Introduction

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Varieties of abstract concepts: development, use and representation in the brain

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The capacity for abstract thought is one of the hallmarks of human cognition. However, the mechanisms underlying the ability to form and use abstract concepts like 'fantasy' and 'grace' have not been elucidated yet. This theme issue brings together developmental, social and cognitive psychologists, linguists, anthropologists, cognitive scientists, neuroscientists, philosophers and computer scientists to present theoretical insights and novel evidence on how abstract concepts are acquired, used and represented in the brain. Many of the contributions conceive concepts as grounded in sensorimotor systems and constrained by bodily mechanisms and structures. The theme issue develops along two main axes, related to the most promising research directions on abstract concepts. The axes focus on (i) the different kinds of abstract concepts (numbers, emotions, evaluative concepts like moral and aesthetic ones, social concepts); (ii) the role played by perception and action, language and sociality, and inner processes (emotions, interoception, metacognition) in grounding abstract concepts. Most papers adopt a cognitive science/neuroscience approach, but the theme issue also includes studies on development, on social cognition, and on how linguistic diversity shapes abstract concepts. Overall, the theme issue provides an integrated theoretical account that highlights the importance of language, sociality and inner processes for abstract concepts, and that offers new methodological tools to investigate them.

This article is part of the theme issue 'Varieties of abstract concepts: development, use and representation in the brain'.

1. Introduction

Compared to concrete concepts like 'bottle', abstract concepts like 'fantasy' refer to more complex situations and do not possess a single and perceptually bounded object as referent; furthermore, their content is more variable both within and across individuals [1,2].

Understanding how abstract concepts might be represented is a crucial problem for contemporary research. This challenge has become particularly topical in recent years, due in large part to the development of embodied and grounded theories of cognition (e.g. [3–12]). In the past few years a number of embodied proposals have been advanced, aiming to show that abstract concepts are grounded in the sensorimotor system, like concrete concepts. Our special theme issue is characterized by an embodied and grounded approach to abstract concepts; at the same time, most contributions recognize that in order to fully account for the representation of abstract concepts an extension beyond purely grounded approach is needed.

Several trends in the recent literature on abstract concepts (review: Borghi *et al.* [13]) provide a background for our special theme issue (figure 1).
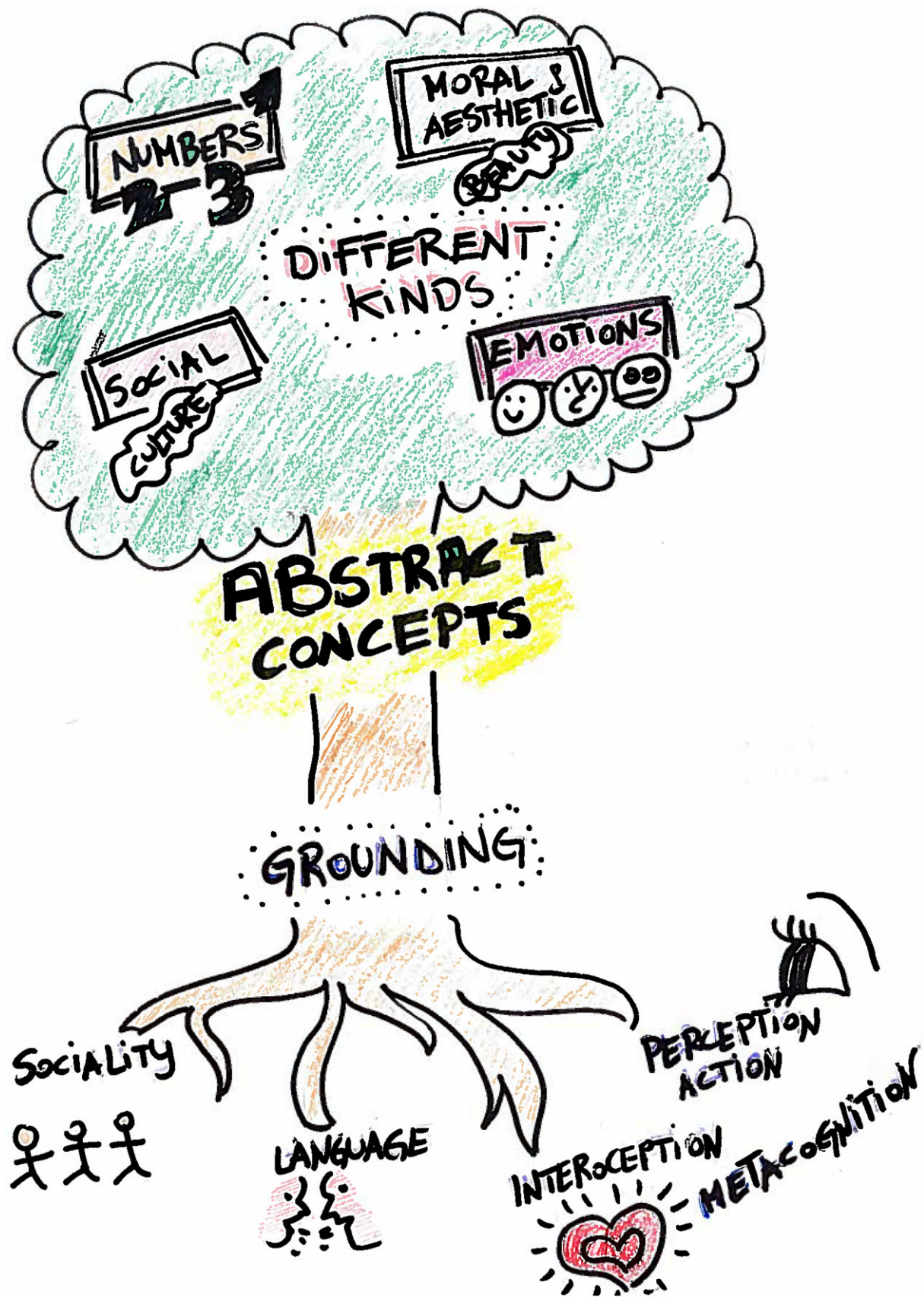
Figure 1. A sketch of our theme issue. The figure illustrates the fact that varieties of abstract concepts exist, and that abstract concepts are grounded in multiple dimensions—perception–action, but also language, sociality and inner processes, in particular interoception and metacognition.

