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Interoception and its role in shaping words meaning: behavioral and electrophysiological explorative evidence on the concreteness of Abstract concepts

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Abstract

According to Embodied theories of language, sensorimotor systems are actively involved in the processing of words meaning. Different studies support this theoretical proposition, showing that modality-specific sensorimotor representations built on actual experiences are reenacted during words processing. While Concrete concepts are thought to rely on reactivation of experiences in exteroceptive modalities; Abstract concepts are thought to reactivate bodily sensations through the interoceptive modality. The main aim of the current thesis is to provide evidence advocating for the prominent role of interoception in embodiment of Abstract concepts, providing additional insight on the body-language coupling adopting behavioral and electrophysiological techniques. In Experiment 1, we compared perceptual strength ratings across languages, explored the importance of interoception in defining Abstract concepts, and addressed its implication for trait measures of empathy and interoceptive sensitivity. Moreover, cluster analysis was conducted with the aim of examining whether perceptual strength ratings could provide a reliable way of distinguishing conceptual categories. In detail, we explored perceptual strength ratings of 40 Abstract and 40 Concrete concepts in Italian, Hebrew, and English native speakers. As far as we are aware of, no previous studies directly compared different languages combining perceptual strength ratings, trait measurements, and clustering analysis. We observed high consistencies between languages for what concerns: 1) pattern of perceptual ratings for Abstract and Concrete concepts for each modality; 2) the importance of interoception in embodiment of Abstract concepts; and 3) the perceptual-based distinction in conceptual categories. In addition, some cross-linguistic differences emerged in relation to the levels in which interoceptive components of concepts influence empathy. In addition, to understand better the contribution of bodily states and interoception to word processing, we further examined the effects of being immersed in a perceptual deprivation chamber aimed at increasing saliency of bodily and internal states on electrophysiological correlates of word processing. To the best of our knowledge no previous studies explored the effect of this kind of manipulation on word processing. Consequently, in Experiment 2, we collected ERPs related to the processing of Abstract and Concrete words, focusing on the N400 and a late N700-like negativity. We hypothesized that the immersion in the perceptual deprivation chamber would reduce the differences between ERPs' amplitudes for Abstract and Concrete words as an effect of increased interoceptive and decreased exteroceptive saliency. In line with our hypothesis, we observed that: 1) the N400 difference between Abstract and Concrete concepts was reduced in the perceptual deprivation chamber; and 2) Abstract concepts elicited stronger late N700-like negativity in the perceptual deprivation chamber. We suggest that increased attentional focus on internal states would reduce the retrieval of sensorimotor components during Concrete concepts processing and facilitate multimodal imagery processes during Abstract words' processing. Taken together, the current thesis supports the bidirectional relationship between bodily states and language processing in which words act as cue to the retrieval of perceptual experiences (language-to-body) and the bodily state facilitate the retrieval of multimodal situated representations (body-to-language). Furthermore, the importance of directing attention towards bodily and internal states and the implications of our results on the Abstract-Concrete distinction are discussed. In conclusion, bodily states appear to be involved in word processing even more than previously thought. Future studies aimed at providing deeper understanding of the body-language coupling including additional physiological measures are recommended.

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1. General introduction

1.1. Words and meanings

One of the most remarkable systems developed to communicate meanings is language. Language is defined as "*the system of words or signs that people use to express thoughts and feelings to each other*" (https://www.britannica.com/dictionary/language). The first part of this definition addresses the means through which language is used (i.e., words or signs). The second part defines the functional role of language: communication of information from one agent (sender) to another (receiver). From a functional perspective, words are in fact considered signs of thoughts representing subjective meanings that are flexibly modulated accordingly to the speakers' needs to communicate (Whitney, 1867). We can define the first part of the definition of language as "how" language is used and the second as "what" is communicated through it. According to de Saussure (1916), language is based on this dual characterization of "how" and "what", that he described in terms of *signifier* and *signified*. In fact, he suggested that signs are composed of a *signifier* (i.e., the form in which the meaning is encoded) and a *signified* (i.e., the meaning of the concept itself which is represented by the signifier). The specific written form of the word "chair" and the phonological pattern of its spoken counterpart that sounds like [ˈtʃɛr] would represent two different linguistic signifier referring to the signified conceptual meaning of "*chair*", i.e., "a furniture that is used to sit". For simplicity, from now on, we will use the term "words" to represent signifier in all their forms, both written and spoken. Looking at the *signified* side, we will use the term "concept" to describe the meaning of a word that is encoded and processed when we are using language. These two aspects of language must necessarily be bounded together to fruitfully use such a complex function. With the term "referential semantics" we identify that branch of linguistics that explores the nature of the link between words (*signifier*) and concepts (*signfified*) (Thrane, 1980).

Words are not always necessarily related to a concrete object as in the "*chair*" example provided before. In fact, words can refer to abstract meanings that are not directly perceivable through senses, are more difficult to imagine, show more interindividual variability, and, unlike words referring to a concrete referent, are not spatially constrained (Schwanenflugel & Stowe, 1989; Setti & Caramelli, 2005; Hoffman, 2016; Borghi et al., 2017). These crucial differences between Abstract and Concrete words would determine differences in how Concrete and Abstract concepts are encoded, stored, recalled, and, more generally, processed. Different theories aimed at exploring the possible functional and structural ontological differences between Abstract and Concrete concepts have been proposed throughout the last century of studies on language and cognition. In the following chapters, I will review the most relevant theories regarding the mechanisms involved in conceptual processing of Abstract and Concrete concepts.

1.2. Early psycholinguistic evidence on the differences between Abstract and Concrete concepts

The earliest and most famous psycholinguistic evidence showing a difference between the processing of Abstract and Concrete concepts is the "Concreteness Effect", demonstrating that Concrete concepts are processed faster and more accurately in comparison to abstract ones during lexical judgment tasks (James, 1975; Paivio, 1971; Kroll & Merves, 1986). Several interpretations have been made for the Concreteness Effect. An explanation for this effect was proposed by the Dual Coding Theory (DCT; Paivio, 1991). According to the DCT, Abstract and Concrete concepts are stored in separated semantic systems. The processing of Concrete concepts would be facilitated by the fact that they would be stored in a double format: a verbal/linguistic format, and a non-verbal/imaginative format. Conversely, Abstract concepts would be stored in a verbal/linguistic format only. Thus, the advantage for Concrete concepts would be elicited by the possibility to access relevant information from multiple systems and by the fact that the non-verbal system would allow to manipulate and process contents more flexibly and in a parallel fashion, in opposition to the rigid and the sequential processing assumed for the verbal system (Clark & Paivio, 1991). In terms of distinctive features, the DCT suggested that Imageability (i.e., the extent to which a concept is easily imagined) would be a conceptual feature crucially involved in the elicitation of the Concreteness effect.

Another explanation for the Concreteness effect was proposed by the Contextual Availability Theory (CAT; Schwanenflugel and Shoben, 1983). According to the CAT, conceptual knowledge would be stored in a single multimodal semantic system and the advantage in behavioral measures (i.e., reaction times and accuracy in recognition tasks) observed for Concrete concepts is due to their stronger and richer associations with contextual information, while the Abstract ones are thought to be associated with contextual information to a much lesser extent. This idea was reinforced by the fact that when abstract concepts were presented in a context providing sufficient related information, the advantage of concrete concepts disappeared (Schwanenflugel & Stowe, 1989). So, the DCT and the CAT differed on the fact that the first is based on the idea that conceptual knowledge is stored in two different semantic systems (verbal and non-verbal), while the latter entails the existence of one semantic system. However, considering that the importance of contextual information in processing of concepts is not in contrast with the DCT main principles, an integrated *context-extended dual coding theory* unifying these two views have been also proposed (Holcomb et al., 1999).

Noteworthy, these theories assumed that Concrete concepts would possess inherently greater semantic richness compared to Abstract ones, albeit the two theories differed in the cognitive dimension explaining such difference. Thus, Concrete concepts have been thought to be richer than Abstract concepts for a long time. Such formulation further influenced how concreteness and abstractness have been operationalized. Abstractness has been typically operationalized as a lack of

Concreteness and very weak efforts were spent in trying to provide a more detailed and valid definition of what abstractness is. This *de facto* drew attention (and scientific efforts) away from a wide portion of the story (see Borghi et al., 2017). The main difficulty encountered in providing a thorough definition of abstractness was related to the lack of perceptual attributes of Abstract concepts. In the last thirty years, a growing body of research programs was aimed at exploring the contents, the functional role, and the structure of Abstract concepts. Some of the most interesting advances in this direction were proposed within the theoretical framework of Embodied Cognition.

1.3. A short perspective on Embodied Cognition

Embodied approaches to the conceptual representation of knowledge were born as a response to the traditional cognitivist approach. The traditional cognitivist approach was a direct consequence of theoretical stances reckoning on the brain-computer metaphor that became popular from the second half of the 20th century, arising from advancements in fields such as computer sciences, artificial intelligence, formal linguistics, and cognitivism (Gardner, 1987). According to such approach, words would be stored in a symbolic arbitrary format that has no direct relation with the features of its referent, and they would be processed through a set of formal computational operations in a specifically dedicated amodal cognitive system (Fodor, 1975; Anderson, 1983; Pylyshyn, 1984; Fodor & Pylyshyn, 1988). Crucially, such amodal system has been theorized to be completely segregated and functionally independent from modality-specific systems, like motor, perceptual, and affective systems. This view was challenged by the suggestion that words as purely formal symbolic entities would necessarily at a certain point be related to a modality-specific content to acquire meaning. Such argument against the amodal view of concepts was called the Symbol Grounding Problem (Harnad, 1990).

Starting from this critical point of view, different scholars took a step back from the traditional cognitivist view and put the accent on the involvement of the affective, motor, and perceptual systems in defining the contents of our experiences and their tight connection with cognitive functions (Barsalou, 2008; Gallese, 2005; Hesslow, 2012). The term *Embodied* reaffirms the fundamental idea that our cognitive system is embedded in a body belonging to the physical word and that cognition takes place from the interplay between the brain, the body, and the world (Foglia and Wilson, 2013). The idea that sensory experiences are central in defining our conceptual knowledge of the world has a long history in philosophy and it comes from British Empiricists like Hume and Locke (see Prinz, 2002). However, Embodied Cognition scholars dramatically expanded Empiricists' conceptualization of how senses shape our conceptual representations by integrating their view with more recent ideas borrowed from fields like cognitive sciences and neuroscience. For example, current formulation of Embodied Cognition include the possibility that conceptual processing could take place outside of awareness (Kemmerer, 2015); that some innate mechanisms could play a role in how humans gather knowledge (Barsalou, 2008); the inclusion of other types of information that are not necessarily sensorial like affective, metacognitive or social (Borghi et al., 2019), and, recently, the view of language as a phylogenetically novel experiential system itself which is involved in the embodiment of concepts in inner mental states (Dove et al., 2022; 2023).

The fundamental mechanism that has been posited in Embodied theories of language is that when we process words' meaning (either in production or comprehension) the brain regions that are engaged during the actual experience of the referents are reactivated to simulate the original experience (for reviews see Barsalou et al., 2003; Binder and Desai, 2011; Meteyard et al., 2012; Pulvermüller, 2013; Buccino et al., 2016). This reactivation (or reenactment) is not an all-or-nothing phenomenon. In fact, different theories suggested that reactivations of modality-specific brain regions can range from a partial reactivation of neural sensorimotor representations during meaning processing to a full simulation of the original experience (Barsalou, 1999; Willems and Casasanto, 2011). It is important to stress that task-specific requirements can affect the extent to which sensorimotor information are recalled, suggesting that shallow language processing can occur when deep semantic processing is not possible or when recruitment of modal areas is not efficient (Louwerse and Jeunieaux, 2008; Louwerse and Connell, 2011). In such cases, processing of linguistic shortcuts showed to have enough heuristic power to provide good enough representations adequate to accomplish useful semantic processing, optimizing the tradeoff between accuracy, response time and task requirements (Connell and Lynott, 2014; Connell, 2019). The idea of language and sensorimotor systems as functionally coupled systems that interact to provide flexible conceptual processing is in line with some recent views suggesting that language itself can be considered a source of experience (Dove, 2022; 2023). The Dual Coding Theory previously described represented a first formulation of coupling between sensorimotor and linguistic systems, but it didn't include the integration of other important dimensions of human experiences such as emotional or social experiences. It has also been proposed that concepts are re-constructed starting from their basic core features every time they are processed in accordance to task requirements. Thus, experiential information from long term memory could be retrieved to generate ad-hoc and flexible representations in accordance with contextual, situational, and task-related features (Connell and Lynott, 2014; Casasanto and Lupyan, 2015). Irrespective of the depth of the simulation occurring during language processing, the theoretical and experimental propositions advocating for a functional role of modality-specific features in conceptual processing are many and robust.

Behaviorally, facilitation or interference effects were observed when sensorimotor systems were systematically called into question during conceptual processing. For example, an interference effect was observed in different studies adopting property verification of concepts presented as visual words whenever there was a switch in the key perceptual modality across consecutive trials (Pecher et al., 2003; 2004; Van Dantzig et al., 2008). Interference has also been observed when conceptual processing relies on a specific perceptual modality which is already engaged by a competing processing in working memory of another object relying on the same modality that requires high attentional demands (Vermeulen et al., 2008). On the other hand, facilitation in conceptual processing have been observed when the processing of a modality-specific stimulus was preceded by the presentation of another stimulus in the same modality, suggesting that sensory priming can also affect access to conceptual meanings depending on the specific task requirements (Vermeulen et al., 2009). Moreover, physical stimulation in the tactile and proprioceptive modalities have been observed to favor the processing of small manipulable objects, but not large non-manipulable objects, thus providing evidence for the causal involvement of tactile modality-specific information in relations to size of objects (Connell et al., 2012).

Besides these examples, many other behavioral studies showed that modality-specific features are functionally involved in semantic processing across different tasks, including modality categorization, word recognition, and conceptual manipulation (see also Connell and Lynott, 2011, 2014; van Dantzig et al., 2011; for reviews see Barsalou et al., 2003, and Pulvermüller, 2005).

1.4. Evidence for modality-specific cerebral activations

The importance of modality-specific features during conceptual processing has also been supported by neuroimaging studies adopting techniques such as fMRI or EEG. There are evidence converging in saying that modality specific sensorimotor systems, sometimes referred as “experiential systems” (Dove, 2022), show increased activity during processing of concepts related to experiences in the same modality. For example, when processing written words representing concepts with high acoustic and auditory features, increased activity has been found in left posterior-superior and middle temporal regions, which are involved in high order auditory processing (Kiefer et al., 2008). Interestingly, such activity was found to arise at around ~150 milliseconds after stimulus onset, suggesting that the recruitment of modal auditory areas would be fast, automatic, and implicitly involved in semantic processing. The recruitment of body-related specific modal areas has also been observed during the processing of verbs representing actions executed with legs, hands, or mouth. Specifically, the motor regions which activity is related to a specific effector (e.g., the portion of the motor cortex that control the legs) were observed to be reactivated during passive reading of sentences referring to the same effector-related verbs (e.g., *to kick*; Hauk et al., 2004). Similarly, the presentation of sentences describing actions have been observed to elicit cortical activity in premotor cortex which is similar to the activity elicited when the actual actions are observed, suggesting that mirror neurons could also play a functionally important role in embodiment of language (Aziz-Zadeh, 2006).

On the same line, processing of hand-related actions produced interference with hand motor responses both when actions were directly observed or when they were presented in verbal form (Garofalo et al., 2022). Other studies adopting neuroimaging techniques showed modality-specific activation for visual, gustatory, and olfactory areas during conceptual processing (Simmons et al., 2007; Barros-Loscertales et al., 2012; Gonzalez et al., 2006). To sum up, an extensive number of studies showed activations of modality-specific regions according to the underlying sensorimotor experiences during conceptual processing (for reviews see Pulvermüller and Fadiga, 2010; Kiefer and Pulvermüller, 2012; Kiefer and Barsalou, 2013).

These studies advocating for the involvement of modality-specific mechanisms during language processing provide a complex tapestry of theoretical positions that share one common underlying thread: bodily states, situated actions, and modality-specific simulations provide the experiential features that are functionally involved in encoding, storage, and retrieval of semantic knowledge.

1.5. The experiential core of conceptual representations

Once established the importance of experiences in embodiment of concepts, it is important to define *which* experiential features are important for conceptual representations. Early attempts in defining which contents are used during language processing were based on the idea that each concept can be defined by the presence or absence of specific features (Garrard et al., 2001; Cree and McRae, 2003). For example, the prototypical concept of "dog" can be characterized by different features like: it has four legs, it barks, it has two eyes, it is loyal, and it has a tail. However, the presence or absence of specific categorical features does not explain how these features are primarily experienced, especially considering that they can in turn be characterized by the presence or absence of other intra-categorical features. As a matter of fact, this relates again to the symbol grounding problem (Harnad, 1990).

To overcome this issue, recent studies moved the discussion from presence/absence of qualitative categorical features to a quantitative examination of basic experiential features. For example, Binder and colleagues (2016) performed an online mega-study with the aim to explore the experiential features associated with a set of 535 diverse concepts and provide an experiential map of concepts' features, examining 1743 participants. They used 65 experiential attributes, belonging to diverse domains like perceptual, motor, social, affective, numerical, temporal, spatial, and cognitive experiences. Each participants rated a single concept for its experiential features, according to participants' subjective experience. Results showed that different conceptual categories were represented by specific pattern of features. Specifically, "abstract entities" obtained greater ratings in features reflecting social experiences, emotional experiences, and temporal/causal features in comparisons to "artefacts" and "living things". In addition, they computed a similarity matrix to calculate within- and between-categories semantic distances measures. Then, they compared their feature-based componential similarity model with a similar language-based model derived from latent semantic analysis (LSA), which is a measure of semantic similarity based on co-occurrences in text corpora (Landauer & Dumais, 1997). This comparison showed that the two models were modestly correlated and that they both reflected a categorical structure of semantic knowledge, even though reflecting different kind of information. However, the feature-based matrix showed greater sensitivity to co-membership highlighted by stronger within-category similarity, suggesting that the exploration of conceptual experiential features could provide more fine-grained and robust categorization of concepts in comparisons to language-based models. This approach highlighted how different experiential features are involved in conceptual processing. However, collecting so many experiential features could be complex and not efficient both in terms of data collection and computation. Thus, other studies tried to reduce the dimensions of experiential features focusing on basic perceptual and motor features.

In fact, another approach based on experiential ratings of perceptual modalities has been proposed by Lynott and colleagues (2009, 2013, 2020). They proposed to explore modality- and effector-specific sensorimotor features of conceptual representations through Perceptual Strength Ratings. Perceptual Strength ratings consisted in ratings on the extent to which a target concept could be experienced through perceptual modalities and specific body parts. Included perceptual modalities were visual, haptic, auditory, olfactory, gustatory modalities and, in more recent versions, interoception (as will be detailed in section 1.9). The body parts included are arm/hand, leg/foot, torso, mouth/throat, and head. Through collection of such ratings, specific pattern of sensorial and motor features for each concept emerged. For example, they showed the prominent role of visual modality in a large variety of concepts, that concepts rated with high visual and haptic experiences resulted to be less experienced through interoception, and that there is a very high correlation between ratings in the auditory dimension and the involvement of head and mouth as effectors (Lynott et al., 2020).

Importantly, maximum perceptual strength ratings (i.e., the highest rating obtained among all the modalities) has been observed to explain reaction times in lexical decision tasks better than other indexes previously adopted in studies on semantic processing, such as Concreteness or Imageability (2012). In sum, studies on Perceptual Strength ratings suggested that sensory components of conceptual representations capture an experiential dimension which is dissociable from other measures typically adopted in early psycholinguistic studies. This would be particularly important in explaining the differences between Abstract and Concrete concepts.

1.6. Current theories on the embodiment of Abstract Concepts

One of the first attempts to fill the void regarding the question of what constitute the experiential basis for Abstract Concepts was the Affective Embodiment Account, proposed by Kousta and colleagues (2009, 2011). In their seminal studies, they provided evidence advocating for the causal involvement of affective experiences in the embodiment of Abstract Concepts and proposed some counterarguments against the dualistic model proposed by Dual Coding Theory. Specifically, they showed that, when lexical and psycholinguistic features of words (e.g., imageability, context availability and mode of acquisition) are controlled, Abstract concepts are processed even faster than Concrete ones. Such advantage for Abstract words was observed to be mediated by their emotional contents, suggesting that the difference in the affective dimension would explain the differences between Abstract concepts and Concrete concepts better than linguistic ones. According to this view, the rostral Anterior Cingulate Cortex, an area associated with control of emotional processing, was found to be engaged by the processing of Abstract concepts (Vigliocco et al., 2014).

Other evidence on the importance of affective information in processing Abstract concepts comes from studies on the mechanisms that underlie the acquisition of such concepts during development (for a review on embodied cognition and language acquisition see Pexman, 2019). For example, emotionally valenced words have been observed to be learned earlier than neutral words (Ponari et al., 2018). Also, children of age 8~9 showed greater precision in processing Abstract words with positive affective valence in comparisons to neutral Abstract words. Moreover, the precision in description of novel Abstract words was greater for valenced words in children of age 7~9 (Ponari et al., 2020). However, children of age 9~10 showed no advantage for valenced over neutral words. This result suggests that emotional valence has an important role in early stages of language learning, while latter experiences would enlarge the dimensions associated with Abstract words including for example affective arousal, social features, and linguistic co-occurrences (Nook et al., 2017).

Similarly, the fact that Abstract words are usually acquired later than Concrete words could be related to the way through which we acquire meanings (i.e., mode of acquisition). In fact, it has been observed that there is a shift from a majority of perceptually acquired meanings to linguistically acquired meanings from 1st to 6th grade (Wauters et al., 2003). Moreover, Ponari and colleagues also showed that children with developmental language disorders showed no significant impairments in identifying and define Abstract words in comparisons to age-matched typically developing children (Ponari et al., 2018), suggesting that Abstract words meaning are correctly learned regardless of language proficiency. Finally, in line with the Affective Embodiment Account, Reggin and colleagues recently showed that both positive and negative valenced Abstract words are acquired earlier than valence-matched Concrete words. Also, Abstract words with low Interoceptive strength and low Mouth action strength ratings were learned at a later stage compared to Concrete concepts while the age of acquisition of Abstract words with high ratings in those dimensions were comparable to Concrete words (Reggin et al., 2021). These results suggest that emotional experiences associated with Abstract concepts seems to have an important role, especially in early stages of language acquisition.

Another very influential theory that explored the acquisition and the uses of Abstract concepts from a multidimensional perspective is the Words As social Tools theory (WAT; Borghi and Binkofski, 2014; Borghi et al., 2019). This view suggests that social, metacognitive, introspective, affective, interoceptive, and purely linguistic experiences are all crucial for the processing of Abstract concepts. According to this view, words are used to shape, organize, infer, and communicate intangible mental states and desires; to pragmatically perform meaningful acts that affect the status of social relations, and prime action with the aim to elicit goal-directed responses in others (Tylen et al., 2010; Gianelli et al., 2013; Glenberg, 2019). Social and linguistic experiences would play a crucial role in the acquisition, representation, and utilization of Abstract concepts. The role played by social interaction as a variable involved in studies on conceptual representations has often been neglected, but recent studies shows that the social dimension has an important role in learning and representing concepts (Arioli et al., 2021; Borghi, 2022; De Felice et al., 2023; Pexman et al., 2023). According to the WAT proposal, other processes that are thought to play a particular role in processing Abstract concepts are *introspection* (Wiemer-Hastings and Xu, 2005) and *metacognition* (Shea, 2018). The involvement of such functions relies on the fact that through them we can reflect on contents of our knowledge and reinforce (or modify) their attributes of values through thinking. Moreover, the confidence in and evaluation of our own mental process can have social implications (Bahrami et al., 2010), thus affecting our practical use of Abstract concepts in social environment, which in turn would affect their associated underlying experience. These processes would be particularly relevant for Abstract concepts, as their meanings are often characterized by uncertainty and greater inter-subjective variability that make necessary to often re-elaborate their contents in our thoughts (Borghi et al., 2023).

