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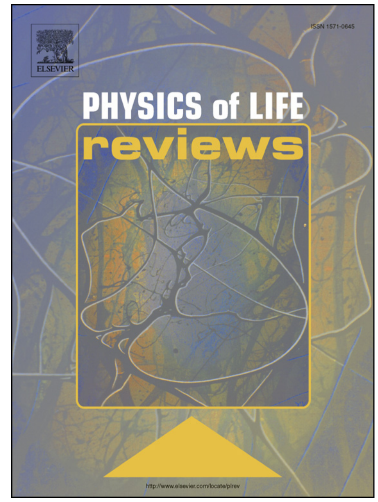

Words as social tools: Language, sociality and inner grounding in abstract concepts

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Highlights

- Words can be considered as tools to perform actions (Words As social Tools, WAT).
- Abstract concepts acquisition is strongly shaped by social and linguistic experience.
- Abstract concepts recruit linguistic (oral motor system) and social brain areas.
- Abstract concepts are affected by differences between spoken languages.
- Abstract concepts are grounded in interoception and metacognition.

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Words As social Tools: language, sociality and inner grounding in abstract concepts

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Abstract

The paper introduces a new perspective on abstract concepts (e.g. "freedom") and their associate words representation, the Words As social Tools (WAT) view. Traditional theories conceptualize language as a way to index referents, a shortcut to access meaning, or a way to access meaning through words associations. WAT goes beyond these theories by identifying additional functions of words and language: words are tools helping us to perform actions and change the state of our social environment, **and** language is a means to improve our thought abilities, to control our behavior and plays a predictive role, helping us to form categories. Most importantly, WAT proposes that language and sociality - along **with** interoceptive and metacognitive processes - are key for the grounding of abstract concepts (ACs) that are more complex, variable, and more detached from perceptual **and motor** experience **than** concrete concepts (CCs). We highlight four tenets of WAT and discuss each of them in light of recent evidence: a. acquisition: compared to concrete concepts, the acquisition of abstract concepts relies more on social and linguistic inputs; b. brain representation: abstract concepts recruit more linguistic and social brain areas; c. mouth activation: due to the relevance of language for representing them, abstract concepts activate more the oral motor system; d. linguistic variability: abstract concepts are more affected by differences between spoken languages. We discuss evidence supporting these four tenets of WAT, and its advantages and limitations compared to other views on abstract concepts. Finally, we outline a conceptual proposal **that specifies how** internal models supporting the representation and processing of ACs **can be** grounded **on** interoceptive, metacognitive, social, and linguistic experience.

Keywords: abstract concepts, abstract words, embodied cognition, inner grounding, inner speech, grounded cognition, language, social cognition, word acquisition, interoception, metacognition

1. Introduction

“When I cannot see words curling like rings of smoke round me I am in darkness—I am nothing.”
— Virginia Woolf, The Waves

The capability for abstract thought is one of the hallmarks of our species. Strikingly, however, despite much research on abstract thought and its neural correlates, we still lack a comprehensive framework to understand this multifaceted phenomenon. The **aim** of this paper is to outline a novel theory on the neural and mental representation of abstract concepts (from now on ACs). Providing a convincing account of ACs has become particularly urgent due to the recent spread of embodied and grounded views of cognition (e.g.[1]): while these approaches have provided robust evidence that concrete concepts are grounded in perception and action systems, it is still unclear how ACs can be similarly explained - given that they are more complex and less directly related to sensorial experience (review: [2]). Explaining ACs represents a difficult challenge, as they are quite heterogeneous and include for example numbers, social concepts, mental states. Below we will first clarify what we mean by ACs and then present our proposal and discuss its empirical basis in light of recent evidence collected either in our lab or in other labs. Finally, we will compare WAT to other theories of ACs, highlighting its strengths and limitations as well as its ability to cover the variety of ACs.

From abstraction to abstractness.

Abstraction. To some extent, all concepts are the product of an abstraction process [3]. For example, the concept of “chair” abstracts from the single characteristics of specific chairs.

Abstraction is even more prominent if we consider superordinate concepts, such as “animal” or “furniture”. However, during the processing of superordinate concepts as “animals” we likely activate a collection of instances **like** cats, elephants, etc., the referents of which are clearly concrete entities [4], [5], [6]). This is not the case for ACs.

Abstractness. This paper focuses on abstractness, a kind of abstraction that goes beyond collections of instances, to encompass various kinds of ACs. **Abstractness concerns knowledge domains that are less spatio-temporally bounded and cannot be fully tracked with exteroceptive senses alone. Prototypical examples of abstract concepts are “fantasy”, “freedom” and “justice”. Characterizing ACs as a unitary kind, however, is a difficult task. ACs come indeed** in a great variety: they span from emotional to numerical concepts, and include concepts as diverse as social roles, mental states, institutional and temporal concepts.

Despite **this heterogeneity**, ACs **still share** some commonalities. Compared to concrete concepts (CCs), ACs are [7] a. more complex: they typically “capture complex configurations of physical and mental events” [8]; b. more detached from physical experience, **although** they might also activate perceptual modalities [9] and interoceptive experience [10] [11]; c. more variable, both across and within participants, in different situations.

Multiple representation space, not dichotomy. In our view, CCs and ACs are not opposed in a dichotomous way [12]; a multidimensional space exists, in which different concepts are distributed as a function of their similarity **along different dimensions [13], one of which is abstractness/concreteness, arranged along a continuum. Indeed any one** concept includes a combination both of concrete and abstract information: for example, a credit card has a concrete, physical referent, but its exchange value can be hardly reduced to the material object it refers to. **The distinction abstractness/concreteness is however too simplified [14], because of the high**

correlations between abstractness/concreteness and other variables. For example, concreteness is highly correlated, even if not equivalent, to imageability [15]. In a recent rating study Villani, Lugli, Liuzza and Borghi (submitted; under review), demonstrated that more abstract concepts obtain higher scores in linguistic rather than perceptual acquisition (Modality of Acquisition, MoA) [16], [17], in social metacognition (feeling that the contribution of others is crucial to let us understand the word meaning) [18], and are evaluated as acquired later than CCs. Hence, abstractness is highly correlated with linguistic MoA, social metacognition, late Age of Acquisition (AoA). Concreteness is instead highly correlated with Body-Object-Interaction [19],[20] imageability[21], [22], context availability[23].

Concepts and words. Where possible we will distinguish between "concepts" and "word meanings". Collapsing "concepts" and "word meanings" would be a mistake: conceptual representations might exist, that do not have a corresponding word. Furthermore, the use of linguistic labels changes the underlying concepts: for example, it has been shown that word use influences perception of objects/entities, and renders categories more compact and discrete ([24], [25] [26]). Even though this distinction is important and we will try where possible to stick to it, in some cases it is difficult to maintain, because most studies on concepts, with the exception of those on prelinguistic infants and with artificial categories, make use of linguistic stimuli. Furthermore, consider that all human concepts are likely strongly influenced to some extent by our faculty to use language.[1]

[1] We will not consider concepts of non-human animals. Even if they might be able to represent some ACs, as "same/different" [27], the human capability for abstractness overcomes that of other animals at a qualitative and quantitative level, likely due to the influence of language.

Concepts kinds. While multiple kinds of ACs exist, in many cases so far they have been considered as a unitary whole (see for exceptions[28] [29] [30] [31], not exhaustive list). The number of papers focusing on specific abstract concepts (e.g. emotion, numbers etc.) is increasing, but a careful and fine-grained investigation of the different kinds of ACs, and of their representation, is currently missing [32], with the exception of a few attempts.

These studies suggest that different kinds of ACs (e.g. numbers, mental states), might rely on at least partially different cognitive mechanisms. For example, Villani, Lugli, Liuzza and Borghi [under review, submitted] found that different mechanisms and dimensions subtended grounding of four different kinds of ACs: ACs referring to space-time, math, and physics (e.g. “reflex”, “space”, “symptom”) were characterized by high scores in concreteness and imageability and low scores in inner grounding (emotion, interoception, metacognition), ACs related to self, social relationship and social institutions (e.g. “charm”, “politeness”, “conflict”, “separation”) were characterized by inner grounding, sensorimotor features and concreteness, emotional and inner states ACs (e.g. “uncertainty”, “irritation”, “instinct”) were characterized especially by inner grounding. Finally, philosophical and spiritual ACs (e.g. “value”, “principle”, “mystery”) were not grounded in any of these dimensions. Desai et al.[33] performed a meta-analysis on four types of abstract concepts (numerical and emotional concepts, morality judgments and theory of mind), examining their similarities and differences through meta-analyses. They demonstrated that all ACs they examined activated areas overlapping those of CCs, in line with a grounded approach. They also demonstrated similarities in the activations of morality and theory of mind concepts, which engage areas related to social and episodic memories or to emotions and imagery. The distinction between abstract concepts in terms of the features they activate has also been highlighted by a recent study with a feature production task [34]. These examples show that it is difficult to argue

that a single mechanism can account for the representation of all ACs. In sum: we propose that, while all ACs are characterized to a larger extent than CCs by linguistic experience, social metacognition, and inner grounding, these mechanisms might have a more or less relevant role depending on the kind of ACs we consider.

2.The WAT proposal: the theory

2.1. WAT in a nutshell: the main tenets

WAT adopts an embodied and grounded (EG) approach to cognition ([35] [1] [36],[30] [37] [38] [39] [40] [41] [42] [43] [44]**; for possible limitations of this approach see**[45] [46]): we assume that conceptualization is based on re-use and exploitation of mechanisms and structures characteristics of the more basic systems supporting perception and action [47] [48] [49]).

In our view both CCs (e.g. "book") and ACs (e.g. "**justice**") re-enact previous multimodal experiences with their referents (simulations) – for example the visual, tactile, acoustic and emotional experience of reading a "book", or **the multimodal experience of "justice" (see below)**. Since the brain is a powerful predictive machine that guides our interactions with the world, simulations play a predictive role: re-enacting previous experiences with objects/entities helps us recognize and interact with them).

EG views have inspired research demonstrating that concepts are grounded in perceptual and motor systems and that words are not arbitrarily linked to their referents but point to them. This "referential" approach has played a crucial role in contrasting propositional views leading to the increasing popularity of EG views. However, most evidence on the grounding of concepts is still limited to CCs. Furthermore, in our view this referential approach does not fully recognize what shown by philosophers since Wittgenstein [50], i.e. that meaning depends on practice [51].

To represent the potentialities of language WAT adopts the metaphor of words as tools. The metaphor is not new (e.g.[52]): Wittgenstein [50] who introduced it, viewed words as tools in a toolbox that can be combined and used in multiple ways; their meaning differs depending on the "language game" of which they are part. In line with and extending Wittgenstein's view, WAT extends the EG approach considering words not only **as** pointers that indicate referents, but **as** social instruments to perform actions with objects and others ([53], [54], [55]) and **as** powerful means to improve thought processes ([52], [56], [57]). Words are tools to perform actions and change the state of our social environment. They are tools for shaping the state of our external environment, modifying our relationships with other **people**. Studies of pragmatics have shown that sentences as "You are married" can be considered as actions that change the status of the relationship between people ([58], [59]). But this is not the whole story. Using a label to refer to a category can change the way in which we perceive the external environment. When perceptual inputs are noisy, hearing words can lead our visual system to generate predictions that facilitate their perception and recognition ([55], [60]). Furthermore, using words can modify the way in which we represent a category. For example, using the word "car" can help to render the category of cars more compact, and it can contribute to a better perception of the category members. This is true also for inner states: using the word "boredom" can help us better track our internal state in a specific moment. We propose that, **although** this phenomenon occurs for both concrete and abstract words, it is particularly pronounced for abstract words. Furthermore, words are tools that shape the state of our own brains/minds: we will argue that the use of inner speech helps us to refine our thoughts. Hence, words are tools to perform action modifying the state of our social environment, and are tools that change the state of our inner processes, helping us formulate predictions and facilitating perception, categorization, and thought. As such they are also tools for shaping the internal state of our minds/brains. We choose the acronym WAT, “Words As social Tools” to emphasize this very fact. Starting from this framework, our proposal on ACs has four specific tenets.

(1). Social and linguistic acquisition of ACs. The acquisition of and CCs and ACs follows different trajectories. While CCs are typically created by **grouping** members **that are perceptually similar**, members of ACs are instead heterogeneous. **As a consequence,** the social and linguistic input is more important to bind them together.

Although many CCs are also acquired in a social/linguistic context, we claim that the role of language and the importance of others for the acquisition of CCs is less relevant than for ACs, because of the frequent presence of the referent of CCs, which is typically single, bounded and easy to identify. Similarly, when we read, hear or use a CC we might easily re-activate its referent, while this process might be more complex in the case of ACs. This difficulty might induce us to use inner speech.

More specifically, we hypothesize that the formation of ACs relies on two important, previously developed abilities: a. the capability to form flexible categories, ascribing the same referent to different categories - for example, ad-hoc and goal derived categories ([61], [62]), or categories formed on the basis of a common goal, whose members are not necessarily perceptually similar. An example of ad-hoc category is “things to bring to the camping place”, which can include items as diverse as pets, books, and toothbrushes (see also “slot-filler categories”, [63], [64]); b. the capability to make use of social competences, as those involved in joint attention and joint action ([65]).

(2). Brain representation of ACs. We contend that the brain representation of CCs and ACs is partially different. While both activate sensorimotor networks, linguistic and social cognition networks are more activated by ACs.

(3). Mouth activation with ACs. From an embodied viewpoint, concepts are grounded in the modalities, and in the same perceptual and motor systems that support their acquisition. Given that ACs are acquired socially and linguistically, their embodied counterpart is the activation of the mouth ([66], [67], [68]). We propose that the sub-vocal pronunciation of words ([69]) is more pronounced in the case of ACs processing, because of the importance of language for their representation. We hypothesize that, the more abstract and complex concepts are, the more we would develop the metacognitive awareness of the limits of our knowledge. We would therefore **need to** use inner speech to retrieve and re-tell to ourselves the word meaning, or to prepare ourselves to ask the word meaning to others ([18]). Crucially, we propose that the activation of inner speech is not simply a side-effect ([70]), but that it is constitutive of ACs processing, as suggested by evidence with interference paradigms that we review later.[2]

(4). Language diversity and ACs. While all concepts are shaped by natural languages, we propose that the influence of linguistic diversity is more marked in the case of ACs, since linguistic experience plays a major role in their representation ([72]).

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[2] **The mouth motor system can be activated also for CCs the content of which directly refers to mouth actions, such as food concepts or concepts directly related to discourse (e.g. "talk") [71]. We however contend that the mechanisms subtending such activation differ: while in the latter case the mouth activation is evoked re-enacting a situation (for example that of eating), in the case of ACs it is functional to the search and retrieval of word meaning. Further research is needed in order to find fine-grained ways to distinguish between the mouth activation led by these different mechanisms.**

The importance of language and sociality for ACs is due to many reasons. Firstly, the diversity of ACs members might generate different hypotheses on the conceptual content; a unifying label can thus work as a sort of "glue" keeping sparse experiences together, contributing to reduce the working memory overload linked to the generation of many hypotheses. Second, linguistic and social inputs are crucial for the acquisition of ACs, since that lack of concrete referents makes perceptual learning harder. Explanations of experts (parents, authorities and experts in the field, and even electronic or written resources) are fundamental to capture the meaning of ACs. Finally, because ACs are complex and their exemplars heterogeneous, we may need to engage (largely unconsciously) in inner speech to re-enact their acquisition and to accompany inner (metacognitive) brain operations, or we may prepare ourselves to ask the word meaning to competent others. Both actual dialogue and inner speech recruit the phono-articulatory system and mouth activation - which then may become fundamental for the embodiment of ACs[3].

It should now be clear that WAT focuses on the mechanisms that underlie the formation and use of ACs ([2]). This focus on mechanisms leads to specific predictions: the more abstract concepts are, the more they are innerly grounded and the more they engage linguistic and social brain areas and recruit the mouth effector. Overall, we maintain that, beyond being grounded in perception and action, ACs are also grounded in linguistic and social experience and in inner experiences (interoception, metacognition). **Specifically, we propose that, compared to CCs, 1) the acquisition and representation of ACs is fundamentally tied to linguistic and social experience; and 2) their grounding is more dependent on "inner" processes of two kinds: interoceptive signals that come from within the body, and metacognitive processes that**

[3] When we refer to language we do not imply that experiential information is translated into amodal, propositional symbols. We focus instead on the linguistic experience, embodied and grounded.

monitor own cognitive processing as opposed to, for example, perceptual processes that are sensitive to the environment outside the organism.

In what follows we will discuss each tenet in light of recent evidence. Then we will sketch the processes that might lead to the formation of ACs and CCs adopting a Bayesian framework.

3. The WAT proposal: evidence

In this section we will discuss evidence that either directly test WAT, or reaches conclusions in keeping with it. We will separately discuss evidence related to each of the four tenets (see Table 1).

3.1. Social and linguistic acquisition of ACs

We will illustrate here evidence on infants, children, and adults that supports the idea that social and linguistic experience is crucial for ACs acquisition.

3.1.1. Infants: the beginning of comprehension

Six- **and** seven-months-olds already know the meaning of CCs, as **they readily understand** words for food ("banana") and body parts ("hand"). Knowledge of the meaning of ACs, instead, develops later. In a study investigating the comprehension of abstract words (e.g. ''eat,'' ''wet,'', "all gone", ''hi'') parents were required to name one of two events in a video, while infants watched ([73]). From 10-13-months **of age**, infants watched the video significantly more than chance level; crucially, their performance increased dramatically at 14 months, not only with CCs but also with ACs.

These data open two alternative possibilities: a. children need to master a richer vocabulary to understand ACs: this is supported by mother-child interactions data showing that mothers tend to use ACs when their referents are absent; b. at 10 and 14 months children develop social abilities that allow them to learn ACs. Indeed, between 9 and 10 months infants refine their capability to follow others' gaze ([74], [75]) and to follow hands of others manipulating objects ([76]), while at 14 months joint attention capabilities are mature ([77], [78]).

Common to both explanations is the idea that partially different mechanisms underlie early and late word learning. Since ACs are acquired later than CCs, they might benefit from the developed social or linguistic competences, or from both. Studies conducted on toddlers support both claims.

3.1.2. Toddlers: flexibility in referential and social competence

After 14 months of age the social abilities of children develop greatly. 14-month-olds respond differently to adult's excited gaze direction depending on what he/she had previously seen ([79]). 15-month-olds expect other people to search for an object where they had previously seen it ([80]).

The ability to follow gaze direction emerges soon ([81]), but only between 12 and 18 months children become aware of what others see and know ([82]). This is clear from evidence by Tomasello and Haberl [83] who had a child, an assistant and an adult playing together with two toys. Then the adult went away and a third toy appeared; when the adult came back and said excitedly "Look at that one!"; both 12- and 18-month-olds correctly referred the expression to the novel object.

At 15 months the dependence on joint attentional scaffolding provided by adults starts to decline ([84]), and the engagement with the object referent and with the speaker becomes progressively less crucial for word learning. 24-month-olds can use the social context to determine whether to attach a novel label to a hidden object rather than to a novel object. If the experimenter indicates that she made a mistake in using a label, 18- and 24-month-olds **associate the novel label with** the second object/action they see ([85] [86]). From 18 months children became increasingly sensitive to the social context: for example, they distinguish whether adults pronouncing a label in great excitement on the phone refer to the object they are playing with or not ([87]). Children are thus able to flexibly dissociate the category from its referent, taking into account the social input.

18 month-olds also start to learn new words while listening to conversations ([88]); this capability is likely related to the vocabulary spurt, occurring around 18 months, but continues to develop. By 24 months children learn nouns, by 30 months new verbs through overhearing [89]); they learn new words even when distracted by interesting toys ([90]).

Later, at the ages of 2 and 3 children become sensitive to linguistic cues linked to referents that are common ground between speaker and listener: for example, when asked to get “the X” (definite article) they are more likely to choose the shared object than when asked to get “a X” ([91]).

In sum, in their 2nd and 3rd year, toddlers develop a rich body of linguistic and social abilities: the ability to flexibly use labels, progressively disengaging from the presence of the referent; the ability to learn through overhearing; the sensitivity to the social context and to linguistic cues referring to common ground elements. We propose that these abilities are not only related to linguistic development in general but specifically to the acquisition of ACs, since the referent of ACs is either not present or not a perceptually identifiable object. In line with this view, below we review work showing that social and linguistic cues become progressively more relevant for word acquisition.

