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REVISTA DE ESTUDOS DA LINGUAGEM

Embodied Simulation as a Mechanism for Understanding Concrete and Metaphorical Language: A Literature Review

Simulação incorporada como mecanismo de compreensão da linguagem concreta e metafórica: uma revisão da literatura

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Abstract: several studies state that the comprehension of the meaning of language is based on concrete and modal simulations. This assertion is evidenced by the activation of sensorimotor brain areas during the processing of movement-related linguistic stimuli. This paper aims to review the literature on embodied simulation as a mechanism for comprehending concrete and abstract language. A literature search was conducted in major international databases for articles related to embodied simulation from the fields of neuroscience and psycholinguistics. In this regard, the article presents a section on embodied simulation as a condition for language comprehension, as well as empirical evidence from neuroscience regarding the activations of sensory and motor areas during the simulation for such comprehension. Subsequently, studies are presented in the psycholinguistic framework that account for these simulation processes in the comprehension of abstract language, more specifically, metaphorical language, taking into account the Conceptual Metaphor Theory. Finally, the evidence presented in the literature reviewed leads one to conclude that simulation is one of the key elements for comprehending concrete and abstract language, as in the case of metaphor. However, for such comprehension, other elements are required such as association, mental images, and imagination that allow for the recreation of abstract concepts that do not directly relate to embodied experiences.

Keywords: language processing; language comprehension; sensorimotor area; embodied simulation; conceptual metaphor.

Resumo: Diversos estudos afirmam que a compreensão do significado da linguagem baseia-se em simulações concretas e modais. Essa afirmação é respaldada pela ativação de áreas cerebrais sensoriomotoras durante o processamento de estímulos linguísticos relacionados ao movimento. O objetivo deste artigo é revisar a literatura sobre a simulação incorporada como mecanismo para a compreensão da linguagem, tanto concreta quanto abstrata. Realizou-se uma pesquisa bibliográfica nas principais bases de dados internacionais para artigos relacionados à simulação incorporada nos campos da neurociência e da psicolinguística. Nesse contexto, o artigo apresenta uma discussão sobre a simulação incorporada como condição para a compreensão da linguagem, juntamente com evidências empíricas da neurociência que apoiam a ativação de áreas sensoriais e motoras durante a simulação para tal compreensão. Em seguida, são examinados estudos sob uma perspectiva psicolinguística que abordam esses processos de simulação na compreensão da linguagem abstrata, particularmente na linguagem metafórica, em consonância com a Teoria da Metáfora Conceitual. Finalmente, as evidências apresentadas na literatura revisada levam à conclusão de que a simulação é um dos elementos-chave para a compreensão da linguagem, tanto concreta quanto abstrata, como no caso da metáfora. No entanto, para essa compreensão, são necessários outros elementos, como associação, imagens mentais e imaginação, que permitem a recriação de conceitos abstratos que não têm uma relação direta com experiências corporais.

Palavras-chave: processamento de linguagem; compreensão da linguagem; área sensório-motora; simulação incorporada; metáfora conceitual.

1 Introduction

Cognitive processes such as perception, attention, memory, creativity, imagination, and language, among others, have been considered to develop without taking into account the physical conditions that motivate such processes (Fierro, 2012). In the case of language, its comprehension was considered to be based on the decoding of linguistic elements from

internal and abstract propositional representations independent of the body. However, the dynamic paradigm in cognitive sciences proposes the interaction between mind, body, and context for the understanding of language and its meaning. From this perspective, language is motivated by bodily, physical, social, and cultural experiences (Ibarretxe-Antuñano, 2013).

One of the theories addressed in the framework of this dynamic paradigm on language processing is the theory of embodied cognition, which suggests that cognition is linked to perception-action processes immersed in sociocultural contexts. In this sense, cognition is linked to the experiences we acquire through our body, which is endowed with sensorimotor capacities that develop from environmental conditions (Eyssartier; Lozada, 2014). This theory also suggests that the understanding of language meaning comes from mental simulations in concrete and modal ways (Galetzka, 2017). The activation of sensorimotor brain areas during the processing of linguistic stimuli related to movement has been evidenced for this.

Embodied cognition and studies that have been conducted from this approach around the comprehension of linguistic expressions (Kompa, 2017) postulate the simulation of the corresponding experiences as one of the necessary conditions for such comprehension, insofar as the representations are similar to those we create when we perceive our environment. However, simulation in abstract language comprehension has been a matter of debate as it is considered that one cannot simulate what one has not experienced. This debate has attempted to be resolved on the basis of Conceptual Metaphor Theory (Lakoff, 1993; Lakoff; Johnson, 1980, 1999), a phenomenon of cognition in which the knowledge of a concrete or known conceptual field is used to structure another more abstract domain (Soriano, 2012); this occurs through the construction of image schemas (Johnson, 1987), understood as preconceptual mental structures that arise from recurrent bodily experiences, enabling the organization of perception and understanding of the world. In line with the above, Varela (1998) states that, for Lakoff, everything that is expressed has a close relationship with experiences; moreover, the human being organizes and expresses everything constructed in the mind through metaphors that are part of a prior physical reality. Generally, conceptual metaphors find their motivation in the sensorimotor experience of the world, in the characteristics of the surrounding environment, and in the body with which one perceives.

Despite the efforts in trying to overcome such debate through behavioral and neurophysiological studies, no final answer is yet available concerning the role of simulation in abstract language comprehension. One of the fundamental questions in understanding said role is how conceptual metaphors allow simulating abstract terms through physical and embodied experiences that have not taken place yet. This paper addresses embodied simulation understood as the reconstruction or recreation of perceptual, motor, or proprioceptive brain states acquired during experience with the world (Valenzuela Manzanares, 2011), and its role as a mechanism for concrete and abstract language comprehension. Accordingly, empirical evidence from cognitive neuroscience regarding the activations of sensory and motor areas during simulation for such comprehension is presented, as well as evidence from psycholinguistics that accounts for these simulation processes in the comprehension of metaphorical language. To this end, a search was made in different databases and 15 studies were selected that met the search criteria according to the interest of this article. Finally, conclusions on the incidence of simulation in the comprehension of general and abstract language and some perspectives for further study are included.