The first is the acknowledgement that it is necessary to distinguish different kinds of abstract concepts and their corresponding brain representations. The second trend is the emergence of multiple representation views. Finally, a third trend explores the variability of abstract concepts across natural languages.

Abstract concepts cover a vast domain, ranging from numbers to emotions, and from social roles to mental state concepts. This heterogeneity is one of the main reasons why it has been difficult to find a theory able to account for the variety of abstract concepts. However, only few papers have started to analyse the different kinds of abstract

concepts, and new methodological tools have facilitated these efforts. Future research will have to explore this domain further and identify sub-typologies of abstract concepts, investigating their differences in content, mechanisms and neural underpinnings. Providing a clear analysis of the different kinds of abstract concepts is therefore crucial and urgent. In our theme issue we have included papers that propose new tools to investigate fine-grained differences between kinds of abstract concepts [14–16] and papers that focus on specific sub-kinds of abstract concepts (e.g. numbers [17]; emotions [18,19]; evaluative concepts like aesthetic and moral ones [20]).

The second trend is the emergence of multiple representation views. According to such approaches abstract concepts are grounded in sensorimotor systems but also involve linguistic, emotional and social experiences as well as internal experiences. For example, embodied approaches could be combined with statistical/distributional approaches that emphasize the importance of linguistic experience [21]. Multiple representation views are the most promising candidates to account for abstract concepts in their diversity and variety. However, the specific mechanisms of such accounts still need to be elucidated. Both abstract and concrete concepts are grounded in perception and action, but to a different extent. Future research will need to convincingly highlight the main dimensions that characterize abstract concepts (linguistic, social, emotional) and to verify whether these dimensions assume different values for different kinds of abstract concepts. In our theme issue we have included a section on grounding of abstract concepts in perception and action systems [22–27] and two sections focusing on the roles of the inner experience (situatedness in inner processes [28], interoception [29] and metacognition [30]) and of the linguistic and social experience in grounding abstract concepts [31–35].

A third trend concerns the variability of abstract concepts across natural languages. Recent research inspired by neo-whorfian ideas shows that natural languages shape the way we think about and use concepts [36,37]. Abstract concepts are more detached from sensory experiences, and so could be more affected by linguistic variability than concrete concepts. As such, one paper in the issue focuses on a specific kind of abstract concepts, i.e. odour concepts, from a crosslinguistic perspective [38].