3.1.3. From toddlers to preschool children: the Emergentist Coalition Model

The relative importance of perceptual and social cues in word acquisition was investigated in order to test the Emergentist Coalition Model ([92], [93],[94]), according to which different processes characterize early and later stages of word learning. In a typical experiment, children at different stages of the word acquisition process – 12-13, 19-20 and 24-25 months – were presented with two objects; the experimenter named either an interesting or a boring object. Even if they were able to detect eye-gaze, 12-month-olds learned the name only when it applied to the perceptually salient object; 19-month-olds were able to overcome perceptual salience and learned the name also when it referred to a boring toy. Older children selected referents taking into account the social input but were still influenced by perceptual salience.

The conclusions these studies allow to draw are highly relevant for us. Because the social input becomes more crucial in the course of development, and ACs develop later than CCs, the acquisition of ACs is likely more influenced by social cues. WAT proposes a further related claim, not tested in these experiments: the social input is crucial for ACs because they are difficult to acquire on the basis of perceptual similarity, since their members are highly heterogeneous.

3.1.4. Preschool children: Studies on testimony

Literature on testimony indicates that preschool children are willing to receive clarifications by adults ([95]). Testimony is particularly relevant with concepts as “God” and “afterlife”, where the environmental inputs are insufficient ([96]). Children do not simply passively receive information but integrate it with their previous knowledge. The persistent use of “why questions” between 3 and 6 years of age testifies that children consider adults as reliable sources of information ([97]). However, around 3-4 years they monitor the accuracy of the information they receive and the speakers’ competences: they prefer to obtain information from people who claim competence rather than ignorance, and from people who do not show uncertainty ([98], [99], [100]). At 4-5 years, they even revoke their trust in familiar informants when they are not accurate, preferring more competent unfamiliar informants ([95]).

3.1.5. From toddlers to adults: hard words and the linguistic bootstrapping hypothesis

Studies on adults support the hypothesis that the acquisition of ACs occurs after a certain amount of CCs has been acquired ([101], [102], [103]). In experiments performed by Gillette et al. [101], adults observed video-clips of mother-child interactions and had to guess the "mystery word" pronounced by the mothers when the videos were silenced. Participants' performance reflected the acquisition order of words in children, and depended on concreteness rather than on word class: for example, the concrete verb "kiss" was acquired before the abstract noun "idea" ([104]). In a further experiment participants were given multiple cues to support acquisition of verbs, from visual to linguistic to syntactic cues; finally they were given both visual cues and syntactic and noun information (syntactic bootstrapping). Each condition led to a better performance than the previous condition. Efficient word learning was possible when multiple cues were present.

On the basis of such evidence, Gleitman et al. ([103]) proposed a developmental pattern of word learning characterized by some similarities with the WAT one (syntactic bootstrapping hypothesis: [105]). According to it, children start acquiring easy words, as concrete concepts, through a word-to-world mapping mechanism. However, words as perspective verbs ("chase"; "give-get") and creedal verbs ("think", "know") cannot be learned solely on the basis of this mechanism. Gleitman argues that the word-to-world mapping mechanism has to be complemented by a different one. Once children have acquired a substantial number of words - mainly nouns, learning proceeds by adding structure to the original machinery, thus allowing acquisition of "hard" words. The syntactic bootstrapping consists in a "probabilistic multiple cues learning process", in which syntax and semantic acquisition are strictly interconnected. Lexical acquisition implies a temporally ordered sequence: to understand the verbs first a certain amount of nouns have to be learned. Obviously, syntax cannot substitute semantics, but it can help learners to narrow their hypothesis on possible word meanings. The crucial role played by syntax would be demonstrated by language development: children first speak one word at the time and do not master syntax; later the speed of language acquisition triples, in correspondence with learning of syntax.

3.1.4. From toddlers to adults: age and modality of acquisition of ACs

Many studies have shown that CCs are acquired earlier than ACs. According to Gentner ([106]), children first learn words with easily discoverable referents, such as proper nouns of animate entities and concrete nouns. Later they acquire also verbs and ACs. Gleitman et al. ([103]) claim instead that the "hard" words are the abstract ones, be they nouns or verbs. Here we consider abstract words independently from their grammatical category. In this respect, literature on Age of Acquisition (AoA) and Modality of Acquisition (MoA) is very informative as to the peculiarity of ACs acquisition, as we will show below.

AoA. In AoA norms participants estimate in years when they learned a word ([107]). **AoA and concreteness are negatively correlated; for example, in a sample of 626 Italian nouns it was found that earlier acquired words are typically rated as more concrete than later acquired ones** [108]. Data indicate that only 10% of the vocabulary of 4-year-olds is composed by ACs, with a progressive increase with age: ACs represent 25% of 5-year-olds words and more than 40% of 12-

year-olds vocabulary [109]). This late learning is clearly compatible with the pivotal role of linguistic experience for ACs.

MoA. MoA ([110]) is measured by asking adults to judge whether words are mainly acquired perceptually (hearing, smelling or touching the word referent, e.g. "chair"), or linguistically (e.g. "century"). Some words are learned through both modalities, depending on the environment in which children grow up (e.g. "tundra"). MoA is correlated (.59) but not correspondent to AoA. Results show that in Grades 1-3 words are mainly acquired perceptually, in Grade 4-6 texts mainly through linguistic input: hence, linguistic input becomes progressively more important with age, and with the increase of the conceptual complexity.

Interestingly, MoA is related to the distinction between scientific and spontaneous everyday concepts proposed by Vygotsky ([111]). According to the author, the adult's guidance is critical for the acquisition of both, but spontaneous concepts are learned during common participation to everyday activities, while scientific concepts require systematic forms of instruction. In his words: ''In the scientific concepts that the child acquires in school, the relation to an object is mediated from the start by some other concept.'' ([111], p. 172).

Overall, literature on MOA indicates that linguistic acquisition modality becomes progressively more important with age; moreover, the input of others might be particularly crucial for scientific concepts, which are often more abstract. Since ACs are acquired later than CCs, the reported evidence implicitly suggests that language is more important for ACs acquisition.

3.1.6. From children to adults: an emotion-based bootstrapping mechanism?

Beyond language and sociality, also emotions can support ACs learning. Kousta et al. [15] have proposed that emotional concepts provide a bootstrapping mechanism, facilitating ACs acquisition:

when dealing with emotion concepts, for the first time children learn to use concepts without objects as referents.

Consistently, abstract emotional abstract words are learnt earlier than abstract neutral words; and in an auditory lexical decision task children aged 8–9 were more accurate with abstract emotional words over neutral words [109]. Such effect disappeared after 9, likely because valence is not necessary for word learning in older children. This result is compatible with WAT, first because it shows that early words are grounded either in concrete referents or in interoceptive and bodily states, second because it supports the claim that a precondition for ACs learning is the capability to form flexible categories, progressively disengaged from the word-object mapping, and third because it indicates that the role of linguistic information becomes prominent later.

3.1.7. Adults: Acquisition of ACs

The role of language is not only crucial for acquisition in children but also for ACs learning in adults, as testified by recent evidence. In some studies mimicking word acquisition adults were presented with novel categories, then they were taught novel names for them ([112],[113]). Participants who had been taught the name and given an explanation of the word meaning were more accurate in a following category recognition task with ACs, but not with CCs. Participants who benefited from the linguistic training more were those whose initial performance with ACs was worse, confirming the importance of linguistic information (label and word meaning explanation) for building ACs.

3.1.8. Acquisition of ACs: how the process might occur.

“If we will observe how children learn languages, we shall find that...people ordinarily show them the thing of which they would have them have the idea; and then repeat to them the name that stands for it, as ..‘sweet’,.. ‘milk’, ‘cat’...” ([114]).

Results discussed in this section support the hypotheses that ACs and ACs learning is strongly constrained by the development of social abilities and the amount of experience with language. In the first phases of development, sensorimotor information would have a major weight in updating ACs representations; later, both social and linguistic information may be important and then, in adulthood, mostly linguistic information might assume a greater role (see Figure 1).

Figure 1. A sketch of the development of ACs, in which both the perceptual and social/linguistic input play a major role, but the distribution varies with age with an increase of the role of the social/linguistic input.

The quote from Locke perfectly describes the first phase of word acquisition, an embodied process where the visual environment plays a major role. Elegant studies with head-mounted cameras by Smith and collaborators clearly demonstrated this (e.g.[115]). Before children start naming objects, visual familiarity with objects critically improves learning of name-object links. Moving in space, children get closer and focus on interesting objects, encoding their similarities and relations ([116]); these moments are optimal to map words and objects, since the referential ambiguity is highly reduced, and children can fully benefit from adults’ linguistic input ([117]). Robust evidence shows that Western-society children extend object names on the basis of shape ([118]), and this likely occurs because shape is grounded in action ([119]).

To acquire abstract words, that do not have a single object as referent, reliance on such an embodied and vision-based statistical learning mechanism might be too costly and the role of the social ([85]) and linguistic context might become more prominent ([120]), even if visualization continues to be crucial ([121]). ACs might then become associated not only to their referents but also to other words ([103]). Importantly ACs acquisition - occurring also through linguistic and social input - is not a disembodied process, as statistical distributional views would contend: below we report and discuss behavioral and fMRI evidence showing that ACs activate the oral motor system, as well as the acoustic system. **Arguing** that multiple inputs undergo the complex process of word learning, the model of developmental course we have traced has affinities with dynamic, system-based models ([122]).

This developmental course, in which perception-action and social-linguistic input have a different weight depending on age and the kind of concepts, is compatible with many of the results we have illustrated. It is namely compatible with: a. the late acquisition of ACs, occurring after the vocabulary burst; b. the increased social abilities of toddlers and children, as revealed by the abilities in gaze following, joint acting, following others' input, and by the increased ability of 3-4 and 5-6-olds to attend to the competence of their information sources; c. the increased linguistic abilities, as that to use labels in absence of their referent, to use linguistic cues linked to referents that are common ground between speaker and listener, to learn through overhearing, to master syntax, to possess a wide vocabulary allowing children to acquire meanings linguistically.

3.2. Brain representation of ACs: social and linguistic networks

ACs recruit mainly linguistic and social brain areas. We will first illustrate neuroimaging results, then evidence on clinical populations supporting this claim.

3.2.1. fMRI and PET: left linguistic network

fMRI and PET studies demonstrated a stronger engagement of language processing networks with ACs than with CCs. Two recent meta-analyses focused on brain activation show that most studies converge in highlighting a higher left-hemispheric activation of ACs compared to CCs, determined by stronger activation for ACs of the left inferior frontal areas, especially left inferior frontal gyrus (LIFG) (mostly pars orbitalis, Broca area), left middle temporal gyrus (LMTG) ([123]) and anterior superior temporal sulcus (STS) ([124])[4] (see also [125], [126]).

LIFG. LIFG is typically linked to phonological processes, lexical retrieval, verbal working memory, syntax, and is involved in sub-vocalizations ([127], [128], [129]. With LIFG TMS stimulations lexical decision is less accurate ([130]). Lesions to LIFG produce deficits in phonological and syntactic processes ([131]). Pars orbitalis plays an emotional-social function within the linguistic network of the brain ([132]).

The activation of LIFG with ACs has been differently interpreted.

Due to high variability and semantic difficulty of ACs, LIFG activation has been ascribed to the longer time in which items are kept in phonological short-term memory to be processed ([133]). This interpretation is compatible with the WAT hypothesis that ACs are characterized by a high degree of uncertainty, likely leading to a longer permanence in working memory, and that we might re-hearse or re-explain the word meaning through inner speech, possibly activating associate words ([134]).

[4] From the meta-analysis by Binder et al. [124], conducted on 120 studies, we will refer to 17 studies on perceptual vs. verbally acquired concepts, the majority of which contrasting CCs and ACs. The meta-analysis by Wang et al. [123] refers to 19 fMRI and PET studies on ACs and CCs.

LIFG could also provide logical functions that characterize ACs. According to Shallice & Cooper, ([135]) in order to represent them we would need to compute logical functions. On the basis of double dissociations found in patients, they propose that two separable systems exist: a feature-based system, common to ACs and CCs, and an additional system specific for ACs. LIFG would either be the location of the semantic representation of ACs, or the system that accesses or builds such representations integrating representations distributed over the left prefrontal cortex. Shallice and Cooper [135] hence postulate a computational machinery similar, but not identical, to that used for syntax and semantic binding ([136], [137]). We argue instead that perceptual symbols are endowed with such productivity and computational power, as demonstrated by Barsalou ([35]), and they guarantee the ability to process ACs. Alternatively, we contend that the linguistic system can offer the adequate computational machinery to support ACs representation, as proposed by Dove ([138]) but without the need of transducing linguistic experience into an amodal representation (see [2] for discussion).

LIFG has also been often associated to semantic control and executive regulation.

Finally, fMRI evidence of recruitment of LIFG (orbitalis and triangularis areas) when reading sentences with emotion-social and social content ([132];[139]) is clearly compatible with the WAT proposal of a link between linguistic and social experience in ACs.

LMTG. LMTG is involved in several aspects of word processing. It is for example implied in text comprehension (meta-analysis: [140]), in accessing word meaning ([141]), in comprehension of ironic and deceitful communication ([142]). During comprehension of non-literal language it works like a multimodal association area within language networks ([143]). Lesions of LMTG und LPTG can be associated with alexia and agraphia for kanji characters ([144]). The difference between ACs and CCs in LMTG activation has been associated to the use of different retrieval strategies, rather than to different representations ([145]).

LSTS. LSTS is engaged during phonological processing and social perception (e.g. face processing, ToM). A meta-analysis with PET and fMRI studies showed different sensitivity of its subregions to language and non-language materials ([146])[5]. A more focused meta-analysis ([147]) revealed that the anterior STS regions were mainly recruited for speech processing, posterior regions for motion processing, AV integration, and face processing. Importantly, the functionality of this area can be determined by the coactivation with other brain areas: when co-activated with inferior frontal cortex, STS is involved in speech processing, when co-activated with medial prefrontal regions is involved in mentalizing.

STG. Hoffman et al. ([148]) showed that, while the Anterior Temporal Lobe (ATL) was engaged during semantic judgments of CCs and ACs, ACs activated more strongly the Superior Temporal Gyrus (STG), a dorsolateral temporal area associated with acoustic experience, while CCs preferentially activated areas associated with visual experience. Mellem et al. ([132]) demonstrated activation of both LSTS and STG based not only on linguistic material but on semantic content related to sociality.

The circuit of activated areas is consistent with the WAT proposal that linguistic and social networks are crucial for ACs. fMRI and PET studies converge in showing a higher engagement of

[5] The middle portion of this region is specialized for processing language, the posterior part, highly versatile, is more sensitive to non-linguistic stimuli, especially emotions. Finally, the horizontal portion and terminal ascending branches (*ft*STS) is divided into two sections, the anterior-dorsal ascending branch engaged during executive functions and motor planning and highly sensitive to linguistic stimuli, and the horizontal stem and posterior-ventral ascending branch supporting semantic processing and more sensitive to non-language material.

LIFG, typically activated for language production, phonological processing, executive control, and socio-emotional contents, of STS and STG, involved in auditory processing and social cognition, and of MTG, typically engaged during read words comprehension and known faces recognition.
The importance of language for ACs is confirmed by studies revealing that in elderly the processing advantage of concrete over ACs (concreteness effect) disappears, likely due to the slower decay of linguistic abilities with age compared to other abilities as visual ones (review: [149]).

ATL. Another crucial area for semantic processing is ATL. Recent focus on ATL is especially interesting, because in the classical aphasiology there was no mention of ATL. The reason for this is the different vascular innervation of ATL and the classical speech areas – Brocas and Wernickes areas. It was never hit by a stroke. Only after semantic dementia was discovered and scrutinized in detail it became obvious that ATL is a crucial language region. Lambon-Ralph and collaborators propose a graded specialization of ATL for ACs and CCs processing [150]. Superior ATL, connected to primary auditory processing areas in posterior STG and specialized for semantic processing of auditory and verbal stimuli, when compared to pictures ([151]), is also engaged during ACs processing ([148]). Ventromedial ATL, engaged more when participants make semantic decisions to pictures relative to words, is more activated for CCs than for ACs.

While the greater engagement of the verbal system for ACs is established, it is debated whether ACs processing is accompanied by simple linguistic rehearsal or also by semantic information.

Scholars namely debate, whether the left inferior frontal and superior temporal regions represent components of a semantic system or not. Adopting an EG stance, we do not see the contrast between linguistic rehearsal and semantics: in our view the simulation of the meaning could namely occur through linguistic rehearsal and involvement of the mouth.

According to Sabsevitz et al. ([152]) posterior areas of frontal regions and anterior areas of temporal regions, more active for ACs and for non-words ([133]), concern primarily phonological working memory. More anterior and ventral regions of IFG, particularly the pars orbitalis, and posterior areas of STS, are not activated by non-words and pertain semantics.

A different view is proposed by scholars who consider ATL the hub where semantic information converges and propose a graded specialization of it ([153]). In this view ATL plays a semantic role, IFG mostly a control function.[6]

Beyond activating pure linguistic and social networks, WAT contends that ACs are also grounded in perception-action systems, as suggested by the involvement of several areas related to domains like attention, emotion, motor coordination (e.g. as right hemisphere regions: superior frontal gryus, precuneus, [154]; anterior cingulate gyrus, amygdala, parieto-occipital junction, [155]; occipital gyrus: [156]). Our view is also compatible with activations linked to the conceptual content. For example Wilson-Mendenhall et al. ([157]) demonstrated that the concept “convince” activates brain regions related to social cognition (e.g. medial prefrontal cortex, STS), while “arithmetic” activates areas related to numerical processing (e.g. bilateral intraparietal sulcus). Similarly, Mellem et al. [132] found activations of LIFG, STS and aSTG while processing socio-emotional and social contents.

3.2.2. Neuropsychological syndromes and ACs

[6] In a synonym judgment task IFG was activated with ACs, in particular when associated to irrelevant contexts, suggesting the necessity of control processes due to the high variability and contextual flexibility of ACs. In contrast, ATL was mostly engaged when the synonym was related to a coherent context, suggesting a representational role ([148]).

The clinical syndromes associated with difficulties with ACs are crucial to understand the mechanisms underlying ACs representation. A well-known double dissociation exists between deep dyslexia, characterized by more errors with ACs when reading aloud (e.g. ability to read “face” but not “faith”) ([158]), and semantic dementia, caused by the bilateral degeneration of ATLs, and herpex encephalitis ([159]) characterized by more errors with CCs (reverse concreteness effect) ([160], [161]). This double dissociation fosters the hypothesis of the existence of two partially distinct systems, for CCs and for ACs processing ([135], [162], [163]).

The pattern is however unclear since recent studies with controlled frequency reported that SD patients perform worse with abstract than with CCs ([161],[164], [165]), questioning the existence of this dissociation. Patterson, Lambon Ralph and collaborators have proposed the hub-and-spoke theory, according to which multimodal experiences encoded in distributed modality-specific regions (spokes) are then integrated by a transmodal hub located bilaterally in the anterior temporal lobes (ATL) ([153], [166]). Crucial evidence favoring this proposal derives from the neuropsychological study of semantic dementia (SD), associated with the selective damage of ATL. However, the data do not lead to unequivocal conclusions: according to some authors, SD involves regions distributed in the temporal and frontal cortex, and in subcortical regions ([167]). Some caution is necessary because of the limits of localization results, of the sparse fMRI results, and also because some evidence shows that semantic dementia spares some ACs, as the numerical ones ([168]; for discussions [169]; [170]; [167]; [171]; [172]).

3.2.3. Deaf children and acquisition of ACs

The WAT view proposes that linguistically conveyed information is crucial for ACs representation. If this is the case, then according to WAT deaf children should have more selective difficulties in acquiring ACs than CCs. We review below some evidence obtained with deaf children that seems to support this prediction.

Wauters et al. ([173]) compared reading comprehension of a large sample of deaf and hearing students between age 6 and 20. While reading comprehension in 1st class did not differ, later hearing children strongly outperformed deaf ones; the two groups showed no difference in word identification. The increase of comprehension difficulties with age can be due to the increasing necessity to master ACs, whose acquisition is mediated by language. Wauters et al. ([174]) tested deaf and hearing children between age 7 and 15 in a self-paced reading task. Results showed an advantage of the perceptually over linguistically acquired words for both groups (effect of MoA); this difference decreased over age only for hearing participants. Importantly, deaf and hearing participants differed only in reading linguistically acquired words and not perceptually acquired ones. **Notice that the difficulties deaf children might have with ACs would derive from the insufficient exposition to acoustically conveyed information. Deaf children have however access to verbal information, and frequently also to information conveyed through sign languages. This study suggests that rich linguistic and social contexts are optimal to acquire ACs for children, and that acoustically conveyed information might be more effective than written explanations and texts. The importance of acoustic information might be more relevant in children, during the first phases of word acquisition, compared to later, when written sources might play a more important role.** Even if the reported evidence is very promising, further research is necessary to further substantiate the hypothesis that poor exposition to linguistic **acoustic stimuli determines selective difficulties in acquisition of ACs, as well as to**

better understand the differences between acoustic and written sources in promoting learning.