2 Methodology

In order to select the articles presented in this review, a literature search was conducted in major international databases for articles related to embodied simulation from the fields of neuroscience and psycholinguistics. These searches included databases and search engines related to scientific publications in the fields of humanities and social sciences, psychology, health, and related sciences, as well as general sciences. The databases and search engines selected were APA PsycNet, Scopus, Science Gate, PubMed, Dialnet, and Science Direct.

Table 1 presents the criteria followed for the review. The search equations included a combination of keywords from neuroscience (embodied cognition, action language, motor cortex, semantic processing, disembodiment) and psycholinguistics (simulation, imagination, body movement, embodied cognition). As a temporal criterion, studies published from 2004 onwards were considered, as this marks the emergence of significant interest in research related to motor area activations during the processing of concrete language (action words) (e.g., Hauk; Johnsrude; Pülvermuller, 2004). The selected language for the search was English, as the majority of literature related to the topic of interest, as well as publications from the most relevant authors in these fields, are predominantly in the English language.

Table 1 – Search Criteria for Scientific Articles in the Databases

Criterion	Specifications
Sources	APA PsycNet, Scopus, Science Gate, PubMed, Dialnet, Science Direct
Search Equations	"neuroscience" AND "embodied cognition"
	"neuroscience" AND "action language"
	"neuroscience" AND "motor cortex"
	"neuroscience" AND "semantic processing"
	"neuroscience" AND "disembodiment"
	"psycholinguistics" AND "simulation"
	"psycholinguistics" AND "imagination"
	"psycholinguistics" AND "body movement"
	"psycholinguistics" AND "embodied cognition"
Inclusion Criteria	Published between 2004 and 2021
	Related to embodied cognition
	Behavioral studies in the field of psycholinguistics
	Neurophysiological studies in the field of neuroscience
Exclusion Criteria	Book chapters, theses

Knowledge Areas	Cognitive neuroscience Cognitive psychology Linguistics Psycholinguistics
Journals	All
Languages	English

Source: Authors' elaboration.

3 Results of the Search

As shown in Table 2, the search conducted in the Pubmed, Science Direct, and APA PsycNet databases for articles in the field of neuroscience yielded a total of 2,244 articles. From these, 14 articles were selected that met all the inclusion criteria and were relevant to the objective of the literature review. However, some of these 14 articles appeared in multiple databases, thus only 7 publications were considered.

In a similar manner, as seen in Table 3, the search conducted in the APA PsycNet, Scopus, Science Gate, Pubmed, and Dialnet databases for articles in the field of psycholinguistics resulted in a total of 454 articles. Among these, 11 articles were selected based on the same criteria. From these 11 articles, 8 were chosen as 3 of them appeared in multiple databases.

Table 2 – Neurophysiological Studies in the Field of Neuroscience

Source	Search Results	Embodied Cognition	Action Language	Motor Cortex	Semantic Processing	Disembodiment	Total
Pubmed	Retrieved	246	26	678	45	7	1,002
	Selected	0	6	1	1	1	9
Science Direct	Retrieved	74	727	113	69	4	987
	Selected	0	3	0	0	1	4
APA PsycNet	Retrieved	18	23	152	62	0	255
	Selected	0	0	0	1	0	1
TOTAL RETRIEVED							2244
TOTAL SELECTED							14

Source: Authors' elaboration.

Table 3– Behavioral Studies in the Field of Psycholinguistics

Source	Search Results	Simulation	Imagination	Body Movement	Embodied Cognition	Total
APA PsycNet	Retrieved	5	9	1	6	21
	Selected	2	1	0	0	3
Scopus	Retrieved	34	15	2	5	56
	Selected	3	0	1	0	4
Science Gate	Retrieved	7	6	1	0	14
	Selected	1	0	0	0	1
Pubmed	Retrieved	108	22	184	47	361
	Selected	1	0	1	0	2
Dialnet	Retrieved	1	0	0	1	2
	Selected	1	0	0	0	1
TOTAL RETRIEVED						454
TOTAL SELECTED						11

Source: Authors' elaboration.

The database that yielded the highest number of results in both neuroscience and psycholinguistics was Pubmed, with a total of 1,002 articles and 361 articles, respectively. The search queries that produced the highest number of results were "neuroscience" AND "motor cortex" and "psycholinguistics" AND "body movement". This suggests that there is a significant interest in the field of neuroscience in exploring the relationship between language processing and the activation of motor areas, highlighting the role of embodied simulation in constructing meaning. Additionally, from the perspective of psycholinguistics, this reinforces the idea that bodily movement and its simulation are crucial for human conceptualization processes.

Taking into account the results obtained from the aforementioned search, the following is a description of the selected studies organized by thematic categories. Firstly, an introduction to embodied simulation in language processing is presented, based on the postulates of relevant authors (Gallese, 2003, 2011; Gallese; Lakoff, 2005; Gallese; Fadiga; Fogassi; Rizzolatti, 1996; Lakoff, 2005; Rizzolatti; Fadiga; Gallese; Fogassi, 1996; Valenzuela, 2012; Ibarretxe-Antuñano, 2013). Secondly, evidence of embodied simulation in the field of neuroscience is described (Argiris; Budai; Maieron; Ius; Skrap; Tomasino, 2020; Aziz-Zadeh; Wilson; Rizzolatti; Lacoboni, 2006; Dreyer; Frey; Arana; Von Saldern Picht; Vajkoczy; Pulvermüller, 2015; Dreyer; Pulvermüller, 2018; Hauk; Johnsrude; Pülvermuller, 2004; Pulvermüller, 2005; Vitale; Padrón; Avenanti; De Vega, 2021). Finally, the selected studies from the field of psycholinguistics are presented (Al-Azary; Katz, 2021; Gibbs, 2006a; Gibbs; Gould; Andric, 2006; Gibbs; Matlock, 2008; Liu; Connell; Lynott, 2021; Semino, 2010; Valenzuela Manzanares, 2011; Wilson; Ritchie, 2008).

4 Embodied Simulation in Language Processing

Embodied simulation is defined as a functional mechanism that mediates the understanding of the meaning of actions, intentions, feelings, and emotions (Gallese, 2011). Gallese and Lakoff (2005) propose that the sensorimotor system allows for the characterization of both sensorimotor and more abstract concepts. In this regard, they consider that conceptual knowledge is embodied, which means that the sensorimotor system not only structures the conceptual content but also characterizes the semantic content of concepts from the interaction of the body with the world.