2. Kinds of abstract concepts

The necessity to provide a precise analysis of the differences between kinds of abstract concepts is now widely recognized. The first part of this section presents two studies proposing new insights and methodological tools that reveal fine-grained differences between kinds of concepts [14,15]; the second part of the section includes papers that focus each on a specific kind of abstract concept (numbers [17], emotions [18,19], moral and aesthetic concepts [20], social concepts [16]).

Desai, Reilly and van Dam [14] investigate the neural basis of four types of abstract concepts (numerical and emotional concepts and two higher-order abstract processes, morality judgements and theory of mind), examining their similarities and differences through meta-analyses. Desai *et al.* demonstrate that all four concepts engage areas largely overlapping with those activated by concrete concepts, indicating that

abstract concepts are indirectly grounded in objects and situations. The results also show significant overlaps in the activations of morality and theory of mind concepts, which are likely processed referring to social and episodic memories or to emotions and imagery. The heterogeneity of abstract concepts and the widespread distribution of their brain representation cast doubts on theories that propose a single mechanism to account for all kinds of abstract concepts.

Ghio, Haegert, Vaghi and Tettamanti [15] present a functional magnetic resonance imaging study, in which they manipulated sentence polarity (affirmative, negative) and different kinds of abstract (mental state, emotion, mathematics) and concrete (related to mouth, hand, leg actions) concepts. This is particularly interesting because sentence polarity is considered to be at the interface between syntax and semantics. Applying a multivariate pattern analysis approach, they find clear distinctions between affirmative abstract, negative abstract, affirmative concrete and negative concrete sentences. Ghio *et al.* conclude that sentential negation polarity modulates brain activation in distributed semantic networks.

Fischer and Shaki [17] provide a review of empirical work on the cognitive signature of numerical knowledge, such as the numerical distance effect and the size effect. The discussed evidence indicates that number concepts are placed along the continuum from abstract to concrete (or modal) representations, where numbers (just like other conceptual knowledge) are treated by recurring to specific sensory-motor experiences.

Winkielman, Coulson and Niedenthal's paper [18] focuses on emotion concepts, a peculiar kind of concepts because they differ from other abstract concepts in having 'some form of bodily information as critical, necessary (but not sufficient) components'. The authors illustrate how emotion concepts are formed, represented and used, reviewing current behavioural and neural literature on them. They propose and defend an embodied theory of emotional concepts, the CODES (context-dependent embodied simulation) view. A crucial assumption of this view is that the link between concepts and somatosensory and motor involvement is highly flexible and context-dependent.

Brookshire and Casasanto [19] use transcranial direct current stimulation (tDCS) to study the link between affective motivation and motor actions. Affective motivation is cerebrally lateralized according to handedness, specifically with the hand typically used to perform approach/avoidance-related actions. Repeated tDCS stimulation increased neuronal excitability in either the participants' left or right dorsolateral prefrontal cortex (DLPF). Such stimulation changed participants' experience of approach-motivated emotions: that is, in right-handers, the experience of approach emotions such as 'enthusiastic' increased after left-excitatory stimulation relative to right-excitatory stimulation. The opposite pattern emerged for left-handers, thus providing evidence for the grounding of emotional concepts in spatio-motor experience.

Within the variety of abstract concepts, moral concepts like 'justice' and 'freedom' have often been considered as a paradigm case, which also presents a challenge for embodied and grounded approaches. In their Opinion piece, *Fingerhut and Prinz* [20] argue that moral concepts belong to the more general domain of evaluative concepts, which also include aesthetic concepts like 'beauty'. In both morals and aesthetics, concepts are used to evaluate things as good or bad, which is

something that goes beyond mere perception. The authors focus in particular on moral badness and aesthetic goodness and argue that, when we conceptualize something as good or bad, we experience our bodily responses to that thing. The moral and aesthetic domains are distinguished by the different emotions that they evoke.

Rice, Hoffman, Binney and Lambon Ralph [16] use data of three neuroimaging studies comparing category-selective responses within the anterior temporal lobes (ATLs) to test the hub-and-spoke theory, which suggests that the ATL contribution to semantic representation is transmodal and concerns all categories. Rice *et al*. compare the hub-and-spoke theory with an alternative theory stating that this region's responses are modality- and category-selective, and respond specifically to socially relevant concepts including faces. The results of the three studies can be accommodated by a graded version of the hub-and-spoke model. An anterior ventral ATL region responds to images of people but also to their spoken names (transmodality), while the 'core' ventral ATL responds more strongly to all conceptual categories.