3.2.4. Autism spectrum disorders and ACs

The WAT view proposes that a rich social context is more pivotal for the acquisition of ACs than of CCs. It hence predicts that difficulties in social interaction might lead to stronger difficulties in the acquisition and mastering of ACs than of CCs. Studies on autistic spectrum disorder (ASD) can be informative on the role of language and sociality in characterizing ACs, since ASD has been associated with difficulties in both social interaction and abstract conceptualization.[7] Here we will highlight some aspects of the literature on ASD that might be relevant for the WAT proposal and deserve further investigation.

Visualization. Autistic individuals perform better in visual than in verbal tasks, and in tasks involving pictures compared to words ([179]); results on many tasks (serial recall, false belief, visual search, spatial recall) converge in showing that they think in pictures, and use visual representations also in tasks that controls solve verbally ([180]). Not casually, a well-known autistic scientist reporting her own experience, entitles her book “Thinking in pictures” ([181]).

[7] One of the most successful theories proposes that autism is a deficit of theory of mind (review: [175]), since the majority of autistic children fail false belief tests ([176]). However, the failure in such test is not predictive of autism; recent views propose that autistic children are rather characterized by a delay in ToM (meta-analysis in [177]). Moving from an embodied perspective, Gallagher ([178]) proposes the alternative interaction theory: children would be characterized from birth by the sensorimotor capability to perceive others’ intentions (primary intersubjectivity); from one year onward they would develop a secondary intersubjectivity, allowing them to engage in shared actions. ASD would hinder the basic intersubjective interaction characterized in primary and secondary intersubjectivity.

Consistently, rehabilitation programs generally benefit of the visual modality, for example using graphical organizers or virtual reality ([182]).

Difficulty with ACs? Generally ASD is associated with difficulties in abstract conceptualization, likely also due to the need to visualize information. For example autistic children perform worse than 4-years-old controls with the mental state concept "believe", and perform better in identifying a false map than a false belief ([183]). There is some contrary evidence, but mainly limited to abstraction processes, not to abstractness.[8]

Sociality deficit and difficulties with ACs. The social deficits characterizing autism might be due to a dysfunctional mirror neuron system ([188], [189]). Dapretto et al. ([190]) found that high-functioning autistic children showed no mirror neuron activity in the IFG (pars opercularis). Crucially, IFG is one of the areas recruited during ACs processing ([133]). Parallels might exist between social competences, the capability to execute and perceive mouth movements, and that to use ACs.

Verbal and auditory capacities. Highly relevant for WAT are studies on the relationship between autism, verbal and auditory capacities. Tager-Flusberg and Joseph ([191]) found a correlation

[8] Eskes et al. ([184]) found no difference between autistic children and controls in a Stroop task with concrete and ACs. Hobson and Lee ([185]) asked participants to rate pictures and words, then to perform a word-picture matching task. Autistic individuals scored lower than controls on emotion-related items (e.g. horror), but not on social-items (e.g. sharing) and on abstract items. While the attempt to distinguish between social concepts, ACs and emotional concepts is highly interesting, the conclusions they draw should be taken with caution since the used ACs used include some superordinate concepts (coniferous), some emotional concepts (horror, surprise, delighted), some social concepts (disagreement, sharing, greeting). Further studies found no difference in categorization of basic and superordinate categories, regardless of whether they were represented with pictures or words ([186]). However, the study focuses on abstraction, not on abstractness. In categorization of animate and inanimate entities autistic children have a peculiar form of selective attention: they attend to dynamic relations endowed with causal connections (e.g. between legs and walking) but ignore other relations that might be important (e.g., entities with legs also possess eyes, wishes, and are alive) ([187]).

between low verbal IQ and lack of social interaction typical of autism in children aged 6-13. Recent proposals have emphasized that ASD children often experience abnormalities in hearing; this deficit can impair them in engaging in joint attention and joint action (review: [192]). The difficulty of autistic children with ACs could thus be due to their difficulty in exploiting the social and linguistic input.

In sum: convergent evidence shows that ASD is associated both with difficulties with ACs acquisition, likely due to the necessity to visualize, with difficulties in social and interactive behavior ([193]). The deactivation of the Broca area typically associated to ACs processing in autistic individuals suggests a strict linkage between linguistic and social dimension. Consistently with our proposal, recent approaches in computational psychiatry interpret ASD as characterized by greater weight assigned to sensory information in updating probabilistic representations of the environment accompanied by the expectation of less changes in action ([194]). The social difficulties are interpreted in terms of how the environment is sampled, ascribing a minor role to action: the social-related features of the environment do not activate inferences as they typically do (for a review, see [195]). Even if the evidence we reviewed suggest a correlation between social difficulties and difficulties with ACs use, there is some divergent evidence, as that showing that performance of autistic individuals does not differ with basic concepts and more abstract superordinate concepts. Furthermore, there is a class of individuals who would seem to be an exception to our generalization: high-functioning individuals with an Autism Spectrum Disorder. Further research is thus needed, in order to better understand whether studies on autism fully confirm the hypothesis that we propose of a correlation between social behavior difficulties and capacity to use and process ACs.

3.2.5. Language, sociality and the brain

Recent neuroimaging studies confirm the prediction of the WAT view that linguistic networks (phonological, semantic, auditory) and social cognition areas are specifically recruited during ACs processing. Neuropsychological studies confirm that the systems for CCs and ACs are not completely overlapping. Finally, literature on non-hearing children shows correlations between auditory impairment and later acquisition of ACs, and studies on autistic spectrum disorder indicate coexistent difficulties in social cognition and abstract conceptualization. Further studies with novel and sophisticated techniques (e.g. [196]) are needed to further explore relationship between linguistic and social network recruitment during ACs processing, and further research on acquisition and use of ACs in non-hearing participants and in autism is necessary to confirm the hypothesis that linguistic and social contexts are pivotal for ACs representation.

3.3. Mouth activation with ACs

In this section we will illustrate evidence showing that the activation of linguistic experience leads to activation of the mouth, and will discuss the mechanisms underlying such activation. We hypothesize that **the more abstract concepts are and the more they** involve metacognitive operations, the more the mouth is activated. We propose that the engagement of the mouth motor system might be required either to re-enact the experience of conceptual acquisition, to use inner speech to help us retrieve word meaning, or to prepare ourselves to refer to others that can complement our lacking knowledge [18].

3.3.1. Mouth activation and studies mimicking conceptual acquisition.

Studies mimicking the acquisition of novel concepts and words in adults demonstrated with a property verification task that responses with the hand were faster with CCs, referring to manipulable objects, while responses with the mouth were faster with ACs ([112]). A categorical recognition task demonstrated that being taught the category name and explained its meaning **speeded up** mouth but not hand responses ([113]). These findings confirm the association between linguistic learning and mouth activation, supporting the hypothesis that the oral motor system is engaged primarily with ACs.

3.3.2. Mouth activation and rating tasks.

The association between ACs and mouth activation was found also in explicit rating tasks in which participants were asked to associate abstract and concrete sentences and words to hand and mouth effectors. Ghio et al. [29] showed that, within abstract sentences, emotional sentences were associated both to hand and mouth, while math-related ones were preferentially linked to the hand, possibly due to the finger counting habit. Crucially, mental states sentences were related to the mouth, in line with WAT predictions.

In two further rating studies with different databases ([108], [16]) Granito et al. [113] and Borghi and Zarcone [197] found that ACs were rated as more related to the mouth than to the hand than CCs **(concrete food words were not considered)**. Both studies extend to words previous evidence on sentences, showing that mouth activation extends beyond mental states concepts to other kinds of ACs. Further research is needed to test whether mouth activation increases as the abstractness of concepts increases, since an inner metacognitive process is more required.

3.3.3. Mouth activation leading to a processing facilitation.

The advantage of the mouth with ACs processing was found also in behavioral implicit tasks. The first behavioral study demonstrating with real words that ACs activate the mouth more than CCs was conducted by Borghi and Zarcone [197]. Participants had to decide whether abstract or concrete definitions matched with following ACs or CCs pressing a key either with the hand or with the mouth. Responses with the hand were overall faster due to the device used, but the difference between response times with the hand and the mouth was much smaller with ACs than with CCs. Mazzuca and Borghi (under review) (see also [198]) used a go-nogo paradigm in which participants responded by pressing a pedal with the foot; when catch-trials appeared they had to press a key that they held with the hand or the mouth (hand vs. mouth conditions). **Contrary to our predictions** no effect was present in a lexical decision task. **Even though studies (e.g.** [199] **have demonstrated that semantics impacts lexical decision, it is possible that the effect was not so strong to emerge also in a task that did not require a semantic judgment. However, in an immediately subsequent word recognition task response times with ACs were faster in the mouth than in the hand condition, while the opposite was true with CCs and emotional words**. Hence recognition is facilitated not only when the mouth is the response effector, but also when it is indirectly activated by holding a device with the mouth. These results also suggest that the mouth activation with ACs is flexibly modulated by the task: it emerges with a recognition task, while it is absent in a lexical decision task, likely because of the more superficial processing it involves.

3.3.4. Mouth activation and studies with interference paradigms in adults

Mouth activation could be simply a byproduct of ACs activation ([70]). To demonstrate its functional role, we used behavioral and neural interference paradigms.

Pleasantness and complexity ratings. Each time we process a word, we do not only simulate its meaning [200] but a simulation of its pronunciation also takes place, involving the oral motor system ([201], [202], [203], [204]). Topolinski and Strack ([69]) demonstrated that the increased fluency of pronunciation simulation, due to exposure, leads to an increased word pleasantness. This exposure effect disappears using interference tasks, as gum chewing, that impede the simulation to be formed (see also [205], [206]). Borghi and Lugli (in preparation) asked participants to rate complexity and pleasantness of CCs and ACs. They were randomly assigned to one of three conditions: during the task execution they had either to squeeze a tennis ball and to chew a gum at the rhythm of a metronome or to suck a candy. We found the predicted interference effect, i.e. a decrease in pleasantness and an increase in complexity ratings for ACs compared to CCs in the gum chewing condition, that implies an active mouth movement. This interference suggests that the mouth activation plays a functional role during ACs processing, modifying their perceived pleasantness and difficulty.

Articulatory suppression. Zannino, Fini, Benassi, Carlesimo and Borghi (in preparation) recently tested the functional role of the mouth activation in a behavioral task. Participants were required to decide whether words were abstract or concrete by pressing a pedal. Responses with ACs were significantly slower than with CCs when participants were assigned to an articulatory suppression condition, in which they had to pronounce "da da da" during words processing. No difference between ACs and CCs was present when participants manipulated a ball during the task. The results suggests that the involvement of the mouth plays a critical role during ACs processing, generating interference. Further studies are however necessary to better qualify both the mechanisms and the specific mouth movements involved in ACs processing.

TMS evidence. In a single pulse Transcranial Magnetic Stimulation (TMS) study participants performed a sentence sensibility task on combinations of concrete and abstract verbs followed by abstract and concrete nouns (e.g. “to caress/ think of - the dog/idea”). Motor evoked potential results on the left primary motor cortex revealed greater peak-to-peak amplitude for CCs when the TMS pulse was delivered on the verb, for ACs when it was delivered on the noun. This result suggests that ACs processing involves activation of the primary motor cortex. The late hand activation for ACs was interpreted as a possible cascade effect of an initial mouth activation, occurring because of the contiguity of hand and mouth brain representation ([207], [208], [209]). Further TMS evidence testing directly the effects of the mouth **stimulation** on ACs processing is necessary to foster this interpretation.

3.3.5. Mouth activation and studies on language acquisition and pacifier use.

We recently found that extended use of pacifier (beyond age 3) has a long-term influence on conceptual development and **selectively affects the acquisition of ACs. Premature children as well as children with health problems, hearing and language disorders were excluded from the sample.** In a first study Barca et al. ([210]) asked 7-year-olds characterized by a different use of pacifier (no use; use until 2 years; use until 3 years; use beyond age 3) to define concrete, abstract and emotional concepts. While pacifier use did not influence the definition accuracy, it clearly affected the network of produced relations: children who never used the pacifier or used it until age 2 distinguished clearly between concrete and ACs, while the distinction was not so sharp for children who used the pacifier beyond age 3. Late users of pacifier seemed **to pay more attention to concrete aspects and less to social and emotional ones**: they referred less to their experience, to social and emotional situations, used less free associations, and used more exemplification and functional relations. Results support WAT: a late use of pacifier might have interfered with acquisition of ACs not allowing to simulate and/or re-explain their meaning through inner speech. Alternatively, the use of pacifier, hiding more the facial expression, might have impeded children to benefit of the social input, particularly crucial for ACs acquisition.

In a further study ([211]) 8-year-olds were presented with concrete, abstract and emotive words and with animal words; they were required to press a button if they read words referring to animals. Children who had used the pacifier beyond age 3 were slower in processing ACs than CCs and emotional concepts. **Importantly, children of the different groups did not differ in socioeconomic status. It is however possible that other variables (e.g. parenting style, breastfeeding) influence late pacifier use; we are now conducting further studies aimed at controlling the potential confounding role of these variables. Overall, results obtained so far suggest that the active involvement of the mouth due to extended use of pacifier affects the acquisition** of ACs, changing the conceptual relations they evoke.

3.3.6. Mouth activation and kinds of ACs

Evidence described so far highlights that the mouth motor system is involved in ACs processing. However, different kinds of ACs exist, that are extremely different. We hypothesize that the advantage of the mouth activation compared to the activation of other effectors (hands in particular) **is characteristics of all ACs, but is more marked for some ACs in particular. Specifically, we hypothesize that such mouth activation is particularly pronounced for pure abstract concepts, due to their high level of abstractness, and for mental state concepts, both because of their high level of abstractness and because** their content invites metacognitive processing. Two pieces of evidence, behavioral and neural, seem to support this claim. Ghio et al. [29] found with explicit ratings that participants associate mental state sentences more with the mouth than with other effectors. Their results show that participants think that also emotions activate the mouth effector, but also activate the hand, consistently with the idea that emotions involve the whole body. In a very recent paper Dreyer and Pulvermueller ([71]) demonstrated that passive reading of abstract emotional and mental nouns involves the face motor areas, similarly to what happens for food related words and to face-related action words. Importantly, however, the involvement of the mouth was particularly marked with mental nouns, consistently with the idea that, being **evaluated as more abstract and involving more metacognitive processes, they might involve inner speech.**

3.3.7. Acoustic activation and ACs processing

If language experience is crucial for ACs representation because of the re-enactment of the acquisition experience, then they should activate more also the acoustic modality. Obviously we do not intend here to neglect the importance of the visual modality (language can be read, not only listened to). However acoustically conveyed words might play a prominent role, especially during acquisition in children, as research on acquisition of ACs in deaf children suggests.

Two experiments with the Extrinsic Simon task ([212], [213]) aimed at testing this hypothesis ([214]). In Experiment 1 participants discriminated the ink color (i.e., green/blue) of ACs and CCs, in Experiment 2 they discriminated the gender of the voice (i.e., male/female) pronouncing ACs and CCs. Their task consisted in pressing one of two buttons associated to the hearing and visual modality through training. When participants had to choose the extrinsically auditory response in response to ACs (Auditory-Abstract condition) response times were faster compared to the other three conditions (Visual-Abstract; Auditory-Concrete; Visual-Concrete) in Experiment 1, and slower in Experiment 2. The result of Experiment 2 can be due to an interference: modality specific attentional resources would be recruited both while perceiving the voice and simulating acoustic stimuli during responses with the auditory button. In sum, results from both experiments are compatible with the WAT suggestion that when we process ACs we internally reproduce their sound.

3.3.8. Mechanisms underlying mouth and acoustic activation

We have illustrated numerous behavioral studies indicating that ACs processing involves the activation of the mouth. ACs processing is characterized by a facilitation of the mouth responses. Consistently, actively using the mouth as during gum chewing interferes online with ACs, while the extended use of pacifier has an offline long-term effect on the conceptual relations evoked by ACs and their processing time. These interference effects suggest that the activation of the mouth does not simply play a side role. Results also show that ACs processing activates the acoustic system.

The involvement of the mouth and of the acoustic modality suggest that, since ACs have heterogeneous exemplars and lack a single referent, language is activated. Different mechanisms might undergo such activation: a. re-enactment of the experience of their acquisition, for which the linguistic and social input was pivotal; b. simulation of pronouncing the word (e.g. [205]) and of the words statistically more associated to its meaning (as hypothesized by distributional statistics view, ([215], [216]); c. social meta-cognition and inner speech: we would need to perform meta-cognitive processes and either to re-explain to ourselves word meaning through inner speech, or to prepare ourselves to ask the word meaning to others

These mechanisms are not necessarily in conflict and might co-occur, but further studies are needed to determine their different weight. **Notice that, because that of abstract and concrete concepts is not a dichotomy, such mechanisms could also be used for CCs, but we propose that these mechanisms and the corresponding mouth activation are involved to a larger extent in processing ACs, because of their higher complexity, detachment from sensory modalities and absence of a clearly bounded and perceivable referent.** We hypothesize that these mechanisms are more active, the more abstract the concepts are. We also hypothesize that the more concepts involve metacognitive processes, the more they are perceived as abstract.

3.4. Variability of ACs across languages

If language and the social context play a pivotal role for ACs representation, ACs should be more influenced by linguistic and cultural diversity than CCs. Let us make some examples (for more details, see [7], chapter 5; [217]). Crosslinguistic evidence has shown that, for CCs, there is a dissociation between naming and sorting tasks: for example, Chinese, Spanish and English speakers name containers differently but converge in sorting them into categories ([72]). Such a convergence is likely not present for ACs.

As an example, consider the extensively investigated abstract concept of time. Numerous studies revealed that temporal concepts are influenced by different practices as the writing direction, and by the metaphors characterizing different languages. For example, in Western cultures time is related to the horizontal dimension, in Eastern culture to the vertical one ([218], [219]); for Greek and Swedish speakers estimates of time are more influenced by length, for English and Spanish speakers by quantity ([220], [221])[9]. The effect of time spatialization is driven also by culturally entrenched biases and changes over development: since the Spanish culture is more future-oriented, Spanish more than Arabic participants intend the future as "ahead" and the past as "behind" ([222], [223]). Hence both language and entrenched cultural practices bias people to flexibly change their implicit way to spatialize time (reviews: [2]; [224]).

Our impression is that, although all concepts are variable, the variability that characterizes abstract concepts such as “time” is far more pronounced than that characterizing concrete concepts as “ring”. Obviously, also concrete concepts as “ring” are grounded in different cultural practices, and our way to use and aesthetically appreciate “rings” is likely modulated by these differences. Still, the fact that the word “ring” refers to an object to wear on a body part, preferably the finger, is likely part of the ring representation that remains constant across cultures and languages. Hence, we do not contend that CCs are not influenced by different languages and cultural practices; we simply mean that part of their representation is likely to remain more stable compared to that of ACs, for which the contextual and linguistic influence is more prominent. This proposal needs to be substantiated by an extensive analysis of current literature and by further research.

The whorfian idea that language shapes thought has recently obtained renewed attention (e.g., [225], [226], [227], [228]; [229]). Even if we are convinced that this idea holds in general, we propose that the effect of linguistic relativity augments particular at the increase of the abstractness level of words. Compared to concrete concepts, ACs should be more permeable and easily influenced first by the different languages, second by the different cultural milieus. One could object that there is plenty of evidence that linguistic differences influence categorization of color (e.g. [230], [231]), and that recent studies have found strong influences of the spoken language on

[9] Consistently in a duration reproduction task in difficult discriminations Swedish speakers were misled by stimulus length, Spanish speakers by stimulus size/quantity.

the representation of odors (e.g. [232], [233]) and musical pitch (e.g. [234]). However, color, odor, musical pitch, have an ambiguous status: similarly to concrete concepts they refer to sensorial modalities, differently from them they do not have an object as referent. Similarly to "freedom", "smell" cannot be seen, manipulated, held ([235]).

This aspect of our proposal should be better substantiated with comparative empirical evidence and further developed, investigating how different spoken languages influence building and representation of CCs and ACs.

Table 1. A summary of the evidence supporting the four tenets of the WAT proposal.