They state that when a subject imagines visualizing something or performing some movement, some of the same areas are activated as when actually observing that something or performing that action. Thus, they hypothesize that the same neural substrate used in imagination is used in comprehension. For example, in the sentence

(1) Harry picks up the glass

imagining the action of picking up the glass or seeing someone picking up the glass is necessary to understand the sentence. The concept of picking up acquires meaning thanks to the ability of human beings to imagine, execute, and perceive such action; therefore, imagination is a form of simulation (Gallese, 2003). Indeed, the authors highlight the role of imagination for understanding and affirm that understanding is imagining, insofar as imagination, like perception and action, is embodied. This implies constant interaction with the world through the body and the brain.

In relation to language, Gallese and Lakoff (2005) suggest that, as the sensorimotor system is multimodal, language, consequently, also makes use of different associated modalities: sight, touch, listening, and motor actions, among others. Thus, they agree with other authors (Ibarretxe-Antuñano; Valenzuela, 2012) that there is no single module for language and that it should be studied in connection with other cognitive faculties.

Gallese (2011) defends an embodied simulation model based on the findings of a particular type of neurons known as mirror neurons in the premotor cortex of macaques. These neurons are defined as premotor neurons that are activated both when an action is performed and when someone else is observed performing it (Gallese; Fadiga; Fogassi; Rizzolatti, 1996; Rizzolatti; Fadiga; Gallese; Fogassi, 1996). These findings are important given the identification of a neural mechanism that allows a direct projection between the visual description of a movement and its execution. In this regard, the authors conclude that mirror neurons allow the understanding of the action in a direct way, through mechanisms of embodied simulation (Gallese, 2011).

5 Embodied Simulation Evidence from Neuroscience

Embodied simulation as a necessary condition for language comprehension is corroborated based on different findings from neuroscience. On this subject, studies that account for simulation in language comprehension in general, based on activations in sensorimotor areas of the cerebral cortex have been developed over the last years.

Hauk, Johnsrude, and Pülvermuller (2004) aimed to present evidence for a somatotopic organization of action word-induced cortical activity along the primary motor cortex and in the premotor cortex. They state that, though Broca's and Wernicke's regions undeniably hold significance in language processing, there is ongoing debate concerning the precise locations of other areas that may potentially contribute to semantic processing. Hence, their research offers evidence that the processing of word meanings triggers distinct activity patterns in regions associated with frontocentral functions, encompassing the motor and premotor cortex.

Thus, building on previous findings (Pulvermüller; Härle; Hummel, 2001), Hauk *et al*. (2004) examined their hypothesis using functional Magnetic Resonance Imaging (fMRI) and presented evidence that action words falling into distinct semantic subcategories, such as those associated with facial, arm, or leg movements, activate the motor cortex in a somatotopic fashion, aligning with the activation pattern observed during real movements of the corresponding body parts. Within their experiment, a total of 50 words drawn from three semantic subcategories were presented to 14 right-handed volunteers in a passive reading task.

The findings indicate that words associated with the arm and leg triggered specific primary motor activation in corresponding body parts. In contrast, stimuli linked to the arm and face activated the premotor cortex. Furthermore, there was observable activation in the left fusiform gyrus, a region situated near the location where the visual word form originates. Nonetheless, it's worth noting that the left inferior temporal cortex is recognized for its role in semantic processing (Price; Friston, 1997). Therefore, the activation observed in the current study might signify shared meaning access processes inherent to all the examined words. This confirms previous studies affirming that action-related word processing activates the premotor cortex (Martin; Wiggs; Ungerleider; Haxby, 1996). Thus, the authors concluded that the cortical activation pattern triggered by an action word mirrors the cortical representation of the specific action denoted by that word.

Subsequently, Pulvermüller (2005) presents a series of perspectives on the relationship between cortical motor areas and areas associated with language. Based on the results obtained in several experimental studies, the author sought to answer questions about the nature of different interactive systems that link information about actions and language in specific cortical areas. In this context, the author contended that, in opposition to the modular viewpoint of information storage and processing, cortical functions could be sustained by distributed and interactive functional systems rather than localized and isolated modules.

Through the use of techniques such as magnetoencephalography, fMRI, Transcranial Magnetic Stimulation (TMS), and positron emission tomography (PET), Numerous studies have demonstrated that the processing of action words leads to the activation of the motor system in a somatotopically precise manner. Thus, the results indicate a model of semantic somatotopy of action words in the motor and premotor cortex. Moreover, Pulvermüller (2005) argues that semantic processing may engage various regions of the cerebral cortex, as demonstrated by researchers such as Huth, de Heer, Griffiths, Theunissen, and Gallant (2016). This perspective challenges the notion that meaning processing is confined to a singular cortical construct. Additionally, the author explored whether stimulating the motor system would affect the recognition of action words with different semantic attributes. In this context, investigations unveiled a distinct impact of motor system stimulation on the processing of action-related words, manifesting in quicker processing times in lexical decision tasks.

Pulvermüller (2005) concluded that investigations into words and phrases linked to actions involving the face, arm, or leg reveal somatotopic activation within the sensorimotor cortex. Additionally, the significance of action-related words is not solely manifested through cortical activity patterns; stimulating the motor system also generates distinct effects on recognizing action words with varying semantic characteristics. Consequently, the author suggests that comprehending language entails connecting language with one's own actions, potentially due to the rapid and automatic integration of sensory and motor information in the brain, which aids in comprehension and learning processes.

The theory of embodied semantics posits that the conceptual representations engaged during the cognitive processing of language encompass, to some extent, the sensorimotor representations requisite for the execution of the concepts being articulated (e.g., Tschentscher, 2017). In line with this perspective, Aziz-Zadeh, Wilson, Rizzolatti, and Lacoboni (2006) endeavored to ascertain whether sentences describing actions executed through distinct effectors (namely, the hand, mouth, and foot) evoke activation in corresponding sectors of the agranular frontal cortex (specifically, the motor and premotor areas) that were previously found to be engaged when individuals observed actions performed by others utilizing the same effectors. To address this inquiry, they devised an experiment wherein participants underwent functional magnetic resonance imaging (fMRI) scans while observing actions executed by the mouth, hand, or foot, followed by scans during the perusal of both literal and metaphorical sentences pertaining to these effectors.