3. Grounding of abstract concepts in multiple systems.

An emergent view proposes that abstract concepts are not only grounded in perception and action, but also in language, sociality and emotions. Section 3a provides evidence that abstract concepts are grounded in sensorimotor system. The contributions of sections 3b and 3c move from the assumption that, since abstract concepts are more detached from sensorial experience than concrete ones, they rely more on the inputs of others and require more internal resources to be processed. Thus, compared to concrete concepts they would rely more on emotions and internal inputs and would involve more linguistic and social experiences.

(a) Grounding in perception and action experience

The contributions in this section focus on how abstract concepts are embodied and grounded in perception and action systems. One paper [22] addresses grounding and embodiment of abstract concepts from a comparative and phylogenetic point of view, another one [23] demonstrates the role and integration of sensorimotor and linguistic experience selecting a special case, that of the concept of causation. Two experimental papers [24,25] demonstrate grounding of concepts of gender, number and time, one paper [26] overviews current computational and robotics studies on grounding of abstract concepts, and finally one paper [27] provides a critical perspective on possible limitations of a grounded approach.

Cuccio and Gallese [22] develop an embodied view on abstract concepts, contrasting it with the so-called Computational and Representational Theory of Mind. In presenting their approach, they start from a comparative phylogenetic perspective. They argue that, phylogenetically, both abstract and concrete concepts are grounded in Embodied Simulation mechanisms and in experience-based bodily regions. At the same time, concrete and abstract concepts might have differences in acquisition and representation. Cuccio and Gallese [22] propose that the Peircean notion of icon and abduction can provide the tools to understand the

mechanisms underlying embodied simulation with both concrete and abstract concepts.

Pulvermüeller [23] analyses learning and grounding of abstract concepts in experience, focusing on a specific example. He namely investigates how, from causal events, we come to form and understand the concept of causation. He proposes a model, specified in its cortical circuits, and identifies two operating mechanisms: family resemblance and linguistic symbols. In the model, semantic anchor neurons connect word forms to word referents; these connections are stronger for concrete than for abstract words. The higher variability of abstract concepts is captured by a family resemblance pattern of partial overlap. Hence, according to the model, different causal actions are put together through family resemblance: causal binding is guaranteed by the similar perception–action features shared by different causal events. Linguistic symbols are then used to put together the different semantic features of the subsets of causal actions.

Just as affective evaluations activate the perceptual contrast between brightness and darkness, *Semin, Palma, Acartürk and Dziuba* [24] draw on research in physical anthropology to advance the hypothesis that the same sensory dimension could also ground the abstract category of gender, with light colours being used to mark the concept of 'female' and dark colours to mark the concept of 'male'. The authors find convergent support for this hypothesis in three experimental studies that employ different paradigms. Whereas the valence–brightness mapping has been understood as a metaphorical mapping, the authors conjecture that conceptual metaphors are not responsible for the gender–brightness mapping whose experiential origins could potentially be linked to a systematic difference in shades of skin colour between the sexes.

Dimensional abstract concepts such as time and numbers are mentally represented along a mental line. In the search for the mechanisms that might generate the spatial bias of time and numbers, *Roman, Flumini and Santiago* [25] explore as a potential candidate the directionality adopted by caregivers when exploring pictures or reading books to their children. The authors presented a speechless comic in either standard (left-to-right) or mirror reversed (right-to-left) form to adult participants, and then asked them to draw three geometrical objects whose relative position is specified by auditorily presented sentences (e.g. 'the square is between the cross and the circle'). The idea is that the directionality induced by the comic exploration affects the construction of a mental model, thus creating a spatial bias that influences the drawing task. Results from three experiments converge in suggesting that the directionality adopted when presenting visual materials to children might induce the early start for spatial biases.

Adopting an embodied and grounded approach to abstract concepts typically assumes that, similarly to concrete concepts, they ultimately have some kind of experiential origin. Detailed computational models of how this process is possible, however, are still very scant. In their contribution, *Cangelosi and Stramandinoli* [26] review the state of the art on this important issue from the perspective of the design of artificial cognitive agents, i.e. robots that are capable of grounding concepts and words by integrating perception and action via direct experience. The authors discuss two main strategies that have been explored to ground concepts without direct sensorimotor experience of their referents. In the 'grounding transfer' strategy, new concepts and words

are acquired via word combinations whose meaning have been previously learned via direct grounding. Alternatively, a different strategy for learning abstract concepts is to combine gestures and action with words, such as in the use of finger counting to teach a child (or a robot) to count. Fully implemented robotic models of both strategies are discussed.