Tenet 1: Social and linguistic acquisition	Tenet 2: Brain representation: social and linguistic networks	Tenet 3: Mouth activation with ACs	Tenet 4: Variability across languages
Infants: early comprehension of ACs at 10-14 months (development of social abilities) 14-30 months: increased role of social input 3-4, 5-6 years: reliance on reliable informants 8-9 years: emotional bootstrapping	fMRI, PET: recruitment of a linguistic and social circuit LIFG STS LMTG LSTG	Evidence with studies mimicking conceptual acquisition on adults. Behavioral evidence with ratings tasks: higher association of ACs to the mouth, particularly of mental states	Studies on the notion of time: variability across languages, writing directions, and culture
AoA: late acquisition of ACs MoA: linguistic acquisition of ACs	ERP: N400 concreteness effect: less activation of visual areas for CCs, more semantic control for ACs	Facilitation: faster RTs of ACs with mouth responses	
Acquisition of novel	Double dissociation:	Interference:	

categories in adults: role of language Interpretation of mystery words in videos by adults: syntactic bootstrapping	partially separated systems between ACs and CCs? But controversial results Autistic spectrum disorder: problems with both sociality and abstractness Non hearing children: more difficulty with acquisition of abstract concepts	Online interference: with active mouth moving (gum chewing) perceived pleasantness of ACs decreases and perceived complexity increases **Online interference: articulatory suppression renders processing of abstract concepts slower** TMS evidence: the hand motor system is activated later with ACs. Possible cascade effect of a previous mouth activation Long-term interference: prolonged pacifier use influences definitions of ACs in 6-year-olds and leads to slower RTs with ACs in 8-year-olds.	

4. Comparison with previous theories

In the next section we will briefly outline similarities and differences of WAT from previous proposals (review: [2]).

Classical views. The Contextual availability view (CAT; e.g. [23], [236]) and the Dual Coding Theory (DCT; e.g. [22], [237]) were the two dominant views on ACs. According to CAT we process and recall better CCs because ACs are associated to a wider number of contexts, but in a weaker manner, rendering their access more difficult. Similarly to CAT, WAT takes into account the heterogeneity of ACs; differently from CAT it is an embodied view and it underlines how labels help keeping together heterogeneous category members, overcoming contextual heterogeneity. Assigning importance to both sensorimotor and linguistic experience WAT takes inspiration by DCT (WAT highlights the role of social experience too). DCT is supported by behavioral, fMRI (e.g. [133]), and EEG evidence (e.g. [238], [239], [240], [241]) showing that CCs activate modality-specific images for shapes, sounds, actions and interoceptive information, while ACs recruit the verbal system. Some recent studies have however shown that abstractness/concreteness is not explained by imageability, as argued by DCT, but by a different degree of perceptual strength ([9]). A major limitation of DCT is the claim that ACs are characterized only by verbal representations, while WAT contends, in line with much evidence, that linguistic information characterizes more ACs, but all concepts are also grounded, even if in different degrees, in perception-action.

Distributional views. Distributional and embodied views are typically contrasting approaches to semantic memory ([242]), even if recently hybrid approaches are emerging ([243]; [244], [216]). Distributional views ([215], [245]) intend word meaning as derived by the network of associated words. Since both CCs and ACs have linguistic associates, ACs do not posit a specific problem for these views. We believe that the intuition of distributional theories that meaning is captured by statistics is fruitful, in particular for ACs, associated to a richer linguistic - but also social and inner - experience ([245], [246], [247], [248]). Distributional theories are however limited by the symbol grounding problem ([249], [250]): to allow full comprehension of meaning the symbols need to refer to their referent, and not only to other symbols. In keeping with this view, according to WAT only part of meaning is captured through statistics and the re-enactment of situated experience is necessary to fully grasp words meaning; in addition, language cannot be reduced to decontextualized word associations but should be conceived more holistically, in strong association with the social context.

Embodied views. WAT's tenet that ACs are grounded in perception-action system is clearly in line with EG views. However, WAT has both similarities and differences from other EG theories.

The motor theory emphasizes the similarities between CCs and ACs, and is supported by evidence showing for example that both passing the pizza/the news activate a directional movement ([251], [252], [253]; [39]; [254]). WAT shares with the motor view the idea that ACs are grounded in the sensorimotor system, but differently from it, it contends that the meaning of ACs is not exhausted through their grounding but relies also on linguistic and social experience, in different degrees depending on the abstractness level.

WAT also has many similarities with the conceptual metaphor view of ACs, according to which ACs are mapped onto concrete domains ([255], [256], [219], [257], [258]; for reviews [259], [224]. The evidence supporting this view is compelling, but it cannot always be generalized, and in many cases metaphors do not exhaust the meaning of ACs ([260]). For example, how can the notion of metaphysics be explained by such a view? Ascribing a major role to the linguistic and social experience, WAT represents thus an extension of both the motor and the conceptual metaphor view that has the potential to explain the representation of a wider range of abstract concepts.

The introspective view, according to which ACs are represented referring to social aspects of situations and introspection ([261]; [14]), has numerous similarities with WAT. Both theories assume that ACs are grounded in situations, and emphasize the importance of social aspects and of inner grounding for their representation. A further subtle aspect links these two theories. The higher activation of the mouth we found with ACs could be the embodied counterpart of the metacognitive processes, particularly when they are phenomenally mediated by introspection as proposed by B&W.

In underlining the importance of the social context for ACs, WAT was strongly inspired by Prinz's ([262], [263]) sign-tracking view. His important contribution consists in highlighting that, while ACs might be grounded in perception, action, and emotional systems, to learn them we might need to track definitions provided by others, particularly if they are authoritative in a given domain.

Multiple representation views. Multiple representation views propose that sensorimotor but also emotional, social and linguistic experience contribute in grounding ACs. They represent a great novelty in recent literature ([264], [32]. WAT is clearly one of this theories – its peculiar contribution consists in underlining how acquisition influences conceptual representation, in highlighting the importance both of linguistic and social experience and in hypothesizing that they affect the body.

Even if not specifically focused on ACs, the LASS view was very inspiring for us because it was the first influential theory considering both sensorimotor and linguistic experience [265], [266]. According to LASS only simulations grant access to meaning, but in linguistic shallow tasks (e.g. lexical decision) linguistic information can work as a shortcut, allowing fast responses ([267]). WAT departs from LASS since it does not consider language only a shortcut to meaning: in line with hybrid views, linguistic associations contribute in capturing meaning together with sensorimotor experience.

The influential Affective Embodiment Account ([15], [268], [269], [270], [271]) shares a lot with WAT. Similarly to WAT, it stresses the role of both sensorimotor and emotional grounding of ACs (see converging evidence: [272], [273], [274], [275], [276]). Similarly to WAT, it focuses on acquisition, underlying how learning emotional words can have a bootstrapping role for ACs learning. There are a number of differences, though. First, WAT focuses more on the differences between kinds of **ACs, due to different combinations of sensorimotor, interoceptive, social and linguistic experience in their representation**. Second, WAT puts more emphasis on linguistic experience and its embodied counterpart, the oral system activation. Finally, WAT stresses more the social experience characterizing ACs acquisition. In the framework of WAT, the emotional activation of ACs could be a byproduct of their peculiar acquisition modality.

The model initially proposed by Paivio has been recently re-proposed, in a more embodied version, by Dove ([138], [56], [277], [278]). According to him, we take advantage of the fact that language is an external amodal symbol system that we learn to manipulate in an embodied and grounded way. The similarity of WAT with Dove's view, that underlines the role of language as a medium for thought, is very strong. Differently from Dove, we do not stress the amodal character of language representation and focus on the importance of linguistic acquisition and on the embodied counterpart of linguistic involvement, i.e. the activation of the mouth motor system.

The hub-and-spoke theory of semantic memory ([153], [166]), not specifically focused on ACs, assumes the existence of both modality specific cortices and of a single amodal hub, localized in the anterior temporal lobe (ATL). In their Dynamic Multilevel Reactivation Framework Reilly et al. ([279]) propose that multiple cortical hubs mediate the relationship between amodal and sensorimotor information. Some evidence inspired by this theory points to the importance of linguistic and acoustic information for ACs ([161]), perfectly in line with WAT. However, in our more embodied view a common amodal region where modality-specific information converges is not necessary ([167]), even if there might be high-level convergence zones ([280], [281]) that support processes such as simulation, recall, and prediction ([282]).

5. Towards a conceptual framework on learning and grounding of ACs

WAT theory makes a number of novel proposals on how ACs are learned and the type of stimuli that are most important for grounding them. We have reviewed a large body of evidence that provides support for this hypothesis; however, there are several important predictions of WAT that remain to be tested empirically. Specifying the WAT theory in a formal way can contribute to further refine its predictions.

As a first step in this direction, in this section we sketch a conceptual model that contextualizes WAT within current theories of embodied representation and predictive processing in the brain. From a Bayesian perspective, one can view concepts as rich generative models that probabilistically connect inner (hidden) variables (e.g. the concept of bottle) to observable streams of exteroceptive, proprioceptive or interoceptive information ([283], [284], [285]; see Figure 2). These models are called *generative* because they afford multimodal predictions, such as the prediction of how a bottle looks like and what we can do with it - which is consistent with the idea of concepts as situated simulations in embodied and grounded cognition ([35]). Importantly, generative models also include conditional (e.g., action-dependent) information and thus they permit predicting how the bottle moves when we rotate it (a motor-sensory contingency) or to anticipate its freshness in case we drink from it (a motor-interoceptive contingency). One can extend the same line of arguments to encompass social contingencies or cultural practices, such as the likelihood of finding a bottle in a supermarket, the expected reactions of others if one drinks from a bottle in public - or even the expected effects of uttering the sentence “give me a bottle”.

Not only these generative models afford the prediction of expected observations given a hidden state (e.g., what I should see when there is a bottle in front of me), but also the opposite operation: the (Bayesian) inference of the hidden state (e.g., a bottle) that is more compatible with my current sensations (e.g., seeing something transparent) and prior or contextual knowledge (e.g., I am in a supermarket). This sort of inference can be cast either as a passive (evidence accumulation) process or a more active (hypothesis sampling) process; in both cases, it permits inferring the (hidden) causes of sensations, and it is at the core of Bayesian treatments of perception and action ([253]). But for this, obviously, one needs to construct the model (and the hidden concept of "bottle") in the first place. This is important because the process of acquisition (and thus the content) of models - aka concept learning or concept induction - might be fundamentally different for CCs and ACs.

Current Bayesian models describe category formation and word learning as inductive problems of the same kind as explained above: one in which the objective is to infer the best hidden cause (e.g., the concept of a container) given the exemplars encountered (e.g., instances of bottles). This is an incremental process, in which as new exemplars (e.g., of items such as bottles or the word *bottle*) are encountered, they are assigned to existing categories (e.g., semantic categories such as containers) - or novel categories are formed if no existing categories can accommodate them ([286], [287], [288], [289]). These models focus principally on CCs and highlight the importance of integrating various sources of evidence, including perceptual evidence and social information such as the gaze or even the intention of a teacher (e.g., to resolve uncertainty about the reference of a given word like *bottle*).

Importantly, Bayesian inference requires this multimodal integration of information to be dependent on the relative precision (inverse variance) of the information sources: the more an information source is precise, the more it is used for model induction and inference. This becomes relevant because the statistics of the information to be included in generative models for CCs and ACs - and the way we acquire or sample this information - is different (see Figure 3). For most CCs, stable and reliable perceptual evidence and motor-sensory contingencies exist, which can form the basis of efficacious generative models. In contrast, exemplars of ACs are often perceptually more diverse, but may correspond to more stable interoceptive information, as in the case of most emotional concepts or metacognitive information for concepts like “truth”, “confidence” or “trust” (see below). Furthermore, ACs may entail more stable social contingencies including word use (e.g., the prediction of uttering the sentence "I want to be free" in front of a supervisor) than motor-sensory contingencies (except perhaps contingencies that guide inner speech, see below) - given the prominent social and linguistic contribution to learning, using and practicing ACs. For this, even if there is nothing fundamentally different in the mechanisms of multimodal integration and (Bayesian) learning of CCs and ACs, the generative models underlying ACs might be more shaped by (or grounded into) rich social, linguistic or interoceptive information than CCs. One can thus use the same arguments about generative models for “bottles” or other concepts that are perceptually rich and for concepts that do not have (stable) perceptual referents but entail stable interoceptive contingencies (e.g**., the concept of** “fear” in the case of a Bogeyman [290,291] or other emotional concepts [292]).

The same framework can also be used to encompass another source of information, which stems from the monitoring of the internal functioning of inferential processes: *metacognitive information*

([293]). One useful illustration is (the sense of) confidence - a widely studied metacognitive judgment about the quality of one's decisions. Numerous studies show that humans and animals are able to rapidly assess the confidence in their choices, and use this information to guide adaptive decisions. Importantly, according to some theories confidence estimation would be based on the metacognitive monitoring of the state of own decision system at decision time, e.g., the subject reports high confidence if his/her decision system has much more evidence in favor of the selected versus the unselected option ([294]). We hypothesize that *the same metacognitive information can be used to build generative models of certain ACs and to ground them.* Concepts that might be (at least partially) grounded in this way are, for example, “confidence”, “conviction”, and “self-esteem”, and “trust” ([295]). Along similar lines, Barsalou ([35]) has proposed that the grounding of some ACs such as “truth” depend on the monitoring of internal, inferential processes, such as the successful (or unsuccessful) matching of expectations and sensations. Within a Bayesian framework, these and other metacognitive signals would not be fundamentally different from other kinds of (exteroceptive, proprioceptive, interoceptive) information - except for the fact that they would result from the monitoring of own inferential processes rather than, say, from the processing of visual or auditory stimuli - and would comply to the same kind of precision-modulated inference and (multimodal) model learning dynamics introduced above. Metacognitive signals would possibly play a prominent role in the grounding of some ACs that - like in the examples of “confidence” and “truth” above - have specific referents in the functioning of cognitive inferential systems.

There is a rather subtle consequence of Bayesian learning of ACs conceived in this way. **The Bayesian mechanism of precision-weighting of information suggests that one should use different kinds of** information to learn (or to infer) CCs versus ACs. As highlighted by Quine [296], there is a ubiquitous problem of indeterminacy of reference when we hear a word like "bottle" -

which may refer to the container, its color, part of it such as its stopper, etc. If one casts category induction (and model learning) as active, hypothesis-testing processes [297,298], one should resolve this indeterminacy problem by preferentially sampling the most precise source of information. For most CCs, this usually includes a combination of linguistic and perceptual (or perceptual-motor) information. For example, we consistently hear the word “bottle” in combination with various other containers and drinks, while we hear the word “stopper” when we see someone opening the bottle, so we rule out the hypothesis that stopper refers to the bottle as a whole. This would imply that we should attend to specific aspect of the sensory-motor situation to learn a reliable generative model. In contrast, imagine hearing the word “fantasy” while observing two babies interacting with objects and building towers. Here, we face the same indeterminacy problem: does the word refer to the babies' characteristics, to the towers, or to what? Since in this case we cannot resolve the indeterminacy problem by (preferentially) focusing on specific sensory-motor detail of the situation, we should disregard them - and focus instead on linguistic and social input provided by others to determine the categorical referents. More generally, Bayesian inference and hypothesis testing rest on a form of gain (or salience) control of perception that entails preferentially attending (disregarding) the most (least) precise sources of information; and this should produce appreciable differences during the acquisition of specific CCs and ACs that rest more on (say) perceptual versus social contingencies.

Figure 2 (realized after Bastos et al. [283]). This figure shows an example of the generative model that underlies (and grounds) a concrete concept: bottle. In a probabilistic framework, generative models describe how exteroceptive, interoceptive and proprioceptive sensations are caused. Intuitively, this figure illustrates the fact that the concept of a bottle links to systematic patterns of e.g., visual, proprioceptive and auditory stimuli (blue nodes); and the generative model represents the causal dependencies between factors that cause these sensations, such as for example the fact that if I execute a drinking action (in the presence of a bottle of water), I should expect a characteristic pattern of proprioceptive, tactile and interoceptive sensations (e.g., the movements of my arm and the taste of water) - i.e., a sensory-motor-interoceptive contingency - or the fact that pouring water produces a characteristic pattern of coordinated acoustic and visual sensations - i.e., a visuo-auditory contingency. The same model also permits planning individual actions such as pouring or drinking, as well as social actions such as giving a bottle to somebody else - and to predict the multimodal effects of these actions. In this illustration, blue nodes represent sensations in various modalities, whereas red and black nodes represent the so-called hidden (non-observable) nodes of the model, which come in two varieties. Red nodes represent hidden causes (e.g., uni- or multi-modal percepts), which model stable causes such as the presence of something red or a bottle in front of me; and black nodes represent hidden states, which model dynamical events and the changes caused by the interactions among causes (e.g., sensory changes due to moving a bottle). The arrows represent the conditional dependencies among hidden and observable variables - or the way these hidden causes and states generate observable exteroceptive, interoceptive and proprioceptive sensations. In other words, the generative model maps from causes (e.g., concepts) to consequences (e.g., visual or auditory sensations), much like the idea of a situated simulation in embodied cognitive theory; and its inversion (using Bayes rule) permits to infer the latent cause of current sensations, e.g., that there is a bottle in front of me. Here, the concept of a bottle is at the apex of the (simplified) hierarchy, which means that it integrates the various multimodal streams. As denoted by colored triangles, these information streams may come from both individual (green) and social (orange) interactions. Note that the figure is simplified in many respects, and only shows sample nodes and causal dependencies for the sake of simplicity. For example, in this figure many aspects that are plausibly part and parcel of the concept of a bottle (including linguistic and social aspects, such as e.g., a contingency between donating a bottle to somebody thirsty and feeling good) are omitted. A more formal treatment of the generative model shown in this figure (along with differential equations that describe the model dependencies) can be found in Bastos et al. [250]. See also [299,300].

Figure 3. This figure shows an example of the generative model that underlies (and grounds) an abstract concept like “freedom”. This figure uses the same format as the previous one. The overall logic of the model (and concept grounding) is exactly the same as for concrete objects. Similarly to concrete concepts, the abstract concept “freedom” might activate the five sensory modalities ([9]), interoception ([10]) as well as proprioception: for example, if it re-enacts a scene like lying on the grass with friends and looking at the sky, it might evoke the tactile sensation of the freshness of the grass near our body, while if it re-enacts the scene of freeing ourselves from a rope it might re-enact the proprioceptive information on our body parts constrained by a rope. Compared to the figure on concrete concepts, here we have emphasized some aspects that are more specific for abstract concepts like the importance of the social dimension (e.g., dialoguing) of inner speech and of the resulting mouth proprioception, and of metacognitive processes; the linkage of the concept of freedom to a very heterogeneous set of (for example) visual sensations.

6. Conclusion: Toward a unified theory of ACs

Multiple representation views come very close to overcome some of the major problems impeding previous attempts to formulate a unifying theory of ACs. Within multiple representation views, WAT offers a particularly promising perspective. We summarize below its main contributions **and limitations and we identify open issues for future research.**

Multiple (grounded) representations. ACs activate multiple representations. Beside sensorimotor experiences, according to WAT such representations are grounded on linguistic, social, interoceptive and metacognitive information. This view has the potential to account for the representation of different kinds of ACs, from emotions to numerical to mental and social concepts since the extent of their grounding in perception and action, sociality, interoception etc. might differ.

Once determined which typologies of ACs exist, precise predictions taking into account which modality is mostly relevant to characterize different ACs should be advanced and tested. For example, preliminary data (Villani et al., under review; submitted) show that the activation of linguistic information characterizes more "pure" ACs, likely because their complexity and heterogeneity require inner brain operations that might be tracked possibly through inner speech[10].

Development. So far the literature on conceptual acquisition and on conceptual representation have been kept separate. WAT bridges the most promising results on conceptual development with behavioral and neuroscientific results on ACs use and representation in adults. We have sketched a possible way in which ACs are acquired, taking into account the embodied experience of interacting with the physical environment but also with others, and the role of language.

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[10] Linguistic information is likely less relevant for numerical concepts, but this might change considering high numbers and use of numbers in a second language.

Many questions remain however unanswered. It should be determined to what extent the modality of acquisition of words influences their brain representation, and the respective weight of the first acquisition of ACs and of the successive learning experiences, in which ACs meaning is extended to new contexts. Furthermore, it should be comprehended whether acquisition and re-explanation through inner speech involve also simulating the cooperation of others to re-hearse word explanations. For example, does the association of acoustic information with ACs mean that we simulate the word pronunciation or that we reenact the social context of word acquisition?