Stemming from frameworks like the Affective Embodiment Account and the Words As social Tools theories, the idea that interoceptive sensations could be important in providing a perceptual basis for Abstract concepts gained increasing attention. Interoception was put in the spotlight by recent studies in the domain of conceptual processing (Connell et al., 2018; Villani et al., 2019; Villani et al., 2021), as well as in the study of its importance in defining the embodied experience of emotions (Critchley and Garfinkel, 2017; Seth, 2018; Zhou et al., 2021). Connell and colleagues (2018) argued that interoception is a perceptual modality which carries information about sensorial features in a large variety of concepts and that its importance is particularly prominent in the processing of Abstract concepts. In fact, the Interoceptive modality was found to be dominant (i.e., obtained the highest score across all modalities) for 13.6% of the Abstract concepts in their dataset, compared to the 3% of Concrete ones. High ratings for interoception were found to characterize those concepts having strong connections with bodily states (e.g., *tired*), cognition (e.g., *think* or *belief*), or high emotional connotations (e.g., *joy* or *fear*) in comparison to concepts categorized as very abstract (e.g., *aptitude*) or concrete (e.g., *chair*). They also showed that interoception ratings were markedly higher for emotion-abstract concepts compared to neutral-abstract concepts and that they were also found to be particularly prominent in characterizing concepts reflecting negative emotions (e.g., *fear* and *sadness*). Similarly, perceptual processing has previously been observed to be enhanced when it comes to negative compared to positive emotion words (Nasrallah et al., 2009). Moreover, the inclusion of interoceptive strength in models aimed at predicting reaction times and accuracy in semantic processing performances (e.g., in lexical decision and word naming tasks) provided better results than when the model included only the five classical perceptual modalities. These results highlighted the important contribution of including interoception for a comprehensive and exhaustive explanation of experiential contents of Abstract concepts, together with the other classical exteroceptive modalities.

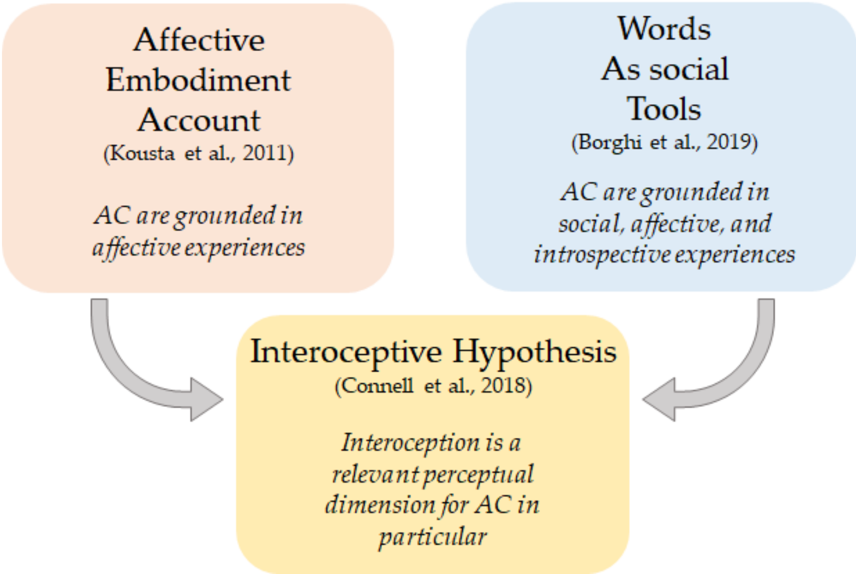

Figure 1. Diagram representing the main theories on the embodiment of Abstract Concepts (AC) in Interoception.

In line with these studies, Villani and colleagues recently showed that difficulty ratings of abstract concepts would be selectively affected by the concurrent performance of an interoceptive task (Villani et al., 2021). In detail, they observed that the difference between difficulty ratings (i.e., the subjective ratings of how much a concepts is considered "difficult to be processed") for Abstract concepts were selectively affected by performing a concurrent heart-beat detection task and a gum chewing task, while the same difference was smaller in the other control conditions involving other domains (i.e., no concurrent task, ball squeezing task, and articulatory suppression task). These two tasks were related to interoception and activation of the mouth system respectively, two domains that has been associated with the processing of Abstract concepts (e.g., Borghi et al., 2019). In fact, besides the role of interoception in grounding Abstract concepts that has already been mentioned, the involvement of the motor articulation of mouth in Abstract concept processing is consistent with some theoretical positions (as the aforementioned WAT proposal) and empirical evidence (Ghio et al., 2013; Mazzuca et al., 2018; Dreyer and Pulvermüller, 2018; Reggin et al., 2021).

Even though interoceptive, affective, and social experiences have been reported to be specifically involved in the representation of Abstract concepts, other kind of modality-specific features are involved in their processing; in the same way that interoceptive, affective, social experiences are to some extent involved in the representation of Concrete concepts (see Connell et al., 2018; Cuccio and Caruana, 2019).

Involvement of the motor system during processing of Abstract concepts has been posited in a seminal paper by Gallese and Lakoff (2005), and then observed in different studies adopting neuroimaging and lesion mapping techniques (Glenberg et al., 2008; Moseley et al., 2012; Dreyer et al., 2015; Vukovic et al., 2017; Dreyer and Pulvermüller, 2018). Activation of modal areas are not limited to motor and premotor regions, but also some evidence for activation of sensorial regions has been found. For example, different studies showed that the visual system is involved in representation of Abstract concepts. In this regard, a study by Harpaintner and colleagues showed that motor and visual components of different types of Abstract concepts elicited modality-specific pattern of activation in fMRI according to the presence of visual or motor features in their conceptual structure (Harpaintner et al., 2020). Abstract and Concrete concepts have been furtherly observed to recruit similar temporo-fronto-parietal circuits recruited during actual interaction with their referents (Del Maschio, 2021). Moreover, the greater involvement of the Broca's area during Abstract concepts processing has also been related to the integration of different complex motor representations of different effectors (Del Maschio, 2021). However, despite semantic meanings are thought to involve multimodal representation for all kind of concepts, it is important to stress that interoceptive, emotional and linguistic features are thought to be prominently important for processing Abstract concepts, while exteroceptive sensorimotor components are thought to be more prominently retrieved during Concrete concepts processing.

1.7. Electrophysiological correlates of Abstract and Concrete concepts

The gathering of all the information necessary to retrieve a meaning from long term semantic memory is thought to underlie the manifestation of specific electrophysiological correlates during word processing. Studies adopting electrophysiological recordings with electroencephalography (EEG) showed some differences in the processing of Abstract and Concrete concepts that could be related to the amount of information that needs to be integrated to process their meanings. The N400 is a negative event related potential that arise at around 400 milliseconds after stimulus onset and it has been primarily observed to be elicited by violation of semantic relatedness in semantic priming paradigm (e.g., coffee-*tea* would elicit lower N400 than coffee-*sofa*) or contextual fit in sentence comprehension (e.g., "I like coffee with *sugar*" would elicit lower N400 than "I like coffee with *shoes*") (Kutas and Hillyard, 1980; Brown and Hagoort, 1993; for a review see Kutas and Federmeier, 2011). Noteworthy, the modulation of N400 has been observed not only at a local prime-target level but it has also been observed in wider expanded context composed by multiple sentences, suggesting that the referential context that generates the N400 could be much wider than the single prime-target particle as previously expected (van Berkum et al., 2003).

Different experimental paradigms designed to explore the functional role of such event-related component showed that it is modulated by different paradigm of word processing ranging from semantic priming to multimodal coupling and it seems to be involved in different both top-down and bottom-up mechanisms of language processing (for a review see Kutas and Federmeier, 2011). Different interpretations have been provided for what concerns the N400 amplitude in relation to words processing. First, the N400 effect has been associated with greater activation of lexical-semantic networks reflecting integration of semantic features of the target word with the context in a stage that follows lexical access (Kounios and Holcomb, 1994; Brown and Hagoort, 1993). A counter interpretation suggests that greater N400 reflect facilitated lexical access, relegating the integration of semantic information as a secondary process (Lau et al., 2008). Another interpretation conceptualized the N400 as a reflection of retrieval and integration of semantic information from long-term memory (Kutas and Federmeier, 2000; Chwilla and Kolk, 2005; Barber et al., 2013). Crucially, this latter view allows interpretation of the N400 at the single-word level suggesting that its amplitude would be proportioned to the amount of semantic information required to process single words meaning, which include also multimodal and sensorimotor components.

Relevant in this context is the fact that Abstract concepts have been consistently reported to elicit lower N400 (i.e., less negative) than Concrete concepts (Kounios and Holcomb, 1994; Barber et al., 2013; Bechtold et al., 2018; Winsler et al., 2018). This N400 concreteness effect has been interpreted as the result of greater sensorimotor information necessary to process meanings of Concrete concepts. The N400 related to concreteness is also thought to be different from the N400 observed in semantic violation studies because of its topographic distribution, which is more frontocentral (rather than centroparietal), and it has been observed to have a longer duration exceeding the typical N400 time-windows (West and Holcomb, 2000; Lee and Federmeier, 2008; Huang et al., 2010). Another component that showed a differential amplitude in relation to concreteness of target words was the N700, a negative deflection arising at approximately 700 milliseconds from stimulus onset (West and Holcomb, 2000; Adorni and Proverbio, 2012; Barber et al., 2013; Bechtold et al., 2018). The N700 has been found to be greater in processing Concrete concepts compared to Abstract concepts and it is thought to reflect mental imagery processes or a top-down semantic processing involving working memory at a post-lexical stage (Adorni and Proverbio, 2012; Gullick et al., 2013). Barber and colleagues (2013) reported greater N400 and N700 for Concrete over Abstract concepts even when Imageability and

Context Availability were controlled, thus suggesting that the greater integration of multimodal sensorimotor features would underlie their amplitude irrespectively for how easy it is to imagine the target concept or recall an associated context. Their conclusion is that Concrete concepts would easily reactivate sensorimotor features in paradigm adopting single-word processing under time pressure, while Abstract concepts seem to require the retrieval of more complex situational, linguistic, and emotional associations to be processed in their full multimodal componential profile. Interestingly, they also observed a facilitatory behavioral effect for Abstract over Concrete concepts that was dissociated from the electrophysiological effects observed in event-related potentials. This could reflect the fact that in some tasks a shallow language processing could facilitate the processing of Abstract over Concrete ones because of their greater amount of superficial lexical associations (Andrews et al., 2009; Connell, 2019).

In sum, different electrophysiological correlates of words processing have been observed to subtend the retrieval of multimodal semantic components of Abstract and Concrete concepts at different stages. Generally, these components were found to be larger for Concrete concepts over Abstract ones. This N400/N700 concreteness effect is thought to be determined by the greater availability of exteroceptive sensorimotor information underlying Concrete concepts. However, further exploration on the impact of contextual cues and task requirements on electrophysiological correlates of words processing could shed new light on the mechanisms involved in processing different types of concepts.

1.8. Divide and conquer: deconstructing the Abstract concepts category

An important issue that flawed the research on Abstract concepts is that most of the studies exploring their semantic components considered them as a monolithic and undivided entity. On the other hand, research programs on Concrete concepts have previously recognized the importance of dividing this macro category in smaller subtypes, for example differentiating living from non-living entities, artifacts, and food (Warrington and Shallice, 1984; Humphreys and Forde, 2001). This was problematic because the study of Abstract concepts as a whole category could have masked inherent semantic variability between those concepts belonging to the abstract macro-category. The earliest distinction within the Abstract concepts' domain was the recognition of emotional concepts as a particular subtype (Altarriba et al., 1999; Kousta et al., 2009). However, first, this was still a coarse distinction because different subcategories could be observed within the broad cluster of emotional concepts and, secondly, this still left room for discussion about subtypes for all the other non-emotional abstract concepts. Recently, some studies explored the internal structure of the Abstract concepts macro-category providing subdivision based on different criteria, like the categorization of properties associated with concepts (e.g., Harpaintner et al., 2018), cognitive dimensions (Troche et al., 2017), or a mix of psycholinguistic, cognitive, and experiential variables (e.g., Villani et al., 2019).

Harpaintner and colleagues (2018) collected relevant properties used to describe semantic meanings for 296 Abstract concepts through a feature-listing task. Participants had to generate words describing properties for each target concept. Each property was then categorized as belonging to a specific domain (i.e., internal state/emotions, social constellation, sensorimotor feature, or verbal association). Hierarchical clustering analysis on such domain-specific categories identified different kinds of Abstract concepts showing that heterogeneous subtypes of concepts can be defined by their multidimensional profiles. Specifically, they identified three clusters: the first was characterized by a prominent role of sensorimotor features; the second was mostly characterized by internal state/emotions features; and the third one was characterized by high verbal associations. Similar results showing strong connection of different Abstract concepts with emotions, internal states, social cognition, and mental states have been observed also by Troche and colleagues (2017).

To date, the most extensive study aimed at exploring subtypes within the domain of Abstract concepts was conducted by Villani and colleagues (2019). A total of 425 Abstract concepts were rated on 15 dimensions ranging from Perceptual Strength ratings, to Imageability, Concreteness, Social, Metacognitive, Affective experiences, and other dimensions. Their results not only mirrored the results obtained in other studies (like Hairpaintner et al., 2018) suggesting that using the distinction between Abstract and Concrete concepts cannot be reduced to a single dimension, but also showed that different kinds of Abstract concepts exhibit specific multidimensional profiles. Specifically, they identified four subtypes of Abstract concepts: Emotional and Mental States concepts; Philosophical and Spiritual concepts; Social and Self concepts; Physical Spatiotemporal and Quantities concepts.

The endeavour of identifying varieties of Abstract concept is complex because the experiences that underlie their semantic features have been observed to exhibit greater inter-subject variability compared to Concrete concepts (Barsalou and Wiemer-Hastings, 2005; Muraki et al., 2022). However, a recent meta-analysis (Conca et al., 2021) examined results from 40 studies and showed that four subkinds of Abstract concepts are often identified on the basis of their distinctive dimensions, namely numerical, affective, social, and mental states/cognitive concepts (see also Desai et al., 2018).

Summarizing this roundup about the experiential components involved in representing Abstract concepts under the lens of Embodied Cognition, a good agreement in identifying social, introspective, and affective experiences playing a pivotal role in embodying different abstract intangible concepts in bodily perception have been observed in literature. This embodiment is more likely to be mediated by the perceptual system that collects information from the internal bodily environment, namely the interoceptive system. In the following chapter, I will review why this perceptual modality is so important and what's its role as an interface linking the processing of bodily, affective, and social experiences.

1.9. The body as a source of information: interoception as an experiential system

The term "interoception" is referred to the function that allows the gathering and the processing of perceptual information coming from inside the body (Cameron, 2001; Craig, 2002). The term "interoception" is opposed to "exteroception" which refers to the perceptual information coming from the outside of the body (e.g., the five classical senses). Specifically, interoception refers to the perceptual information gathered from the visceral organs, and it is thought to be particularly important in subtending the perception of one's own physiological internal state (Craig, 2014). This important function has multiple implications for psychophysiological well-being as it allows monitoring of internal states and the consequent satisfaction of physiological needs, promoting evolutionarily advantaging behaviors or exacerbating dysfunctional behaviors (Damasio and Carvalho, 2013; Pinna and Edwards, 2020).

Sensations coming from the autonomic nervous system which innervates visceral organs reach the brain in the basal and posterior portions of the ventral medial nucleus and then are projected to the insular cortex and the cingulate motor cortex (Craig, 2014). These two target regions in the brain subtend two different aspects of interoceptive processing, with the first being involved in the processing of sensorial and awareness aspects of bodily homeostatic control, and the latter being involved in processing of motivational aspects and the coordination of the response mediating between internal (e.g., physiological needs) and external (e.g., resource availability) environmental states (Medford and Chritchley, 2010; Strigo and Craig, 2016). For this reason, the insular cortex, especially the portion that receive inputs from the thalamus (i.e., the dorsal posterior insular cortex) is also called "primary interoceptive cortex", mirroring the name and the role of primary sensory cortices involved in exteroception (Nieuwenhuys, 2012; Wilson-Mendenhall et al., 2019). The viscero-thalamo-cortical pathway involving insular cortex is particularly developed in humans, and it supports the processing of affective bodily feelings, pain, itch, muscle ache, bowel movements, affective touch, as well as homeostatic information about hunger, thirst, “air hunger”, and other physiological needs (Craig, 2009; 2014; Heimer and Van Hoesen, 2006). Crucially, the regions involved in interoceptive processes have been observed to be involved in the processing of emotional experiences (Damasio et al., 2000; Phan et al., 2002; Adolfi et al., 2017).

The relationship between perception from visceral organs and emotional experiences has been proposed by different authors throughout the ages (James, 1890; Schandry, 1981; Damasio, 1994; Pollatos et al., 2005; Schachter and Singer, 1962; Davey et al., 2023). In line with this view of emotions, experience of emotions would be elicited by changes in the physiological state of the body. At the cerebral level, the region that is thought to underlie the binding of interoceptive sensations (especially cardiovascular, gastroenteric and respiratory signals) to emotional responses and prosocial functions is the anterior insular cortex (Gogolla, 2017; Singer et al., 2009). In fact, sensorial information coming from different districts of the body are integrated in the insular cortex with the aim to build representations of the global subjective state that are important in the identification and experience of adaptive emotional responses (Critchley and Garfinkel, 2017).

Yet the study of the impact of interoceptive sensations in regulating emotional and social experiences is not limited to the insular cortex. The interoceptive signals are transmitted to the central nervous system from the periphery and *viceversa* through afferent and efferent pathways. These pathways are divided into two main branches of the autonomic nervous system, namely the sympathetic and the parasympathetic systems. These two systems show complementary functionality, with the first system mediating the so-called “fight or flight” responses and the latter mediating the “rest and digest” responses (Shimizu and Okabe, 2007; McCarty, 2016). Of particular interest in the context of emotion regulation and social interaction is the parasympathetic system and one of its main pathways, the vagus nerve (Porges, 2003).

Its involvement in social interactions and emotion regulation, with deep implications for psychophysical well-being, was posited by the Polyvagal theory (Porges, 2001; Porges, 2009). The polyvagal theory provided a neurophysiological phylogenetically defined perspective on the role of the mammalians' parasympathetic system in social behaviors and affective regulations. Such a system would work as a modulator of visceral states with the aim to promote calmness, feelings of safety, and self-soothing behaviors (Porges, 2022; Hastings and Miller, 2014). This regulatory function is achieved through the modulatory activity exerted by two subbranches of the vagal system (from which the name poly-vagal theory was crafted) (Porges, 2001). The combined action of the ventral and dorsal vagal subsystems allows the regulation of bodily arousal during social engagement, thus providing a mechanism for the regulation of emotional responses in interacting agents. According to the polyvagal theory, our peripheral nervous system evolved to provide us the tools to regulate our own physiological and emotional experiences and, through the regulation of facial expression, vocal interactions, respiration, and more broadly, the supradiaphragmatic social interface system, help regulating our behavior and others through social interactions. In line with this view, different studies found a relationship between measures of interoceptive accuracy and empathic behaviors (Ernst et al., 2013; Grynberg and Pollatos, 2015; Shah et al., 2017; Raimo et al., 2022).

In conclusion, the implication of the interoceptive system from peripheral pathways to cerebral regions, in emotion experience and regulation has been extensively explored and reported in literature. Interoceptive function of collecting sensorial information from the peripheral visceral organs is comparable to the function exerted by exteroceptive modalities and it provides an experiential basis for emotionally relevant events (Nieuwenhuys, 2012) and allows the integration of bodily experiences in coherent situated representation of events (Wilson-Mendenhall et al., 2019). Of particular interest in this context is the fact that the intensity of emotional experiences (arousal) has often been reported to be positively related to interoceptive awareness (Barret et al., 2004; Dunn et al., 2010; Pollatos et al., 2005; Mishra et al., 2022). Crucially, emotional experiences and interoception were observed to contribute together to the retrieval of autobiographical memories (Matsumoto et al., 2022), emotional memories (Pfeifer et al., 2017), as well as being implicated for prospective memory (Umeda et al., 2016). Thus, a link between retrieval of subjective experiences and their bodily/emotional features has been observed to be grounded in interoception.

Following this line of research, a recent theoretical proposal suggested that cognition is in fact synergetic with bodily and affective states and that their interaction is mediated by both exteroceptive and interoceptive components (Zhou et al., 2021). This framework stemmed from the idea that emotional experiences are constructed from the interaction of three terms: the subjective interpretation of internal bodily states, their contextualization with external triggers, and the association of a meaningful linguistic label to past related experiences (Barret, 2006; 2017; Lindquist et al., 2016; Brooks et al., 2017). In this view, the term "affective state" refers to internal states that allow the evaluation of objects or events as good or bad and activates behaviors of approach or avoidance. On the other hand, the term "emotion" refers to the meaning assigned to each affective state in a specific cultural system (Lindquist et al., 2016). Zhou and colleagues (2021) enlarged this view suggesting that differences in conceptualizing emotions across cultures would be defined by two concepts, namely bodily transparency, and cognitive granularity. The concept of transparency describes how much an emotion-laden word in a specific language refers directly to bodily sensations, the concept of granularity refers to how much emotion-laden words are specific in describing particular emotional experiences. The interaction of these levels of emotional description would explain how bodily-related linguistic labels used to describe affective states would interact with cognitive related language in determining emotional experiences.

Considering the putative role of experiences in providing components of semantic knowledge, we conclude that the processing of concepts carrying emotional values and referring to social interactions could rely on the reactivation of the sensorimotor brain regions and peripheral districts associated with socio-affective processes. In turn, this would promote the involvement of insular, cingulate, and parasympathetic branches of autonomous nervous system, which are related to experiences in the social and emotional domains, in the embodiment of Abstract concepts in bodily experiences.

1.10. The studies in the current project

Considering all the evidence reported in literature and the idea of conceptual processing as a process that involves bodily states more than was previously thought, we implemented two experiments to explore the impact of bodily states in words comprehension. In these experiments, Interoception was the main modality of interest in the exploration of how concepts relate to the body.

The first experiment was designed to address whether interoceptive experiences in relation to Abstract concepts was robust across different languages, in comparison to other modalities. In our hypothesis, Abstract concepts would be mostly characterized by Interoception while Concrete concepts would be mostly characterized by exteroceptive modalities. In addition, we hypothesized that the Interoception ratings for concepts would show a positive correlation with measures of bodily sensitivity and empathy. We expected to find similar patterns across languages, especially for what concern the perceptual strength ratings and the connection with bodily sensitivity. We adopted the Perceptual Strength ratings to address the importance of perceptual modalities, with a specific focus on interoception, in the embodiment of Abstract concepts and its relationship with higher order functions like bodily awareness and empathy. In literature, very few attempts were made to directly address these connections and no studies we are aware of explored similarities and differences between different languages.

There are approximatively ~6500 different languages all over the world (Hammarström, 2016). It is interesting that similar perceptual, bodily, social, and emotional experiences can be described in each of the existing different language, with every language having its own grammatical, syntactical, and phonological set of rules. In other terms, individuals possess different bodies and use different languages to represent similar concepts.

