely used to interfere with the inner speech in cognitive tasks [154-155]. Participants were asked to decide as fast as possible whether a word was abstract or concrete during the subvocal repetition of a syllable, the manipulation of a softball, or without doing anything (baseline). Results indicate that the articulatory suppression significantly impacted the processing of abstract words compared to concrete words, while in the manipulation condition, the magnitude of the effect was reduced. Such evidence speaks in favor of the idea that abstract concepts processing might rely more on linguistic components than concrete concepts processing. It also suggests that social metacognition might be mediated by inner speech [14]: we presumably talk to ourselves through internal dialogue to better master complex meanings or to ask someone for a linguistic contribution dispelling uncertainties. Yet, processes entailing inner speech do not exhaust the complexity of grounded mechanisms accounting for abstract concepts representation. In the following sections, we provide evidence detailing how more situated–and yet, as we will claim, primarily embodied–processes contribute to the mastering and refining of our abstract conceptual repertoire.

4.5 **Grounding Abstract concepts in social interactions.** While concrete concepts can be easily understood by experiencing their referents through the body, the grounding in the sensorimotor system apparently fails to explain abstract concepts compellingly, without the integration of other systems like the linguistic one. Abstract concepts are acquired and mastered through the language itself, which can be intended as a sophisticated skill, or a "self-constructed cognitive niche" [156], grounded in sociality. Transmitting a meaning implies selecting relevant features of objects to form a labeled–and thereby recognizable–category. When creating a category related to a concrete entity i.e., " cat", we usually extract common features from perceptually similar exemplars located under the same semantic umbrella. We distinguish this *abstraction* process from the *abstractness* process that leads to the formation of abstract concepts [8]. The members of categories like "justice" or "democracy" do not have many common features and are pretty heterogeneous [low dimensional categories, 157]; typically, we cannot rely solely on our perceptual system to detect their similarities. Being abstract concepts among the most complex expressions of the interconnection between language and thought, they are challenging for philosophers, psychologists, and linguists. While in the case of concrete concepts, perceptually experiencing objects is a crucial step for creating and updating our basic knowledge of the world, negotiation and social exchanges seem to be the dynamic substratum of abstract concepts [63, 14, 158]. As already mentioned, according to the WAT proposal, the social origin of abstract concepts might be expressed by the mouth motor activation, which

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testifies the preparation to complement our knowledge by asking someone reliable to provide an explanation or to validate a meaning [social metacognition: 14, 8, 159, 149]. Such social validation of abstract concepts can be either vertical–or asymmetric–, as in the case of a kid who asks the teacher the meaning of a word, or horizontal–or symmetric–, as in the case of two peers discussing a concept. This two-folded notion of social metacognition, in which the contribution of others is not only intended in terms of hierarchically ordered linguistic exchanges but also as the symmetrical negotiation and co-construction of meanings, helps us unraveling a further possible mechanism leading to the relevance of language and sociality in abstract conceptual knowledge. In fact, in both cases, individuals must be successfully coordinated to share and verbalize a meaning; indeed, language and communication can be considered joint actions [160]. This aspect is especially evident in discussions that take place among peers concerning, for instance, politicized concepts. To illustrate, consider a concept like *freedom*: being an abstract concept, its definition encompasses several different situations; it can therefore be flexibly re-negotiated and articulated for contextual purposes [161]. Currently, for instance, it is debated whether enforcing laws promoting vaccination against Covid-19 represents a limitation to basic principles of personal freedom. So, the concept of *freedom* is constantly updated and revised in light of social changes, and this process of redefinition is made possible by social actors discussing and negotiating its meaning. Importantly, discussions available to the general public through social media, and social exchanges like casual conversations amongst peers, might all contribute to the grounding and reinforcement of specific abstract concepts. Both these mechanisms can be condensed into the idea of social metacognition as a grounding source. In fact, we hypothesize that when we retrieve the concept of *freedom*, linguistic and social experiences related to both vertical and horizontal social validation of meanings might be re-enacted to refine our conceptual repertoire. In two recent studies carried out in our lab with children and adults, we found evidence outlining the crucial role of sociality in the grounding of abstract concepts. In the first study [162], we employed thermal imaging while 5-7 years old children performed a lexical decision task with concrete and abstract words. Response times analysis revealed that children employed more time to process abstract than concrete words, indicating that the concreteness effect was present also in response times in very young children. More crucially, thermal imaging results revealed that the parasympathetic system was more active when listening to abstract words than concrete ones. This system has been associated with prosocial behaviors, thus confirming our hypothesis that, when processing abstract concepts, the need of others is more pronounced. In the second study implemented through kinematics techniques [163], participants were asked to perform a joint action task [164, 165] with two avatars who embodied two real confederates. Before and after the motor interaction task, participants took part in a concept guessing task, which consisted of guessing the concept evoked by a visual image. The confederates provided participants with hints to guess the correct concept associated with the image. One confederate helped to guess abstract concepts, while the other helped participants to guess concrete concepts. The results show that participants asked for more hints for abstract concepts compared to concrete concepts. Alongside this, participants were also aware of their higher need for others' help when