In general, the results revealed that both the tasks of action observation and sentence reading elicited substantial activation in a wide array of subcortical and cortical visual regions. More specifically, and in relation to the action observation tasks, bilateral activations in the ventral premotor cortex were evidenced. In relation to the comprehension of literal sentences, a clear congruency was observed in the premotor cortex of the left hemisphere between the effector-specific activations stemming from visually presented actions and those associated with actions delineated within literal sentence descriptions. These findings imply a pivotal involvement of mirror neuron areas in the reconstruction of sensorimotor representations during the conceptual processing of actions conveyed through linguistic stimuli.

In relation to metaphorical language, numerous researchers have suggested that the comprehension of metaphorical sentences could be contingent upon the presence of embodied representations. However, within the framework of this study, Aziz-Zadeh *et al*. (2006) found that, in the context of metaphorical sentences, there was no statistically significant interaction observed between cortical areas in either the left or right hemisphere. Furthermore, the authors mention that the outcomes yielded by their investigation concerning metaphorical language warrant cautious interpretation, primarily because the study does not provide a detailed elaboration on the methodological considerations involved.

In conclusion, the authors highlight that the alignment observed between cortical sectors activated during the observation of actions and those activated by their verbal descriptions signifies compelling evidence for the engagement of premotor areas possessing mirror neuron properties in the reconstruction of sensorimotor representations during the conceptual processing of linguistic sentences describing these actions. Moreover, these findings lend substantial support to the key role of premotor areas in shaping embodied semantic representations of actions, irrespective of whether such representations originate from visual or linguistic modalities.

In accordance with the tenets of embodied cognition theories, the comprehension of action language is intrinsically linked to the activation of perceptual and motor processes, facilitating the simulation of the action being referred to. However, a different and more recent line of research looks forward to finding if the opposite is also true; that is, if stimulation of the sensorimotor areas brings any benefit for action language processing and comprehension.

Based on this premise, Vitale, Padrón, Avenanti, and de Vega (2021) conducted a study with transcranial direct current stimulation (tDCS) to find out if excitatory modulation of the motor cortex improved performance in comprehension and recall of action-related language. Consequently, through the implementation of an experimental design, they sought to examine whether alterations in motor excitability, induced by transcranial direct current stimulation (tDCS), could serve as predictors for subsequent alterations in behavioral outcomes pertaining to memory performance.

Fifty undergraduate students, all of whom were native Spanish speakers, participated in a delayed language memory task, which drew inspiration from previous behavioral studies (e.g., Dutriaux; Dahiez; Gyselinck, 2018; Dutriaux; Gyselinck, 2016). In the experimental procedure conducted by Vitale *et al*. (2021), transcranial direct current stimulation (tDCS) was administered over the left primary motor cortex (M1) of the participants prior to their engagement in the memory task. This task involved the memorization and subsequent recollection of sentences containing manual action and attentional verbs. Additionally, the researchers recorded Motor Evoked Potentials (MEP) and conducted surface Electromyography (EMG) measurements to discern any alterations in motor excitability induced by the application of tDCS.

The behavioral results revealed superior retention of sentences involving manual actions in comparison to those containing attentional verbs, thus confirming the beneficial impact of left primary motor cortex (M1) tDCS on memory performance for action-oriented sentences. Notably, within the MEP data, positive associations between changes in M1 excitability and memory enhancements specific to action-related content were evident across both experimental and control groups. Consequently, the study by Vitale *et al*. (2021) substantiates the pivotal role of M1 in the precise processing of linguistic meanings, providing empirical support for the theory that higher-order cognitive functions are intrinsically linked to the human motor system.

Contrary to the aforementioned research, Argiris, Budai, Maieron, Ius, Skrap, and Tomasino (2020) evidenced in a recent study that neurosurgical lesions inflicted upon the sensorimotor cortex do not exert an influence on the processing of action verbs. This finding does not provide support for the embodied view of sensorimotor regions being necessary for tasks of action-verb processing. With a central inquiry revolving around the necessity of sensorimotor regions in conceptual processing, Argiris *et al*. (2020) conducted an investigation aimed at discerning whether these regions exert an impact on the execution of tasks ostensibly entailing sensorimotor engagement.

Patients afflicted with glioma tumors encompassing the pre-central and post-central regions underwent an extensive assessment comprising a battery of neuropsychological examinations and experimental tasks that probed into both motor imagery and verbal conceptual processing. This comprehensive evaluation was further supplemented by the acquisition of neurophysiological data encompassing fMRI signals, assessments of white matter integrity employing diffusion tensor imaging (DTI), as well as measurements of MEP. More

specifically, the neuropsychological tests included measures of nonverbal intelligence, visuospatial and verbal short-term memory, language comprehension, visual-conceptual, and visuomotor tracking, among others. The experimental tasks assessed abilities such as general motor imagery, conceptual knowledge of actions, and lexical grammar processing, along with others (Argiris *et al.*, 2020).

These authors found that tasks requiring the lexico-semantic processing of action-related words remained unaffected in the presence of lesions encompassing the sensorimotor area. In fact, patients performed well on the different tasks and had complete conceptual knowledge of the semantic relatedness of actions. These findings align with prior research conducted by Maieron, Marin, Fabbro, and Skrap (2013), which suggests that the capacity of neurosurgical patients to successfully execute an action verb-naming task is not contingent upon damage to the primary motor cortex.

With this study, Argiris *et al*. (2020) demonstrate the importance of considering action representations in patients with focal lesions. Taken together, the cognitive neuropsychological assessments conducted enabled the authors to directly examine the postulations of the embodied concept of conceptual processing, proposing that sensorimotor regions are not essential for lexico-semantic processing, contrary to what comprehensive embodied theories would predict.

As presented, various research from neuroscience and neuropsychology (e.g., Argiris *et al.*, 2020; Aziz-Zadeh *et al.*, 2006; Hauk *et al.*, 2004; Pulvermüller, 2005; Vitale *et al.*, 2021) suggest that motor and somatosensory regions are potentially implicated in the semantic processing of concrete action-related words. Additionally, the investigation of the potential role of sensorimotor areas in abstract meaning processing remains an area of ongoing research, as emphasized by Dreyer, Frey, Arana, von Saldern Picht, Vajkoczy, and Pulvermüller (2015), due to the absence of definitive findings concerning abstract language processing. Notably, recent functional magnetic resonance imaging (fMRI) studies have provided evidence of the involvement of the left sensorimotor cortex in the processing of abstract emotional words, such as love, displaying activation patterns akin to those observed for action words.