The importance of subjectivity in experiencing different events in different ways have been has brought forth in the introduction of the current thesis, in particular when discussing the processing of Abstract concepts and the perceptual experience underlying emotionally laden concepts in interoception (section 1.9.). The use of linguistic labels that differ from language to language can possibly guide some of these subjective differences and allow the emergence of language-specific patterns of perceptual experiences despite referring to the very same concept (Kemmerer, 2019). Thus, the exploration of cross-linguistic differences is one of the most important steps in promoting our understanding of how language is universally structured, without the bias of focusing solely on western languages (for a discussion on the topic see Henrich et al., 2010). For these reasons, we collected data from Italian, Hebrew, and English native speakers using the same procedures and items.

The second experiment was designed to explore the electrophysiological correlates of spoken words processing in different environmental conditions, comparing the effects elicited by rooms with different structure and light conditions, which may lead to differential effect in internal experiences in general and, more specifically, interoception perceptions. To this aim we compared a squared white room and a sensory deprivation room aimed at fostering relaxation and promoting deployment of attention towards internal states (e.g., increased saliency of interoception or metacognitive processes) at the expense of exteroception. We hypothesized that focusing on internal states would affect the electrophysiological correlates of processing Concrete and Abstract concepts, amplifying the correlates related to the gathering of information for Abstract concepts and reducing Concrete ones. Specifically, we expected to find enhanced N400 and N700 components related to Abstract concepts in the sensory deprivation room compared to the white room. Further, we hypothesized that such enhancement would positively correlate with measures of vagal tone.

2. Experiment 1: A cross-linguistic study on perceptual components of concepts and the role of interoception in embodying meanings

2.1. Introduction

2.1.1. Abstract and Concrete concepts rely differently on bodily sensations

To shortly recap the main themes discussed in the introduction, Embodied Theories of Language posit that during the processing of word meaning we recall the sensorimotor experiences that occurred during the interaction with the referent of the said word (Barsalou, 2008; Meteyard et al., 2012; Kiefer and Barsalou, 2013). For example, while processing the meaning of the word "tree" we retrieve those sensorimotor features that characterize our experiences with trees, like for example visual components related to color and shape of trees we encountered in our life. According to this view, modality-specific information is retrieved during the processing of words meaning (Barsalou et al., 2003; Kiefer and Pulvermuller, 2012). The sensorial information retrieved for the processing of Concrete concepts (i.e., those concepts that can be perceived through senses, like touch or vision) are identifiable in the sensorial channels conveying information from outside our body (namely exteroception). On the other side, some studies showed that processing Abstract concepts involves the retrieval of experiential features related to bodily sensations and affective experiences (Kousta et al., 2011; Connell et al., 2018; Villani et al., 2021). Both bodily sensations and affective experiences have been related to the activation of the interoceptive system (Barrett et al., 2004; Damasio and Carvalho, 2013; Terasawa et al., 2013; Wiens, 2005), which is the system involved in sensing the physiological state of internal organs (Craig, 2003).

Exploration of such experiential features can be studied using Perceptual Strength ratings (Lynott and Connell, 2013; Lynott et al., 2020). Briefly, Perceptual Strength ratings are based on the extent to which a concept can be experienced through senses. For example, the concept "guitar" would probably be rated with high ratings in auditory modality and low ratings in the gustatory modality, while "steak" would obtain low ratings in the auditory modality and high ratings in the gustatory modality. With the addition of Interoception among the modalities allowed to better define not only all types of conceptual representations in a more thorough way but also allowed to better define the perceptual contents of Abstract concepts (Lynott et al., 2020; Connell et al., 2018). In fact, Abstract concepts have been observed to have greater ratings in Interoception compared to Concrete concepts and the exploration of Abstract concepts' semantic profile greatly benefitted from such observation (Connell et al., 2018; see also Binder et al., 2016). In fact, the renewed attention to experiential profiles of Abstract concepts recently led to a better characterization of their internal dimensions. The exploration of experiential features of concepts showed that Abstract concepts are not a unitary group, but they are rather composed by different subtypes of concepts. Classifications proposed on the basis of property association (Harpaintner et al., 2018), cognitive dimensions (Troche et al., 2017), different experiential dimensions (Villani et al., 2019), or even cerebral correlates observed in an adaptation study using fMRI (Conca et al., 2021), suggested the existence of different kinds of Abstract Concepts. Despite using different methodologies and different kinds of data, these studies showed that Abstract concepts can be divided in subtypes that range from concepts mostly detached from sensorimotor information (e.g., philosophical concepts like "utopia" or "freedom"), to concepts rooted in emotional or cognitive experiences (e.g., like "attention" or "thinking"), to concepts that are more grounded in sensorimotor or spatiotemporal frames (e.g., mathematical concepts like "subtraction" or concepts derived from physics like "acceleration"). However, no study we are aware of addressed whether Perceptual Strength ratings alone would be informative enough to provide a fine-grained categorization of concepts that goes beyond the Concrete/Abstract dichotomy. In order to do so, we need to address the importance of bodily information in processing Abstract and Concrete concepts through interoception.

2.1.2. Exploration of Interoception as an interface between bodily states and social interactions

Interoception is an important function as it gathers and integrates physiological information from the periphery of the nervous system in a coherent representation of bodily sensations that provides stability to the organism (Bernston et al., 1993; Craig, 2009). Moreover, the view that Interoception has implications for emotional regulation, wellbeing and social interactions gained more and more interests (Tsakiris and Critchley, 2016; Fotopoulou and Tsakiris, 2017; Khalsa et al., 2018). For example, ability in interoceptive accuracy tasks have been associated with increased empathy (Grynberg and Pollatos, 2015; Mul et al., 2018; Shah et al., 2017; Raimo et al., 2022) or with the engagement of the neural mechanisms associated with empathy (Fukushima et al., 2011; Ernst et al., 2016; Adolfi et al., 2017). Also, as explored in the general introduction, interoception is tightly connected with emotional experiences. The idea that links bodily perception, social interaction, and emotional experience is that the better we can recognize and process our internal states, the better we can correctly infer affective states from others (Terasawa et al., 2014; Ondobaka et al., 2017; Palmer and Tsakiris, 2018). This process involves the integration of our own emotional experiences and their physiological interoceptive correlates in coherent representations of our internal states that are in turn used to predict and infer others' emotional states during social interactions (Seth, 2013; Fotopoulou and Tsakiris, 2017; Ondobaka et al., 2017). These recent advancements are in accordance with the polyvagal theory (Porges, 2011; 2022), according to which the regulation of the parasympathetic branch of the autonomic nervous system which innervates visceral organs has an important role in regulating the sense of safety and trust in others. So, a tuned perception of bodily feedback would regulate our engagement in social behaviors (Hastings and Miller, 2014).

According to Garfinkel and colleagues (2015) it is possible to identify three distinct dimensions of interoception: accuracy, awareness, and sensibility. Interoceptive accuracy refers to the objective performance in correctly detecting interoceptive sensations (e.g., heart-beat detection task); interoceptive awareness refers to the metacognitive process subtending the ability to correctly evaluate one's own accuracy in perceiving interoceptive states (e.g., testing the relationship between the actual interoceptive accuracy performance and the subjective awareness of it); interoceptive sensibility refers to the self-evaluation of one's own interoceptive functions collected through questionnaires or confidence ratings (e.g., the Body Perception Questionnaire; Porges, 1993).

Importantly, the autonomic nervous system and other cerebral districts associated with interoception and social engagement (e.g., insular cortex) are thought to underlie an important prosocial skill: empathy (Siegel, 2010). One of the most accepted definitions describes empathy as the emotional response mirroring others' emotional and mental states through perspective taking (Cuff et al., 2016). As discussed in the general introduction (see chapter 1.9), being able to perceive one's own internal state embodied in interoception is thought to play a role in understanding others emotional states (e.g., Grynberg and Pollatos, 2015) and the ability to take others' perspective (Heydrich et al., 2021). Crucially, both bodily awareness and empathy have been found to be modulated by culture (Ma-Kellams, 2014; Chentsova-Dutton and Dzokoto, 2014; Hollan et al., 2012; Cassels et al., 2010). In fact, different studies in the embodied cognition framework suggest that culture shapes our sensorimotor experiences through the adoption of culture-specific habits that define how we interact with others and how we regulate our own emotional and bodily responses during social interactions (Leung et al., 2011; Kwon et al., 2021).

2.1.3. Experimental hypotheses

In the current study, we further suggest that some insight from the relationship between bodily perception and prosocial behavior could come from the exploration of the embodiment of concepts. In fact, we hypothesize that the more one is able to embody the meaning of words in interoception, the more it would show greater awareness of its own bodily reactions and greater empathy levels. This would provide further evidence for the connection between these different domains. However, it is also important to recognize that the social and affective experiences could differ in accordance with the social rules and habits of the environment in which they are established.

In fact, the cultural and social milieu in which we are embedded are thought to shape how we interact and express emotions in social environments (Ibanez et al., 2022; Zhou et al., 2021). In fact, humans live and engage in social interaction in real contexts that have culturally defined rules and habits that affect our representation of the world (Kwon et al., 2021). The only study that explored the differences in the extent to which perceptual strength ratings could predict RTs in lexical decision tasks between two languages was proposed by Vergallito and colleagues (2020). Specifically, running the same analysis on two datasets related to Italian and English words respectively, they found Imageability being the best predictor of RTs in the Italian sample, whereas Minkowski distance, followed by Maximum Perceptual Strength, revealed to be the best predictors in the English sample, partially replicating what was observed by Connell and Lynott (2012) and Lynott and colleagues (2020). To date, Perceptual Strength ratings have been collected for different languages (Italian: Repetto et al., 2022; Dutch: Speed and Brysbaert, 2021; French: Miceli et al., 2021). However, to the best of our knowledge, no systematic attempts aimed at comparing perceptual profiles of concepts across different languages are reported in literature.

For this reason, we decided to explore cross-linguistic differences comparing Italian, Hebrew, and English native speakers on: 1) Perceptual Strength ratings in six perceptual modalities; 2) correlations between perceptual modalities and the effect of each modality in determining the Abstractness/Concreteness ratings; 3) correlations of interoceptive strength ratings with bodily sensibility measures and with empathy scores; 4) the importance of interoception in characterizing and distinguishing Abstract and Concrete concepts; and 5) perform a data-driven examination of distinct subtypes beyond the Abstract/Concrete concepts dichotomy based on their perceptual profiles.

We hypothesize that interoception would characterize Abstract concepts more than Concrete ones and that exteroceptive modality (especially Vision and Touch) would characterize Concrete concepts more than Abstract ones. Additionally, we hypothesized that the perceptual strength ratings of concepts would not show strong differences across languages both in their absolute values and in the importance of each modality in providing a correct categorization of concepts. However, we also hypothesize that a positive correlation of Perceptual Strength ratings for Interoception with bodily sensitivity measures and empathy could show some cross-linguistic differences because of their culture-dependent nature.

2.2. Materials and methods

2.2.1. Participants

A total of 632 participants filled in the online survey. After a first data check, different participants (N = 8) were excluded because their data showed patterns which reflected unlikely natural responses (e.g., providing maximum or minimum scores for all the questionnaires). Of the final 624 participants that were included in the analysis, 208 were Italian native speakers (mean age = 38.7, SD = 15.2, Males/Females = 56/152), 208 were Hebrew native speakers (mean age = 33.7, SD = 15.2, Males/Females = 40/168), and 208 were English native speakers (mean age = 33, SD = 16.4, Males/Females =

47/161). All participants signed an informed consent, and their data were treated according to the GDPR regulation for privacy. Other studies that adopted the Perceptual Strength ratings with a large set of words subdivided in the whole set of words in smaller lists and had each item rated by approximatively 20 participants (e.g., Lynott et al., 2020; Repetto et al., 2022). Especially one of the seminal papers in which this questionnaire was adopted (Lynott et al., 2020) had an average of 18 participants rating each item (min = 10 max = 74). In the current study, the average of participants that rated each item in each language is 52 (min = 42, max = 63).

2.2.2. Materials

The data collection was implemented as an online survey composed by a questionnaire on bodily awareness (i.e., the Body Perception Questionnaire), a questionnaire on empathy (i.e., the Empathy Quotient), and a set of questions aimed at collecting information about the perceptual components of concepts (i.e., Perceptual Strength ratings and Abstractness/Concreteness ratings).

The Body Perception Questionnaire (BPQ) is a self-report measurement of awareness and reactivity in respect to sensations coming from inside the body (Porges, 1993) and is based on the polyvagal theory (Porges, 2011). It is considered a measure of interoceptive sensitivity. In detail, it is composed by three different scales: one is designed to explore the awareness of one's own bodily functions (BPQ-I), while the other two scales measure the reactivity to the bodily functions related to the organs located above and below the diaphragm, respectively named the supradiaphragmatic (BPQ-II Supra) and the subdiaphragmatic (BPQ-II Sub) reactivity scales. We adopted the BPQ-I subscale of awareness in its short form (Cabrera et al., 2019) as a measure for interoceptive sensibility. The BPQ-I is composed of 26 items, the BPQ-II Supra is composed of 15 items and the BPQ-II Sub is composed by 6 items. The validated Italian translation was adopted in the current study (Cerritelli et al., 2021). The Hebrew version was kindly provided by Tali Sahar and it's currently under validation (unpublished translation).

Empathy Quotient (EQ) is a questionnaire designed to assess the cognitive and emotional aspects of empathy and provide a self-report measure for empathic behaviors. The EQ is based on the Empathizing-Systemizing theory of empathy from Baron-Cohen (2002; Greenberg et al., 2018) and it is designed to address the empathizing component of social behavior. In the current study, we adopted the Empathy Quotient in its short form, composed of 22 items (Wakabayashi et al., 2016). For the Italian sample, the validated translation was provided by Antonio Preti (Preti et al., 2011), while the Hebrew version was provided by Revital Naor-Ziv (unpublished translation).

The perceptual components of concepts were collected using the perceptual Strength ratings proposed by Lynott and colleagues (Lynott and Connell, 2013; Lynott et al., 2020). In this questionnaire, participants had to rate each target concept for how much they can experience it through different perceptual modalities. The original version of the questionnaire included the classical five modalities, namely Vision, Hearing, Smell, Taste, and Touch. More recent versions included also Interoception, operationalized as "sensations coming from inside the body" (Lynott et al., 2020). Perceptual Strength ratings were collected on a 1-to-5 scale with the two poles labeled as "not at all" and "greatly". The full original questionnaire also included ratings of body parts associated with each concept but in the current study we decided to focus on perceptual components only. The distinction between abstract and concrete concepts can be expressed as a graded continuum rather than a dichotomic distinction (Wiemer-Hastings et al., 2001; Wiemer-Hastings and Xu, 2005). For this reason, each participant was furtherly asked to rate each concept for how much they think of it as an abstract or a concrete concept adopting a 1-to-5 scale, with "abstract" and "concrete" as the two opposed poles (Brysbaert et al., 2014).

A total of 80 words describing 40 abstract and 40 concrete concepts were selected for the perceptual strength rating task. Items were selected among different databases in Italian, English and Hebrew (Villani et al., 2019; Brysbaert et al., 2014; Levy-Drori

& Henik, 2006). For the 40 concrete concepts, words which were present in all the databases of interest in the three languages (i.e., Italian, English and Hebrew) were included. We selected three main subcategories of concrete words classically used in literature: animals, food, and manipulable tools (see for example Carota et al., 2012). Moreover, a fourth subcategory of natural objects was included to evaluate ratings for non-living and non-artificial concrete objects. Each subcategory was composed of 10 items. Since the databases used three different scale ranges for Concreteness ratings, we transformed the ratings in z-scores within each dataset. Then, we built a cross-language index of concreteness by averaging the z-scores. Finally, we selected the items that obtained the highest averages z-scores in all three databases. The rationale of this operation was to create a list of words characterized by high level of concreteness in all languages of interests adopting the most objective possible criterion. Unfortunately, the Food category didn't reach the number of 10 words because there were not enough food related words in the Italian database (N = 8). To balance the number of words across lists, we selected two additional words that were included at least in the English and Hebrew database showing comparable Concreteness ratings (i.e., *Cheese* and *Steak*).

For the 40 abstract concepts, we collected words which were present in the Italian and English databases. Even if the Hebrew database included some abstract words, the number of these words were not sufficient to take in consideration the Hebrew norms (Number of AC < 10). Unfortunately, no other database with Hebrew abstract words was found in the literature. As for Concrete concepts, different subcategories were taken in account for Abstract Concepts. Recent studies suggested that abstract concepts can be divided in different categories according to their experiential features (see Kiefer & Harpaintner, 2018; Villani et al., 2019). Thus, we decided to focus on four categories of abstract concepts identified by Villani and colleagues (2019): Emotional & Mental State concepts (EMS), Philosophical & Spiritual concepts (PS), Self & Social concepts (SS) and Physical, Spatio-temporal & Quantitative concepts (PSQ). The selection of highly abstract words followed the same procedure adopted for concrete words. We transformed Concreteness ratings in z-scores in the Italian and English databases and averaged them to obtain a cross-linguistic index of Concreteness. Then, the words with lowest averaged z-scores in each category were selected to obtain a list of words describing abstract concepts across languages. Since the conceptual questionnaire included a total of 80 words and that asking all participants to rate all the concepts would be particularly demanding in terms of time and effort, the whole set of words was divided in four lists each containing 20 words. Each list included 10 abstract and 10 concrete words selected across all categories (see Table 1).

Concrete Words				**Abstract Words**			
Animals	**Food**	**Natural**	**Tools**	**Emotional & Mental States**	**Philosophical & Spiritual**	**Physical Spatiotemporal & Quantity**	**Social & Self**
Cat	Steak	waterfall	Pencil	Hope	Infinity	Effect	Curiosity
Horse	Salad	Snow	Umbrella	Justice	Immortality	Consequence	Kindness
Dog	Candy	Paper	Plate	Peace	Fate	Subtraction	Tact
Bird	Butter	Gold	Violin	Importance	Utopia	Acceleration	Inspiration
Elephant	Sugar	Thorn	Vase	Idea	Salvation	Direction	Contempt
Mosquito	Cake	Sunrise	Pillow	Tolerance	Mediocrity	Part	Love
Mouse	Wine	Rain	Bottle	Conscience	Honor	Activity	Nostalgia
Frog	Cheese	River	Coin	Optimism	Logic	Symbol	Correctness
Cow	Food	Waterfall	Knife	Doubt	Inclination	Space	Attention
Shark	Beverage	Metal	Hammer	Silence	Awareness	Destination	Happiness

Table 1. Words included in the study divided by Type (Concrete and Abstract) and subtype. Subtypes for Abstract concepts were chosen according to the formulation proposed by Villani and colleagues (2019).

2.2.3. Analysis

As a measure of internal consistency, inter-rater reliability was computed using Cronbach's alpha coefficient (Bland and Altman, 1997). This coefficient can range from 0 to 1, with 0 indicating inconsistencies between items and 1 indicating that scores for each item are the same across participants. Cronbach's alpha for each questionnaire included in the current study were computed separately for each language. For what concern the Perceptual Strength ratings, the alpha for each modality was computed separately for each list and then their coefficients were averaged across lists (a similar approach can be found in Lynott et al., 2020).

Analysis of Perceptual Strength ratings were fitted using a cumulative link mixed model (clmm). This method was adopted for two main reasons. The first is that Cumulative Link Mixed Models have been recently suggested to be the best approach to analyze ordinal ratings, as in our case (Taylor et al., 2022). Secondly, inclusion of random effects addresses inter-subject variability in ratings (Baayen, 2004). So, Perceptual Strength ratings were modeled using the *clmm* function of the *ordinal* package (Christensen, 2015). The fixed factors were Modality (Vision vs Touch vs Hearing vs Smell vs Taste vs Interoception), Type of concepts (Abstract vs Concrete), Language (Italian vs Hebrew vs English), and their double and triple interactions. Also, Age (as continuous covariate) and the Age × Language interaction were inserted in the model to address the effect of the covariate across groups. The random effect structure of each model was selected according to the maximal structure that assured convergence (Barr et al., 2013). So, data were modeled using varying intercepts for each word and participant, plus a varying slope by Modality for each participant. As not all participants rated all the words examined in the study, it was not possible to insert a varying slope by word for each participant. An additional model was fitted to observe whether the Abstractness/Concreteness ratings were different for Type of concepts (Abstract vs Concrete) and for Language (Italian vs Hebrew vs English). In this case, the random structure that assured convergence avoiding overfitting consisted in a varying intercept for each word and participant plus a varying slope for type of concepts by participant. Both the general model on Perceptual Strength ratings and the model on Abstractness/Concreteness were tested using analysis of deviance with the likelihood-ratio chi-square test (χ^2) implemented in the *Anova.clmm* function from the *RVAideMemoire* package (Hervè, 2020). Bonferroni corrected post-hoc were tested for each significant interaction using *emmeans* function from the *emmeans* package (Lenth et al., 2019).

Since we were further interested in assessing the contribution of each modality in predicting Abstractness/Concreteness ratings, we computed a set of multiple linear regression analyses. For each language, Abstractness/Concreteness was included as the dependent variable while all perceptual modalities were included as predictor. The Variance Inflation Factor (VIF) was computed on all predictors for each regression to control for multicollinearity. Another set of multivariate analysis were computed to address whether ratings for Interoception were associated with Empathy Quotient scores and with the scores of the three subscales of the Body Perception Questionnaire, namely Body Awareness, Bodily Reactivity above the diaphragm, and Bodily Reactivity below the diaphragm. Each multivariate regression was computed separately for the three languages. The *pillai* statistics for each multivariate regression and the results of significant regressions are reported.

Since we were interested in exploring the importance of each perceptual modality in determining the classification of concepts as abstract or concrete, we employed a Random Forest classifier in order to assess whether the perceptual ratings alone would be sufficient to provide a reliable discrimination between abstract and concrete concepts and identify the modality that has a prominent importance in the discrimination process. Random Forest is a learning method that allows the classification of each single observation onto predefined categorical variables. We used the six perceptual modalities to train the algorithm in distinguishing abstract and concrete concepts. The permutation feature importance is an index describing the decrease in accuracy of the classification when a single feature is shuffled, thus representing an index of how much the accuracy of the model depends on each feature (Breiman, 2001; Dries and Strobl, 2020). Permutation importance of each perceptual modality was computed to identify the most important perceptual modalities for their relevance in providing a correct classification as Abstract or Concrete concepts using the *permimp* function from the *permimp* package. In addition, to measure the performance of Random Forest classifiers in each language, we report the Out-Of-Bag estimation of error rate, indicating the percentage of errors in the classification, and the area under the Receiver Operator Characteristic (ROC) curve, which is an evaluation metric reflecting the accuracy of the classifier on a 0 to 1 scale (Hand, 2009).

Finally, to explore the perceptual composition of different subtypes of concepts we ran a set of hierarchical clustering analyses for each language. This analysis was designed to observe whether the perceptual ratings provided by participants could be used to detect different subtypes of concepts and their distinctive perceptual profiles (for similar approaches see Villani et al., 2018; Harpaintner et al., 2018). We adopted the *hcut* function from the *factoextra* package. Euclidean distance was used to compute the dissimilarity matrix as a measure of distance between items, as often done in psycholinguistic studies (see Everitt et al., 2001). The *Ward.D2* clustering method, which minimizes within-group dispersion based on a sum-of-squares criterion (Ward, 1963; Murtagh and Legendre, 2014), was adopted. The number of clusters was determined using the gap statistics which provides the best number of clusters computing the total within intra-cluster variation across different clustering solutions in comparison to a null reference distribution (Tibshirani et al., 2001). This approach would maximize the compactness and discriminability of clusters. By clustering the data separately for each language, we were not only able to explore the subdivision within each language, but we could further compare the clustering solutions between languages. We computed the Fawlked and Mallows index (1983) to compare the hierarchical clustering solution across pairs of language. The Fowlkes-Mallows Index (FM) is a measure of similarity that ranges from 0 to 1, with 0 meaning no similarity and 1 as maximum similarity between clustering solutions. The FM index is implemented in r in the *FM_index* function from the *dendextend* package. In order to obtain a measure of significance, we computed the critical FM index under null hypothesis and compared this value with the FM index obtained by comparing the two models (with 99% confidence level, one-sided, and assuming normal asymptotic distribution). The estimated FM index under the null hypothesis is computed through a random permutation of labels in the clustering solution and it indicates the hypothesized value in case the two clustering solutions were not similar. Thus, the rejection of the null hypothesis implies that the clustering solutions are not different.