Language. WAT puts a strong emphasis on the role of language for ACs acquisition. According to WAT language is not only a way to index referents ([242]), a shortcut to access meaning ([265]), or a way to access meaning through words associations, as argued by distributional theories ([215]). Language is all this, but it is also more: words are tools helping us to perform actions and change our social environment ([301], [302], [303]), means to improve our thought abilities ([57]; [111]), to control our behavior ([54]), to formulate predictions against which sensory information can be evaluated ([304]), to form categories ([24]).

The potentialities of language are maximally exploited in representing ACs: labels can help us to glue together the heterogeneous members of ACs ([7]), and inner speech can improve the capability of our brain to track information on internal states and processes and to introspectively look at ourselves ([261]). Further research is needed to understand the role played by inner grounding, its relation with inner speech, and to verify whether the weight of inner grounding and language are particularly relevant for some kinds of ACs (e.g. for mental states more than for numerical concepts).

We have seen that linguistic and social brain networks are recruited during ACs processing. However, contrasting views are present, and further research is needed to identify the possible functional roles of the different circuits, and their decay with age.

Another issue is that most studies on ACs consider isolated words. Research is needed, aimed to explore the role of linguistic context. Does the presence of context reduce the abstractness of concepts, hence the activation of linguistic information[11]?

Finally, we propose that from the strict linkage between ACs and language derives a higher variability of ACs across languages. Further research is needed to substantiate this claim.

Sociality. According to WAT, the social context plays a crucial role for ACs acquisition, and mastering of ACs requires the development of social competences as the ability to identify reliable information sources. Further studies are needed to verify the relative importance of social and emotional experience for word learning. For example, “anguish” is a strongly emotional word and “truth” is not, but both concepts might be acquired in an emotionally rich social context. In other words: emotions pertain more to grounding, sociality pertains both grounding but also the context of acquisition. Importantly, the different weight of emotional and social grounding might depend also on the considered ACs. For example, Catricala’ et al. ([305]) demonstrated that patients with primary progressive aphasia were impaired only in social concepts, and Alzheimer’s disease patients had difficulties with all ACs but not with emotion concepts.

We hypothesize that word abstractness and use of linguistic information are correlated. Is **abstractness also highly correlated** to social information, since linguistic and social experience are strictly interwoven during acquisition?

[11] Question raised by Jesse Prinz, Berlin 2016.

Embodiment. We have described evidence showing that the mouth is more activated during ACs processing. Results with interfering paradigms suggest that the motor system activation plays a fundamental functional role. However, such activation does not seem to involve all kinds of ACs – for example, numerical concepts activate more the hand ([29]). **We hypothesize this is likely due to finger counting experience (**[306]**,** [307]**), and that using numbers higher than 10, typically perceived as more abstract, the involvement of the mouth would increase** Further research is needed to determine whether the recruitment of the oral motor system is constitutive for comprehension, and whether and how it is modulated by task and kind of ACs.

Inner grounding. According to WAT, ACs are grounded on perceptual systems that detect information on the inside world. While the role of emotional processes has been underlined (e.g. [276], we focused in particular on metacognitive processes. Specifically, we predict that metacognitive processes are related to mental states concepts, and that such processes are related to the activation of the mouth effector. Recent evidence is consistent with this approach. Dreyer and Pulvermueller ([71]) have shown that mental words strongly activate face/articulator (but not hand/arm) motor cortex and elicit similar dynamics in inferior frontal and superior temporal cortex. Importantly, as emphasized by the authors, these perisylvian language areas share the activation pattern with articulatory motor cortex.

We also propose that another form of metacognition, that we call “social metacognition”, characterizes more abstract than concrete concepts (for further development of these arguments, see Borghi et al. [18]). In the case of ACs, we might realize more often that our knowledge is not adequate, and that we might need the help of competent others to complement our knowledge ([262]; [308]). Further research is needed to further investigate how different kinds of metacognitive processes are related to different kinds of ACs, and how metacognition is linked to imagery and abstractness (see Figure 4).

Kinds of abstract concepts. While multiple kinds of ACs exist, so far they have been typically considered as a unitary whole (see for exceptions [28], [309]**, [29],** [310]**, [31], not exhaustive list). The literature dedicated to specific kinds of abstract concepts, such as emotional, numerical, social, aesthetic, causal ACs is increasing (see section of the recent special issue by Borghi et al. [32] dedicated to this: [30],** [311]**,** [312]**,** [313]**,** [314]**,** [315]**, [33],** [316]**). A careful and fine-grained investigation of the different kinds of ACs, of their similarities and differences, and of their representation, is however currently missing ([32], [33], [34], Villani et al., submitted, under review). Further research is needed, to investigate the mechanisms underlying processing of all kinds of abstract concepts, and those that are activated specifically for some kinds of ACs (e.g. interoception for inner states and emotional ACs). A further limitation of the current literature that need to be addressed and solved in future research is the lack of unitary methodological criteria to select abstract concepts: some studies used questionnaires on imageability, others on abstractness/concreteness, but evidence has shown that these two dimensions are correlated but not equivalent [15].**

Figure 4. Our hypothesis on the distribution of different kinds of perceptual information, i.e. exteroceptive (including proprioceptive), interoceptive and metacognitive information - for different kinds of ACs (not exhaustive list).

To conclude: WAT aims to predict and explain results on acquisition and use of ACs in infants, children and adults, on ACs brain representation, and on ACs variability across natural languages. It aims to take into account the differences between ACs but at the same time be sufficiently general to offer an explanation for all kinds of ACs, and to focus both on mechanisms and on ACs' content. The **Bayesian** model we developed in section 5 is a first step in this direction, but further work is needed to refine it, support it, or disconfirm it.

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References

Figure captions

Figure 1. A sketch of the development of ACs, in which both the perceptual and social/linguistic input play a major role, but the distribution varies with age with an increase of the role of the social/linguistic input.

Figure 2 (realized after Bastos et al. [283]). This figure shows an example of the generative model that underlies (and grounds) a concrete concept: bottle. In a probabilistic framework, generative models describe how exteroceptive, interoceptive and proprioceptive sensations are caused. Intuitively, this figure illustrates the fact that the concept of a bottle links to systematic patterns of e.g., visual, proprioceptive and auditory stimuli (blue nodes); and the generative model represents the causal dependencies between factors that cause these sensations, such as for example the fact that if I execute a drinking action (in the presence of a bottle of water), I should expect a characteristic pattern of proprioceptive, tactile and interoceptive sensations (e.g., the movements of my arm and the taste of water) - i.e., a sensory-motor-interoceptive contingency - or the fact that pouring water produces a characteristic pattern of coordinated acoustic and visual sensations - i.e., a visuo-auditory contingency. The same model also permits planning individual actions such as pouring or drinking, as well as social actions such as giving a bottle to somebody else - and to predict the multimodal effects of these actions. In this illustration, blue nodes represent sensations in various modalities, whereas red and black nodes represent the so-called hidden (non-observable) nodes of the model, which come in two varieties. Red nodes represent hidden causes (e.g., uni- or multi-modal percepts), which model stable causes such as the presence of something red or a bottle in front of me; and black nodes represent hidden states, which model dynamical events and the changes caused by the interactions among causes (e.g., sensory changes due to moving a bottle).

The arrows represent the conditional dependencies among hidden and observable variables - or the way these hidden causes and states generate observable exteroceptive, interoceptive and proprioceptive sensations. In other words, the generative model maps from causes (e.g., concepts) to consequences (e.g., visual or auditory sensations), much like the idea of a situated simulation in embodied cognitive theory; and its inversion (using Bayes rule) permits to infer the latent cause of current sensations, e.g., that there is a bottle in front of me. Here, the concept of a bottle is at the apex of the (simplified) hierarchy, which means that it integrates the various multimodal streams. As denoted by colored triangles, these information streams may come from both individual (green) and social (orange) interactions. Note that the figure is simplified in many respects, and only shows sample nodes and causal dependencies for the sake of simplicity. For example, in this figure many aspects that are plausibly part and parcel of the concept of a bottle (including linguistic and social aspects, such as e.g., a contingency between donating a bottle to somebody thirsty and feeling good) are omitted. A more formal treatment of the generative model shown in this figure (along with differential equations that describe the model dependencies) can be found in Bastos et al. [250].

[1]

Figure 3. This figure shows an example of the generative model that underlies (and grounds) an abstract concept: freedom. This figure uses the same format as the previous figure. The overall logic of the model (and concept grounding) is exactly the same as for concrete objects. Similarly to concrete concepts, the abstract concept “freedom” might activate the five sensory modalities ([9]), interoception ([11], [10]) as well as proprioception [261]: for example, if it re-enacts a scene like lying on the grass with friends and looking at the sky, it might evoke the tactile sensation of the freshness of the grass near our body, while if it re-enacts the scene of freeing ourselves from a rope it might re-enact the proprioceptive information on our body parts constrained by a rope. Compared to the figure on concrete concepts, here we have emphasized some aspects that according to WAT

are more specific for abstract concepts. e.g., the importance of the social dimension (e.g., dialoguing) of inner speech and of the resulting mouth proprioception, and of metacognitive processes; the linkage of the concept of freedom to a very heterogeneous set of (for example) visual sensations.

Figure 4. Our hypothesis on the distribution of different kinds of perceptual information, i.e. exteroceptive (including proprioceptive), interoceptive and metacognitive information - for different kinds of Acs (not exhaustive list).

[1] Barsalou LW. Grounded cognition. Annu Rev Psychol 2008;59:617–645.

[2] Borghi AM, Binkofski F, Castelfranchi C, Cimatti F, Scorolli C, Tummolini L. The challenge of abstract concepts. Psychol Bull 2017;143:263–92. doi:10.1037/bul0000089.

[3] Spunt RP, Kemmerer D, Adolphs R. The neural basis of conceptualizing the same action at different levels of abstraction. Soc Cogn Affect Neurosci 2016;11:1141–51. doi:10.1093/scan/nsv084.

[4] Heit E, Barsalou LW. The instantiation principle in natural categories. Mem Hove Engl 1996;4:413–51. doi:10.1080/096582196388915.

[5] Murphy GL, Wisniewski EJ. Categorizing objects in isolation and in scenes: what a superordinate is good for. J Exp Psychol Learn Mem Cogn 1989;15:572–86.

[6] Borghi AM, Caramelli N, Setti A. Conceptual information on objects' locations. Brain Lang 2005;93:140–51. doi:10.1016/j.bandl.2004.09.004.

[7] Borghi AM, Binkofski F. The problem of definition. Words Soc. Tools Embodied View Abstr. Concepts, Springer; 2014, p. 1–17.

[8] Barsalou LW. Abstraction in perceptual symbol systems. Philos Trans R Soc Lond B Biol Sci 2003;358:1177–87. doi:10.1098/rstb.2003.1319.

[9] Connell L, Lynott D. Strength of perceptual experience predicts word processing performance better than concreteness or imageability. Cognition 2012;125:452–65. doi:10.1016/j.cognition.2012.07.010.

[10] Connell L, Lynott D, Banks B. Interoception: the forgotten modality in perceptual grounding of abstract and concrete concepts. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0143.
[11] Connell L, Lynott D, Carney J. Interoception: The Forgotten Modality in Perceptual Grounding of Concepts. Proc. Cogn. Sci. Soc., 2017.
[12] Wiemer-Hastings K, Krug J, Xu X. Imagery, Context Availabilty, Contextual Constraint and Abstractness. Proc. Annu. Meet. Cogn. Sci. Soc., vol. 23, 2001.
[13] Troche J, Crutch S, Reilly J. Clustering, hierarchical organization, and the topography of abstract and concrete nouns. Front Psychol 2014;5:360. doi:10.3389/fpsyg.2014.00360.
[14] Barsalou LW, Dutriaux L, Scheepers C. Moving beyond the distinction between concrete and abstract concepts. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0144.
[15] Kousta S-T, Vigliocco G, Vinson DP, Andrews M, Del Campo E. The representation of abstract words: why emotion matters. J Exp Psychol Gen 2011;140:14–34. doi:10.1037/a0021446.
[16] Della Rosa PA, Catricalà E, Vigliocco G, Cappa SF. Beyond the abstract-concrete dichotomy: mode of acquisition, concreteness, imageability, familiarity, age of acquisition, context availability, and abstractness norms for a set of 417 Italian words. Behav Res Methods 2010;42:1042–8. doi:10.3758/BRM.42.4.1042.
[17] Wauters LN, Tellings AEJM, van Bon WHJ, Mak WM. Mode of acquisition as a factor in deaf children's reading comprehension. J Deaf Stud Deaf Educ 2008;13:175–92. doi:10.1093/deafed/enm050.
[18] Borghi AM, Barca L, Binkofski F, Tummolini L. Abstract concepts, language and sociality: from acquisition to inner speech. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0134.
[19] Bennett SDR, Burnett AN, Siakaluk PD, Pexman PM. Imageability and body-object interaction ratings for 599 multisyllabic nouns. Behav Res Methods 2011;43:1100–9. doi:10.3758/s13428-011-0117-5.
[20] Siakaluk PD, Pexman PM, Aguilera L, Owen WJ, Sears CR. Evidence for the activation of sensorimotor information during visual word recognition: the body-object interaction effect. Cognition 2008;106:433–43. doi:10.1016/j.cognition.2006.12.011.
[21] Paivio A, Clark JM, Khan M. Effects of concreteness and semantic relatedness on composite imagery ratings and cued recall. Mem Cognit 1988;16:422–30.
[22] Paivio A. Mental representations: A dual coding approach. Oxford University Press; 1990.
[23] Schwanenflugel PJ, Akin C, Luh WM. Context availability and the recall of abstract and concrete words. Mem Cognit 1992;20:96–104.
[24] Lupyan G. Linguistically modulated perception and cognition: the label-feedback hypothesis. Front Psychol 2012;3:54. doi:10.3389/fpsyg.2012.00054.
[25] Lupyan G, Winter B. Language is more abstract than you think, or, why aren't languages more iconic? Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0137.
[26] Mirolli M, Parisi D. Towards a Vygotskyan cognitive robotics: The role of language as a cognitive tool. New Ideas Psychol 2011;29:298–311. doi:10.1016/j.newideapsych.2009.07.001.
[27] Flemming TM, Thompson RKR, Fagot J. Baboons, like humans, solve analogy by categorical abstraction of relations. Anim Cogn 2013;16:519–24. doi:10.1007/s10071-013-0596-0.
[28] Crutch SJ, Troche J, Reilly J, Ridgway GR. Abstract conceptual feature ratings: the role of emotion, magnitude, and other cognitive domains in the organization of abstract conceptual knowledge. Front Hum Neurosci 2013;7:186. doi:10.3389/fnhum.2013.00186.
[29] Ghio M, Vaghi MMS, Tettamanti M. Fine-grained semantic categorization across the abstract and concrete domains. PloS One 2013;8:e67090. doi:10.1371/journal.pone.0067090.

[30] Ghio M, Haegert K, Vaghi MM, Tettamanti M. Sentential negation of abstract and concrete conceptual categories: a brain decoding multivariate pattern analysis study. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0124.
[31] Roversi C, Borghi AM, Tummolini L. A marriage is an artefact and not a walk that we take together: an experimental study on the categorization of artefacts. Rev Philos Psychol 2013;4:527–542.
[32] Borghi AM, Barca L, Binkofski F, Tummolini L. Varieties of abstract concepts: development, use and representation in the brain. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0121.
[33] Desai RH, Reilly M, van Dam W. The multifaceted abstract brain. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0122.
[34] Harpaintner M, Trumpp NM, Kiefer M. The semantic content of abstract concepts: A property listing study of 296 abstract words. Front Psychol 2018;9.
[35] Barsalou LW. Perceptual symbol systems. Behav Brain Sci 1999;22:577–609; discussion 610-660.
[36] Barsalou LW. On Staying Grounded and Avoiding Quixotic Dead Ends. Psychon Bull Rev 2016;23:1122–42. doi:10.3758/s13423-016-1028-3.
[37] Borghi AM, Caruana F. Embodiment theories. Int Encycl Soc Behav Sci Sect Cogn Neurosci 2013:317–333.
[38] Gallese V, Lakoff G. The Brain's concepts: the role of the Sensory-motor system in conceptual knowledge. Cogn Neuropsychol 2005;22:455–79. doi:10.1080/02643290442000310.
[39] Glenberg AM, Gallese V. Action-based language: a theory of language acquisition, comprehension, and production. Cortex J Devoted Study Nerv Syst Behav 2012;48:905–22. doi:10.1016/j.cortex.2011.04.010.
[40] Glenberg AM, Witt JK, Metcalfe J. From the Revolution to Embodiment: 25 Years of Cognitive Psychology. Perspect Psychol Sci J Assoc Psychol Sci 2013;8:573–85. doi:10.1177/1745691613498098.
[41] Meteyard L, Cuadrado SR, Bahrami B, Vigliocco G. Coming of age: a review of embodiment and the neuroscience of semantics. Cortex J Devoted Study Nerv Syst Behav 2012;48:788–804. doi:10.1016/j.cortex.2010.11.002.
[42] Pulvermüller F, Fadiga L. Active perception: sensorimotor circuits as a cortical basis for language. Nat Rev Neurosci 2010;11:351.
[43] Cappa SF, Pulvermüller F. Cortex special issue: language and the motor system. Cortex J Devoted Study Nerv Syst Behav 2012;48:785–7. doi:10.1016/j.cortex.2012.04.010.
[44] Gallese V. Mirror neurons and the social nature of language: the neural exploitation hypothesis. Soc Neurosci 2008;3:317–33. doi:10.1080/17470910701563608.
[45] Pecher D. Curb Your Embodiment. Top Cogn Sci 2018;10:501–17. doi:10.1111/tops.12311.
[46] Pecher D, Zeelenberg R. Boundaries to grounding abstract concepts. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0132.
[47] Anderson ML. Neural reuse: a fundamental organizational principle of the brain. Behav Brain Sci 2010;33:245–66; discussion 266-313. doi:10.1017/S0140525X10000853.
[48] Borghi AM. Language comprehension: action, affordances and goals. Lang. Action Cogn. Neurosci., Psychology Press; 2012, p. 143–162.
[49] Pulvermüller F. Neural reuse of action perception circuits for language, concepts and communication. Prog Neurobiol 2018;160:1–44. doi:10.1016/j.pneurobio.2017.07.001.
[50] Wittgenstein L. Philosophical investigations. John Wiley & Sons; 2009.
[51] Noë A. Out of our heads: Why you are not your brain, and other lessons from the biology of consciousness. Macmillan; 2009.

[52] Clark A, Toribio J. Magic Words: How Language Augments Hum an Computation. Lang. Mean. Cogn. Sci., Routledge; 2012, p. 33–51.
[53] Borghi AM, Scorolli C, Caligiore D, Baldassarre G, Tummolini L. The embodied mind extended: using words as social tools. Front Psychol 2013;4:214. doi:10.3389/fpsyg.2013.00214.
[54] Lupyan G, Bergen B. How Language Programs the Mind. Top Cogn Sci 2016;8:408–24. doi:10.1111/tops.12155.
[55] Lupyan G, Clark A. Words and the world: Predictive coding and the language-perception-cognition interface. Curr Dir Psychol Sci 2015;24:279–284.
[56] Dove G. Thinking in words: language as an embodied medium of thought. Top Cogn Sci 2014;6:371–89. doi:10.1111/tops.12102.
[57] Dove G. Language as a disruptive technology: abstract concepts, embodiment and the flexible mind. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0135.
[58] Searle JR. Indirect speech acts 1975.
[59] Searle JR. A taxonomy of illocutionary acts 1975.
[60] Lupyan G, Ward EJ. Language can boost otherwise unseen objects into visual awareness. Proc Natl Acad Sci U S A 2013;110:14196–201. doi:10.1073/pnas.1303312110.
[61] Barsalou LW. Ad hoc categories. Mem Cognit 1983;11:211–227.
[62] Barsalou LW. Ideals, central tendency, and frequency of instantiation as determinants of graded structure in categories. J Exp Psychol Learn Mem Cogn 1985;11:629.
[63] Nelson K. Where do taxonomic categories come from? Hum Dev 1988;31:3–10.
[64] Lucariello J, Nelson K. Slot-filler categories as memory organizers for young children. Dev Psychol 1985;21:272.
[65] Tomasello M, Carpenter M. Shared intentionality. Dev Sci 2007;10:121–5. doi:10.1111/j.1467-7687.2007.00573.x.
[66] D'Ausilio A, Pulvermüller F, Salmas P, Bufalari I, Begliomini C, Fadiga L. The motor somatotopy of speech perception. Curr Biol CB 2009;19:381–5. doi:10.1016/j.cub.2009.01.017.
[67] D'Ausilio A, Craighero L, Fadiga L. The contribution of the frontal lobe to the perception of speech. J Neurolinguistics 2012;25:328–335.
[68] Lieberman P. Human language and our reptilian brain: The subcortical bases of speech, syntax, and thought. Harvard University Press; 2009.
[69] Topolinski S, Strack F. Motormouth: mere exposure depends on stimulus-specific motor simulations. J Exp Psychol Learn Mem Cogn 2009;35:423–33. doi:10.1037/a0014504.
[70] Mahon BZ, Caramazza A. A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. J Physiol Paris 2008;102:59–70. doi:10.1016/j.jphysparis.2008.03.004.
[71] Dreyer FR, Pulvermüller F. Abstract semantics in the motor system? - An event-related fMRI study on passive reading of semantic word categories carrying abstract emotional and mental meaning. Cortex J Devoted Study Nerv Syst Behav 2018;100:52–70. doi:10.1016/j.cortex.2017.10.021.
[72] Malt B, Wolff P. Words and the mind: How words capture human experience. Oxford University Press; 2010.
[73] Bergelson E, Swingley D. The acquisition of abstract words by young infants. Cognition 2013;127:391–7. doi:10.1016/j.cognition.2013.02.011.
[74] Beier JS, Spelke ES. Infants' developing understanding of social gaze. Child Dev 2012;83:486–496.
[75] Brooks R, Meltzoff AN. The development of gaze following and its relation to language. Dev Sci 2005;8:535–43. doi:10.1111/j.1467-7687.2005.00445.x.