Through the examination of two patients afflicted with focal lesions in their frontocentral sensorimotor cortices, Dreyer *et al*. (2015) contribute insights into the functional engagement and indispensability of specific brain regions in the recognition of words belonging to particular semantic categories. The inclusion of abstract words in the stimulus set would offer the opportunity to investigate whether the pivotal role attributed to these sensory modal areas is exclusive to the processing of words associated with concrete concepts or if it extends to the domain of abstract words as well.

Employing a lexical decision task, these researchers discerned that the identification of nouns belonging to various semantic categories, encompassing domains such as food, animals, tools, and abstract-emotional concepts, exhibited noteworthy impairment when a lesion was located within the sensorimotor cortex. Remarkably, one of the patients, afflicted with a lesion in the dorsolateral central sensorimotor systems proximate to the hand area, displayed a distinct deficit primarily in the recognition of words related to tools. Conversely, another patient, who bore a lesion centered within the left supplementary motor area, predominantly manifested difficulties in processing abstract-emotional words. Similar results, lending support to embodied cognition theories, were found following auditory (Bonner; Grossman, 2012; Trumpp; Kliese; Hoenig; Haarmeier; Kiefer, 2013), and visual (Gainotti, 2010; Pulvermüller; Cooper-Pye; Dine; Hauk; Nestor; Patterson, 2010) lesions for auditory or visually semantic word processing.

These results highlighted the role of the motor cortex in the semantic processing of both action-related and abstract emotional concepts. The analysis of the obtained data provides evidence that the motor system may indeed be necessary to recognize and process words of specific semantic categories and that the supplementary motor area may be relevant for the processing of abstract-emotional symbols. Dreyer *et al*. (2005) concluded by stating that the results of their study are consistent with the premise that cognition is based on distributed action-perception circuits in the cerebral cortex.

Subsequently, Dreyer and Pulvermüller (2018) conducted an event-related fMRI study on the passive reading of semantic word categories that have emotional and abstract mental meanings. This time, the authors looked for evidence on the meaning processing of other non-emotional abstract words, which they call in their study mental words, such as thought or logic. In this context, the authors endorse the proposition that modality-specific sensorimotor areas hold relevance in the processing of concrete words employed to describe actions, but they also sought to test whether mental words would only activate amodal semantic systems.

Contrary to what was expected, the findings derived from their investigation reveal a distinct engagement of the facial motor areas in the processing of mental words, akin to the patterns observed for words related to actions involving the face. This outcome received validation when subject-specific Regions of Interest (ROIs) delineated through motor localizers were scrutinized.

In their study, Dreyer and Pulvermüller (2018) reached the conclusion that the involvement of motor systems in semantic processing transcends the confines of concrete words, encompassing certain abstract mental symbols that were previously considered entirely disembodied and unrelated to semantically linked sensorimotor processes. Additionally, they underscored the significance of their findings for the field of neurocognition within semantics and underscored the clinical applications. They placed particular emphasis on the role of brain activations as indicators of cognitive processes and their associations with "causal" investigations involving lesions and TMS.

Thus, from a neuroscientific perspective, the studies discussed in this section show, on the one hand, that language is processed in distributed neural structures. Indeed, some of the aforementioned authors agree that there is a relationship between the processing of linguistic stimuli associated with actions and the somatotopic activation of the motor and premotor cortex. Furthermore, they assert that the stimulation of the motor system elicits distinct effects in the recognition of action words belonging to various semantic categories. On the other hand, it has also been argued that sensorimotor regions are not necessary to process action-verb language. This phenomenon was observed in neurosurgical patients who had focal lesions in regions corresponding to somatotopic representations, as their performance on verbal processing tasks remained within the normal range.

All in all, the neuroscientific evidence at hand contributes to the ongoing discourse surrounding the role played by sensorimotor regions in conceptual processing, and more specifically, the role of simulation in concrete, as well as in abstract language comprehension. This tension indicates that more research is needed, at least from the neuroscientific perspective.

6 Simulation Evidence from Psycholinguistics

Although the studies presented above provide evidence of the embodied simulation as an important condition for language comprehension, the literature reflects that the theory of embodied cognition presents certain tensions, because apparently there is no direct explanation that accounts for the comprehension of abstract language, which does not reflect a sensorimotor substrate. Likewise, this approach fails to explain how abstract ideas are embodied and how understanding words that do not denote action and whose execution cannot be simulated is possible (Valenzuela Manzanares, 2011; Kompa, 2017). Regarding the above, the Conceptual Metaphor Theory (Lakoff, 1993; Lakoff; Johnson, 1980, 1999), proposed within the framework of cognitive linguistics, considers that everyday abstract concepts are metaphorical and that, in turn, the understanding of metaphors is embodied.

Since metaphor functions as a mechanism that allows understanding abstract concepts, as well as performing abstract reasoning (Lakoff, 1993), the Conceptual Metaphor Theory highlights the experiential relationship that subjects construct with the environment in which they live and the bodies with which they perceive, that is, all their sensory and motor experience to account for concepts and abstract ideas. Hence, the processes of simulation, which are defended in the understanding of language, make sense for the comprehension of abstract concepts that can be converted into concrete ones, based on the projections between domains.

According to the above, the present section compiles research and reviews from a psycholinguistic approach to provide evidence on how the comprehension of abstract concepts (at the same time metaphorical) also involves simulation processes, as does the comprehension of general language. From this simulation approach to the understanding of general and metaphorical language, embodied experiences acquire a relevant role in comprehension and in the ontological correspondences that are made between the entities of the domains involved allowing for the comprehension of an abstract idea or concept in terms of a concrete one.

As part of the literature reviewed from this perspective, Gibbs, Gould, and Andric (2006) presented evidence on the mental images individuals generate when interpreting metaphorical expressions involving actions that are not physically feasible. The hypothesis posits the feasibility of constructing cohesive mental imagery for such expressions, as numerous abstract concepts can be comprehended through the lens of tangible entities, facilitated by conceptual metaphors like

(2) Ideas are physical entities.

In order to validate the hypothesis, two experiments were undertaken. The initial experiment required participants to generate mental representations for both metaphorical and non-metaphorical actions, alongside responding to inquiries concerning the formed mental images. Subsequently, in the second experiment, participants performed identical tasks but under varied conditions: observing the experimenter executing a pertinent bodily action, imitating the relevant bodily action, and mentally envisioning themselves performing an action demonstrated by the experimenter.