2.3. Results

2.3.1. Inter-rater reliability

The inter-rater reliability for the questionnaires (EQ, BPQ-I, BPQ-II Supra, and BPQ-II Sub) computed using Cronbach's Alpha for each language showed overall a good reliability (total average = .87), with coefficients ranging from .77 (BPQ-II Sub in the Italian native speakers sample) to .95 (BPQ-I in the English native speakers sample; see Table 2).

Language	EQ	BPQ-I	BPQ-II Supra	BPQ-II Sub
Italian	0.878	0.931	0.847	0.771
Hebrew	0.871	0.938	0.876	0.82
English	0.901	0.952	0.911	0.809

Table 2. Inter-rater reliability for each of the adopted questionnaires in each language. EQ = Empathy Quotient, BPQ-I = Body Perception Questionnaire Bodily Awareness, BPQ-II Supra = Body Perception Questionnaire Supradiaphragmatic Bodily Reactivity, BPQ-II Sub = Body Perception Questionnaire Subdiaphragmatic Bodily Reactivity.

The inter-rater reliability regarding the Perceptual Strength ratings showed overall good level of reliability for each modality within and between languages (all > .75; see Table 3). The modality that showed the lowest overall alpha was Taste, probably because the Taste ratings for non-food related concepts were more prone to individual variability.

Language	Vision	Hearing	Touch	Taste	Smell	Interoception
Italian	0.802	0.847	0.786	0.79	0.844	0.884
Hebrew	0.852	0.842	0.804	0.757	0.778	0.821
English	0.886	0.897	0.891	0.775	0.855	0.888

Table 3. Inter-rater reliability alpha values for each modality in each language.

2.3.2. Perceptual Strength ratings

In the analysis of Perceptual Strength Ratings, we observed significant main effects of Modality [$\chi^2 = 1283.4$; $p < .001$] and Language [$\chi^2 = 67.3$; $p < .001$]. Moreover, the Modality × Type [$\chi^2 = 9029.7$; $p < .001$], the Modality × Language [$\chi^2 = 73.2$; $p < .001$], and the Type × Language [$\chi^2 = 165.3$; $p < .001$] double interactions resulted significant. Finally, the triple Modality × Type × Language interaction resulted significant [$\chi^2 = 241.2$; $p < .001$]. The Bonferroni corrected post-hoc analysis for the triple interaction showed that Abstract concepts were rated with greater Interoception compared to Concrete concepts in all languages (AC Ita = 3.97, CC Ita = 2.71, p < .001; AC Heb = 4.07, CC Heb = 2.25, p < .001; AC Eng = 3.21, CC Eng = 2.18, p < .001; see Figure 1 and Table 4). On the contrary, Concrete concepts were rated with greater Vision, Touch, and Smell compared to Abstract concepts in all languages (see Figure 2 & 3 and Table 4). Perceptual strength for Taste did not significantly differ between Abstract and Concrete concepts in the Italian sample only (AC Ita 2.07= CC Ita = 2.58, p = .07), while in the other languages resulted to be greater for Concrete compared to Abstract concepts (see Figure 2 & 3 and Table 4). The perceptual strength ratings in the Hearing modality resulted not different between Concrete and Abstract concepts in all languages (AC Ita = 3.14, CC Ita = 3.24; AC Heb = 2.86, CC Heb = 2.83; AC Eng = 2.71, CC Eng = 2.92, all p = .99).

In addition, ratings for Abstract and Concrete concepts resulted significantly different between languages (see Figure 2 and Table 4). More specifically, Italian participants showed greater perceptual strength ratings for Concrete concepts in Interoception, Touch, and Taste in comparison to Hebrew and English participants. Concrete concepts showed no differences between languages for what concern the Visual modality. Finally, Concrete concepts obtained greater ratings in the Hearing modality in Italian sample in comparison with Hebrew only, while Hebrew showed no differences with English. For what concern Abstract concepts, Italians showed greater ratings in all modalities in comparison to English participants and in Vision, Taste, and Smell in comparison to Hebrew. Interestingly, English and Hebrew did not differ in any of the modality for both Abstract and Concrete concepts, with the only exception of Interoception ratings for concrete concepts in which both Italians and Hebrew showed greater ratings compared to English participants.

To further test whether Sex and List (since the composition of each list was fixed) could show some significant effects on the ratings, an additional linear model was fitted with both sex and list, as well as their interaction with language, as fixed effects. This additional analysis showed that neither Sex, List, or their interaction with language showed significant effects on ratings of abstract and concrete concepts (all p > .26).

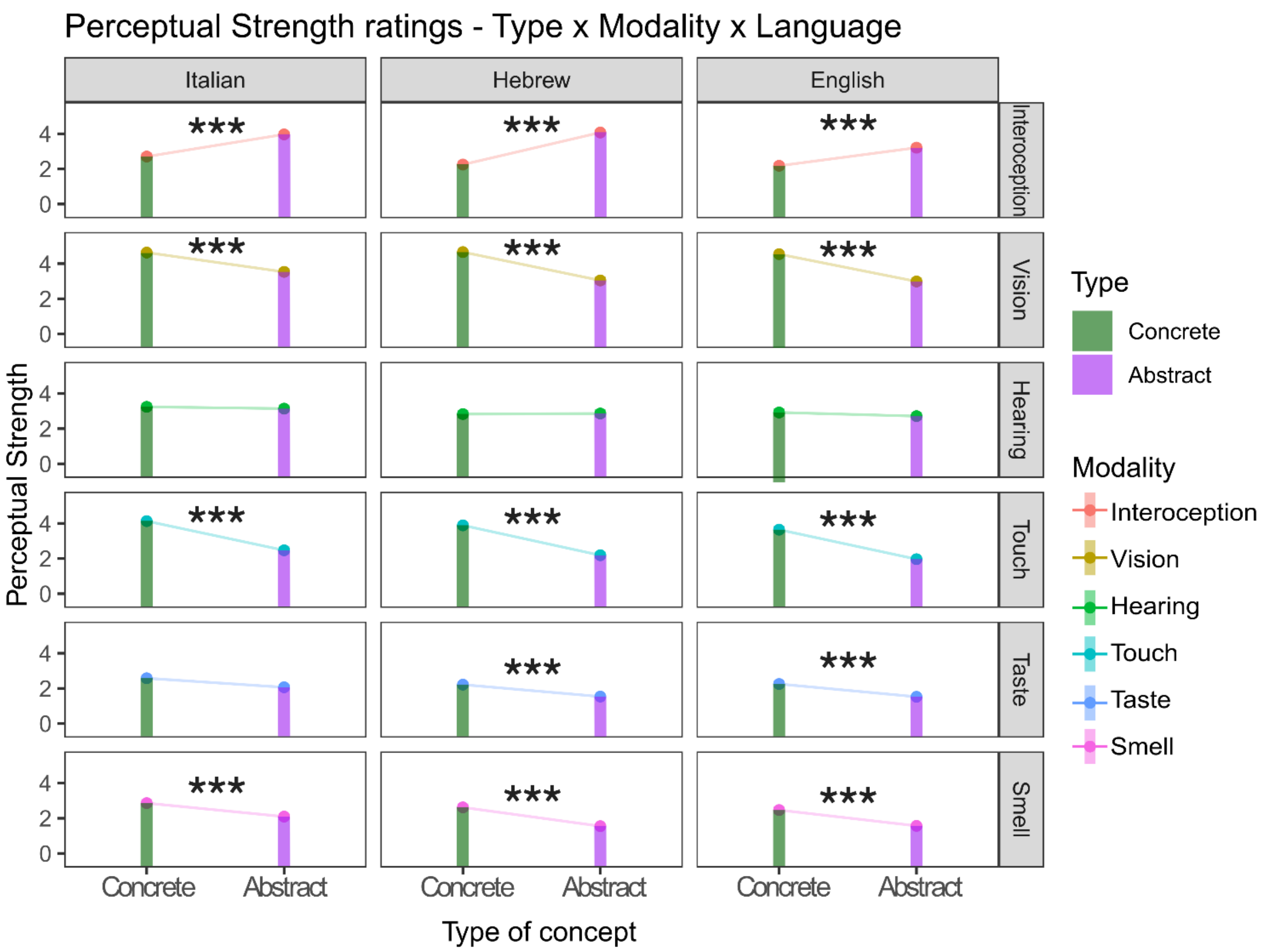

*Figure 2. Comparisons of Perceptual Strength Ratings for Concrete and Abstract concepts in each Language (columns) and each Modality (rows). Bonferroni adjusted significance level: *** = p < .001*

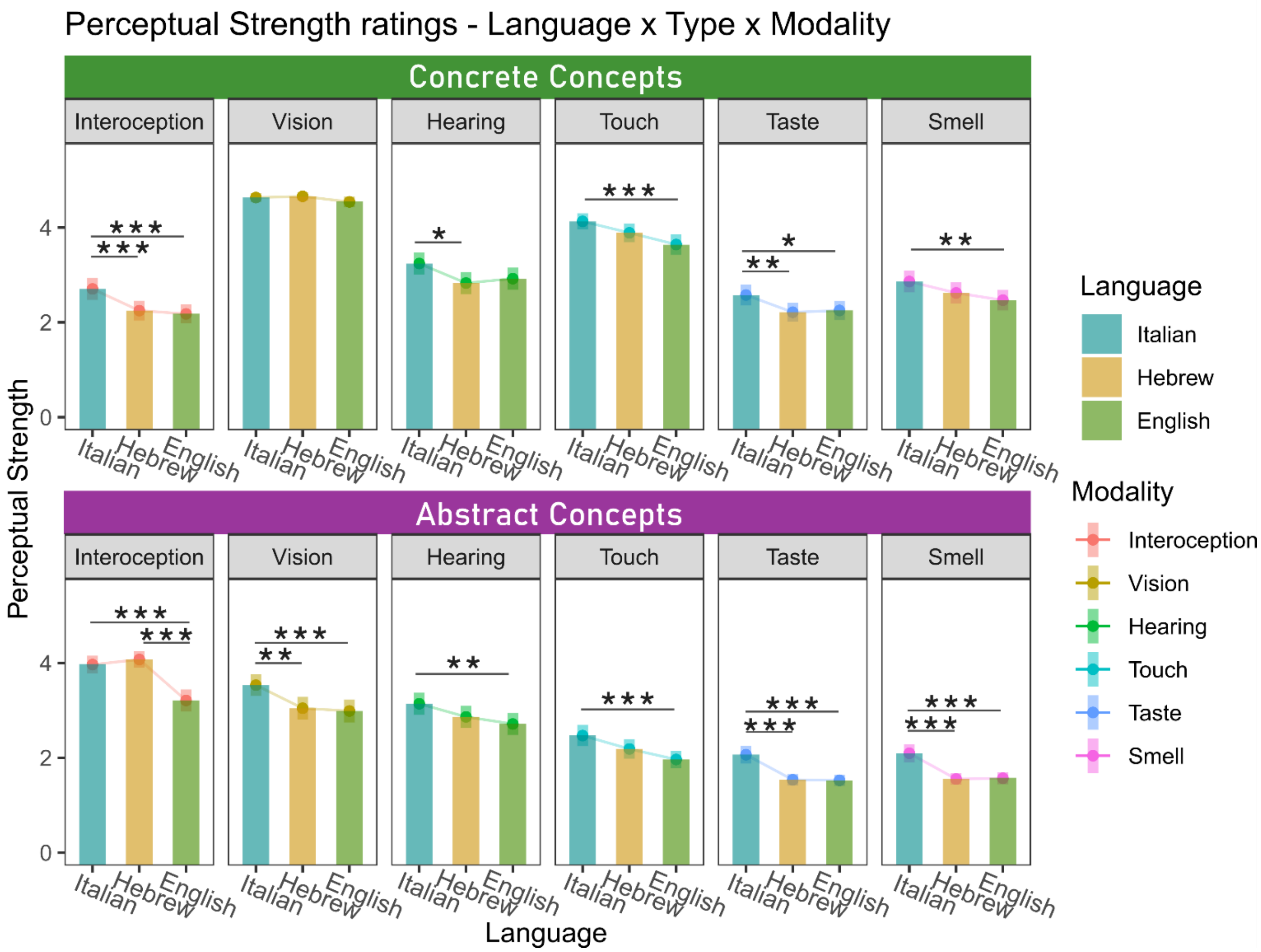

*Figure 3. Comparisons of Perceptual Strength Ratings between Languages for Concrete concepts (upper panels) and Abstract concepts (lower panels) for each Modality (columns). Italians obtained greater scores in all modalities compared to English participants (with the only exception for the Visual and Hearing ratings for Concrete concepts) and to Hebrew participants in Interoception, Hearing, and Taste for what concern Concrete concepts, and Vision, Taste, and Smell for Abstract concepts. Hebrew and English participants showed a significant difference in Interoception for Abstract concepts while all the other comparisons were not significant. Bonferroni adjusted significance levels: * = p < .05, ** = p < .01; * p < .001.*

Language	Modality	Type	Mean	SE	95% CI
Italian	Interoception	Concrete	2.71	0.1174	[2.48 2.94]
		Abstract	3.97	0.0956	[3.78 4.15]
	Vision	Concrete	4.63	0.0471	[4.54 4.73]
		Abstract	3.53	0.1157	[3.31 3.76]
	Hearing	Concrete	3.24	0.118	[3.01 3.47]
		Abstract	3.14	0.1189	[2.91 3.37]
	Touch	Concrete	4.13	0.0872	[3.96 4.3]
		Abstract	2.47	0.1145	[2.24 2.69]
	Taste	Concrete	2.58	0.112	[2.36 2.8]
		Abstract	2.07	0.0947	[1.88 2.25]
	Smell	Concrete	2.86	0.1166	[2.63 3.09]
		Abstract	2.1	0.0978	[1.9 2.29]
Hebrew	Interoception	Concrete	2.25	0.1057	[2.04 2.46]
		Abstract	4.07	0.0895	[3.9 4.25]
	Vision	Concrete	4.66	0.0443	[4.57 4.75]
		Abstract	3.05	0.1226	[2.8 3.29]
	Hearing	Concrete	2.83	0.1188	[2.6 3.06]
		Abstract	2.86	0.1188	[2.63 3.1]
	Touch	Concrete	3.89	0.1001	[3.69 4.09]
		Abstract	2.19	0.1047	[1.98 2.39]
	Taste	Concrete	2.21	0.1014	[2.02 2.41]
		Abstract	1.54	0.0604	[1.42 1.65]
	Smell	Concrete	2.62	0.1137	[2.4 2.84]
		Abstract	1.55	0.0628	[1.43 1.68]
English	Interoception	Concrete	2.18	0.103	[1.98 2.38]
		Abstract	3.21	0.1183	[2.98 3.44]
	Vision	Concrete	4.54	0.0562	[4.43 4.65]
		Abstract	2.99	0.1231	[2.75 3.23]
	Hearing	Concrete	2.92	0.1193	[2.69 3.16]
		Abstract	2.71	0.1176	[2.48 2.94]
	Touch	Concrete	3.64	0.1099	[3.43 3.86]
		Abstract	1.96	0.094	[1.78 2.15]
	Taste	Concrete	2.25	0.1028	[2.05 2.45]
		Abstract	1.52	0.0593	[1.41 1.64]
	Smell	Concrete	2.47	0.1104	[2.25 2.69]
		Abstract	1.57	0.0642	[1.44 1.69]

Table 4. Perceptual Strength ratings for Concrete and Abstract concepts for each language separately. SE = standard error; CI = 95% confidence intervals.

2.3.3. Perceptual modalities and Abstractness/Concreteness

A multiple regression was computed for each Language to predict Abstractness/Concreteness ratings from ratings in each modality (i.e., Vision, Touch, Hearing, Taste, Smell, and Interoception). A significant regression equation was observed for each language: Italian [$F(6,73) = 53.44$, $p < .001$, $R^2 = .81$], Hebrew [$F(6,73) = 127.2$, $p < .001$, $R^2 = .91$], and English [$F(6,73) = 65.31$, $p < .001$, $R^2 = .84$]. In all languages, the Abstractness/Concreteness ratings were significantly predicted by Vision (Italian $\beta = .72$, $p < .001$; Hebrew $\beta = .69$, $p < .001$; English $\beta = .78$, $p <$), Touch (Italian $\beta = .33$, $p < .01$; Hebrew $\beta = .22$, $p < .01$; English $\beta = .29$, $p < .01$), and Interoception (Italian $\beta = -.53$, $p < .001$; Hebrew $\beta = -.54$, $p < .001$; English $\beta = -.51$, $p < .001$), while Smell, Taste, and Hearing did not significantly predicted the dependent variable (all > .19; see Figure 3). The Variance Inflation Factor was optimal for all the regressors in each of the computed models (VIF < 5.0), showing the absence of collinearity between regressors.

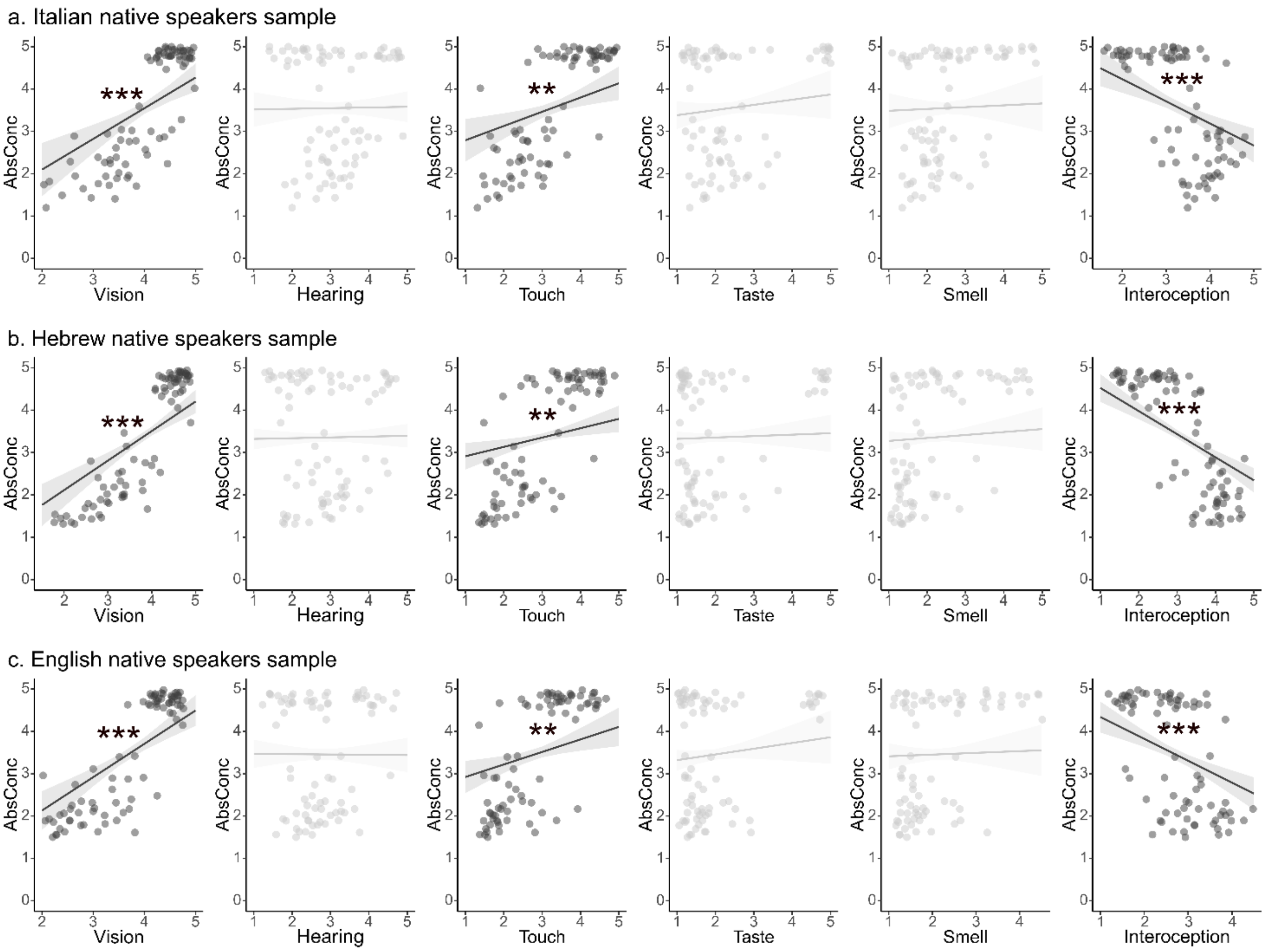

*Figure 4. Results of the multiple regression analysis having Abstractness/Concreteness (AbsConc in the graphs) as dependent variable and perceptual modalities as regressors. Significant regressions are highlighted in darker color. In all languages, AbsConc ratings were significantly predicted by Vision, Touch and Interoception. Interoception showed a negative relation with AbsConc, while Vision and Touch showed a positive relationship. Significance levels: ** = p < .01, *** = p < .001.*

2.3.4. Multivariate analysis on the impact of Interoceptive ratings on Empathy and Bodily Sensitivity

The multivariate analysis on the Italian sample was significant [Pillai's Trace = .054, $F(4,193) = 2.71$, $p < .05$]. Univariate F tests showed that Interoception ratings were positively associated with Empathy Quotient scores [$\beta = 1.57$, $t = 2.09$, $F(1,196) = 4.39$, $p < .05$] and with Body Awareness subscale scores [$\beta = 1.54$, $t = 2.39$, $F(1,196) = 5.75$, $p < .05$], while Bodily Reactivity above and below the diaphragm were not associated with Interoception (both $p > .49$; see Table 5).

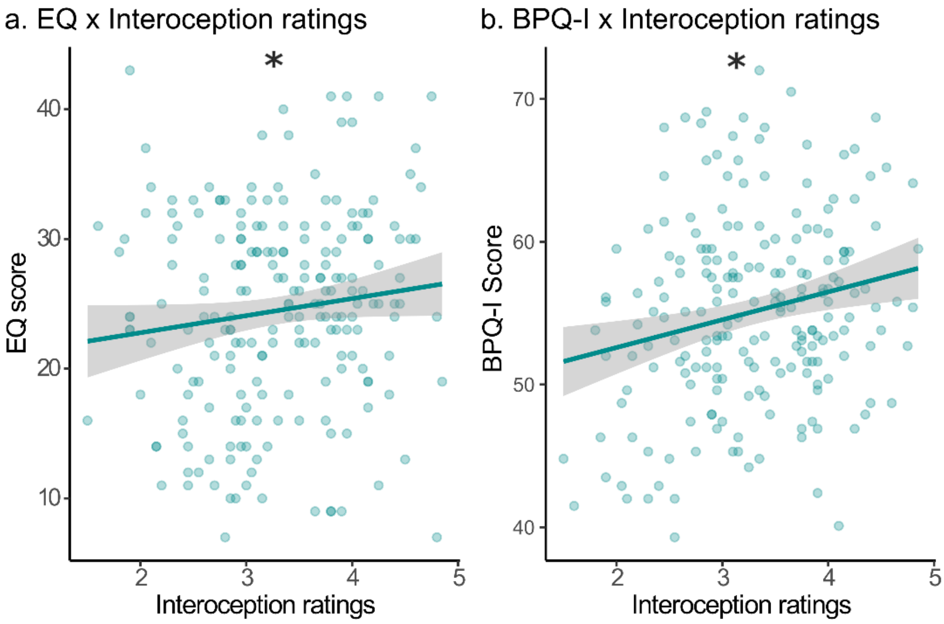

Figure 5. Significant correlation between Interoception ratings by Empathy Quotient (a) and Bodily Awareness (b) resulted from the multiple regression analysis in the Italian native speakers sample. EQ = Empathy Quotient, BPQ-I = Bodily Awareness.