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guessing the meaning of abstract compared to concrete concepts. The metacognitive feeling or assessment of the limits of their knowledge might have led participants to rely more on available social actors and to show more deference [149]. Moreover, data from the human–avatar motor interaction task show that the need to rely on others influences participants' ability to interact. Participants' performance was more synchronous with the avatar embodying the confederate associated with guessing abstract concepts than with the one associated with concrete ones. This last result suggests that during verbal interactions involving abstract concepts, linguistic actors are particularly tuned in building up new insights on complex meanings. Remarkably, this fine attunement entails a physical and bodily synergy that might support and enhance linguistic exchanges.

Theories of cognitive evolution suggested that the development of abstract representations might respond to the need of being connected with conspecifics [166, 167]. Sharing abstract concepts entails a deep agreement of thoughts among individuals adhering to a system of values within a community. Indeed, social cohesion within and among groups is created and maintained through a dynamic network of co-built knowledge. In this sense, abstract concepts are not only the "glue" holding together sparse and heterogeneous information, but they also represent a "social glue" by providing a common reference of knowledge within societies [168]. If abstract concepts are intrinsically social in their origin and function, we could expect that any verbal interaction with abstract content might promote a sense of "psychological closeness"—provided that social actors draw from the same source of collective knowledge. We recently tested this hypothesis in a study [169] where participants were asked to write sentences through an online platform starting from abstract and concrete concepts. In one condition (i.e., "social condition"), participants conversed in dyads. In another condition (i.e., "individual condition"), they wrote sentences cued by abstract and concrete words independently, but knowing that on the other side of the screen, another person was doing the same—and that later they would read what the other had written. After each conversation or verbal production, we measured psychological distance through the Self-Other inclusion test (iOS) [170]. From the results emerged that conversing increased the psychological closeness between participants compared to the condition in which participants were not conversing, regardless of the abstract or concrete content of the verbal production. Looking at the results of the "social condition" alone, we found that conversations on abstract concepts were perceived as more demanding, and the contribution of the paired participants as more relevant when compared to conversations on concrete concepts. These findings suggest that in conversations prompted by abstract concepts, the contribution of others might be perceived as necessary because of the spontaneous dialogical approach to master abstract, complex meanings. Moreover, the higher the other's contribution in the conversation about abstract concepts, the more the psychological closeness increased between the interlocutors—while this was not the case for conversations elicited by concrete concepts. In keeping with the social metacognition proposal, when mastering complex and abstract meaning, we might prepare ourselves to a constructive dialogue to dispel ambiguities and increase the mental connection with the interlocutor. Finally, the role of linguistic and social interaction for abstract concepts processing is corroborated by a study in preparation [171].

Participants categorized different kinds of concrete (tools, food) and abstract words (theoretical, institutional concepts) primed by images representing a social-action (dancing together), linguistic-social (dialogue), and linguistic-textual (reading a book) situations, and a control condition (landscape). As predicted, the critical primes, but not the control one, modulated the processing of abstract but not of concrete concepts, slowing down response times. We interpreted the results, arguing that the linguistic and social experiences activated by the prime might conflict with similar resources necessary to form a simulation of the word's meaning. From these recent studies, we can conclude that social interactions appear to be the shared ground of abstract concepts acquisition and evolution.

5. Conclusion

This paper addresses the role played by the sensorimotor system across various processes, including perception and recognition of objects, conceptual acquisition, and abstract concepts and word processing. The involvement of the sensorimotor system at these different levels clearly indicates that the traditional distinction between low-level processes, like perception, and high-level processes, such as conceptualization and language, does not hold. Our results fit perfectly with theories of reuse [2, 3], according to which higher-level systems–such as language–build on lower-level ones. Once demonstrated and taken for granted the pivotal role of the sensorimotor system, the main suggestion of our paper is that future research should better understand how and to what extent this system is involved in different processes. Here, we focused on two aspects that we believe might offer precious insights in this pursuit and have illustrated their importance in light of recent evidence in our lab and in labs with which we collaborated. The first aspect is the flexibility of the engagement of the sensorimotor system under multifarious circumstances. We have seen through examples on affordances that their activation, hence the involvement of the sensorimotor system, is strongly influenced by the physical and social context. The second aspect is the different levels of involvement of the sensorimotor system, the role of which can be integrated and flanked by that of other systems. As we fleshed out throughout the paper, when abstractness increases, concepts are more detached from sensory modalities, and language acquires a prominent role. However, this does not rule out sensorimotor components. On the contrary, we discussed studies providing evidence that varying sensory modalities are still active, even if to a lesser extent, or in different forms. Understanding the mechanisms underlying this flexibility and the level of involvement of our sensorimotor system representsin our view two significant challenges for future research.

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