The results of these experiments led to the conclusion that the mental images constructed by the participants for the metaphorical actions show an embodied comprehension of the metaphorical meaning of the expressions presented. In other words, the comprehension

of metaphorical language entails the engagement of embodied simulations. Additionally, the authors stated that the findings were consistent with different types of empirical research from psycholinguistics on non-metaphorical language processing and highlighted the significance of embodied and perceptual simulation in cognitive and linguistic endeavors.

Wilson and Gibbs (2007) agreed that people rely on bodily expressions when referring to abstract entities, as many abstract concepts can be comprehended through the lens of conceptual metaphors. For instance, the metaphorical treatment of ideas, such as digesting, chewing, or holding on to them, illustrates this phenomenon.

In their study, it was hypothesized that body movements related to metaphors improve the simulations created by individuals when comprehending various metaphorical expressions that incorporate verbs. To confirm this hypothesis, two experiments were conducted, with reading times being recorded as a measure. The results indicated that participants were faster to understand metaphorical sentences when they had previously performed a related bodily action (Experiment 1), or when they imagined the specific bodily movement (Experiment 2) than when they did not perform any movement or when they first performed an action that did not coincide with anything performed previously.

The results indicated that real or imagined bodily action has a direct effect on the immediate comprehension of metaphorical expressions related to verbs because people generally conceptualize many abstract concepts through metaphorical and embodied terms. It was also clarified that the evidence presented is not applicable to all types of metaphors, since there are other types of metaphorical language that do not contemplate bodily sensations and actions, or that have source domains that are not directly tied to embodied experiences. However, it was suggested that certain aspects of how people derive the meanings of metaphors unrelated to embodied experiences may still involve processes that entail bodily simulation, as individuals construct imaginative scenarios in which metaphors acquire significance.

Ritchie (2008) conducts a comparison between two approaches to metaphorical processing that propose mechanisms for embodiment in metaphor interpretation, based on the concept of simulation. Firstly, Gibbs (2006a) puts forth a perspective on simulation wherein the listener mentally envisions performing the action described by the language. Additionally, Gibbs considers simulation as a mechanism to explain how listeners can infer the speaker's intention by simulating the speaker's internal state at the time of utterance. Conversely, Ritchie (2006), drawing upon the perceptual simulation theory of cognition (Barsalou, 1999; 2008), suggests that language, in general, activates partial simulation of multiple perceptual experiences associated with the metaphor's vehicle derived from a particular experience.

To carry out this comparison, the metaphors

(3) Grief is a journey.

(4) Healing is a journey.

(5) Forward not back.

(6) Talk is a Journey.

were analyzed in the light of both approaches. These metaphors were chosen based on their emergence from one of the most widely used conceptual metaphors across different languages and cultures to express experiences and processes

(7) X is a journey.

The metaphors identified were taken, respectively, from an essay by Obst (2003); conversations between Jo Berry, whose father was a victim of an IRA bombing and Pat Magee, the individual responsible for the bombing (Cameron, 2007); a speech by Tony Blair (2005) at the Labour Party spring conference in Gateshead; and a conversation between a group of scientists engaged in an environmental remediation project and members of the affected communities.

The analysis conducted allowed Ritchie to conclude that simulation occurs at various degrees, based on the metaphor used and the situation it's employed in. Similarly, it is proposed that when simulating the object or action referred to by the metaphor, it involves utilizing perceptual simulators at a nuanced level. This is built upon a specific subset of knowledge that the listener has about the speaker, and that is complemented by the listener's understanding of the context. This led the author to propose the convergence of both approaches to achieve a comprehensive model of embodied metaphor interpretation.

An additional scholarly work that considers the function of embodied simulation and, additionally, the role of imagination within the context of metaphor comprehension theory can be found in the review presented by Gibbs and Matlock (2008). First, a review of studies conducted within the framework of cognitive science regarding embodied simulation in both cognition and language use, in general, was presented (Bavelas; Kenwood; Johnson; Phillips, 2002; Clark; Krych, 2004; Glenberg; Kaschak, 2002; Knuf, Aschersleben; Prinz, 2001; Kourtzi; Kanwisher, 2000; Tversky, 2000; Zwaan; Taylor, 2006, among others). Second, evidence based on psycholinguistic experimental studies, in which embodied simulation is perceived in the process of metaphorical comprehension, was exposed (Boroditsky; Ramscar, 2002; Gibbs; Gould; Andric, 2006; Matlock; Ramscar; Boroditsky, 2004, 2005; Wilson; Gibbs, 2007; Richardson; Matlock, 2007; among others).

Gibbs and Matlock (2008) stated that studies from neuroscience, regarding simulation, revealed evidence of activations of brain regions linked to the visual processing of movement, both in situations involving actual physical movement and in implicit contexts. This suggests that individuals construct mental simulations of real-life events. Additionally, studies in psycholinguistics have demonstrated the significance of embodied simulations in the comprehension of language, encompassing both general language comprehension and the interpretation of specific linguistic expressions such as metaphors. These metaphorical language simulations are not abstract mental constructs but are instead grounded in a tangible bodily perception stemming from the imagination of the moving body. This phenomenon suggests that individuals engage in embodied simulations of actions, even when these actions may not be physically feasible.

The authors also suggested that classical or similarity metaphors of the type A is B, which are typically not associated with embodied actions and are comprehended from processes of categorization or comparison, may be comprehended through the generation of embodied simulations when inferring their metaphorical meanings. This is consistent with Wilson and Gibbs' (2007) proposal that people could deduce the meanings of metaphors not linked to embodied experiences from embodied simulation processes, where imaginative processes allow for constructing meaning. Evidence of the embodied nature of an A is B metaphor will be also presented later by Al-Azary (2018).

In 2010, Semino conducted a comprehensive review of research that focused on the employment of metaphors associated with the realm of pain. The review examined how these metaphors contribute to embodied simulation, considering that pain constitutes a fundamental and intrinsic human experience (Aldrich; Eccleston, 2000; Avenanti *et al.*, 2005; Avenanti *et al.*, 2006; De Souza; Frank, 2000; Gibbs; Gould; Andric, 2006; Jackson; Meltzoff; Decety, 2005; Kövecses, 2008; Lascaratou, 2007, 2008; Minio-Paluello *et al.*, 2009; Osaka *et al.*, 2004; Pither, 2002; Singer *et al.*, 2004; Söderberg; Norberg, 1995; Wicker *et al.*, 2003; Xu *et al.*, 2009; among others).