The multivariate analysis on the Hebrew sample was significant [Pillai's Trace = .13, $F(4,198) = 7.95$, $p < .001$]. Univariate F tests showed that Interoception ratings were positively associated with Empathy Quotient scores [$\beta = 1.71$, $t = 2.16$, $F(1,201) = 4.68$, $p < .05$], with Body Awareness subscale scores [$\beta = 2.80$, $t = 3.57$, $F(1,201) = 12.8$, $p < .001$], with Bodily Reactivity above the diaphragm [$\beta = 3.00$, $t = 4.14$, $F(1,201) = 17.17$, p < .001], and with Bodily Reactivity below the diaphragm [β = 2.71, t = 3.25, F(1,201) = 10.6, p < .01] (see Table 5).

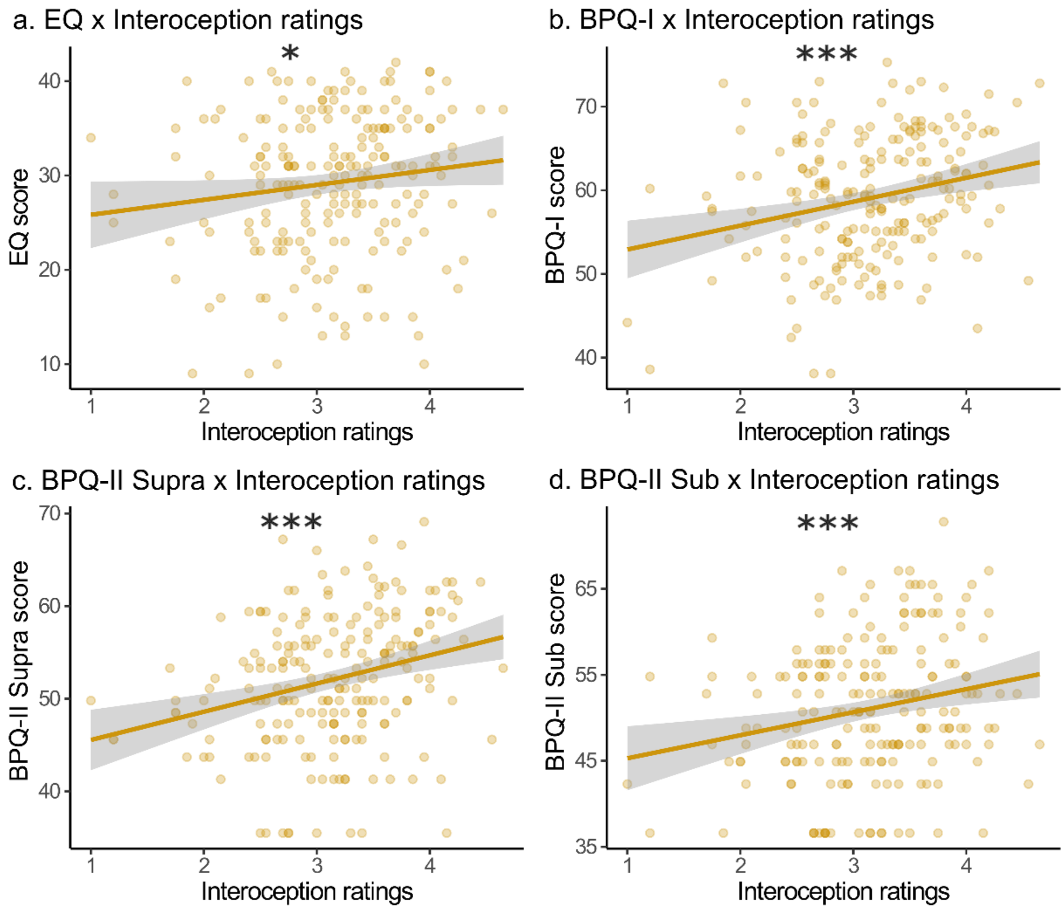

Figure 6. Significant correlation between Interoception ratings by Empathy Quotient (a), Bodily Awareness (b), Bodily reactivity in supradiaphragmatic organs (c), and Bodily reactivity in subdiaphragmatic organs (d) resulted from the multiple regression analysis in the Hebrew native speakers sample. EQ = Empathy Quotient, BPQ-I = Bodily Awareness, BPQ-II Supra = Bodily reactivity in supradiaphragmatic organs, BPQ-II Sub = Bodily reactivity in subdiaphragmatic organs.

The multivariate analysis on the English sample was significant [Pillai's Trace = .051, F(4,199) = 2.67, p < .05]. Univariate F tests showed that Interoception ratings were positively associated with Body Awareness subscale scores [β = 1.78, t = 2.17, F(1,202) = 4.73, p < .05] and with Bodily Reactivity below the diaphragm [β = 1.44, t = 2.04, F(1,202) = 4.17, p < .05], while its association with Bodily Reactivity above the diaphragm and Empathy Quotient scores only approached significance (p = .06 and p = .07, respectively; see Table 5).

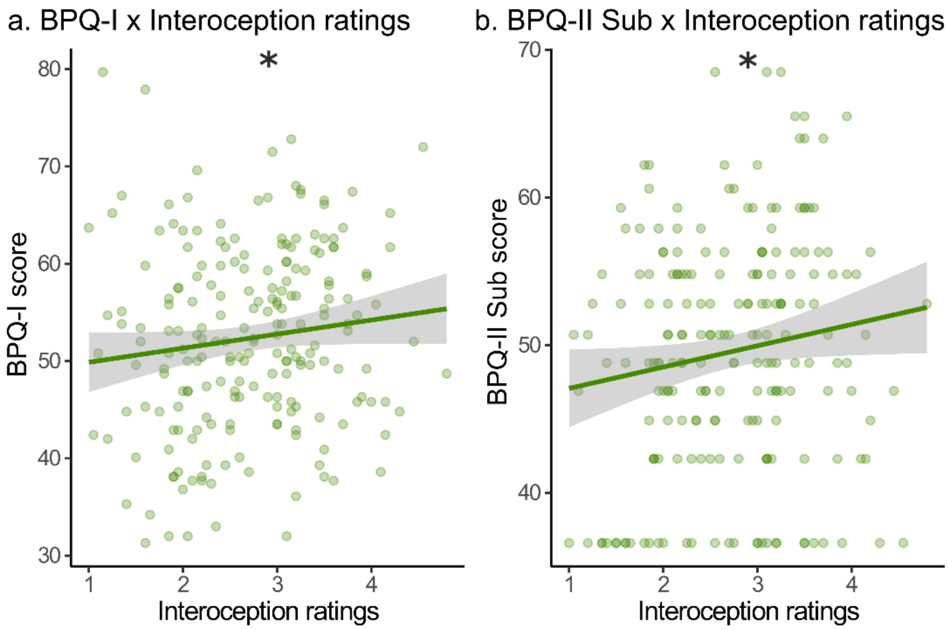

Figure 7. Significant correlation between Interoception ratings by Empathy Quotient (a), Bodily reactivity in subdiaphragmatic organs (b) in the English native speakers sample.

		Empathy Quotient	BPQ-I	BPQ-II Supra	BPQ-II Sub
Italian	β	**1.57**	**1.54**	.45	-.07
	p-value	**.037***	**.017***	.41	.91
Hebrew	β	**1.71**	**2.80**	**3.00**	**2.71**
	p-value	**.031***	**< .001*****	**< .001*****	**< .001*****
English	β	1.45	**1.78**	1.31	**1.44**
	p-value	.06	**.031***	.07	**.042***

Table 5. Standardized β coefficients and p-values of the regression of Interoception ratings for each of the questionnaires in each language. Significant regressions are reported in bold. BPQ-I = Bodily Awareness, BPQ-II Supra = Bodily reactivity in supradiaphragmatic organs, BPQ-II Sub = Bodily reactivity in subdiaphragmatic organs.

2.3.5. Importance of modalities in determining a correct classification of Abstract and Concrete concepts

The Random Forest classifier trained on the Italian sample showed an Out-of-bag error rate of 17.26% with class error rate of .17 for Concrete concepts and .16 for Abstract concepts. The conditional permutation importance analysis showed that the most important modality that contributes to a correct classification was Interoception (.025), followed by Touch (.020), Hearing (.008), and then all the other modalities (see Figure 8). The area under the ROC curve was .92 (see Figure 9).

The Random Forest classifier trained on the Hebrew sample showed an Out-of-bag error rate of 14.5% with class error rate of .11 for Concrete concepts and .18 for Abstract concepts. The conditional permutation importance analysis showed that the most important modality that contributes to a correct classification was Interoception (.037), followed by Vision (.021), Hearing (.011), and then all the other modalities (see Figure 8). The area under the ROC curve was .95 (see Figure 9).

Finally, the Random Forest classifier trained on the English sample showed an Out-of-bag error rate of 18.82% with class error rate of .15 for Concrete concepts and .22 for Abstract concepts. The conditional permutation importance analysis showed that the most important modality that contributes to a correct classification was Interoception (.023), followed by Touch (.020), Vision (.015), and then all the others (see Figure 8). The area under the ROC curve was .92 (see Figure 9).

Overall, the Random Forest classifiers trained on each language separately showed good performance as indicated by the percentage of out-of-bag errors estimation (all < 19%) and the area under the ROC curves (all > .91) (see Figure 9). Moreover, there was a good agreement on the ranking of the importance of each modality in the discrimination of Abstract and Concrete concepts. In detail, Interoception was ranked as the most important modality in each model built on each language (see Figure 8). The second most important modality was Touch for both Italian and English native speakers, while in the Hebrew native speakers sample, Vision was the second most important modality.

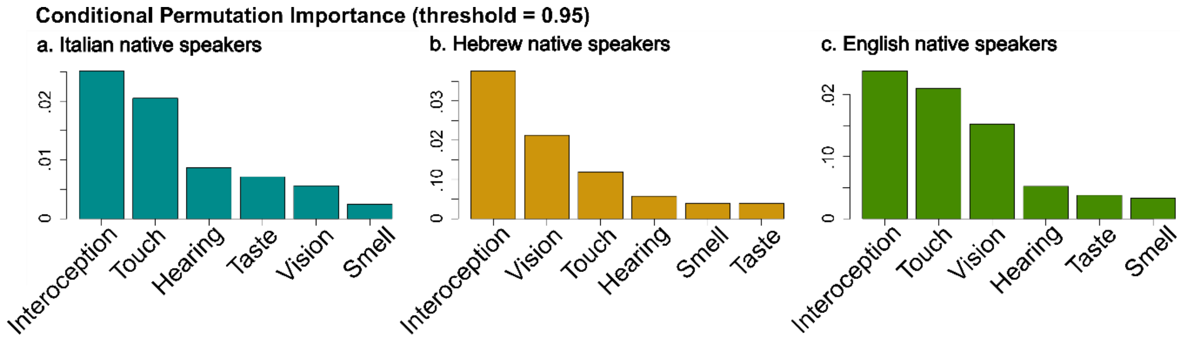

Figure 8. Conditional Permutation Importance for Random Forest classifiers in each Language. This index represents the importance of each predictor (perceptual modality) in providing an efficient classification as Abstract or Concrete concepts in each Random Forest model. In all languages, Interoception was the most important modality.

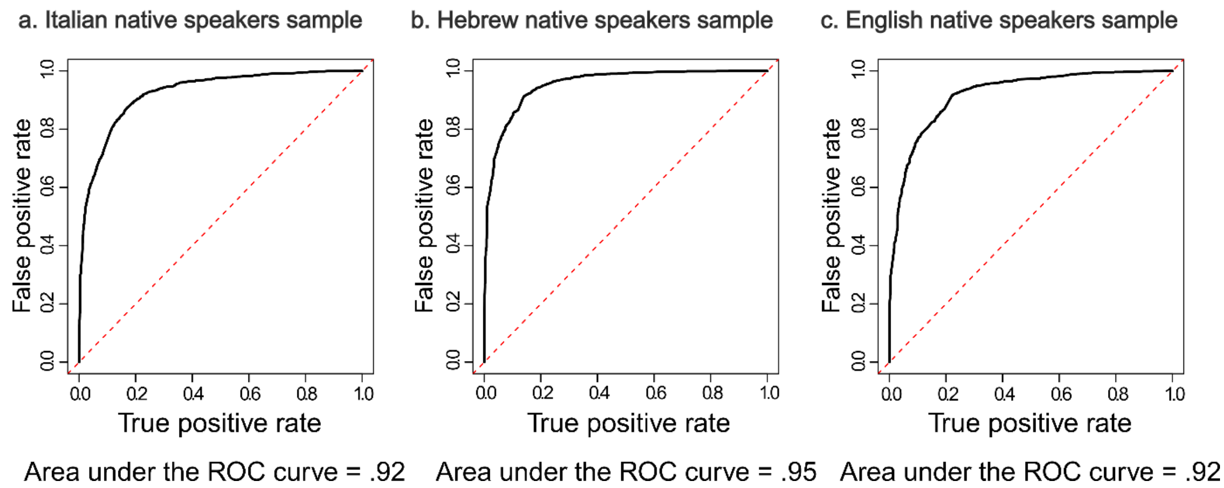

Figure 9. Receiver operating characteristic (ROC) curves for the Random Forest classifies in each language. The red dotted line represents the null performance under random categorization, the black lines represent the actual performance of each classifier. In all languages, classifiers performed well in classifying Abstract and Concrete concepts solely using perceptual strength ratings as predictors, as also highlighted by the area under the ROC curve which exceeded .91 in all languages.

2.3.6. Hierarchical Clustering results

The suggested number of clusters according to the gap statistics was seven for the Italian and the English samples, and eight for the Hebrew sample. Looking at the contents of clusters in each language separately, we observed some recurrent patterns.

2.3.6.1. Hierarchical Clustering – Italian native speakers sample

In the Italian native speaker sample, the first cluster was characterized by high Interoception ratings (mean = 3.78; see Table 6 and Figure 10.a) and it included 29 concepts, most of which were Abstract concepts belonging to the subtype of Emotional and Mental States (N = 10), a mixture of other subtypes of abstract concepts (Physical

Spatiotemporal and Quantities = 8, Philosophical and Spiritual = 5, Social and Self = 4), and two concrete concepts (i.e., *shark* and *sunrise*). The distinctive characteristics of cluster 1, which could be called "General abstract concepts", was the high Interoception and the high Vision ratings counterbalanced by low Taste, Touch and Smell. The second cluster was characterized by overall high perceptual strength ratings across all modalities (mean of all modalities = 3.61; with highest ratings in Vision = 4.12 and Interoception = 4.08) and it included 10 concepts, most of which were abstract concepts belonging to the Social and Self subtype (N = 6), two concepts belonging to the Physical Spatiotemporal and Quantity subtype, and two concrete concepts (i.e., *snow* and *water*). The third cluster was characterized by high Taste (mean = 4.88), and it included all the 10 concrete concepts belonging to the subcategory of "food". The fourth cluster was characterized by high ratings in Vision and Hearing (mean = 4.54 and 4.41, respectively), and it included 9 Concrete concepts, most of which were Animals (N = 5), followed by Natural objects and Tools (N = 2 for both). The distinctive characteristic of cluster 4 was the inclusion of concrete entities or tools usually associated with noise (e.g., *violin*, *hammer,* or *elephant*). The fifth cluster was characterized by high Vision and Touch (mean = 4.57 and 4.51, respectively) and it included 12 concrete concepts, belonging to the subtypes of Tools (N = 8) and Natural objects (N = 4). The sixth cluster was characterized by overall high perceptual strength ratings across all modalities (mean = 3.79) but compared to cluster 2 it had lower Interoception (2.86 vs 4.08), lower Taste (2.21 vs 3.18) and higher Smell (3.95 vs 2.95). Cluster 6 included 5 concepts, four of which were Animals, and one was a Natural object (i.e., *rain*). The distinctive characteristics of cluster 6 was that it included two pets (i.e., *cat* and *dog*), two familiar animals (i.e., *horse* and *cow*) and a familiar natural event like *rain*, all of which are particularly associated with smell (second only to cluster 4 composed by Food concepts). Finally, the seventh cluster was characterized by high Interoception (mean = 3.53) but overall low perceptual strength (mean of all modalities = 2.07) and it included 5 concepts, all belonging to the subcategory of Philosophical and Spiritual concepts.

	General Abstract concepts	High Perceptual Abstract	Food	Noisy Animals/Tools /Natural	Concrete Objects	Highly abstract concepts	Familiar Animals/Natural
Vision	**3.57**	**4.12**	**4.46**	**4.54**	**4.57**	**2.26**	**4.80**
Hearing	3.07	3.71	2.06	**4.41**	2.66	2.09	4.49
Taste	1.93	3.19	**4.89**	1.60	1.78	1.49	2.21
Smell	2.01	2.95	4.09	2.11	2.14	1.50	3.93
Touch	2.37	3.64	3.86	3.63	**4.52**	1.58	**4.50**
Interoception	**3.78**	**4.08**	3.25	2.55	2.18	**3.54**	2.87

Table 6. Perceptual Strength Ratings for each cluster (columns) identified in the Italian native speakers sample. Bold indicates the two highest perceptual strengths characterizing each cluster.

2.3.6.2. Hierarchical Clustering – Hebrew native speakers sample

Looking at the Hebrew native speakers sample, the first cluster was characterized by high Vision and Interoception (mean = 3.97 and 3.21, respectively; see Table 7 and Figure 10.b) and it included 8 concepts, most of which were abstract concepts belonging to the Physical Spatiotemporal and Quantity subtypes (N = 6), and two concrete concepts (i.e., *shark* and *sunrise*). The second cluster was characterized by high Interoception (mean = 4.41) and it included 21 Abstract concepts, most of which were Emotional and Mental States concepts (N = 8), and Social and Self concepts (N = 6). Interestingly, the concepts included in the cluster 1 and 2 in the Hebrew sample (total N = 29) showed an overlap of 79.3% with the cluster 1 in the Italian sample (N = 29), suggesting that cluster 1 and 2 in Hebrew native speakers sample equals the category of "General abstract concepts" in the Italian native speakers sample. The third cluster was characterized by high Taste (mean = 4.78) and it included all the 10 concrete concepts belonging to the subcategory of "food". The fourth cluster was characterized by high Vision and Hearing (mean = 4.93 and 4.03, respectively) and it included 7 concrete concepts, five of which were Animals and two were Tools. The distinctive characteristics of cluster 4, as in the cluster 4 from the Italian sample, was the inclusion of concrete entities or tools usually associated with noise (e.g., *violin*, *hammer,* or *elephant*). Similarly to what observed in the Italian sample, the fifth cluster was characterized by high Vision and Touch (mean = 4.56 and 4.29, respectively) and it included 13 concrete concepts, belonging to the subtypes of Tools (N = 8) and Natural objects (N = 5). The overlap between the Italian and the Hebrew cluster 5 was total as all the concepts belonging to the Italian cluster 5 were also included in the Hebrew cluster 5. The only difference was the inclusion of the concept "*snow*" in such cluster in the Hebrew sample. The sixth cluster was characterized by high overall perceptual strength across all modalities (mean = 3.36) with the only exception of Taste (mean = 1.61) and it included 7 concrete concepts, four of which were Animals and three were Natural objects. Interestingly, also this cluster showed strong resemblance with the Italian cluster 6 as both include pets and familiar animals (e.g., *cat*, *cow*, *horse*, and *dog*) and one the concept *rain*. However, in the Hebrew sample, cluster 6 also included other concepts related to water, specifically they were "river" and "waterfall" that in the Italian sample were included in the cluster 4 which was associate with noisy natural entities and animals. The seventh cluster was characterized by high Interoception (mean = 3.75) but overall low perceptual strength (mean of all modalities = 1.64) and it included 8 Abstract concepts, most of which belonging to the subcategory of Philosophical and Spiritual concepts (N = 6), two belonging to the Emotional and Mental States subcategory, and one belonging to Physical Spatiotemporal and Quantities. This seventh cluster was very similar to the seventh cluster in the Italian sample as it included mostly highly abstract concepts characterized by high interoception and low exteroceptive strength ratings. Finally, the eight cluster was characterized by high perceptual strength ratings across all modalities (mean of all modalities = 3.71; with highest ratings in Interoception = 4.41 and Vision = 3.93) and it included 5 concepts, most of which were abstract concepts belonging to the Social and Self subtype (N = 4) and one Natural concrete concept (i.e., *water*). This cluster has very strong similarity with the cluster 2 in the Italian sample as both show great overall perceptual strength ratings, high Interoception and Vision, and they both includes *curiosity*, *happiness*, *love*, *nostalgia*, and *water*. In addition to these concepts, Italian cluster 2 includes *activity*, *attention*, *effect*, and *inspiration* that in the Hebrew sample were included in the cluster 2 composed by Abstract concepts, and *snow* that in the Hebrew sample was included in the cluster 5 composed by Concrete concepts.

	Mildly Abstract concepts	High Perceptual Abstract	Food	Noisy Animals/Tools /Natural	Concrete Objects	Highly abstract concepts	Visual concepts	Familiar Animals/ Natural
Vision	3.01	**3.93**	**4.53**	**4.49**	**4.57**	**2.13**	**3.97**	**4.65**
Hearing	**3.20**	3.80	1.95	**4.03**	2.24	1.95	2.27	**4.20**
Taste	1.61	3.37	**4.79**	1.16	1.58	1.26	1.27	1.62
Smell	1.60	3.02	4.05	1.64	1.88	1.29	1.49	3.40
Touch	2.29	3.78	3.73	3.32	**4.30**	1.59	2.04	3.79
Interoception	**4.08**	**4.41**	2.63	2.07	1.99	**3.76**	**3.21**	2.54

Table 7. Perceptual Strength Ratings for each cluster (columns) identified in the Hebrew native speakers sample. Bold indicates the two highest perceptual strength characterizing each cluster.