[76] Yu C, Smith LB. Hand-Eye Coordination Predicts Joint Attention. Child Dev 2017;88:2060–78. doi:10.1111/cdev.12730.
[77] Buresh JS, Woodward AL. Infants track action goals within and across agents. Cognition 2007;104:287–314. doi:10.1016/j.cognition.2006.07.001.
[78] Moll H, Koring C, Carpenter M, Tomasello M. Infants determine others' focus of attention by pragmatics and exclusion. J Cogn Dev 2006;7:411–430.
[79] Moll H, Carpenter M, Tomasello M. Fourteen-month-olds know what others experience only in joint engagement. Dev Sci 2007;10:826–35. doi:10.1111/j.1467-7687.2007.00615.x.
[80] Onishi KH, Baillargeon R. Do 15-month-old infants understand false beliefs? Science 2005;308:255–8. doi:10.1126/science.1107621.
[81] D'Entremont B, Hains SM, Muir DW. A demonstration of gaze following in 3-to 6-month-olds. Infant Behav Dev 1997;20:569–572.
[82] Akhtar N, Carpenter M, Tomasello M. The role of discourse novelty in early word learning. Child Dev 1996;67:635–645.
[83] Tomasello M, Haberl K. Understanding attention: 12- and 18-month-olds know what is new for other persons. Dev Psychol 2003;39:906–12.
[84] Carpenter M, Nagell K, Tomasello M. Social cognition, joint attention, and communicative competence from 9 to 15 months of age. Monogr Soc Res Child Dev 1998;63:i–vi, 1–143.
[85] Tomasello M, Akhtar N. Five questions for any theory of word learning. Becom. Word Learn. Debate Lex. Acquis., Oxford Univ. Pr.; 2000, p. 179–186.
[86] Tomasello M, Strosberg R, Akhtar N. Eighteen-month-old children learn words in non-ostensive contexts. J Child Lang 1996;23:157–76.
[87] Baldwin DA, Markman EM, Bill B, Desjardins RN, Irwin JM, Tidball G. Infants' reliance on a social criterion for establishing word-object relations. Child Dev 1996;67:3135–53.
[88] Floor P, Akhtar N. Can 18-month-old infants learn words by listening in on conversations? Infancy 2006;9:327–339.
[89] Akhtar N, Jipson J, Callanan MA. Learning words through overhearing. Child Dev 2001;72:416–430.
[90] Akhtar N. The robustness of learning through overhearing. Dev Sci 2005;8:199–209.
[91] Schmerse D, Lieven E, Tomasello M. Young children use shared experience to interpret definite reference. J Child Lang 2015;42:1146–57. doi:10.1017/S0305000914000555.
[92] Hollich GJ, Hirsh-Pasek K, Golinkoff RM, Brand RJ, Brown E, Chung HL, et al. Breaking the language barrier: an emergentist coalition model for the origins of word learning. Monogr Soc Res Child Dev 2000;65:i–vi, 1–123.
[93] Golinkoff RM, Hirsh-Pasek K. Baby wordsmith: From associationist to social sophisticate. Curr Dir Psychol Sci 2006;15:30–33.
[94] Hirsh-Pasek K, Golinkoff RM, Hennon EA, Maguire MJ. Hybrid Theories at the Frontier of Developmental Psychology: The Emergentist Coalition Model of Word Learning as a Case. Weav Lex 2004:173.
[95] Corriveau K, Harris PL. Choosing your informant: weighing familiarity and recent accuracy. Dev Sci 2009;12:426–37. doi:10.1111/j.1467-7687.2008.00792.x.
[96] Harris PL, Koenig MA. Trust in testimony: how children learn about science and religion. Child Dev 2006;77:505–24. doi:10.1111/j.1467-8624.2006.00886.x.
[97] Tizard B, Hughes M. Young children learning. John Wiley & Sons; 2008.
[98] Koenig MA, Clément F, Harris PL. Trust in testimony: children's use of true and false statements. Psychol Sci 2004;15:694–8. doi:10.1111/j.0956-7976.2004.00742.x.
[99] Sabbagh MA, Shafman D. How children block learning from ignorant speakers. Cognition 2009;112:415–422.

[100] Mangardich H, Sabbagh MA. Children remember words from ignorant speakers but do not attach meaning: evidence from event-related potentials. Dev Sci 2018;21:e12544.
[101] Gillette J, Gleitman H, Gleitman L, Lederer A. Human simulations of vocabulary learning. Cognition 1999;73:135–76.
[102] Snedeker J, Gleitman L. Why it is hard to label our concepts. Weav Lex 2004;257294.
[103] Gleitman LR, Cassidy K, Nappa R, Papafragou A, Trueswell JC. Hard words. Lang Learn Dev 2005;1:23–64.
[104] Gentner D, Boroditsky L. Individuation, relativity, and early word learning. Lang Acquis Concept Dev 2001;3:215–256.
[105] Gleitman L. The structural sources of verb meanings. Lang Acquis 1990;1:3–55.
[106] Gentner D. Why verbs are hard to learn. Action Meets Word Child Learn Verbs 2006:544–564.
[107] Gilhooly KJ, Logie RH. Age-of-acquisition, imagery, concreteness, familiarity, and ambiguity measures for 1,944 words. Behav Res Methods Instrum 1980;12:395–427.
[108] Barca L, Burani C, Arduino LS. Word naming times and psycholinguistic norms for Italian nouns. Behav Res Methods Instrum Comput J Psychon Soc Inc 2002;34:424–34.
[109] Ponari M, Norbury CF, Vigliocco G. Acquisition of abstract concepts is influenced by emotional valence. Dev Sci 2018;21. doi:10.1111/desc.12549.
[110] Wauters LN, Tellings AE, Van Bon WH, Van Haaften AW. Mode of acquisition of word meanings: The viability of a theoretical construct. Appl Psycholinguist 2003;24:385–406.
[111] Vygotsky LS. Thought and language (rev. ed.). Cambridge, ma: mit Press; 1986.
[112] Borghi AM, Flumini A, Cimatti F, Marocco D, Scorolli C. Manipulating objects and telling words: a study on concrete and abstract words acquisition. Front Psychol 2011;2.
[113] Granito C, Scorolli C, Borghi AM. Naming a Lego world. The role of language in the acquisition of abstract concepts. PloS One 2015;10:e0114615. doi:10.1371/journal.pone.0114615.
[114] Locke J. An essay concerning human understanding. 1841.
[115] Clerkin EM, Hart E, Rehg JM, Yu C, Smith LB. Real-world visual statistics and infants' first-learned object names. Philos Trans R Soc Lond B Biol Sci 2017;372. doi:10.1098/rstb.2016.0055.
[116] Wojcik EH, Saffran JR. The ontogeny of lexical networks: toddlers encode the relationships among referents when learning novel words. Psychol Sci 2013;24:1898–905. doi:10.1177/0956797613478198.
[117] Pereira AF, Smith LB, Yu C. A bottom-up view of toddler word learning. Psychon Bull Rev 2014;21:178–85. doi:10.3758/s13423-013-0466-4.
[118] Landau B, Smith LB, Jones SS. The importance of shape in early lexical learning. Cogn Dev 1988;3:299–321.
[119] Smith LB. Action alters shape categories. Cogn Sci 2005;29:665–79. doi:10.1207/s15516709cog0000_13.
[120] Yu C, Ballard DH. A unified model of early word learning: Integrating statistical and social cues. Neurocomputing 2007;70:2149–2165.
[121] D'Angiulli A, Griffiths G, Marmolejo-Ramos F. Neural correlates of visualizations of concrete and abstract words in preschool children: a developmental embodied approach. Front Psychol 2015;6:856. doi:10.3389/fpsyg.2015.00856.
[122] Thelen E. L., Smith (1994). A Dynamic Systems Approach to the Development of Cognition and Action. Cambridge, MA: MIT Press; n.d.
[123] Wang J, Conder JA, Blitzer DN, Shinkareva SV. Neural representation of abstract and concrete concepts: a meta-analysis of neuroimaging studies. Hum Brain Mapp 2010;31:1459–68. doi:10.1002/hbm.20950.

[124] Binder JR, Desai RH, Graves WW, Conant LL. Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. Cereb Cortex N Y N 1991 2009;19:2767–96. doi:10.1093/cercor/bhp055.
[125] Wang X, Wu W, Ling Z, Xu Y, Fang Y, Wang X, et al. Organizational Principles of Abstract Words in the Human Brain. Cereb Cortex N Y N 1991 2017:1–14. doi:10.1093/cercor/bhx283.
[126] Della Rosa PA, Catricalà E, Canini M, Vigliocco G, Cappa SF. The left inferior frontal gyrus: A neural crossroads between abstract and concrete knowledge. NeuroImage 2018;175:449–59. doi:10.1016/j.neuroimage.2018.04.021.
[127] Fiebach CJ, Friederici AD. Processing concrete words: fMRI evidence against a specific right-hemisphere involvement. Neuropsychologia 2004;42:62–70.
[128] Fiebach CJ, Ricker B, Friederici AD, Jacobs AM. Inhibition and facilitation in visual word recognition: prefrontal contribution to the orthographic neighborhood size effect. NeuroImage 2007;36:901–11. doi:10.1016/j.neuroimage.2007.04.004.
[129] Barca L, Cornelissen P, Simpson M, Urooj U, Woods W, Ellis AW. The neural basis of the right visual field advantage in reading: an MEG analysis using virtual electrodes. Brain Lang 2011;118:53–71. doi:10.1016/j.bandl.2010.09.003.
[130] Papagno C, Fogliata A, Catricalà E, Miniussi C. The lexical processing of abstract and concrete nouns. Brain Res 2009;1263:78–86. doi:10.1016/j.brainres.2009.01.037.
[131] Bookheimer S. Functional MRI of language: new approaches to understanding the cortical organization of semantic processing. Annu Rev Neurosci 2002;25:151–88. doi:10.1146/annurev.neuro.25.112701.142946.
[132] Mellem MS, Jasmin KM, Peng C, Martin A. Sentence processing in anterior superior temporal cortex shows a social-emotional bias. Neuropsychologia 2016;89:217–24. doi:10.1016/j.neuropsychologia.2016.06.019.
[133] Binder JR, Westbury CF, McKiernan KA, Possing ET, Medler DA. Distinct brain systems for processing concrete and abstract concepts. J Cogn Neurosci 2005;17:905–917.
[134] Binder JR, Frost JA, Hammeke TA, Bellgowan PS, Springer JA, Kaufman JN, et al. Human temporal lobe activation by speech and nonspeech sounds. Cereb Cortex 2000;10:512–528.
[135] Shallice T, Cooper RP. Is there a semantic system for abstract words? Front Hum Neurosci 2013;7:175. doi:10.3389/fnhum.2013.00175.
[136] Hagoort P. How the brain solves the binding problem for language: a neurocomputational model of syntactic processing. NeuroImage 2003;20 Suppl 1:S18-29.
[137] Hagoort P. On Broca, brain, and binding: a new framework. Trends Cogn Sci 2005;9:416–23. doi:10.1016/j.tics.2005.07.004.
[138] Dove G. Three symbol ungrounding problems: Abstract concepts and the future of embodied cognition. Psychon Bull Rev 2016;23:1109–21. doi:10.3758/s13423-015-0825-4.
[139] Martin A. GRAPES-Grounding representations in action, perception, and emotion systems: How object properties and categories are represented in the human brain. Psychon Bull Rev 2016;23:979–90. doi:10.3758/s13423-015-0842-3.
[140] Ferstl EC, Neumann J, Bogler C, von Cramon DY. The extended language network: a meta-analysis of neuroimaging studies on text comprehension. Hum Brain Mapp 2008;29:581–93. doi:10.1002/hbm.20422.
[141] Acheson DJ, Hagoort P. Stimulating the brain's language network: syntactic ambiguity resolution after TMS to the inferior frontal gyrus and middle temporal gyrus. J Cogn Neurosci 2013;25:1664–77. doi:10.1162/jocn_a_00430.

[142] Bosco FM, Parola A, Valentini MC, Morese R. Neural correlates underlying the comprehension of deceitful and ironic communicative intentions. Cortex J Devoted Study Nerv Syst Behav 2017;94:73–86. doi:10.1016/j.cortex.2017.06.010.
[143] Rapp AM, Mutschler DE, Erb M. Where in the brain is nonliteral language? A coordinate-based meta-analysis of functional magnetic resonance imaging studies. NeuroImage 2012;63:600–10. doi:10.1016/j.neuroimage.2012.06.022.
[144] Sakurai Y, Mimura I, Mannen T. Agraphia for kanji resulting from a left posterior middle temporal gyrus lesion. Behav Neurol 2008;19:93–106.
[145] Noppeney U, Price CJ. Retrieval of abstract semantics. NeuroImage 2004;22:164–70. doi:10.1016/j.neuroimage.2003.12.010.
[146] Liebenthal E, Desai RH, Humphries C, Sabri M, Desai A. The functional organization of the left STS: a large scale meta-analysis of PET and fMRI studies of healthy adults. Front Neurosci 2014;8:289. doi:10.3389/fnins.2014.00289.
[147] Hein G, Knight RT. Superior temporal sulcus--It's my area: or is it? J Cogn Neurosci 2008;20:2125–36. doi:10.1162/jocn.2008.20148.
[148] Hoffman P, Binney RJ, Lambon Ralph MA. Differing contributions of inferior prefrontal and anterior temporal cortex to concrete and abstract conceptual knowledge. Cortex J Devoted Study Nerv Syst Behav 2015;63:250–66. doi:10.1016/j.cortex.2014.09.001.
[149] Borghi AM, Setti A. Abstract Concepts and Aging: An Embodied and Grounded Perspective. Front Psychol 2017;8:430. doi:10.3389/fpsyg.2017.00430.
[150] Binney RJ, Hoffman P, Lambon Ralph MA. Mapping the Multiple Graded Contributions of the Anterior Temporal Lobe Representational Hub to Abstract and Social Concepts: Evidence from Distortion-corrected fMRI. Cereb Cortex N Y N 1991 2016. doi:10.1093/cercor/bhw260.
[151] Visser M, Lambon Ralph MA. Differential contributions of bilateral ventral anterior temporal lobe and left anterior superior temporal gyrus to semantic processes. J Cogn Neurosci 2011;23:3121–3131.
[152] Sabsevitz DS, Medler DA, Seidenberg M, Binder JR. Modulation of the semantic system by word imageability. NeuroImage 2005;27:188–200. doi:10.1016/j.neuroimage.2005.04.012.
[153] Ralph MAL, Jefferies E, Patterson K, Rogers TT. The neural and computational bases of semantic cognition. Nat Rev Neurosci 2017;18:42.
[154] D'Esposito M, Detre JA, Aguirre GK, Stallcup M, Alsop DC, Tippet LJ, et al. A functional MRI study of mental image generation. Neuropsychologia 1997;35:725–30.
[155] Perani D, Cappa SF, Schnur T, Tettamanti M, Collina S, Rosa MM, et al. The neural correlates of verb and noun processing. A PET study. Brain J Neurol 1999;122 (Pt 12):2337–44.
[156] Jessen F, Heun R, Erb M, Granath DO, Klose U, Papassotiropoulos A, et al. The concreteness effect: evidence for dual coding and context availability. Brain Lang 2000;74:103–12. doi:10.1006/brln.2000.2340.
[157] Wilson-Mendenhall CD, Simmons WK, Martin A, Barsalou LW. Contextual processing of abstract concepts reveals neural representations of nonlinguistic semantic content. J Cogn Neurosci 2013;25:920–35. doi:10.1162/jocn_a_00361.
[158] Coltheart M, Patterson K, Marshall JC. Deep dyslexia since 1980. Routledge; 1987.
[159] Warrington EK, Shallice T. Category specific semantic impairments. Brain 1984;107:829–853.
[160] Bonner MF, Vesely L, Price C, Anderson C, Richmond L, Farag C, et al. Reversal of the concreteness effect in semantic dementia. Cogn Neuropsychol 2009;26:568–579.
[161] Hoffman P, Lambon Ralph MA. Reverse concreteness effects are not a typical feature of semantic dementia: evidence for the hub-and-spoke model of conceptual representation. Cereb Cortex N Y N 1991 2011;21:2103–12. doi:10.1093/cercor/bhq288.

[162] Plaut DC, Shallice T. Deep dyslexia: A case study of connectionist neuropsychology. Cogn Neuropsychol 1993;10:377–500.
[163] Rüschemeyer S-A, Brass M, Friederici AD. Comprehending prehending: neural correlates of processing verbs with motor stems. J Cogn Neurosci 2007;19:855–865.
[164] Jefferies E, Patterson K, Jones RW, Lambon Ralph MA. Comprehension of concrete and abstract words in semantic dementia. Neuropsychology 2009;23:492–9. doi:10.1037/a0015452.
[165] Giffard B, Laisney M, Desgranges B, Eustache F. An exploration of the semantic network in Alzheimer's disease: Influence of emotion and concreteness of concepts. Cortex 2015;69:201–211.
[166] Patterson K, Nestor PJ, Rogers TT. Where do you know what you know? The representation of semantic knowledge in the human brain. Nat Rev Neurosci 2007;8:976.
[167] Martin A, Simmons WK, Beauchamp MS, Gotts SJ. Is a single "hub," with lots of spokes, an accurate description of the neural architecture of action semantics? Comment on "Action semantics: a unifying conceptual framework for the selective use of multimodal and modality-specific object knowledge" by van Elk, Van Schie and Bekkering. Phys Life Rev 2014;11:261–262.
[168] Halpern CH, Glosser G, Clark R, Gee J, Moore P, Dennis K, et al. Dissociation of numbers and objects in corticobasal degeneration and semantic dementia. Neurology 2004;62:1163–1169.
[169] Gainotti G. The format of conceptual representations disrupted in semantic dementia: a position paper. Cortex 2012;48:521–529.
[170] Kiefer M, Pulvermüller F. Conceptual representations in mind and brain: theoretical developments, current evidence and future directions. Cortex 2012;48:805–825.
[171] McCaffrey J. Reconceiving conceptual vehicles: Lessons from semantic dementia. Philos Psychol 2015;28:337–354.
[172] Simmons WK, Martin A. The anterior temporal lobes and the functional architecture of semantic memory. J Int Neuropsychol Soc 2009;15:645–649.
[173] Wauters LN, Van Bon WH, Tellings AE. Reading comprehension of Dutch deaf children. Read Writ 2006;19:49–76.
[174] Wauters LN, Tellings AE, Van Bon WH, Mak WM. Mode of acquisition as a factor in deaf children's reading comprehension. J Deaf Stud Deaf Educ 2007;13:175–192.
[175] Rajendran G, Mitchell P. Cognitive theories of autism. Dev Rev 2007;27:224–260.
[176] Baron-Cohen S, Campbell R, Karmiloff-Smith A, Grant J, Walker J. Are children with autism blind to the mentalistic significance of the eyes? Br J Dev Psychol 1995;13:379–398.
[177] Happé FG. The role of age and verbal ability in the theory of mind task performance of subjects with autism. Child Dev 1995;66:843–855.
[178] Gallagher S. Understanding interpersonal problems in autism: Interaction theory as an alternative to theory of mind. Philos Psychiatry Psychol 2004;11:199–217.
[179] Kamio Y, Toichi M. Dual access to semantics in autism: Is pictorial access superior to verbal access? J Child Psychol Psychiatry 2000;41:859–867.
[180] Kunda M, Goel AK. Thinking in pictures as a cognitive account of autism. J Autism Dev Disord 2011;41:1157–1177.
[181] Grandin T. Thinking in pictures: And other reports from my life with autism. Vintage; 2006.
[182] Knight V, McKissick BR, Saunders A. A review of technology-based interventions to teach academic skills to students with autism spectrum disorder. J Autism Dev Disord 2013;43:2628–2648.
[183] Leslie AM, Thaiss L. Domain specificity in conceptual development: Neuropsychological evidence from autism. Cognition 1992;43:225–251.
[184] Eskes GA, Bryson SE, McCormick TA. Comprehension of concrete and abstract words in autistic children. J Autism Dev Disord 1990;20:61–73.