The reviewed studies showed that the use of this type of expression can serve as a foundation for eliciting empathic reactions since evidence has shown the activation of specific neural regions associated with the representation of painful experiences when observing another individual undergoing pain. Likewise, Semino points out that pain metaphors can present variations in their potential to generate simulation responses, as well as in their intensity and complexity. This may be due to the conventional or innovative nature of metaphorical usage in relation to the experience of pain. Furthermore, the author argued that the key attributes defining metaphorical descriptions of pain encompass the level of detail, textual complexity, and creativity.

Valenzuela Manzanares (2011) also presented a review of some experimental studies from psycholinguistics (Glenberg; Kaschak, 2002; Stanfield; Zwaan, 2001; Zwaan *et al.*, 2002), as well as works in the field of neuroscience (Pulvermüller *et al.*, 2000, 2001) that accounted for embodied and sensorimotor aspects as an instrument for cognitive processes and conceptual representations. The above, within the framework of the embodied cognition thesis, makes use of the concept of simulation for comprehension of language in general. Studies that showed the role of embodied simulation and degrees of simulation, as well as domain coactivation in abstract language comprehension were also presented (Gibbs; Matlock, 2008; Ritchie, 2008; Semino, 2010; Wilson; Gibbs, 2007).

Similarly, the limits of embodied cognition were exposed when language goes from literal to abstract since it does not seem to have a direct explanation for abstract domains that are not related to sensory or motor experiences. Regarding the above, Lakoff and Johnson's conceptual metaphor proposal was evoked as a possible explanation for such a limit, as it proposes that abstract thought is anchored to embodiment by means of projections of information coming from concrete domains. However, the Conceptual Metaphor Theory has also been subject to controversy, since conceptual metaphors have been studied on the basis of a linguistic methodology; moreover, it is difficult to demonstrate the existence of such structures in our mind. Due to the above, disciplines other than cognitive linguistics, such as cognitive psychology and social psychology, have begun to investigate and have provided empirical evidence of the existence and functioning of this conceptual structuring mechanism.

In Al-Azary and Katz (2021) cross-modal priming experiments were carried out to identify at what point properties related to embodied simulation are activated during online metaphoric comprehension. To do this, participants were asked to listen to metaphors. After the offset of each metaphor's vehicle, they had to read the stimulus that was displayed on the screen, which could be a word, related or unrelated to the metaphor's vehicle. Some of the related words were bodily actions, others corresponded to general abstract associations. From the reading times of these words, unfamiliar metaphors were found to activate sensorimotor properties; conversely, familiar metaphors were evident in activating general abstract

associations. In general, the experiments carried out in this study showed the implication of sensorimotor simulations when processing novel metaphors.

Before this study, three experiments were carried out by Al-Azary (2018), who studied the role of sensorimotor simulation in nominal metaphors. Al-Azary conducted two studies in which participants assessed the degree of comprehensibility of a set of nominal metaphors. The metaphors were constructed such that the vehicles of the metaphors (i.e., B, in metaphor A is B) differed on Body-Object Interaction (BOI). Thus, the vehicle bicycle, e.g.,

(8) Life is a bicycle.

represented the high-BOI, given the ease a person has of physically interacting with a bicycle, and the word rainbow, e.g.,

(9) Life is a rainbow.

represented the low-BOI, given the difficulty a person has of physically interacting with a rainbow. The findings indicated that participants scored low-BOI metaphors as more understandable, contrary to what would be expected from an embodied cognition approach.

In the third study, participants generated comprehensible metaphors and, subsequently, proceeded to interpret them. For such creation, participants were presented with abstract words representing the topics; then, they had to choose, from the list provided, a concrete word for each topic. The results showed that participants chose more low-BOI words as vehicles; however, they generally used perceptual-embodied language to interpret them.

In a more recent study, Liu, Connell, and Lynott (2021) studied the role of embodied simulation and linguistic distributional patterns in the representation of concepts during the processing of metaphors under time constraints. Assuming that the linguistic component operates at a shallow and speedy level, it allows for shortcuts in language processing. This would imply that for the processing of metaphorical expressions, people would opt more for the linguistic component when the expression does not require in-depth processing and time is limited. Thus, for the processing of

(10) Supply can be bright.

the linguistic distributional pattern suggests that supply and bright frequently appear together in language, leading to the use of a shortcut in cases of time constraints, before resorting to embodied simulation, which is more costly and time-consuming.

To corroborate the above assumptions, participants were exposed to different time constraints to perform semantic processing tasks. In the initial experiment, they engaged in a sensibility judgment task, encountering metaphorical sentences presented for durations of one, two, and three seconds. For each sentence presented, they had to indicate whether the sentence made sense or not by answering yes or no. In the subsequent experiment, participants undertook an interpretation generation task, constrained by time intervals of two, five, and eight seconds. In this task, participants were tasked with determining whether they could formulate a meaning for the presented metaphorical sentence. In cases where participants answered yes, they were asked to write down the meaning.

It was found that there is an interaction between the linguistic and embodied components during metaphorical processing; likewise, greater engagement of the embodied component was found when time constraints were less and when in-depth processing of interpretation generation was carried out than during the more superficial processing of sensibility judgment, which corroborates that the embodied component requires more effort and time. Regarding the linguistic component, the shortcut hypothesis was not corroborated.

In conclusion, the studies mentioned in this section showed that the evidence on the role of simulation and embodied experiences in the comprehension of general and abstract language, the latter understood as metaphorical language, is also ample, heterogeneous, and not conclusive. As some of the authors stated, generalizing the results found so far in all types of metaphors is not possible, since there is still a lack of evidence confirming the role of simulation in the comprehension of certain expressions. Furthermore, there are other issues to explore regarding the topic of interest of this review that will be addressed in the next section.