2.3.6.3. Hierarchical Clustering – English native speakers sample

In the English native speakers sample, the first cluster was characterized by high Interoception and Vision (mean = 3.37 and 3.31, respectively; see Table 8 and Figure 10.c) and it included 12 Abstract concepts, five of which were Social and Self concepts, followed by Physical Spatiotemporal and Quantities concepts (N = 4), two Philosophical and Spiritual concepts, and one Emotional and Mental States concept. The second cluster was characterized by high Taste (mean = 4.60) and it included all the 10 concrete concepts belonging to the subcategory of “food”. The concepts belonging to the food category were identified as a particular subcategory of concepts in each language (as cluster 3 in Italian and Hebrew samples), probably because of their peculiar profile with high Taste and Smell ratings. The third cluster was characterized by high Vision (mean = 4.57), followed by Hearing (mean = 4.04) and Touch (mean = 3.38) and it included 14 Concrete concepts, most of which belonging to Animal subcategory (N = 9), three Natural objects, and two Tools. This cluster was very similar to the cluster including noisy natural entities and animals observed in the other languages (as cluster 4 in both Italian and Hebrew). The main difference between the English and the other languages was that in the English sample, pets and familiar animals were included in this bigger cluster that included almost all the animals (9 out of 10), while in the other languages they formed an almost independent cluster. The fourth cluster was characterized by high Vision and Touch (mean = 4.34 and 4.03, respectively) and it included 13 Concrete concepts, belonging to the subtypes of Tools (N = 8) and Natural objects (N = 5). This cluster also showed very strong similarities with the cluster 5 observed in Italian and Hebrew samples, with an overlap of 92.3% with the Italian (with only "*snow*" as mismatch between the two) and 100% with the Hebrew clustering solutions. The fifth cluster was characterized by high Interoception (mean = 3.10) and overall low ratings in all other modalities (mean of all other modalities = 2.09) and it included 20 Abstract concepts, most of which were Emotional and Mental States (N = 9), followed by Philosophical and Spiritual concepts (N = 8), two Social and Self concepts, and finally one Physical Spatiotemporal and Quantities concept. It seems that this cluster includes overall highly Abstract concepts, similarly to what was observed for Italian's and Hebrew's cluster 7 which was characterized by a similar perceptual strength profile and composed mostly by Philosophical and Spiritual concepts. The main difference with the other two languages is that Emotional and Mental States concepts were included in this "highly abstract concepts" cluster in the English sample, while in the Italian and Hebrew samples they were included in the cluster representing "General abstract concepts" and "Mildly abstract concepts", respectively. The sixth cluster was characterized by high Vision (mean = 3.94) and overall low ratings in all other modalities (mean of all other modalities = 1.81) and it included 7 concepts, most of which were Physical Spatiotemporal and Quantities concepts (N = 5), and two concrete concepts (i.e., *shark* and *sunrise*). This cluster was very similar to cluster 1 observed in the Hebrew sample, as it was also composed by four overlapped Physical Spatiotemporal and Quantity concepts (i.e., *direction*, *part*, *space*, and *symbol*), as well as *shark* and *sunrise*. In the Italian sample, all these concepts were included in cluster 1 which was generally composed by Abstract concepts, most of which belonging to Emotional and Mental

States or Physical Spatiotemporal and Quantity concepts. Finally, the seventh cluster was characterized by overall high perceptual strength ratings across all modalities (mean of all modalities = 3.53; with highest ratings in Interoception = 4.02) and it included 4 concepts, most of which were abstract concepts belonging to the Social and Self subtype (N = 3), and one Natural concept (ie., *water*). Also, this cluster showed strong similarities with the high perceptual cluster 8 in the Hebrew sample since all of the concepts included in the English cluster 7 were included in the Hebrew cluster 8, plus "*curiosity*". Also, all concepts included in the English cluster 8 were included in the Italian cluster 2. In particular, the concepts *happiness*, *love*, *nostalgia*, and *water*, were included in all languages in such cluster.

	Mildly Abstract concepts	High Perceptual Abstract	Food	Noisy Animals/Tools /Natural	Concrete Objects	Highly abstract concepts	Visual concepts
Vision	**3.31**	**3.91**	**4.29**	**4.53**	**4.34**	2.45	**3.94**
Hearing	3.00	3.66	1.96	**4.05**	2.35	**2.49**	2.19
Taste	1.86	3.16	**4.60**	1.52	1.61	1.42	1.31
Smell	1.99	2.80	3.77	2.43	1.85	1.42	1.45
Touch	2.35	3.64	3.41	3.38	**4.03**	1.71	1.96
Interoception	**3.37**	**4.03**	2.93	2.10	1.85	**3.10**	**2.19**

Table 8. Perceptual Strength Ratings for each cluster (columns) identified in the English native speakers sample. Bold indicates the two highest perceptual strength characterizing each cluster.

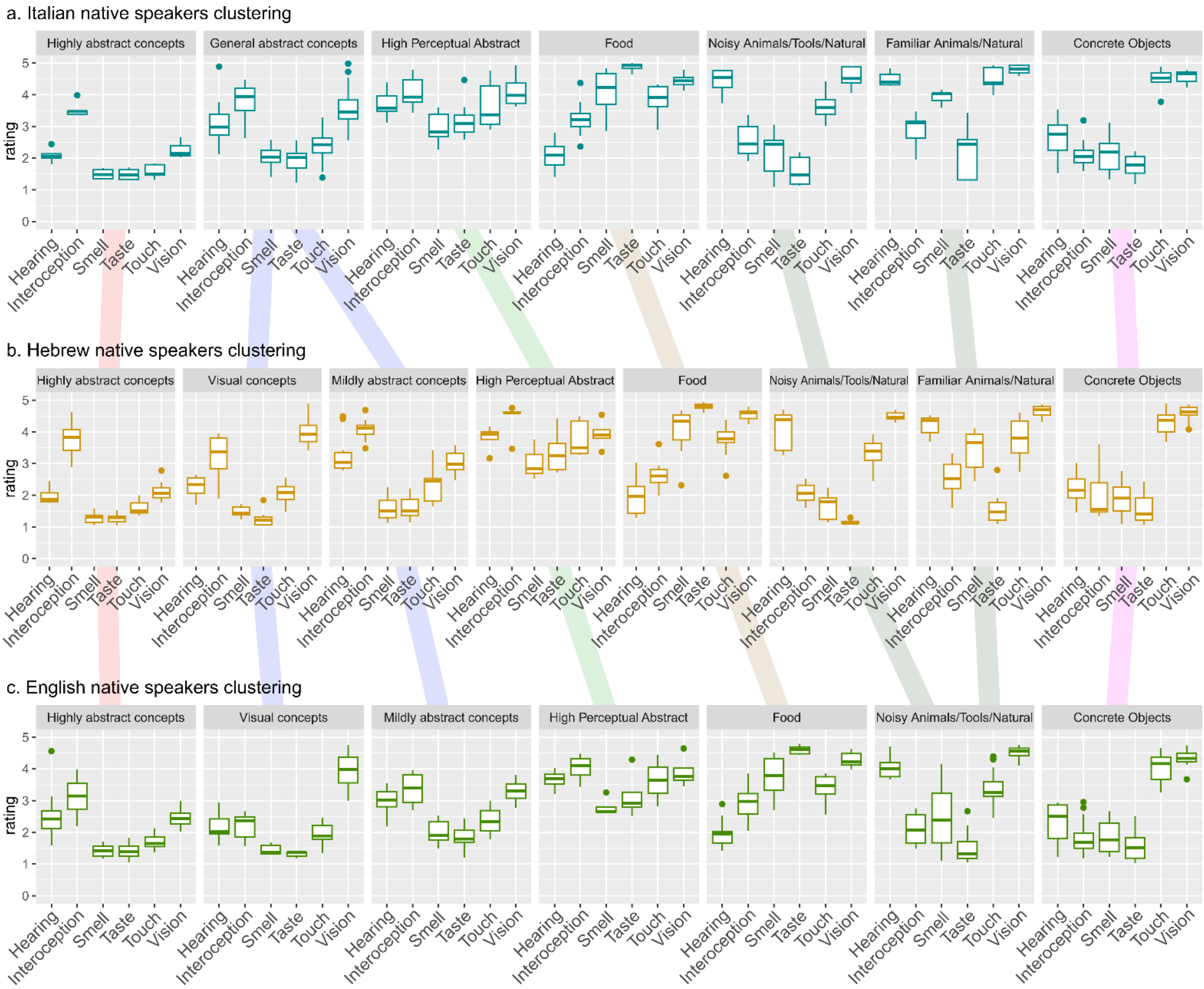

*Figure 10. Perceptual Strength ratings for each cluster identified in each language. Lines represent median, hinges represent first and third quartiles, whiskers represent 1.5*IQR (Inter Quartile Range), and dots represent outliers. Translucent colored lines on the background connect clusters sharing strong similarities across languages. The cluster named "General abstract concepts" in the Italian native speakers sample contain similar items and share perceptual similarities with the combined clusters "Visual concepts" and "Mildly abstract concepts" identified in English and Hebrew native speakers samples. Same goes for "Noisy Animals/Tools/Natural" in the English native speakers sample that includes concepts that belongs to "Noisy Animals/Tools/Natural" and "Familiar Animals/Natural" in Hebrew and Italian native speakers sample. All other clusters showed a direct 1:1 correspondence between languages.*

Comparisons of clustering solutions between languages

The Fowlkes-Mallows index used to compare each pair of hierarchical clustering solutions showed that Italian and Hebrew were similar (FM = .59, $p < .001$), Italian and English were similar (FM = .60, $p < .001$), and Hebrew and English were similar (FM = .66, $p < .001$). In all cases, we rejected the null-hypothesis that the couples of clustering solutions were not-similar with a confidence interval of 99%.

2.4. Experiment 1 Discussion

The current study was designed to address the perceptual strength profile for Concrete and Abstract concepts in three different languages and to explore whether the ratings related to the Interoception modality would be particularly involved in 1) representing Abstract concepts; 2) predicting empathic behavior and bodily sensitivity. We hypothesized to observe no differences across languages for what concern Perceptual Strength ratings for Abstract and Concrete concepts as we suggested that the perceptual features underlying their experience it would be culture-invariant. Similar results were expected for what concern the relationship between Interoception and bodily sensitivity measures, while the strength of the relationship between Interoception and empathy could show much greater inter-language variability as empathy is a complex prosocial behavior which could be greatly affected by inter-individual variability and cultural habits.

2.4.1. Perceptual Strength ratings for Concrete and Abstract concepts within each language

For what concern the comparison of Perceptual Strength ratings of Concrete and Abstract concepts, our results for all languages mirrored the results already observed in single languages studies that did not perform cross-linguistic comparisons (e.g., for English and Italian native speakers see Lynott et al., 2020; and Repetto et al., 2022). Specifically, Concrete concepts obtained greater ratings in Vision, Touch, Taste, and Smell, in comparison to Abstract concepts suggesting that these modalities convey information from outside our body would be important in defining Concrete concepts in all languages. The only exception of Taste that showed no differences between Abstract and Concrete concepts in the Italian sample (see following discussion for an interpretation). On the other hand, Interoception obtained higher ratings for Abstract concepts compared to Concrete ones in all languages. This result was in line with our initial hypothesis 1, and with studies suggesting the importance of this modality in the embodiment of Abstract concepts (e.g., Connell et al., 2018; Villani et al., 2021).

The Auditory modality showed no significant differences between Concrete and Abstract concepts in all languages. A possible interpretation is that different Abstract concepts adopted in the current study are associated with social interactions (e.g., *love* and *nostalgia*) or with cognitive domain (e.g., *attention* and *silence*). This result is in line with a recent study by Banks and Connell suggesting that a subcategory of Abstract concepts, namely externally focused social concepts, are characterized by Auditory features compared to, for example, internally focused concepts which are in turn characterized by Interoception (Banks and Connell, 2023). It is also possible to hypothesize that such concepts could be related to the experience of introspective examination through inner speech and metacognitive processes, thus activating the auditory loop involved in internal dialogue (Wiemer-Hastings and Xu, 2005; Shea, 2018; Borghi et al., 2023). The idea that an exteroceptive modality like the Auditory one could underlie the experiences of both Abstract and Concrete concepts goes well with the idea that their distinction could be better described as a continuum, rather than being two separated ontologically different entities (see also Barsalou et al., 2018). The cross-linguistic similarities were furtherly observed in the multiple regression analysis showing that ratings for Abstractness/Concreteness were strongly predicted by a negative relationship with Interoception ratings and by positive relationships with Vision and Touch. It is important to underline that the Abstractness/Concreteness index was constructed with two opposite polarities, with lower scores indicating that the word is rated as Abstract and higher scores indicating the word as Concrete. So, saying that Abstractness/Concreteness ratings were negative related to Interoception can be rephrased as: the more a concept was rated as Abstract the more was associated with Interoception, while on the contrary, the more was rated as Concrete and the more was associated with Vision and Touch. This pattern was observed in all languages. Interestingly, another similarity between languages has been observed in the results of the Random Forest classifier. In fact, all tested languages showed that the most important modality in providing a good performance in the classification of a concept as Abstract or Concrete was Interoception. This result suggests that despite subtle differences in perceptual ratings for each modality could be observed, the Interoceptive dimension is the one that most defines the abstractness or concreteness of each concept in the model which includes all perceptual modalities.

2.4.2. Cross-linguistic *differences* in Perceptual Strength Ratings for Concrete and Abstract concepts

Despite great similarities in comparing ratings Abstract and Concrete concepts within each language, some differences emerged in the direct comparisons of Perceptual Strength ratings across languages. Especially, we observed that Italians showed greater ratings for a large variety of modalities in both types of concepts in comparisons to Hebrew and, to a greater extent, English participants. However, it is possible that the cross-linguistic differences observed in the current study were the result of different response styles in ratings-based surveys. In fact, as pointed out by Van Herk and colleagues (2004), Italians tend to provide greater ratings compared to other western countries (for similar results see also Williams, 1991; Harzing, 2006). The same study suggested that cross-cultural differences in ratings derived by response style could be not indicative of differences in underlying behaviors and processes (Van Herk, 2004). The idea that the observed differences could be due to differences in response styles is corroborated by the fact that when observing the impact of each modality in determining Abstractness/Concreteness ratings and the perceptual-based clustering solutions, no systematic differences between Italians with the other languages have been observed.

However, it is important to address whether actual cross-linguistic differences could still be identified in underlying some of the differences in ratings observed between languages. The results most likely reflect a true cross-cultural difference is the ratings regarding the difference between Abstract and Concrete concepts in the gustatory modality and the ratings for the Interoceptive experiences in Abstract concepts.

In fact, in the current study Italians showed not only significantly greater gustatory ratings for both Abstract and Concrete concepts in comparisons to Hebrew and English participants, but they also were the only language group that did not show significant differences between Abstract and Concrete concepts in such modality. The fact that Abstract concepts are rated as "tastier" in the Italian sample in comparisons to the other languages could be interpreted with the fact that the meaning of some words belonging to the gustatory domain in Romance languages (like Italian) went through changes over time shifting from a purely perceptual content (e.g., "*gustare*" as "eating something with pleasure") to a more psychological dimension characterized by positive affects (e.g., "gustare" in Italian is often referred to "strongly enjoying and liking something outside the domain of food/beverage consumption"). This shift is even more evident in Spanish (which is also a Romance language) according to which the verb "*gustar*" has practically lost its perceptual meaning and assumed the meaning of the verb "liking" (for a more detailed discussion see Galac, 2020). Another example of a perceptual/cognitive connection in the gustatory modality in Romance language is the ancient Latin verb "*sapio*" from which the current Italian verb "sapere" stemmed, which means both "to know" and "to taste", providing another example of meaning shift from a gustatory to a cognitive domain. Another investigation of the changes between Classic Latin perceptual adjectives and current Italian language suggested that a robust shift from lower domains (i.e., perceptual) to higher domains (i.e., cognitive or affective) occurred over time through the use of metaphors (Lievers and De Felice, 2019). In line with the idea that gustatory related words carry relevant emotional meanings in current Italian language, the use of metaphorical expressions involving this modality (e.g., using the adjective "sweet" to describe a nice person) has been observed to elicit greater activity in cerebral regions related to emotional processes in comparisons to their non-metaphorical expressions (Citron and Goldberg, 2014). Thus, it is plausible that in the Italian sample, Abstract concepts would obtain greater gustatory ratings because of the wide use of metaphor reflecting affective meanings in such modality.

For what concern the Interoception ratings for Abstract concepts, we observed significantly lower ratings for English participants in comparisons to both Italian and Hebrew ones. This is the only statistically significant differences between English and Hebrew participants. While the Italian greater Interoception ratings for Abstract concepts could be prone to the response bias described before, we suggest that the greater Interoception ratings for Abstract concepts provided by Hebrew speakers could reflect an actual cross-linguistic difference. Western philosophy has its roots in the ancient Greek and Roman philosophy which were characterized by a strong body/soul dualism (Schroer and Staubli, 2013). This difference in the philosophical traditions can be reflected in words meanings. For example, the word "soul" in modern English represents a concept that do not belong to the physical world, and it is independent from the bodily realm as it represents the immaterial entity that leave the body after death. In current Hebrew, *népēš* means "spirit" or "soul", intended as "vital spirit", but in biblical ancient Hebrew it has the double meaning of "throat" or "breath", highlighting the corporeal connotation of such highly Abstract philosophical concept. Similarly, the terms *lebab* (heart) and *rāḥam* (womb) can be translated with "mind/knowledge" and "compassion", respectively (Schroer and Staubli, 2013), thus reflecting a semantic coupling of body parts with cognitive/affective Abstract meanings.

Similar conclusions can be drawn by a recent cross-linguistic examination of verbs and their associated body parts. In fact, in a recent study comparing Hebrew and English speakers on associations of body parts with 103 target verbs, Hebrew speakers provided a greater number of body parts (e.g., *brain* or *head*) in association with cognitive dimensions (e.g., *search*, *hate*, *like*), while English speakers were observed to associate the cognitive dimension to a less embodied effector like *mind* (Maouene et al., 2023). Interestingly, they further observed a greater number of associations of *hand palm* (Hebrew: *kaf yad*) with verbs associated with religious or spiritual actions (e.g., *praying, blessing*) and they further suggested that these associations would eventually increase the saliency of the effector "hand palm" on other verbs related to everyday action (e.g., *putting*, *writing*, *cutting*). Thus, Hebrew speakers' semantic representation of Abstract concepts could reflect greater embodied aspects because of the historical philosophic and cultural attitude in coupling inner and emotional states with body parts, as reflected by greater interoception ratings for Abstract concepts.

2.4.3. Cross-linguistic *differences* of Interoception ratings in empathy and body perception

Further cross-linguistic differences emerged in the relationship of Interoception ratings with Empathy, Bodily Awareness, and Bodily Reactivity above and below the diaphragm. Specifically, Empathy levels were observed to be positively associated with Interoception ratings for concepts in the Italian and Hebrew samples, but not in the English sample. Cultural-based variations regarding the rules of social interactions could determine differences in the modulation of the interests in others' feeling and their related interoceptive experience (Cheon et al., 2010; Kwon et al., 2021). Interestingly, some English words expressing prosocial attitudes (i.e., *sympathy*, *compassion*, and *empathy*) have been observed to show some differences in the expressed attitude in relation to their Russian translational counterparts (i.e., *socˇuvstvie*, *sostradanie*, and *soperezˇivanie*). Specifically, differences were found for what concern the affective content and the valence (either positive or negative) associated with the underlying social experience of such words which were stronger in the Russian words (Gladkova, 2010). When comparing collectivistic (e.g., eastern) to individualistic (e.g., western) cultural environments, some differences in the ability to assume the others' perspective have been observed. In detail, greater ability in perspective-taking have been found when comparing Americans with Iranians (Yaghoubi Jami et al., 2019), and Chinese (Wu and Keysar, 2007). However, different studies suggests that empathy is a complex process that could be modulated differently by cultural habits and that some dimension of empathy, like cognitive or affective dimensions, appears to be differently modulated by individualistic versus collectivistic cultures (for different results see Cassels et al., 2010; Chopik et al., 2017). Future research will be needed to detect more detailed and fine-grained effects of culture and language on empathic behaviors. However, with the current study we suggest that the embodiment of concepts in interoception could provide some insights in this regard.

On the other hand, Interoception ratings were positively associated with the Bodily Awareness scores of the Body Perception Questionnaire in all languages. This result suggests that the connection between the ability to embody concepts in our interoceptive experiences and the awareness of our bodily states are linked to each other, regardless of the language of reference. It is possible to interpret this results in light of the fact that being aware of one's own bodily experiences relates to embodiment of conceptual knowledge is similar across different languages unlike social experiences, that showed greater culture-based variability. Noteworthy, Bodily Awareness scores were greater for Hebrew participants in comparisons to both English and Italian participants. This is in line with the observation that non-Western cultures often exhibit greater self-report somatic awareness (Ma-Kellams, 2014). However, our regression analysis showed that greater bodily awareness is associated with greater embodiment of conceptual representations regardless of the overall inter-language score, suggesting that awareness in perceiving internal bodily signals could play a role as a universal mechanism putatively involved in embodiment.

The greatest inter-language differences were observed for what concern the Interoception ratings and the Bodily Reactivity subscales. In fact, Interoception ratings from Hebrew participants were positively related to both Supradiaphragmatic and

Subdiaphragmatic reactivity scales; in the English sample we observed a positive relationship between Interoception ratings and Subdiaphragmatic reactivity scores only, while in the Italian sample none of these relationships resulted significant. Considering that: 1) experience of social interaction is thought to be modulated by contextual and cultural habits; 2) reactivity in the supradiaphragmatic visceral organs is thought to reflect sensitivity in detecting changes in the autonomic activity of those organs involved in controlling the bodily social interface; 3) Hebrew native speakers showed greater empathy scores and a significant correlation between empathy scores and interoception ratings; and 4) Hebrew native speakers also showed greater Interoception ratings for Abstract concepts; one may suggest that the association between interoception ratings and bodily reactivity in the supradiaphragmatic organs is caused by culturally-mediated social habits.

2.4.4. Similarities and differences between Languages in the Clustering analysis

Clustering analysis using perceptual strength ratings as predictors showed a good overall accordance when comparing solutions in each language, with the perceptual profiles for each cluster showing very similar patterns. Noteworthy, the overlap in clusters' composition between languages provides support to the distinction in subtypes provided by Villani and colleagues (2019). When compared to the *a priori* categorization in subtypes of Abstract concepts, our analysis suggests that each cluster can be associated to a specific subtype of Abstract concepts. We identified one cluster mostly based on Social and Self concepts ("High perceptual"), one cluster mostly based on Philosophical and Spiritual concepts ("Highly abstract concepts"), and a set of clusters mostly based on a mixture of Emotional and Mental State plus Physical Spatiotemporal and Quantities concepts ("General abstract concepts" in the Italian sample, and the coupled "Visual concepts" and "Abstract concepts" in the other languages). However, some crucial differences in how concepts are grouped together have been observed. In fact, while those clusters reflecting subtypes of

Concrete concepts showed greater agreements across languages, the boundaries of those clusters reflecting different types of Abstract concepts were more blurred. Specifically, the cluster named "General abstract concepts" resulted larger in the Italian sample (N = 29) and it included mostly concepts that belonged to the Emotional and Mental States (EMS; N = 10) and Physical Spatiotemporal and Quantities (PSQ; N = 8), while in the English and Hebrew samples, these two subtypes of concepts were divided in two main clusters, one characterized mostly by the inclusion of PSQ concepts, named "Visual concepts" (Hebrew N = 8, English N = 5), and the other by the inclusion of EMS concepts, named "Mildly abstract concepts" (Hebrew N = 8, English N = 9). What all these clusters have in common is the perceptual profiles which appeared to be characterized by high Interoception, followed by Vision and Hearing, with the only exception of the "Visual concepts" in the English sample that had the Visual modality as the most prominent, although the concepts included in such cluster almost totally overlapped with the Hebrew sample. This crucial difference suggests that despite English native speakers tend to not rely on interoceptive components for such concepts, they are still grouped together as a specific subtype of concepts because of their perceptual general profile. Differently from Concrete concepts, Abstract concepts embodiment in Interoception can be modulated by cultural habits and influenced by the linguistic co-occurrences with other semantically related words belonging to other types of concepts (Kwon et al., 2021; Wingfield and Connell, 2022). Moreover, the results reported in the current study are in line with those view suggesting that Abstract concepts are prone to greater subjective variability in their experiential components (Barsalou and Wiemer-Hastings, 2005; Muraki et al., 2022; Borghi et al., 2017). Nonetheless, the level of accordance observed in the current dataset can be considered high, especially considering that this clustering analysis have been performed on a very limited set of variables corresponding to perceptual strength modalities that have widely been thought to provide particularly informative features for Concrete concepts. We observe that the inclusion of other experiential features outside perceptual ratings exploring emotional or social dimensions, like for example affective ratings, would dramatically increase the clustering performances observed in the current study allowing a much more fine-grained distinction between subtypes of Abstract concepts, as proposed by other researchers (e.g., Villani et al., 2019). However, the exploration of Perceptual Strength alone produced very interesting clustering of Abstract concepts that resemble the ones observed in literature.