[185] Hobson RP, Lee A. Emotion-related and abstract concepts in autistic people: Evidence from the British Picture Vocabulary Scale. J Autism Dev Disord 1989;19:601–623.
[186] Tager-Flusberg H. Basic level and superordinate level categorization by autistic, mentally retarded, and normal children. J Exp Child Psychol 1985;40:450–469.
[187] Johnson CR, Rakison DH. Early categorization of animate/inanimate concepts in young children with autism. J Dev Phys Disabil 2006;18:73–89.
[188] Iacoboni M. Failure to deactivate in autism: the co-constitution of self and other. Trends Cogn Sci 2006;10:431–433.
[189] Oberman LM, Ramachandran VS. The simulating social mind: the role of the mirror neuron system and simulation in the social and communicative deficits of autism spectrum disorders. Psychol Bull 2007;133:310.
[190] Dapretto M, Davies MS, Pfeifer JH, Scott AA, Sigman M, Bookheimer SY, et al. Understanding emotions in others: mirror neuron dysfunction in children with autism spectrum disorders. Nat Neurosci 2006;9:28.
[191] Tager-Flusberg H, Joseph RM. Identifying neurocognitive phenotypes in autism. Philos Trans R Soc Lond B Biol Sci 2003;358:303–314.
[192] Siegal M, Blades M. Language and auditory processing in autism. Trends Cogn Sci 2003;7:378–380.
[193] Parish-Morris J, Hennon EA, Hirsh-Pasek K, Golinkoff RM, Tager-Flusberg H. Children with autism illuminate the role of social intention in word learning. Child Dev 2007;78:1265–87. doi:10.1111/j.1467-8624.2007.01065.x.
[194] Friston KJ, Stephan KE, Montague R, Dolan RJ. Computational psychiatry: the brain as a phantastic organ. Lancet Psychiatry 2014;1:148–158.
[195] Palmer CJ, Lawson RP, Hohwy J. Bayesian approaches to autism: Towards volatility, action, and behavior. Psychol Bull 2017;143:521.
[196] Cukur T, Nishimoto S, Huth AG, Gallant JL. Attention during natural vision warps semantic representation across the human brain. Nat Neurosci 2013;16:763.
[197] Borghi AM, Zarcone E. Grounding Abstractness: Abstract Concepts and the Activation of the Mouth. Front Psychol 2016;7:1498. doi:10.3389/fpsyg.2016.01498.
[198] Mazzuca C, Lugli L, Nicoletti R, Borghi AM. Abstract, emotional and concrete concepts and the activation of mouth-hand effectors. PeerJ Prepr 2018;6:e26559v1.
[199] Chumbley JI, Balota DA. A word's meaning affects the decision in lexical decision. Mem Cognit 1984;12:590–606.
[200] Jirak D, Menz MM, Buccino G, Borghi AM, Binkofski F. Grasping language–a short story on embodiment. Conscious Cogn 2010;19:711–720.
[201] Barca L, Pezzulo G. Unfolding visual lexical decision in time. PloS One 2012;7:e35932. doi:10.1371/journal.pone.0035932.
[202] Barca L, Pezzulo G. Tracking second thoughts: continuous and discrete revision processes during visual lexical decision. PloS One 2015;10:e0116193. doi:10.1371/journal.pone.0116193.
[203] Barca L, Benedetti F, Pezzulo G. The effects of phonological similarity on the semantic categorisation of pictorial and lexical stimuli: Evidence from continuous behavioural measures. J Cogn Psychol 2016;28:159–170.
[204] Barca L, Pezzulo G, Ouellet M, Ferrand L. Dynamic lexical decisions in French: Evidence for a feedback inconsistency effect. Acta Psychol (Amst) 2017;180:23–32.
[205] Topolinski S, Maschmann IT, Pecher D, Winkielman P. Oral approach-avoidance: affective consequences of muscular articulation dynamics. J Pers Soc Psychol 2014;106:885–96. doi:10.1037/a0036477.

[206] Topolinski S, Lindner S, Freudenberg A. Popcorn in the cinema: Oral interference sabotages advertising effects. J Consum Psychol 2014;24:169–176.
[207] Scorolli C, Jacquet PO, Binkofski F, Nicoletti R, Tessari A, Borghi AM. Abstract and concrete phrases processing differentially modulates cortico-spinal excitability. Brain Res 2012;1488:60–71. doi:10.1016/j.brainres.2012.10.004.
[208] Scorolli C, Binkofski F, Buccino G, Nicoletti R, Riggio L, Borghi AM. Abstract and concrete sentences, embodiment, and languages. Front Psychol 2011;2:227. doi:10.3389/fpsyg.2011.00227.
[209] Sakreida K, Scorolli C, Menz MM, Heim S, Borghi AM, Binkofski F. Are abstract action words embodied? An fMRI investigation at the interface between language and motor cognition. Front Hum Neurosci 2013;7:125. doi:10.3389/fnhum.2013.00125.
[210] Barca L, Mazzuca C, Borghi AM. Pacifier Overuse and Conceptual Relations of Abstract and Emotional Concepts. Front Psychol 2017;8:2014. doi:10.3389/fpsyg.2017.02014.
[211] Barca L, Mazzuca C, Borghi AM, Barca L, della Battaglia VSM. Pacifier overuse interferes with children's abstract word processing. Open Sci Framew Oct 2017;9.
[212] De Houwer J. The extrinsic affective Simon task. Exp Psychol 2003;50:77.
[213] Moors A, De Houwer J. Automatic appraisal of motivational valence: Motivational affective priming and Simon effects. Cogn Emot 2001;15:749–766.
[214] Scerrati E, Lugli L, Borghi AM, Nicoletti R. Is the acoustic modality relevant for abstract concepts? An investigation with implicit measures. Model. Conf. ACTION Lang. Cogn. Rome, 2016.
[215] Landauer TK, Dumais ST. A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. Psychol Rev 1997;104:211.
[216] Andrews M, Frank S, Vigliocco G. Reconciling embodied and distributional accounts of meaning in language. Top Cogn Sci 2014;6:359–70. doi:10.1111/tops.12096.
[217] Borghi AM, Capirci O, Gianfreda G, Volterra V. The body and the fading away of abstract concepts and words: a sign language analysis. Front Psychol 2014;5:811. doi:10.3389/fpsyg.2014.00811.
[218] Boroditsky L. Does language shape thought?: Mandarin and English speakers' conceptions of time. Cognit Psychol 2001;43:1–22.
[219] Boroditsky L, Fuhrman O, McCormick K. Do English and Mandarin speakers think about time differently? Cognition 2011;118:123–9. doi:10.1016/j.cognition.2010.09.010.
[220] Casasanto D. Who's afraid of the big bad Whorf? Crosslinguistic differences in temporal language and thought. Lang Learn 2008;58:63–79.
[221] Bylund E, Athanasopoulos P. The Whorfian time warp: Representing duration through the language hourglass. J Exp Psychol Gen 2017;146:911–6. doi:10.1037/xge0000314.
[222] de la Fuente J, Santiago J, Román A, Dumitrache C, Casasanto D. When you think about it, your past is in front of you: how culture shapes spatial conceptions of time. Psychol Sci 2014;25:1682–90. doi:10.1177/0956797614534695.
[223] Román A, Flumini A, Santiago J. Scanning of speechless comics changes spatial biases in mental model construction. Philos Trans R Soc Lond B Biol Sci 2018;373.
[224] Winter B, Marghetis T, Matlock T. Of magnitudes and metaphors: explaining cognitive interactions between space, time, and number. Cortex J Devoted Study Nerv Syst Behav 2015;64:209–24. doi:10.1016/j.cortex.2014.10.015.
[225] Boroditsky L. Linguistic relativity. Encycl Cogn Sci 2006.
[226] Casasanto D. Linguistic relativity. Routledge Handb Semant 2016:158–174.

[227] Dolscheid S, Shayan S, Majid A, Casasanto D. The thickness of musical pitch: psychophysical evidence for linguistic relativity. Psychol Sci 2013;24:613–21. doi:10.1177/0956797612457374.
[228] Majid A, Bowerman M, Kita S, Haun DB, Levinson SC. Can language restructure cognition? The case for space. Trends Cogn Sci 2004;8:108–114.
[229] Reines MF, Prinz J. Reviving Whorf: The return of linguistic relativity. Philos Compass 2009;4:1022–1032.
[230] Roberson D, Davidoff J, Davies IR, Shapiro LR. Color categories: Evidence for the cultural relativity hypothesis. Cognit Psychol 2005;50:378–411.
[231] Winawer J, Witthoft N, Frank MC, Wu L, Wade AR, Boroditsky L. Russian blues reveal effects of language on color discrimination. Proc Natl Acad Sci 2007;104:7780–7785.
[232] Majid A, Burenhult N. Odors are expressible in language, as long as you speak the right language. Cognition 2014;130:266–270.
[233] Majid A, Burenhult N, Stensmyr M, De Valk J, Hansson BS. Olfactory language and abstraction across cultures. Phil Trans R Soc B 2018;373:20170139.
[234] Dolscheid S, Shayan S, Majid A, Casasanto D. The thickness of musical pitch: Psychophysical evidence for linguistic relativity. Psychol Sci 2013;24:613–621.
[235] Cimatti F, Flumini A, Vittuari M, Borghi AM. Odors, words and objects. Riv Ital Filos Linguaggio 2016;10.
[236] Schwanenflugel PJ, Stowe RW. Context availability and the processing of abstract and concrete words in sentences. Read Res Q 1989:114–126.
[237] Paivio A, Khan M, Begg I. Concreteness and relational effects on recall of adjective-noun pairs. Can J Exp Psychol Rev Can Psychol Exp 2000;54:149–60.
[238] Adorni R, Proverbio AM. The neural manifestation of the word concreteness effect: an electrical neuroimaging study. Neuropsychologia 2012;50:880–91. doi:10.1016/j.neuropsychologia.2012.01.028.
[239] Kanske P, Kotz SA. Concreteness in emotional words: ERP evidence from a hemifield study. Brain Res 2007;1148:138–48. doi:10.1016/j.brainres.2007.02.044.
[240] Kounios J, Holcomb PJ. Concreteness effects in semantic processing: ERP evidence supporting dual-coding theory. J Exp Psychol Learn Mem Cogn 1994;20:804–23.
[241] West WC, Holcomb PJ. Imaginal, semantic, and surface-level processing of concrete and abstract words: an electrophysiological investigation. J Cogn Neurosci 2000;12:1024–37.
[242] Glenberg AM, Robertson DA. Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. J Mem Lang 2000;43:379–401.
[243] Louwerse MM. Knowing the Meaning of a Word by the Linguistic and Perceptual Company It Keeps. Top Cogn Sci 2018;10:573–89. doi:10.1111/tops.12349.
[244] Louwerse MM. Embodied relations are encoded in language. Psychon Bull Rev 2008;15:838–44.
[245] Moffat M, Siakaluk PD, Sidhu DM, Pexman PM. Situated conceptualization and semantic processing: effects of emotional experience and context availability in semantic categorization and naming tasks. Psychon Bull Rev 2015;22:408–19. doi:10.3758/s13423-014-0696-0.
[246] Recchia G, Jones MN. The semantic richness of abstract concepts. Front Hum Neurosci 2012;6:315. doi:10.3389/fnhum.2012.00315.
[247] Zdrazilova L, Sidhu DM, Pexman PM. Communicating abstract meaning: concepts revealed in words and gestures. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0138.
[248] Zdrazilova L, Pexman PM. Grasping the invisible: Semantic processing of abstract words. Psychon Bull Rev 2013;20:1312–1318.
[249] Harnad S. The symbol grounding problem. Phys Nonlinear Phenom 1990;42:335–346.

[250] Cangelosi A, Harnad S. The adaptive advantage of symbolic theft over sensorimotor toil: Grounding language in perceptual categories. Evol Commun 2001;4:117–142.
[251] Glenberg AM, Sato M, Cattaneo L. Use-induced motor plasticity affects the processing of abstract and concrete language. Curr Biol CB 2008;18:R290-291. doi:10.1016/j.cub.2008.02.036.
[252] Glenberg AM, Sato M, Cattaneo L, Riggio L, Palumbo D, Buccino G. Processing abstract language modulates motor system activity. Q J Exp Psychol 2006 2008;61:905–19. doi:10.1080/17470210701625550.
[253] Guan CQ, Meng W, Yao R, Glenberg AM. The motor system contributes to comprehension of abstract language. PloS One 2013;8:e75183. doi:10.1371/journal.pone.0075183.
[254] Cuccio V, Gallese V. A Peircean account of concepts: grounding abstraction in phylogeny through a comparative neuroscientific perspective. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0128.
[255] Lakoff G. Mapping the brain’s metaphor circuitry: metaphorical thought in everyday reason. Front Hum Neurosci 2014;8:958. doi:10.3389/fnhum.2014.00958.
[256] Lakoff G, Johnson M. Metaphors we live by. University of Chicago press; 2008.
[257] Ijzerman H, Semin GR. The thermometer of social relations: mapping social proximity on temperature. Psychol Sci 2009;20:1214–20. doi:10.1111/j.1467-9280.2009.02434.x.
[258] Jamrozik A, McQuire M, Cardillo ER, Chatterjee A. Metaphor: Bridging embodiment to abstraction. Psychon Bull Rev 2016;23:1080–9. doi:10.3758/s13423-015-0861-0.
[259] Pecher D, Boot I, Van Dantzig S. Abstract concepts: Sensory-motor grounding, metaphors, and beyond. Psychol. Learn. Motiv., vol. 54, Elsevier; 2011, p. 217–248.
[260] Semin GR, Palma T, Acartürk C, Dziuba A. Gender is not simply a matter of black and white, or is it? Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0126.
[261] Barsalou LW, Wiemer-Hastings K. Situating abstract concepts. Grounding Cogn Role Percept Action Mem Lang Thought 2005:129–163.
[262] Prinz JJ. Furnishing the mind: Concepts and their perceptual basis. MIT press; 2004.
[263] Prinz JJ. Beyond human nature: How culture and experience shape our lives. Penguin UK; 2012.
[264] Bolognesi M, Steen G. Editors’ Introduction: Abstract Concepts: Structure, Processing, and Modeling. Top Cogn Sci 2018.
[265] Barsalou LW, Santos A, Simmons WK, Wilson CD. Language and simulation in conceptual processing. Symb Embodiment Mean 2008:245–283.
[266] Simmons WK, Hamann SB, Harenski CL, Hu XP, Barsalou LW. fMRI evidence for word association and situated simulation in conceptual processing. J Physiol Paris 2008;102:106–19. doi:10.1016/j.jphysparis.2008.03.014.
[267] Connell L, Lynott D. Flexible and fast: linguistic shortcut affects both shallow and deep conceptual processing. Psychon Bull Rev 2013;20:542–50. doi:10.3758/s13423-012-0368-x.
[268] Vigliocco G, Kousta S, Vinson D, Andrews M, Del Campo E. The representation of abstract words: what matters? Reply to Paivio’s (2013) comment on Kousta et al. (2011). J Exp Psychol Gen 2013;142:288–91. doi:10.1037/a0028749.
[269] Vigliocco G, Kousta S-T, Della Rosa PA, Vinson DP, Tettamanti M, Devlin JT, et al. The neural representation of abstract words: the role of emotion. Cereb Cortex N Y N 1991 2014;24:1767–77. doi:10.1093/cercor/bht025.
[270] Barber HA, Otten LJ, Kousta S-T, Vigliocco G. Concreteness in word processing: ERP and behavioral effects in a lexical decision task. Brain Lang 2013;125:47–53. doi:10.1016/j.bandl.2013.01.005.

[271] Ponari M, Norbury CF, Rotaru A, Lenci A, Vigliocco G. Learning abstract words and concepts: insights from developmental language disorder. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0140.
[272] Dreyer FR, Frey D, Arana S, von Saldern S, Picht T, Vajkoczy P, et al. Is the Motor System Necessary for Processing Action and Abstract Emotion Words? Evidence from Focal Brain Lesions. Front Psychol 2015;6:1661. doi:10.3389/fpsyg.2015.01661.
[273] Newcombe PI, Campbell C, Siakaluk PD, Pexman PM. Effects of emotional and sensorimotor knowledge in semantic processing of concrete and abstract nouns. Front Hum Neurosci 2012;6:275. doi:10.3389/fnhum.2012.00275.
[274] Siakaluk PD, Knol N, Pexman PM. Effects of emotional experience for abstract words in the Stroop task. Cogn Sci 2014;38:1698–717. doi:10.1111/cogs.12137.
[275] Siakaluk PD, Newcombe PI, Duffels B, Li E, Sidhu DM, Yap MJ, et al. Effects of Emotional Experience in Lexical Decision. Front Psychol 2016;7:1157. doi:10.3389/fpsyg.2016.01157.
[276] Lenci A, Lebani GE, Passaro LC. The Emotions of Abstract Words: A Distributional Semantic Analysis. Top Cogn Sci 2018;10:550–72. doi:10.1111/tops.12335.
[277] Dove G. Beyond perceptual symbols: a call for representational pluralism. Cognition 2009;110:412–31. doi:10.1016/j.cognition.2008.11.016.
[278] Dove G. On the need for Embodied and Dis-Embodied Cognition. Front Psychol 2010;1:242. doi:10.3389/fpsyg.2010.00242.
[279] Reilly J, Peelle JE, Garcia A, Crutch SJ. Linking somatic and symbolic representation in semantic memory: the dynamic multilevel reactivation framework. Psychon Bull Rev 2016;23:1002–14. doi:10.3758/s13423-015-0824-5.
[280] Damasio AR, Damasio H. Cortical systems for retrieval of concrete knowledge: The convergence zone framework. Large-Scale Neuronal Theor Brain 1994;6174.
[281] Damasio AR. The brain binds entities and events by multiregional activation from convergence zones. Neural Comput 1989;1:123–132.
[282] Binder JR. In defense of abstract conceptual representations. Psychon Bull Rev 2016;23:1096–108. doi:10.3758/s13423-015-0909-1.
[283] Bastos AM, Usrey WM, Adams RA, Mangun GR, Fries P, Friston KJ. Canonical microcircuits for predictive coding. Neuron 2012;76:695–711. doi:10.1016/j.neuron.2012.10.038.
[284] Pezzulo G, Rigoli F, Friston K. Active Inference, homeostatic regulation and adaptive behavioural control. Prog Neurobiol 2015;134:17–35. doi:10.1016/j.pneurobio.2015.09.001.
[285] Pezzulo G, Rigoli F, Friston KJ. Hierarchical Active Inference: A Theory of Motivated Control. Trends Cogn Sci 2018;22:294–306. doi:10.1016/j.tics.2018.01.009.
[286] Anderson JR. The adaptive nature of human categorization. Psychol Rev 1991;98:409.
[287] Goodman N, Tenenbaum JB, Black MJ. A Bayesian framework for cross-situational word-learning. Adv. Neural Inf. Process. Syst., 2008, p. 457–464.
[288] Sanborn A, Griffiths T, Navarro D. A more rational model of categorization 2006.
[289] Thaker P, Tenenbaum JB, Gershman SJ. Online learning of symbolic concepts. J Math Psychol 2017;77:10–20.
[290] Pezzulo G. Why do you fear the bogeyman? An embodied predictive coding model of perceptual inference. Cogn Affect Behav Neurosci 2014;14:902–11. doi:10.3758/s13415-013-0227-x.
[291] Pezzulo G, Iodice P, Barca L, Chausse P, Monceau S, Mermillod M. Increased heart rate after exercise facilitates the processing of fearful but not disgusted faces. Sci Rep 2018;8:398. doi:10.1038/s41598-017-18761-5.