7 Conclusions

As indicated by empirical findings, simulation in abstract language comprehension continues to be an ongoing debate that has tried to be resolved through neurophysiological and behavioral measures in neuroscientific and psycholinguistic studies, respectively. Nonetheless, despite the efforts from neuroscience regarding the activations of sensorimotor areas during simulation for language comprehension, as well as from psycholinguistics regarding the role of conceptual metaphor theory for the comprehension of more abstract language, no final answer has been provided. Evidence from neuroscience is not conclusive in relation to abstract language, while evidence from psycholinguistics is inferential and subject to different interpretations.

The difference in such evidence obtained from both disciplines has revealed a need for interdisciplinary work between neuroscience and psycholinguistics, in such a way that their contributions can complement each other both methodologically and theoretically to account for the comprehension of concrete and abstract language. This interaction is evidenced by the number of studies found in the literature review, where studies from neuroscience have been published in the last 10 years, despite a 20-year time window being considered, in contrast to the studies from psycholinguistics, which show publications dating back 20 years, according to the selected timeframe. This suggests that the interest in the comprehension of abstract language has been and continues to be a subject of study in psycholinguistics, and more recently, in neuroscience, which has provided its techniques, instruments, and experimental designs to provide empirical evidence to support theoretical postulates.

From the perspective of the neuroscience studies addressed in this review, modular language processing is increasingly being questioned, since the evidence shows that there is a bilateral activation of motor and premotor regions when processing concrete and abstract linguistic stimuli. Likewise, although most evidence points to a direct relationship between sensorimotor area activations during simulation for the comprehension of concrete and metaphorical language (e.g., Hauk *et al.*, 2004; Pulvermüller, 2005; Aziz-Zadeh *et al.*, 2006; Vitale *et al.*, 2021), there is also emerging evidence against embodied postures for language comprehension (e.g., Argiris *et al.*, 2021) suggesting that sensorimotor regions

may not be indispensable for lexical or semantic processing, contrary to what complete embodied theories would propose.

Also, although neuroscience has tried to explain the relationship between the activation of sensorimotor regions and the understanding of abstract and concrete language, the evidence in favor of metaphorical language comprehension is still incipient. In this regard, studies involving abstract language recognition and processing such as the ones developed by Dreyer *et al*. (2015) and Dreyer and Pulvermüller (2018) provide evidence that the supplementary motor area may be relevant for the processing of abstract symbols. Thus, the involvement of motor systems in semantic processing isn't confined solely to concrete words; it also encompasses certain abstract mental symbols that were previously believed to be completely disembodied.

Alternatively, studies approached from psycholinguistics led to the conclusion that conceptual metaphor allows for the activation of imaginative processes that, in turn, stimulate simulation for the comprehension of abstract concepts, based on the embodied experiences people acquire in relation to the environment. The findings regarding the role of real or imagined bodily simulations are not generalizable to all types of metaphorical expressions, but to those that involve actions that have already been experienced or that can be experienced on the physical or imaginative level. The above indicates that embodied actions are not central conditions in the understanding of metaphor, so it is suggested that the way in which people deduce and construct the meanings of metaphors not linked to embodied experiences could be due to bodily simulations and imaginative processes.

It is also possible to conclude that the understanding of abstract language uses different mechanisms and variables that are combined depending on the type and familiarity of the expression, such as simulation processes, the subject's sensorimotor experience, the context of use, the inferences that the receiver can make about the intention of the interlocutor and the linguistic component.

In general, the evidence provided in the works presented above, both from neuroscience and psycholinguistics, allows concluding that simulation is one of the key elements for comprehending both concrete and abstract language, as in the case of metaphor. However, for such comprehension, other elements are required such as association, mental images, and imagination, which allow the recreation of abstract concepts that do not directly relate to embodied experiences. In addition, as Kompa (2017) and Dreyer and Pulvermüller (2018) concluded, it is reasonable to affirm that the processing of linguistic expressions, including metaphorical ones, depends on certain factors such as the nature of the task. Given the above, it is important to conduct studies that delve deeper into the role of simulation for comprehension by taking into account the above-mentioned variables.

Regarding the perspectives emerging from neuroscience studies, it is posited that cortical semantic correspondence can be reasonably hypothesized for words denoting tangible entities associated with patterns of action or perception. Therefore, the authors suggest determining the possibility of interpreting aspects of the meaning of other words within the cortex in a similar way, for example, abstract elements of language. Thus, the authors raise a question about whether the somatotopy of action-related words persists when these words are embedded in phrases featuring idiomatic or metaphorical expressions, where the literal meaning of the action is lost, as in the expression presented in Pulvermüller (2005)

(11) pull my arm

versus

(12) pull my leg

Furthermore, the literature consulted suggests that studies on motor area activations during the processing of metaphorical abstract language should be addressed since the findings in this regard are not conclusive to making generalizations on the subject in question. Carrying out studies that account for brain activations during the processing of classical metaphorical expressions that do not involve actions and those that are related to movement would also be important. This would make it possible to determine whether embodied simulation, as one of the necessary conditions for comprehension, is required in all cases.

Regarding further studies from psycholinguistics, Wilson and Gibbs (2007) suggest that finding evidence regarding the fact that people infer meanings of metaphoric expressions that do not involve actions through bodily simulation mechanisms is necessary since they are able to recreate such expressions by building imaginative scenarios. Ritchie (2008) also raises some concerns that should be addressed in future studies regarding which aspects of a communicative situation influence expressive language processing at different levels: a surface level (relationship with other language components), a deeper conceptual level (partial activation of perceptual simulations) and a very deep conceptual level (activations of complete schemas). The author also asks about the difference between the surface level and the deep level in terms of the impact they may have on the construction of meaning and fluency in a communicative situation. He also emphasizes the necessity for researchers to remain attentive to the interplay among diverse simulations elicited by metaphorical expressions and their influence on social interactions and cognitive context.

With respect to embodied simulation in the pain domain, Semino (2010) proposes to develop experimental work involving verbal stimuli, given that studies mainly use visual stimuli. Semino considers that understanding how individuals react to verbal depictions of others' pain is important, since it is in the verbal form that pain experiences are usually shared, mainly subjective pain experiences, which require greater empathy. Finally, Al-Azary and Katz (2021) suggest developing additional studies to determine whether simulation is present in high-familiar nominal metaphors with offline methods, given that in their study they found that, during online processing, people do not use bodily-actions associates for this type of expressions.

Authors contribution

All authors of the article contributed equally to the conception, preparation of the manuscript, data collection, data analysis, discussion of results, and review and approval.

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