Another interesting observation on the clustering of Concrete concepts arises from the comparisons of those clusters composed by Animals. In the Italian and in the Hebrew samples, Animals were distributed in two clusters: one including noisy animals (e.g., mosquito) and a separate one including familiar animals/pets (e.g., cat). In the English sample, these two groups were collapsed in one cluster. Analyzing the two clusters with animals identified in Italian and Hebrew samples, it emerges that the main differences between noisy animals cluster and the familiar animal/pets cluster differs mostly for the Smell and the Interoceptive modalities. In both languages, the cluster with familiar animals/pets showed greater ratings in such dimensions compared to the one with noisy animals. These differences could reflect the fact that the olfactory and the interoceptive modality are often associated with emotional processing (Soudry et al., 2011; Sullivan et al., 2015; Tsakiris and Critchley, 2016; Palmer and Tsakiris, 2018). In comparison, the one cluster including animals in the English sample showed lower interoception (English = 2.09 vs Italian = 2.86 and Hebrew = 2.54) and lower Smell (English = 2.43 vs Italian = 3.92 and Hebrew = 3.40) compared to the cluster with familiar animals/pets in the other languages, while ratings in the same modalities were much similar with the cluster including noisy animals in the other two languages. It is very important to underline that English participants also showed a large variance for what concern Smell in the cluster including animals (Smell scores at percentiles: 25%= 1.67; 75% = 3.22; delta = 1.55), suggesting that this dimension could still carry some information in differentiating noisy animals from familiar animals/pets but that this distinction would be hidden by the differences in Interoception ratings that in contrast showed a much lower variance (Interoception scores at percentiles: 25%= 1.65; 75% = 2.55; delta = 0.9). In conclusion, we argue that the distinction between subtypes of Abstract concepts in the Italian and Hebrew native speakers samples showed a good consistency, while the clustering in the English native speakers sample in the Abstract domain, and in some Concrete subtypes, was blurred by a lower impact of Interoception ratings in comparison with the other languages. We hypothesize that including additional affective ratings as a measure for emotional experience would strongly improve not only the clustering for Abstract concepts, but it would provide important information for the representation of Concrete concepts too.

2.5. Limitations and Conclusions

In the current study, we addressed the importance of Interoception in the embodiment of Abstract and Concrete concepts in three languages. Some small cross-linguistic differences were observed, especially in the perceptual experiences related to Abstract concepts and their classification in subtypes.

In this regard, one of the main limitations of the current study is that 80 nouns are quite a limited number of target words in relation to the enormous range of lexical items utilized every day in different cultural milieu. Thus, the exploration of the relationship between conceptual embodiment in perception and the experiences in the bodily and social domains could benefit from increasing the number of words. Moreover, this would also allow us to better define the perceptual profiles of specific subtypes of concepts, overcoming the limited and coarse dichotomic distinction in Abstract and Concrete concepts. Consequently, we suggest that future studies aimed at addressing the fine-grained categorization of conceptual representations between different languages should take in account a larger variety of concepts, and eventually collecting sensorimotor ratings and other basic experiential features like affective ratings. It would be particularly interesting to further analyze and explore the inter-rater reliability results, with a particular focus on which types or subtypes of concepts exhibit the greater inter individual differences. Future studies should be designed to address this interesting issue, but it would be important to enlarge the number of conceptual subtypes and select the words belonging to each subtype adopting a much more fine-grained resolution.

In conclusion, we showed results advocating for Interoception as a crucial modality for embodiment and that, regardless of differences across languages, it is important for categorizing concepts as being Concrete or Abstract. We conclude that such modality must be included in models aimed at exploring experiential features of Abstract concepts.

Moreover, we explored how the embodiment of concepts in the interoceptive modality would relate to empathy and body perception. In this regard, we observed that interoception ratings predicted bodily awareness transversally in all languages, while the empathy scores and the bodily reactivity scales (which is associated with the social engagement system) have been observed to be consistently predicted by Interoception ratings by Hebrew native speakers participants, while Italian and English native speakers participants showed mixed results. These results suggests that embodiment of conceptual meanings is associated with bodily sensitivity to internal functions regardless of the cultural milieu of reference, while the involvement of social-oriented experiences in conceptual meanings could be more culture-dependent.

3. Experiment 2: Effects of being immersed in a perceptual deprivation chamber on the processing of Abstract and Concrete Concepts

3.1. Introduction

According to Embodied Language Theories, the processing of words' meaning is affected by the state of the sensorimotor system, especially for what concern the involvement of those modality-specific sensorimotor regions that are activated during the experience of words' referent (Gallese and Lakoff, 2005; Barsalou et al., 2008; Kiefer and Pulvermuller, 2012; Moseley and Pulvermuller, 2018). In fact, the processing of meaning of a concept that refers to a physical and tangible referent has been observed to activate sensorimotor regions associated to the interaction with such referent (Kiefer and Pulvermuller, 2012). This mechanism of sensorimotor reenactment is thought to be important not only for Concrete concepts processing but also for those concepts that doesn't have a physical form. In fact, some studies suggested that Abstract Concepts could rely on the retrieval of bodily, affective, and social experiences that was first experienced through sensations coming from the interoceptive system (Borghi and Binkofski, 2014; Connell et al., 2018; Harpaintner et al., 2018), namely the system involved in the perception of information coming from inside the body (Craig, 2003; Herbert and Pollatos, 2012). In a recent study, Villani and colleagues (2021) observed that performing a task involving the monitor of interoceptive sensations would selectively interfere with the processing of words representing social and abstract concepts, providing experimental evidence in favor of the embodiment of abstract concepts in interoceptive processes. Through a heart-beat detection task they artificially manipulated the activation of the modality-specific system involved in interoception. Yet, to the best of our knowledge, no other experiments tested conceptual processing of Abstract and Concrete concepts adopting an artificial manipulation of interoception.

Other possible mechanisms involved in the representation and processing of Abstract concepts are metacognition and inner speech (Wiemer-Hastings and Xu, 2005; Shea, 2018; Borghi et al., 2023). Such functions would be particularly important in processing Abstract concepts because they allow the grounding in the experience of internal dialogue intended as a mean to facilitate communication in social environments and to promote cognitive and affective appraisal of events referred to Abstract entities. As example, embodiment in internal states could be important in experiencing those events involving concepts like "*friendship*", "*happiness*", "*knowledge*", and many other Abstract entities referring to social, emotional, and cognitive events, as postulated by the Words as Social Tools theory (Borghi et al., 2019). Our brain constantly builds modal states collecting and connecting all those different kinds of information that are relevant for each specific experience we encounter in our daily life (e.g., bodily, affective, social, linguistic, etc.). These modal states are then reenacted during the processing of those words that captured relevant features of those experiences (Barsalou et al., 2008). Thus, considering their multifaced and inherent complex nature, Abstract concepts are thought to represent multimodal experiences grounded in sensorimotor, social, affective, and linguistic domains which are then integrated in situated simulations of real-life events (Barsalou et al., 2008; Barsalou, 2009).

3.1.1. ERP components of semantic processing

Electrophysiological event-related potentials (ERP) related to the processing of word recognition include the well-documented N400 component (Kutas and Federmeier, 2011) and other late components (especially the late negative components like the N700; Barber et al., 2013; Winsler et al., 2018). These components have been observed to be affected by concreteness and other psycholinguistic and linguistics variables like Imageability, number of letters, or measures of phonological and orthographical similarity with other words (Hauk et al., 2006). Classically, the processing of Abstract concepts has been associated with reduced N400 and N700 components when compared to Concrete concepts. This concreteness effect has been associated to the different amount of sensorial information that needs to be integrated for what concern the N400 (Kutas and Federmeier, 2000; Chwilla and Kolk, 2005; Barber et al., 2013), and to the post-lexical recruitment of imagery and working memory processes for the N700 (Adorni and Proverbio, 2012; Barber et al., 2013; Bechtold et al., 2018).

Noteworthy, the N400 was also found to be greater for words with high orthographic neighborhood (i.e., words with similar orthographic properties) and high lexical associates suggesting that lexical features could also be involved in the semantic processing of single words (Laszlo and Federmeier, 2011). In fact, N400 amplitude has been observed to be associated with pattern of co-occurrences in text corpora suggesting that such component reflects at least in part a linguistic based representation (van Petten, 2014).

Emotional valence has been also observed to modulate semantic processing in relation to concreteness in the late stages of word processing, suggesting that top-down post-lexical processes are involved in the process (Pauligk et al., 2019). In addition, a recent study on emotion-laden words processing showed that subjective significance and emotional factors can strongly influence word processing at the electrophysiological level throughout early and late components (Imbir et al., 2023).In light of the literature showing modulation of N400 and N700 subtending processes of sensorimotor integration and imagery, we suggest that an exploration of the electrophysiological modulation of these components occurring for a large number of psycholinguistic and experiential variables would be necessary to unfold the sensorimotor information which are captured and recalled during conceptual processing.

3.1.2. Exploration of physiological internal states (HRV)

A window on the state of interoceptive system can be opened through exploration of Heart Rate Variability (HRV). HRV is a measure of the extent to which fluctuations in time between consecutive heart beats occur and it is thought to reflect the state of the autonomic nervous system (Sztajzel, 2004). Different indexes of HRV can be extracted, each one reflecting a specific physiological meaning and the involvement of a specific branch of the autonomic nervous system (Laborde, 2017; Pham et al., 2021). One of these indexes is the vagal tone, reflecting the activation of the vagus nerve. As discussed in the general introduction (see section 1.9), the vagus nerve belongs to the parasympathetic branch of the autonomic nervous system and it is thought to be involved in the regulation of physiological responses during social interactions and in emotional regulation (Porges, 2011). The involvement of the vagus nerve in the processing of Abstract concepts is suggested by the reviewed literature as this peripheral system is a functionally important portion of the interoceptive system that is actively engaged during different interpersonal, emotional, and introspective experiences, which are in turn thought to be crucial in the embodiment of such concepts (Connell et al., 2018; Borghi et al., 2019). Thus, we decided to explore whether an objective measure of vagal tone could correlate with electrophysiological measures of words comprehension when comparing Abstract and Concrete concepts. We will take in consideration the Root Mean Square of Successive Differences (RMSSD) which is a measure of HRV which is thought to reflect vagal tone (Shaffer and Ginsberg, 2017) and it was further positively associated with performances in interoceptive accuracy (Lischke et al., 2021). Correlations between EEG signals and HRV components were found in relation to alertness (Qi and Gao, 2020), mental fatigue (Melo et al., 2021), or Rolandic mu rhythm (Triggiani et al., 2016). At the best of our knowledge, no study explored the relationship between measures of parasympathetic activity, such as the RMSSD, and amplitude of ERPs associated with conceptual processing, such as the N400 and the N700.

3.1.3. Internal states emerging from inside out: the OVO Whole-Body Perceptual Deprivation chamber

As previously mentioned, a study by Villani and colleagues adopted an interoceptive based secondary task to manipulate interoception during the execution of a primary conceptual task (2021). The manipulation of interoception and the exploration of its effects on cognitive functions is considered a major challenge for current neuroscientific research (Weng et al., 2021). Currently, no study we are aware of explored the effect of artificially altered interoceptive states on the processing of spoken words' meaning. We aimed to induce this artificial modulation through immersion in an altered sensory environment. Such altered sensory environment was provided by the OVO Whole-Body Perceptual Deprivation chamber, a special room designed to induce states of relaxation, inner directed attention, metacognitive processes and increased interoceptive saliency, in the form of a human-sized egg. The kind of deprivation provided by this chamber is not an absolute reduction in the level of stimulation but rather it is better described as a reduced patterning of perceptual stimulation (Rossi, 1969). Such reduced perceptual patterning has been observed to promote altered states of consciosunsess, characterized by a variety of experiences like merging of different perceptual modalities or altered time and space perception (Glicksohn et al., 2019). The experience of perceptual deprivation have been furtherly associated with increased internally directed attention and saliency of bodily states, with participants reporting more perceptual phenomena resulting more prone to report bodily sensations (Lloyd et al., 2012).

In a previous study, Ben-Soussan and colleagues (2019) observed that the immersion in the OVO chamber would increase insular low frequency band power (< 6 Hz), suggesting that the absence of external stimulation would enhance the saliency of bodily information from the interoceptive system. In line with this study, other qualitative data adopting a phenomenological approach shows that the OVO chamber enhance the saliency on the internal state of the body and promote a state of cognitive dedifferentiation, characterized by merging of different sensorimotor components in complex entities (Pellegrino et al., 2023). The OVO chamber is designed to provide a *Ganzfeld*-like monochromatic lighted visual field with no visuospatial references irradiated with a uniformly colored light (Wackermann et al., 2008). For its properties, green colored light has been chosen to provide a state of neutral relaxation in an immersive environment (Kubel et al., 2021). The modulation of delta-to-alpha frequencies have been often observed to subtend mechanisms involved in internally directed attentional focus (Cooper et al., 2003; Harmony, 2013; Ben-Soussan et al., 2019; Glicksohn et al., 2019). Crucially, some studies showed that the direction of attentional resources towards internal states were associated with inhibition of irrelevant sensory stimulation (Ceh et al., 2020), inhibition of sensorimotor cortices (Cooper et al., 2003), and increased heart-beat evoked potentials, a neural correlate of interoceptive accuracy (Petzschner et a., 2019). Noteworthy, increased activity in the theta band, followed by increased activity in the delta band, has been observed to subtend elicitation of N400 in a lexical decision task (Steele et al., 2013). Also, upper theta band (6-7.5 Hz) was found to subtend the N400 component associated with the processing of semantically different types of concepts (animate vs inanimate; Roehm et al., 2004).

Taken together, these studies provide support to the idea that being immersed in an environment that promotes attentional focus towards internal states could influence increased interoceptive saliency, decreased exteroceptive saliency, and language processing.

3.1.4. Significance of the current study and experimental hypotheses

With the current study, we aimed to explore the effect of being immersed in the OVO chamber on the lexical processing of spoken words on electrophysiological correlates of words processing. The considered ERPs are thought to reflect sensorimotor integration (N400) and post-lexical processing in working memory (late N700-like). We expected to observe a modulation of such components in the OVO condition compared to a regular squared white room (henceforth, White Room) and we expected that this modulation would have been selectively observed during the processing of Abstract concepts. More specifically, since the exposition to the altered sensory room would increase the saliency of internal states in terms of interoceptive information and internal dialogue, we expect that the electrophysiological components related to Abstract words processing would result in increased amplitude (i.e., more negative) N400 and late N700-like components. As an alternative hypothesis, the immersion in the OVO chamber would not just increase the saliency of internal states but it would also reduce the saliency of exteroceptive information inhibiting the sensorimotor system (Cooper et al., 2003), thus reducing the amplitude of ERPs related to Concrete concepts processing. In both cases we hypothesized a greater similarity in terms of ERP, that is a reduced difference between the amplitude observed language related ERPs between Abstract and Concrete concepts. Moreover, we expected to find a correlation between the differential amplitude of Abstract and Concrete concepts as a function of vagal tone, as literature suggested that the parasympathetic nervous system could be involved in Abstract words processing.

3.2. Methods

3.2.1. Participants

A total of 20 participants have been enrolled in the study (mean age = 28.9; SD = 8.77; Males/Females ratio = 10/10). All participants were right-handed and had normal or corrected-to-normal vision. Several studies adopting similar cluster-based permutation analysis in context of exploring linguistic material have similar sample size (~20 participants included in the final analysis; Bechtold et al., 2023; Rahimi et al., 2022; Farahibozorg et al., 2022; Strauß et al., 2014; 2015; Popp et al., 2016). Exclusion criteria for enrollment were the presence of symptoms related to at least one among claustrophobia, mild-to-strong anxiety, and mood disorders. The rationale behind the selection of these exclusion criteria was that the OVO-WBPD chamber that was used to promote altered sensory states is a small room in which the particular sensory experience could trigger anxious reaction in susceptible participants.

3.2.2. Stimuli

The target words were selected among the stimuli used in experiment 1. The first selection included 40 concepts (20 Abstract and 20 Concrete) selected on the basis of their number of syllables. Then, the final set of 36 words was selected according to their psycholinguistic features. Psycholinguistic norms for Italian language were extracted from the PhonItalia database which report norms for more than 120000 Italian lexical items (Goslin et al., 2014). In the current study, we finally adopted 16 Abstract words, 16 Concrete words, and 4 Pseudowords (see Table 9). Words for Abstract and Concrete concepts were balanced in terms of different psycholinguistic variables that could affect our outcomes, such as number of letter (AC = 7.37, CC= 7.56; p = .68), number of phonemes (AC = 7.31, CC= 7.37; p = .88), phonological uniqueness point (AC = 4.75, CC= 6.62; p = .50), phonological neighborhood size (PhonN; AC = 2.06, CC= 2.31; p = .68), and phonological neighborhood density measures as Phonological Levensthein Distance (PLD; AC = 2.25, CC= 2.15; p = .50).

Abstract words	Concrete words	Pseudowords
1. Justice	1. Metal	1. Catipo
2. Idea	2. Bottle	2. Merello
3. Hope	3. Elephant	3. Tolluca
4. Silence	4. Hammer	4. Lofità
5. Nostalgia	5. Coin	
6. Conscience	6. Pencil	
7. Happiness	7. Horse	
8. Love	8. Sugar	
9. Infinity	9. Violin	
10. Destiny	10. Cheese	
11. Curiosity	11. Salad	
12. Activity	12. Mosquito	
13. Honor	13. Waterfall	
14. Salvation	14. Steak	
15. Symbol	15. Pillow	
16. Logic	16. Candy	

Table 9. Words included in the current study (translated in English).

In line with the general suggestions in the literature, the pseudowords included in the study were created by phonologically plausible combination of syllables from the Abstract and Concrete concepts' words included in the study and, like most of the other words, were composed by three syllables. The final four pseudowords included in the study were: *catipo*, *merello*, *lofità* and *tolluca*. Spoken words were used in the current study. Differently from most of the studies about exploring ERPs in word recognition tasks that adopted visual presentation of stimuli, we decided to use spoken words because it was not possible to provide an immersive experience in the deprivation room while looking at a screen. Words included in the final datasets were composed of three (N = 24) or four syllables (N = 8). All words were recorded by a male voice in a sound attenuated room through a steady Shure SH200 microphone, with a sampling rate of 44.1 kHz, using the Audacity software (Audacity Team, 2021). Average word duration was 702.41 milliseconds with a standard deviation of 72.97 milliseconds. After recording, each word was stretched using the Praat software (Boersma and Weenink, 2023) in order to last exactly 700 milliseconds without affecting the pitch. In this way, we assured that the presentation of each word ended exactly at 700 milliseconds after stimulus onset, thus eliminating duration as a possible confounding variable (see Ferrand et al, 2017). Stimuli and EEG triggers were presented using E-Prime 2.0 (Psychology Software Tools, Pittsburgh, PA).

3.2.3. Experimental procedure

First, participants were asked to provide some basic information about their visual acuity and habits that could affect experimental outcomes and measurements such as average hours of sleep, coffee and cigarette consumption, and eventual experience with meditation practices. Then, the Italian translation of the short version of the Bodily Awareness scale of the Body Perception Questionnaire were administered to address participants' self-report bodily sensitivity to bodily functions (Cerritelli et al., 2021). After BPQ, participants were asked to rate each of the words included in the study for their imageability, emotional arousal, emotional valence, and for their perceptual components adopting the Perceptual Strength ratings. Imageability was addressed by responding to a Likert scale having "very easy to imagine" and "very difficult to imagine" as opposite poles on a 1-to-7 continuum (Altarriba et al., 1999). Emotional arousal and valence were addressed using the non-verbal scale of the Self-Assessment Manikin (Bradley and Lang, 1994). Then, participants rated each concept for their perceptual component on a 1-to-7 scale version of the Perceptual Strength rating test (Lynott and Connell, 2013) on different perceptual modalities: Vision, Hearing, Touch, Taste, Smell and, most importantly for the current study, Interoception (operationalized as "feelings from inside the body"; Lynott et al., 2020).

After this preliminary behavioral data collection, and after the montage of the system for electrophysiological measures (for details see paragraph 2.4), participants were asked first to rest in a sit position for a total of ten minutes and then to perform a Lexical Decision Go/No-go task (LDT). The resting state phase served as acclimatation to let the participants feel comfortable and habituate them to the environment. In the LDT, participants were instructed to respond to uncommon meaningless pseudowords (15% of trials), and to not respond to common meaningful words (75% of trials). In this way, we assured that participants would have paid attention to critical stimuli (i.e., meaningful words) allowing the observation of lexical processing without the influence of motor response on the EEG signal. The LDT task was repeated three times in each of the two rooms (see Figure 11.a). This allowed to have a reliable number of repetitions for time-locked event related EEG analysis (Luck, 2014). In the end, we collected 48 trials associated with Abstract concepts and 48 trials associated with Concrete concepts for each room. Each trial was composed of 700 ms of auditory word presentation and an additional random inter-trial interval ranging from 1500 to 2000 ms (see Figure 11.b). So, the final duration of each trial randomly ranged from 2200 to 2900 ms. Participants were instructed to respond to pseudowords by moving their right index finger as fast as possible in the more accurate way. The order of room was counterbalanced across participants and each participant remained in each room for no more than 16 minutes, with approximatively 5 minutes and a half of which were occupied by the LDT performance.

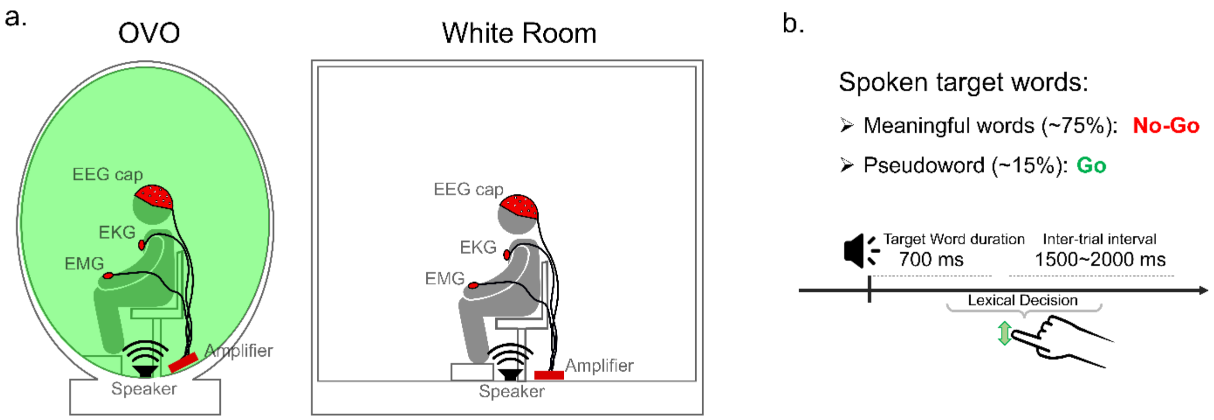

Figure 11. Schematic of the two environmental conditions adopted in the current study (a). Example of a single trial (b). Acronym used to describe the data collected by the electrodes showed in the panel a: EEG = electroencephalography; EKG = electrocardiography; EMG = electromyography.