[292] Barrett LF. The theory of constructed emotion: an active inference account of interoception and categorization. Soc Cogn Affect Neurosci 2017;12:1–23. doi:10.1093/scan/nsw154.
[293] Fleming SM, Daw ND. Self-evaluation of decision-making: A general Bayesian framework for metacognitive computation. Psychol Rev 2017;124:91–114. doi:10.1037/rev0000045.
[294] De Martino B, Fleming SM, Garrett N, Dolan RJ. Confidence in value-based choice. Nat Neurosci 2013;16:105–10. doi:10.1038/nn.3279.
[295] Castelfranchi C, Falcone R. Trust theory: A socio-cognitive and computational model. vol. 18. John Wiley & Sons; 2010.
[296] Quine W, Van O. Word and object: An inquiry into the linguistic mechanisms of objective reference. 1960.
[297] Friston K, Adams RA, Perrinet L, Breakspear M. Perceptions as hypotheses: saccades as experiments. Front Psychol 2012;3:151. doi:10.3389/fpsyg.2012.00151.
[298] Donnarumma F, Costantini M, Ambrosini E, Friston K, Pezzulo G. Action perception as hypothesis testing. Cortex 2017. doi:10.1016/j.cortex.2017.01.016.
[299] Friston KJ, Lin M, Frith CD, Pezzulo G, Hobson JA, Ondobaka S. Active Inference, Curiosity and Insight. Neural Comput 2017:1–51. doi:10.1162/neco_a_00999.
[300] Friston K, FitzGerald T, Rigoli F, Schwartenbeck P, Pezzulo G. Active Inference: A Process Theory. Neural Comput 2016;29:1–49. doi:10.1162/NECO_a_00912.
[301] Borghi AM, Cimatti F. Words as tools and the problem of abstract words meanings. Proc. 31st Annu. Conf. Cogn. Sci. Soc., vol. 31, 2009, p. 2304–2309.
[302] Borghi AM, Cimatti F. Embodied cognition and beyond: Acting and sensing the body. Neuropsychologia 2010;48:763–773.
[303] Scorolli C, Daprati E, Nico D, Borghi AM. Reaching for Objects or Asking for Them: Distance Estimation in 7- to 15-Year-Old Children. J Mot Behav 2016;48:183–91. doi:10.1080/00222895.2015.1070787.
[304] lupyan clark interface - Google Scholar n.d. https://scholar.google.it/scholar?hl=it&as_sdt=0%2C5&q=lupyan+clark+interface&btnG=#d=gs_cit&p=&u=%2Fscholar%3Fq%3Dinfo%3AonQJZwPc2JIJ%3Ascholar.google.com%2F%26output%3Dcite%26scirp%3D0%26hl%3Dit (accessed October 2, 2018).
[305] Catricalà E, Della Rosa PA, Plebani V, Vigliocco G, Cappa SF. Abstract and concrete categories? Evidences from neurodegenerative diseases. Neuropsychologia 2014;64:271–81. doi:10.1016/j.neuropsychologia.2014.09.041.
[306] Fischer MH. Finger counting habits modulate spatial-numerical associations. Cortex J Devoted Study Nerv Syst Behav 2008;44:386–92. doi:10.1016/j.cortex.2007.08.004.
[307] Cangelosi A, Stramandinoli F. A review of abstract concept learning in embodied agents and robots. Phil Trans R Soc B 2018;373:20170131.
[308] Shea N. Metacognition and abstract concepts. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0133.
[309] Setti A, Caramelli N. Different domains in abstract concepts. Proc. XXVII Annu. Conf. Cogn. Sci. Soc., Cognitive Science Society, Inc; 2005.
[310] Ghio M, Vaghi MMS, Perani D, Tettamanti M. Decoding the neural representation of fine-grained conceptual categories. NeuroImage 2016;132:93–103. doi:10.1016/j.neuroimage.2016.02.009.
[311] Fischer MH, Shaki S. Number concepts: abstract and embodied. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0125.
[312] Winkielman P, Coulson S, Niedenthal P. Dynamic grounding of emotion concepts. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0127.

[313] Fingerhut J, Prinz JJ. Grounding evaluative concepts. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0142.
[314] Rice GE, Hoffman P, Binney RJ, Lambon Ralph MA. Concrete versus abstract forms of social concept: an fMRI comparison of knowledge about people versus social terms. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0136.
[315] Brookshire G, Casasanto D. Approach motivation in human cerebral cortex. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0141.
[316] Pulvermüller F. The case of CAUSE: neurobiological mechanisms for grounding an abstract concept. Philos Trans R Soc Lond B Biol Sci 2018;373. doi:10.1098/rstb.2017.0129.

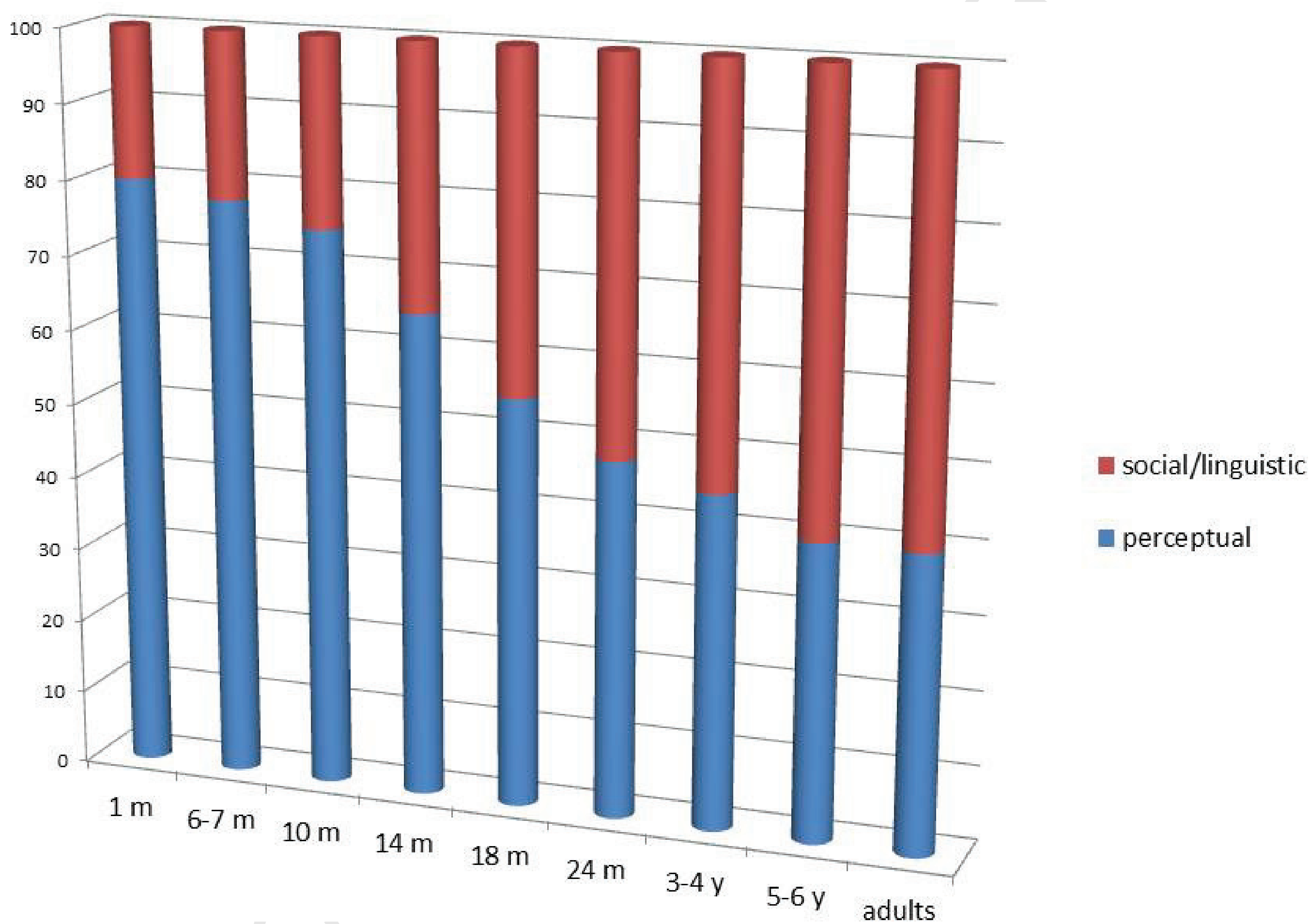

100
90
80
70
60
50
40
30
20
10
0
1 m
6-7 m
10 m
14 m
18 m
24 m
3-4 y
5-6 y
adults
social/linguistic
perceptual

Figure1

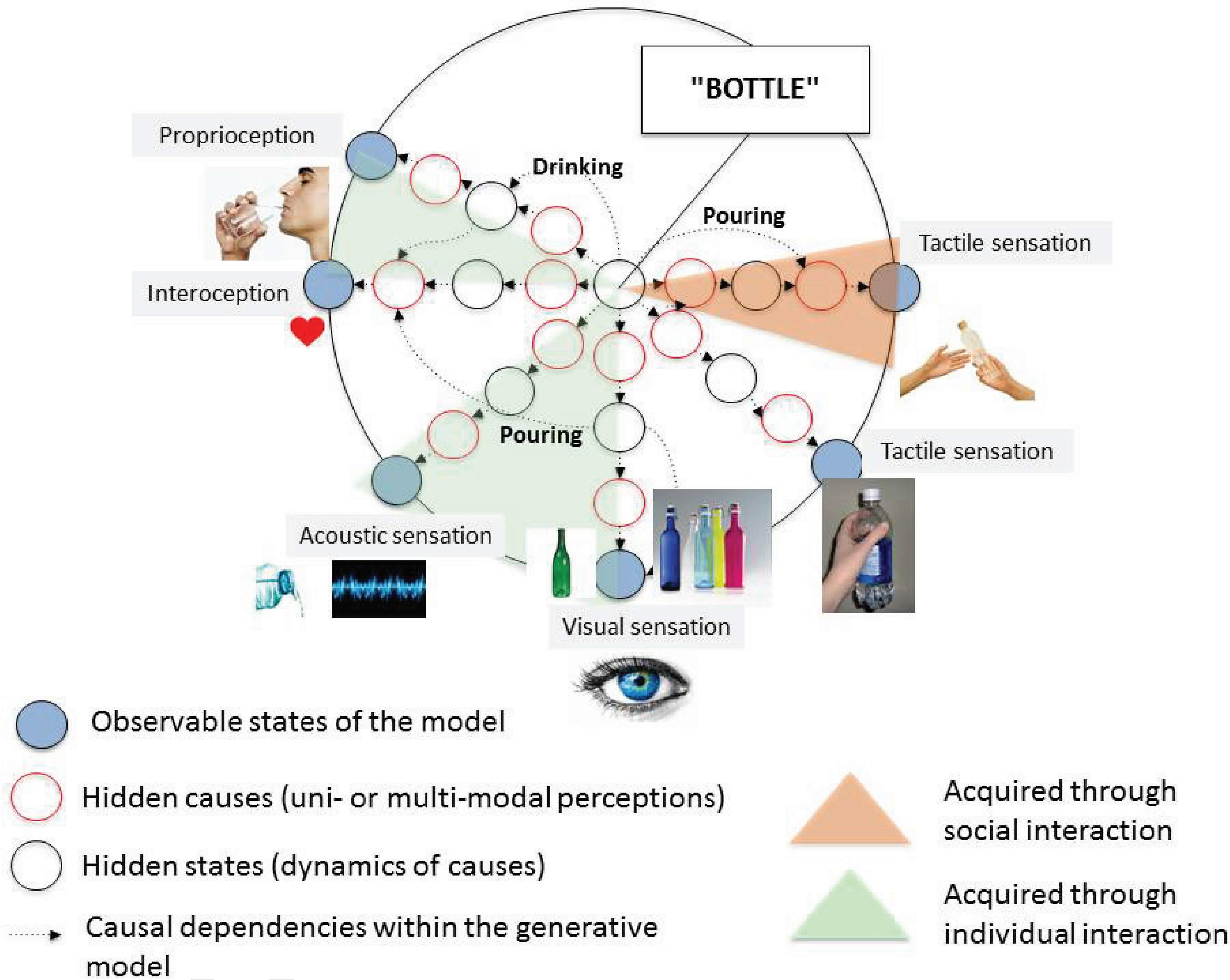

"BOTTLE"
Proprioception
Drinking
Pouring
Tactile sensation
Interoception
Pouring
Tactile sensation
Acoustic sensation
Visual sensation
Observable states of the model
Hidden causes (uni- or multi-modal perceptions)
Hidden states (dynamics of causes)
Causal dependencies within the generative model
Acquired through social interaction
Acquired through individual interaction

Figure2

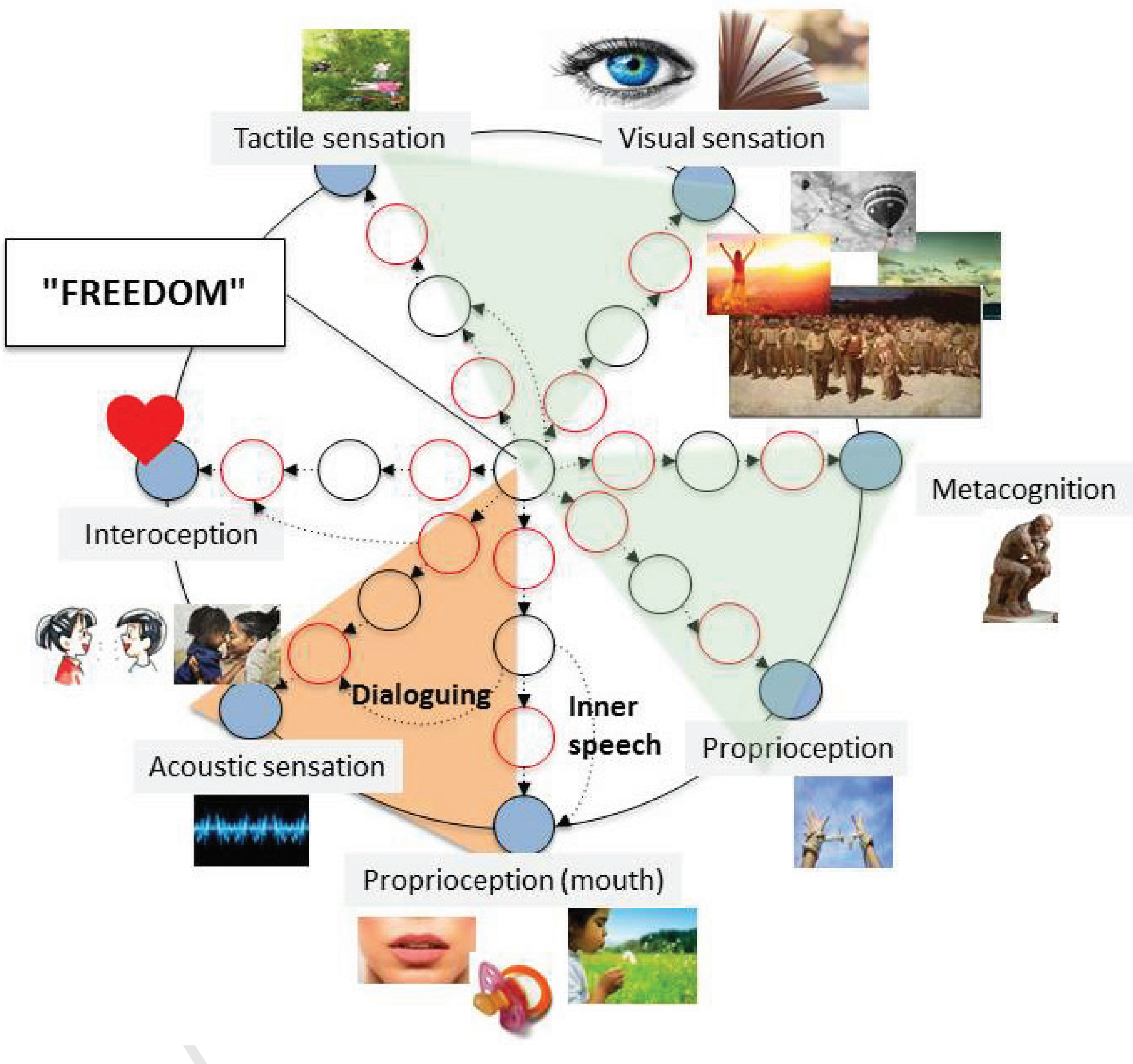
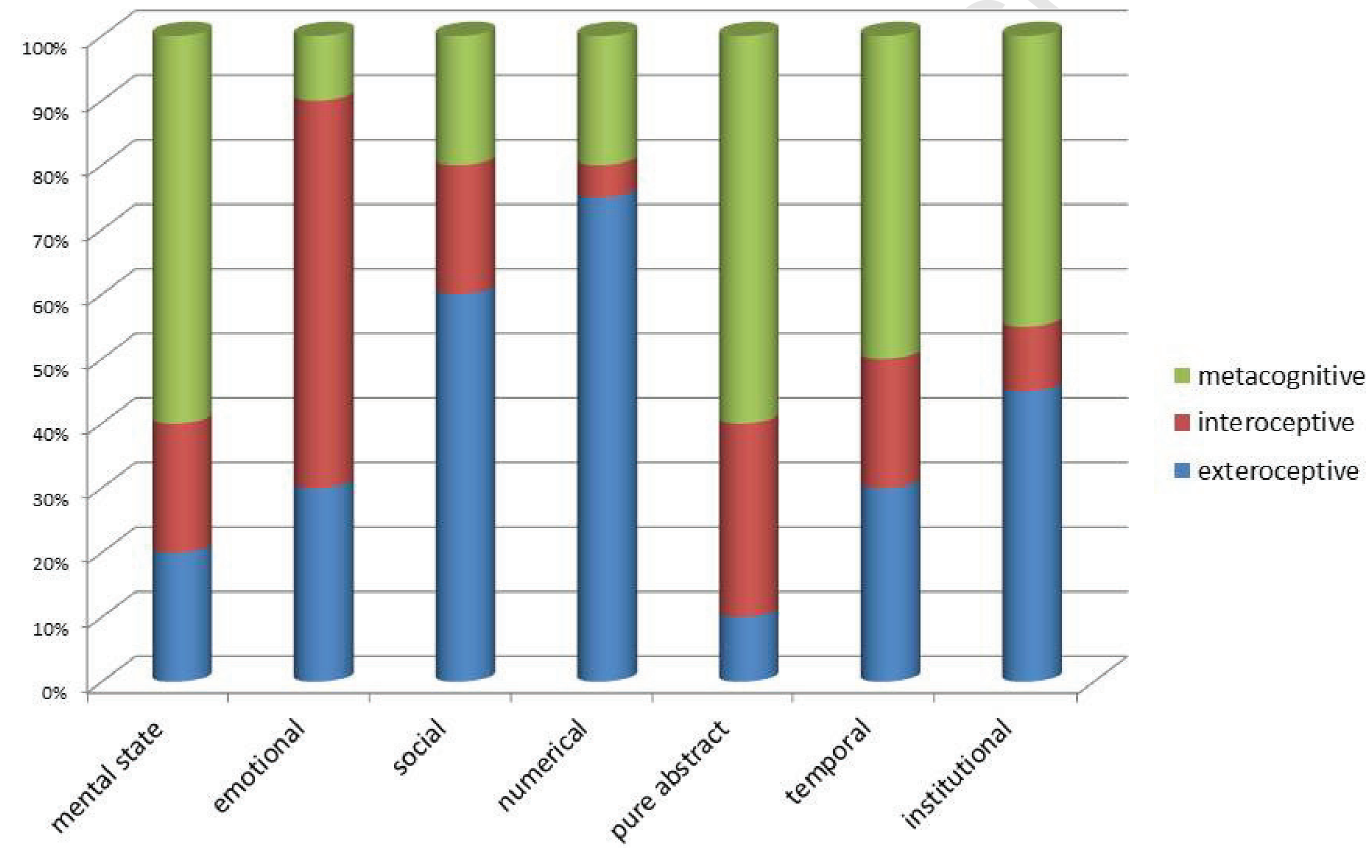

Tactile sensation
Visual sensation
"FREEDOM"
Interoception
Metacognition
Dialoguing
Inner speech
Acoustic sensation
Proprioception
Proprioception (mouth)

Figure3



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
mental state
emotional
social
numerical
pure abstract
temporal
institutional
metacognitive
interoceptive
exteroceptive

Figure4