In their Opinion piece, *Pecher and Zeelenberg* [27] raise doubts on whether sensory-motor grounding alone can fully explain abstract concepts. Reviewing the key tenets of two important approaches (conceptual metaphor theory and situated conceptualization), they insist that the indirect grounding strategy that these approaches assume has been challenged by recent evidence indicating that even concrete concepts are not always grounded in sensory-motor processes. From this perspective, hybrid models that combine sensory-motor experience and language emerge as a more viable option.

(b) Grounding in inner experience

The papers in this section focus on the importance of the distinction between external versus internal situational elements [28] and investigate theoretically and empirically how inner experiences, especially interoception [29] and metacognition [30], influence abstract concepts representation.

Challenging standard approaches in the literature, *Barsalou, Dutriaux and Scheepers* [28] propose to abandon the traditional distinction between concrete and abstract concepts. The authors insist that concepts emerge to support situated action, i.e. the action of an embodied agent embedded in a physical and social environment. In this view, a concept derives its meaning in interaction with other concepts representing other situational elements together with their integration. As a consequence, Barsalou *et al.* [28] claim that current approaches that study concepts in isolation have provided a distorted account. According to the authors, a more complete understanding of concepts requires their study in the context of situated action. In this perspective—the situated conceptualization framework—the authors offer a new account of abstract concepts in terms of two new distinctions: (i) external versus internal situational elements, and (ii) situational elements versus situational integrations.

Connell, Lynott and Banks [29] focus on the grounding of concepts on interoception (i.e. sensation within the body). They present a mega-study based on the collection of modality-specific ratings of perceptual strength for over 30 000 words. Analysis of naming and lexical decision response time on a selected sample of 500 concepts documents the importance of interoceptive information for the perceptual grounding of abstract concepts, and even more of emotional concepts.

Going beyond merely sensorimotor resources, in his Opinion piece, *Shea* [30] explores whether metacognition about concepts—the thoughts and feelings that thinkers have about a concept—can itself ground abstract concepts. Focusing on how abstract concept can be grounded in characteristics that make them distinctive from one another, Shea identifies two examples of this possibility. One such example is the judgement that we should defer to others in how a given concept is used. Shea argues that metacognitive deference can either be explicit or implicit, but that in both forms it can provide a new resource to understand how some abstract concepts are grounded. Another example is our internal

assessment of which concepts are useful. Although metacognition is potentially important for grounding concrete concepts as well, this resource, together with the connection to a wider group of concept-users that it enables, is especially important for abstract concepts.

(c) Grounding in linguistic and social experience

The contributions in this section focus on the role of linguistic and social experience for abstract concepts. The section focuses on how language and social interaction shape abstract concepts [31,32,34], on how the re-enactment of linguistic experience might have an embodied counterpart, i.e. the activation of the mouth [32], and on the role of iconicity in concrete and abstract concepts [33,34]. One paper [35] casts doubts on the exclusive importance ascribed to language for conceptual acquisition, when linguistic information is dissociated by a grounded approach. Finally, a paper [38] explores how different natural languages influence the concept of odour, assuming in a neo-whorfian perspective that our concepts are shaped by the various spoken languages.

Borghi, Barca, Binkofski and Tummolini [31] propose that words, as social tools, extend our cognitive capabilities and induce us to rely on others to complement our knowledge. In their view, the WAT (Words As social Tools) view, linguistic, social and inner experience play a role of paramount importance for abstract concepts. Consistently with this view, they illustrate recent evidence obtained with children and adults showing that the activation of linguistic experience leads to the involvement of the mouth motor system, and discuss the mechanisms underlying such involvement. The activation of the mouth motor system could be due to the re-enactment of the acquisition and experience, to the re-explanation of the word meaning through inner speech, or to a metacognitive mechanism. Specifically, the authors focus on a process that they call 'social metacognition'. This process implies the recognition of the inadequacy of our concepts and the need to rely on others' competence/knowledge to integrate them.

Dove [32] focuses on the role played by language in concepts, proposing that language is an external symbolic system that we use in an embodied way, endowed with a powerful influence on our cognition: in his words, 'language is an ontogenetically disruptive cognitive technology that expands our conceptual reach'. He reviews theoretical and empirical literature on this issue and advances four predictions, discussing them in light of recent evidence: (i) concepts are grounded first of all directly in action, perception and emotional system; (ii) language plays a major role in the representation of abstract concepts; (iii) language influence is flexible and context-dependent; (iv) the role of language differs over the course of development.

Lupyan and Winter [33] address two apparently related questions: how abstract is language, and why isn't language more iconic (iconicity = similarity between form of words and word meanings)? They demonstrate that abstractness is a pervasive linguistic phenomenon, and contend that in order to understand it we should turn to language. Language namely describes facts that guide our actions, it helps categorization, and language statistics provide a rich source of knowledge. The authors propose that languages are not highly iconic exactly because abstractness is so pervasive. Highly iconic words do not have an arbitrary relationship to their referents, they are more concrete and connected to

more specific contexts than abstract words. If languages were highly iconic they would lose some of the flexibility that guarantee the possibility to abstract. Iconicity would thus render it more difficult, both to learn and to express abstract meanings. By not being iconic, 'words can take on a life of their own, helping to carve joints in nature'.

Zdrazilova, Sidhu and Pexman [34] used a novel task, the taboo task, in which participants had to communicate the meanings of concrete and abstract words without using the target-word. Results reveal clear differences: with abstract words, participants referred more to people and to introspection and used more metaphorical and beat gestures, whereas with concrete words they referred more to objects and entities and their speech was accompanied by more iconic gestures. Consistently with multiple representation views, abstract concepts referenced different kinds of experiences, especially internal and social ones.

Ponari, Norbury, Rotaru, Lenci and Vigliocco [35] question the different role that language (in particular the statistical co-occurrence of words) might have for the acquisition of abstract and concrete words. They study the performance of children with Developmental Language Disorder (DLD) in an auditory lexical decision task and in a semantic definition task, with the hypothesis that, given their linguistic deficit, this group's performance should be worse for abstract words than for concrete ones. The absence of a different accuracy between the two types of concepts, the authors suggest, questions the supposedly prominent role of linguistic information for abstract words.

Odours are often considered difficult to conceptualize and notoriously difficult to verbalize: for this reason, *Majid, Burenhult, Stensmyr, de Valk and Hansson* [38] asked Dutch and Jahai speakers, i.e. speakers from a population of hunter-gatherers of the Malay Peninsula, to name odours, measuring response times and facial expressions. Compared to Dutch speakers, Jahai speakers were both more succinct and quicker in naming odours, using abstract concepts (e.g. musty) rather than referring to concrete odour sources (e.g. smells like lemon). Emotional reactions to odours instead did not differ across the two cultures/languages. The variation of odour terms across cultures suggests that different cultures and languages can differently shape our concepts—and this might happen in particular for concepts that do not refer directly to a concrete, single object, as do odour concepts.

4. Conclusion

The theme issue has succeeded in putting together state-of-the-art research on abstract concepts, in suggesting new methodological tools and in identifying new research directions. The contributions help us to reach some preliminary conclusions that might be reframed as questions useful to pave the way for further research.

First, the very notion of abstract concepts should be rethought, in light of the variability of the results concerning different kinds of abstract concepts. The old fashioned contrast between concrete and abstract concepts should be discarded in favour of the idea of a multidimensional space, in which concepts differing both in abstractness level and along other content dimensions are distributed; importantly, in some cases the role of these dimensions and what is abstract and concrete can vary depending on the culture and the spoken language.

Second, while embodied and grounded sensorimotory foundations of abstract concepts are not under discussion, at the same time the majority of contributions converge in showing that to fully account for abstractness other sources of experience beyond perception and action should be considered. Among these, interoception, sociality and language play a major role.

Third, the contributions highlighted the necessity of an integrated perspective that considers both conceptual acquisition and development (two papers focused on this [31,35]) and conceptual representation in the brain.

Future research should then lead to the emergence of a multiple representation view, flexible enough to account for abstract concepts in their varieties, and to explain their acquisition and representation. We hope that this theme issue has contributed to paving the way for further research on abstractness, this ubiquitous and extremely sophisticated characteristic of human cognition and language.

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