After completion of the LDT task in both rooms, a semi-structured interview was administered to each participant with the aim to collect phenomenological data on the experience in both environments (not reported in the current manuscript).

3.2.4. EEG and HRV recording

As for electrophysiological measures, an EEG cap for measuring cerebral electrophysiological activity, one bipolar electrode on the chest for measuring Heart

Rate Variability, and one bipolar electrode on the right wrist to record EMG activity related to the movement of the index finger as a response for the Go/No-go task were adopted. Crucially, the collection of responses provided through the movement of the right index finger was chosen because we wanted to maximize the immersive effect of the OVO chamber by avoiding the presence of any external device for data collection, such as buttons or keyboards.

All data were recorded through an EEGoSports mobile EEG system from ANT Neuro (Enschede, Netherlands) with a sample rate of 1000 Hz and a digital high-pass filter of 0.01 Hz. The cap adopted in the study was a 32 silver-silver chloride (Ag/AgCl) electrodes WaveGuard cap with a 10/10 layout. The electrode CPz was used as the online reference. A conductive gel was then injected between the cap and the scalp in order to reduce the impedance and improve the signal transmission to the electrodes. Impedance was kept below 5kΩ for all recordings.

The bipolar electrode for collecting finger responses was placed on the right wrist with the negative pole on the bone on the internal side of the wrist and the negative pole on a spot on the external side of the forearm. The position of the positive pole was identified by asking the participant to move the right index finger and scanning the spot with the most prominent muscular contraction by visual and tactile inspection. The bipolar electrode for the recording of heart beats was placed with the negative pole on the upper part of the sternum (or on one clavicle in case of chest hair for the best adherence of the pad) and the positive one positioned approximately in the middle of the left ribs. The quality of the heartbeats and EMG signals were visually evaluated by two researchers before the start of each recording.

3.2.5. Analysis

3.2.5.1. Behavioral data analysis

Abstract and Concrete words were compared for their Imageability, Valence, Arousal, and Perceptual Strength Ratings modalities (i.e., Vision, Hearing, Touch, Taste, Smell, and Interoception) using a set of Bonferroni adjusted t-tests ($\alpha = 0.05/9 = 0.005$).

In order to test whether perceptual strength ratings could predict psycholinguistic variables scores, the scores obtained from all perceptual modality in the Perceptual Strength ratings were entered in a set of multiple regressions having Imageability, Arousal and Valence as the dependent variable. Additionally, Abstractness/Concreteness scores were assigned to each word according to the ratings obtained in study 1 and used as a dependent variable to observe which modality would predict such ratings. We didn't collect Abstractness/Concreteness ratings from the participants enrolled in this study because we did not want to influence the EEG data collection by cueing participants in thinking about the words for their Abstractness/Concreteness dimension. Importantly, Valence and Abstractness/Concreteness ratings were centered as the two poles of each variable represented two opposite qualities resulting in meaningless zero-points: Positive and Negative were the poles for Valence, Abstract and Concrete were the poles for Abstractness/Concreteness (Dalal and Zickar, 2012). Bonferroni correction was applied to control for multiple comparisons ($\alpha = 0.05 / 20 = 0.0025$). Adjusted p-values will be reported in the current manuscript.

3.2.5.2. EEG preprocessing

EEG data were downsampled from 1000 Hz to 200 Hz. Line noise was cleaned using ZapLine (Klug and Kloosterman, 2022). First, data were high-pass filtered at 0.5 Hz using a kaiser filter (β = 4.98, passband ripple = 0.002, order = 1604). Then, EEG signals were re-referenced to a common averaged reference and epoched from -0.5 to +2 seconds in relation to words onset. No low-pass filtering was adopted in order to avoid any possible distortion in the data and to avoid reduction of the high-frequency signal related to muscular activity in this step. In fact, muscular, eye-related, heartbeat, and other artifacts were then identified and excluded using the Independent Component Decomposition provided by the AMICA toolbox (Palmer et al., 2012).

Then, non-cerebral sources of EEG signal were identified through visual inspection of topographic distribution, time course, distribution of time-locked deflections, and spectral power. Additionally, probabilistic estimation of source with ICLabel was used to help the classification and identification of artifactual components (Pion-Tonachini et al., 2019).

After selection of artifactual independent components, raw data was loaded again. Then, line noise was excluded, a 0.1 Hz high-pass and a 30 Hz low-pass kaiser filters were applied, and data were re-referenced to a common average. Then, ICA weights from the first pre-processing procedure were applied to the new dataset and the artifactual independent components identified in the previous step were excluded. The exclusion of artifactual components from the data in two different steps was done because the ICA decomposition is particularly sensitive to low frequency oscillations (<0.5 Hz; Klug and Gramann, 2021), while the target components of our study (e.g., N400 and N700) have been observed to be attenuated when the low-pass filtering is greater than 0.3 Hz (Tanner et al., 2015). Consequently, in order to perform a reliable ICA decomposition and to avoid distortion of the components of interests we used two different preprocessing steps, one aimed at extracting ICA weights using a 0.5 Hz high-pass filter, and a second one filtered at 0.1 Hz on which the ICA weights previously adopted were applied (for a similar approach see Visalli et al 2021).

3.2.5.3. ERP analysis

The first data analysis was conducted using the FieldTrip toolbox in MATLAB (Oostenveld et al., 2011). We performed nonparametric cluster-based permutation analysis with the specific aim to test the differences between Abstract and Concrete words' electrophysiological correlates in the OVO chamber and the White Room. Independent T-test comparisons allowed us to examine significant differences between types of word in the two rooms without assuming a priori region of interests or time windows. In our case, this feature was particularly useful as very few studies explored spoken word comprehension and the few studies adopted showed variability in the pattern of ERP timing in comparison to the larger number of studies on written words (see for examples Hunter, 2013; Dufour et al., 2013; Winsler et al., 2018).

Spatiotemporal clusters reaching the threshold for significance were obtained for each electrode-time sample, testing all the 32 electrodes and a time window ranging from the onset of stimulus to 2 seconds after the stimulus onset. This allowed us to observe potential unexpected effects in non-conventional time-windows adopted in studies on conceptual processing. The distance method with a maximum distance of 10 mm and the maximum sum of cluster-level statistics were adopted to identify the clustering solutions. The minimum acceptable cluster dimension was two neighboring electrodes. The Monte Carlo method with 1000 random permutations was adopted to test statistical inferences and avoid multiple comparison issues (Ludbrook, 1994).

Following the results from the cluster-based permutation analysis, we further analyzed ERP amplitudes controlling for different psycholinguistic variables in R Studio. Clean EEG single-trials epochs time-locked to the onset of each target (-200 ~ 2000 ms) were exported for each single participant. In a first step, the event-related components of interests were identified according to the results obtained in the cluster-based permutation analysis, according to the relevant literature, and through a visual inspection of the ERP time course. The final components and their respective time windows included in the analysis were: N400 (500~550 ms), and a late N700-like time window (1700~1800 ms). The late N700-like component was found to be significantly increased in Abstract concepts in the OVO chamber in the previous cluster-based analysis and thus it was included in the second analysis to explore whether other psycholinguistic variables could be involved in its modulation. In the cluster-based permutation analysis, the N400 was observed to be related to concreteness regardless of the room. Then, it was included in the second analysis to explore whether the interaction with the room could reveal to be sensitive to psycholinguistic variables included as continuous factors. In fact, the second analysis was conducted because we suggest that the continuous factor could capture some more nuanced effects in the modulation of ERP components which could have not been observed in analysis adopting categorical factorial distinction like the first one. Since inter-subjective differences are of greater relevance in psycholinguistic studies, we adopted a mixed multilevel modelling approach (for a similar approach see Winsler et al., 2019). This approach allows to address the influences of multiple variables of interest while controlling for potential collinearity issues (see Winsler et al., 2019; Payne et al., 2015). Additionally, this approach allowed to account for both inter-item and inter-subject variance in the analysis without losing possibly informative data through averaging (Sacchi and Laszlo, 2016). Since the N400 concreteness effect has been typically found to be stronger for central and midfrontal electrodes (Winsler et al., 2019; Barber et al., 2013; Lee and Federmeier, 2008; Welcome et al., 2011), we decided to focus our analysis on a frontocentral ROI composed by Cz, FC1, FC2, and Fz averaged amplitudes. Amplitudes of the N400 and late N700-like components were modeled separately using the *lmer* function (lme4 package). Room (OVO vs White Room), and Order of rooms (OVO first vs White Room first) were included in the model as categorical fixed effects to test for experimental condition and to control for potential influence of order, respectively. Imageability, Valence, Arousal, Abstractness/Concreteness, and Interoception, were entered as continuous fixed effects. Double interactions of Imageability, Valence, Arousal, Abstractness/Concreteness, and Interoception with Room, as well as the Room by Order interaction, were also included in the model to address differences between experimental conditions. A parsimonious random effect structure was modeled since the maximal random effect structures have been observed to possibly cause overfitting and/or convergence issues (Bates et al., 2015), or having negligible effects on data analysis in ERP studies (Stites and Laszlo, 2015). So, subjects and Items were included in the model as random intercepts. More complex random effects' structures (e.g., Items varying slopes for each Subject, or inclusion of by-Subject varying slopes for any of the fixed effect) were tested and led to convergence issues. Main effects and interactions in each model were tested using the *Anova* function of the car package adopting the Wald Chi-Squared statistical test (χ^2). Post hoc analysis for significant main effects and interactions were conducted using the *emmeans* (for categorical variables) or the *emtrends* (for continuous factors) function from the emmeans package. Test of slopes for significant effects of continuous variables was computed using confidence intervals, in which when the null value (i.e., slope coefficient = 0) is not included between the upper and lower confidence interval then the slope coefficient is to be considered different from a null coefficient (Aiken et al., 1991).

3.2.5.4. HRV analysis

First, time intervals between consecutive heartbeat peaks (R-R intervals) in the task period were extracted separately for the White Room and the OVO experimental conditions. Then, Heart Rate Variability measures were computed using the Kubios software (Kubios HRV Standard, Version 3.0.0; Tarvainen et al., 2014). We extracted an index which has been observed to be associated with vagal tone, namely the Root Mean Squared of Successive Differences between heartbeats (RMSSD). The RMSSD values have been normalized through logarithmic transformation (Shapiro Wilk normality test post transformation results were RMSSD WhiteRoom: $W = .97$, $p = .79$; and RMSSD OVO: $W = .95$, $p = .44$).

3.2.5.5. Correlations of HRV indexes and ERP components

An index representing the difference in amplitude between Abstract and Concrete concepts was computed separately for each participant and each room. This index was named ΔConcreteness and it was computed for each of the component of interest (i.e., the N400 and N700-like). Negative scores of ΔConcreteness indicated that the amplitude for Concrete concepts was greater than the one for Abstract concepts, while positive scores indicated the opposite pattern. We computed a set of Pearson correlation of the ΔConcreteness amplitude with the log transformed RMSSD index with the aim to observe whether the differential amplitude between Abstract and Concrete concepts would be associated with an index of vagal activity.

3.3. Results

3.3.1. Behavioral results

In the following section, results regarding the comparison of Concrete and Abstract concepts in Imageability, Arousal, Valence, and Perceptual Strength ratings will be discussed. All p-values are Bonferroni corrected.

3.3.1.1. Comparisons of ratings for Abstract and Concrete concepts

Concrete concepts obtained significantly greater ratings for Imageability (CC = 6.65, AC = 5.31, $p < .001$) and all exteroceptive modalities in the Perceptual Strength ratings (Vision: CC = 6.32, AC = 4.29; Hearing: CC = 4.68, AC = 3.80; Touch: CC = 5.46, AC = 3.10; Taste: CC = 3.70, CC = 2.47; Smell: CC = 3.65, AC = 2.42; all $p < .001$). On the contrary, Abstract concepts obtained significantly greater ratings for Arousal (CC = 2.49, AC = 3.28, $p < .001$), Valence (CC = -.14, AC = .14, $p < .05$), and Interoception (CC = 3.35, AC = 5.16, $p < .001$).

3.3.1.2. Imageability, Arousal, Valence, and Abstractness/Concreteness by Perceptual Strength ratings

Imageability ratings were significantly predicted by Vision [$\beta = .11$, t-value = 3.27, $p < .05$, $\eta_p^2 = .02$] and Touch [$\beta = .12$, t-value = 3.50, $p < .01$, $\eta_p^2 = .02$]. Arousal ratings were significantly predicted by Hearing [$\beta = .08$, t-value = 3.14, $p < .05$, $\eta_p^2 = .02$], Taste [$\beta = .09$, t-value = 3.02, $p < .05$, $\eta_p^2 = .02$], and Interoception [$\beta = .15$, t-value = 6.17, $p < .001$, $\eta_p^2 = .06$]. Abstractness/Concreteness ratings were significantly predicted by Vision [$\beta = .14$, t-value = 5.55, $p < .001$, $\eta_p^2 = .05$], Touch [$\beta = .18$, t-value = 7.94, $p < .001$, $\eta_p^2 = .09$], and Interoception [$\beta = -.21$, t-value = -11.07, $p < .001$, $\eta_p^2 = .17$]. Valence ratings were not predicted by any of the perceptual modalities included as regressors (all $p > .46$).

3.3.2. ERP results

3.3.2.1. Cluster-based permutation analysis results

The cluster-based permutation analysis on the Concreteness effect comparing Abstract and Concrete concepts beyond room showed a significant difference in a frontal cluster in the 500-560 time-window with Abstract concepts showing higher (i.e., less negative) amplitude compared to Concrete concepts (mean amplitude AC = -0.13 μV, mean amplitude CC = -1.05 μV, differential = -0.91 μV, p = .02, cluster statistics = 387.20; see Figure 12). Direction, topographic distribution, and latency are compatible with the N400 component.

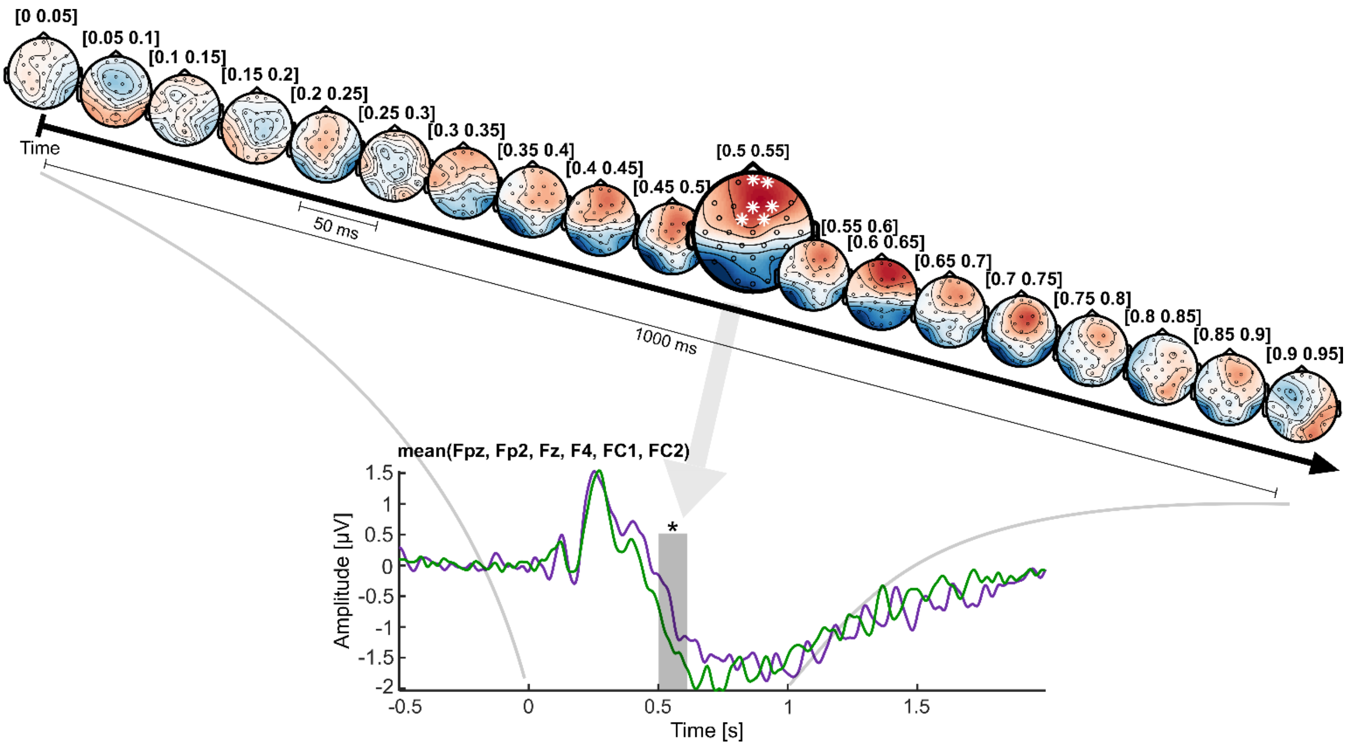

*Figure 12. The upper panel shows the time course of the ERP showing the difference between Abstract and Concrete concepts. Time windows in square brackets are expressed in seconds. Scalp distribution for the time window that showed significant differences is enlarged. The electrodes that showed significant differences related to words' type are highlighted with white asterisks and their averaged amplitude is shown in the bottom panel. * = p < .05.*

The cluster-based permutation analysis comparing Abstract and Concrete concepts in the White Room showed no significant results (all p > .25).

The cluster-based permutation analysis comparing Abstract and Concrete concepts in the OVO showed a significant effect of word type in the 1700-1800 time-window, with Abstract concepts showing a greater centroparietal negativity compared to Concrete concepts (mean amplitude AC = -0.53 μV, mean amplitude CC = 0.46 μV, differential = 0.99 μV, p = .009, cluster statistics = -566.29; see Figure 13).

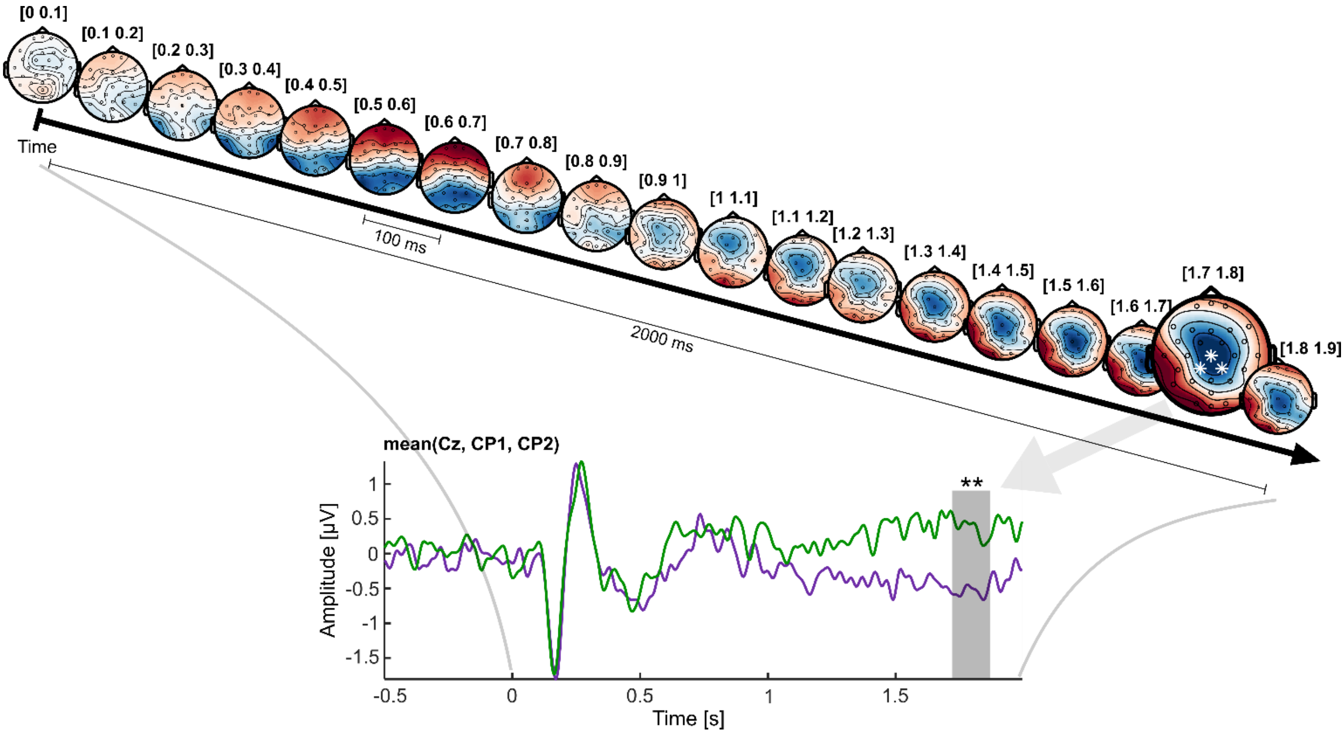

*Figure 13. The upper panel shows the time course of the ERP showing the difference between Abstract and Concrete concepts in the OVO chamber. Time windows in square brackets are expressed in seconds. Scalp distribution for the time window that showed significant differences is enlarged. The electrodes that showed significant differences related to words' type are highlighted with white asterisks and their averaged amplitude is shown in the bottom panel. ** = p < .01.*

3.3.2.2. N400 component related to continuous Abstractness/Concreteness ratings

A significant main effect of Abstractness/Concreteness in the N400 time window [χ^2 = 5.46, df = 1, p < .05]. Also, a main effect of Order of the rooms were observed [χ^2 = 4.55, df = 1, p < .05]. Significant Room × Abstractness/Concreteness [χ^2 = 4.39, df = 1, p < .05] and Room × Imageability interactions have been found [χ^2 = 6.21, df = 1, p < .05].

Post-hoc analysis on the main effect of Abstractness/Concreteness mirrored what observed in the first analysis, with amplitudes of the N400 component was associated with Abstractness/Concreteness (β = -.23; Figure 14.a), 95% CI [lower = -.42, CI upper

= -.03], with greater concreteness ratings associated with greater negative amplitudes. Post-hoc for the main effect of Order showed that amplitudes for N400 were generally lower when participants started with the OVO chamber (mean amplitude = -.39 μV) rather than when they started with the White Room (mean amplitude = -1.62 μV; difference = -1.22, df = 18, t = -2.13, p < .05; Figure 14.b). However, the interaction of Room × Order was not significant (p = .82), suggesting that the effect of Order did not vary in the two rooms.

Post-hoc analysis showed that the slope representing the amplitudes of the N400 component related to Abstractness/Concreteness in the White Room was significantly different from the slope in the OVO chamber ($\beta_{\text{White Room}}$ = -.31, β_{OVO} = .01, df = 1217, t = -2.36, p < .05). Specifically, the 95% confidence interval analysis showed that the negative slope related to Abstractness/Concreteness ratings in the White Room was significantly different from zero, 95% CI [lower = -.11, upper = -.50], while the slope related to the OVO chamber was not, 95% CI [lower = .19, upper = -.19]. This means that in the White Room we observed the classical well-established N400 Concreteness effect with a proportional increase of the N400 amplitude in relation to words' concreteness, while in the OVO chamber this effect disappeared showing no differences related to Abstractness/Concreteness (see Figure 14.c). Post-hoc analysis for the Room × Imageability interaction showed a significant difference between slopes describing the amplitude of the N400 in the two rooms [$\beta_{\text{White Room}}$ = .13, β_{OVO} = -.09, df = 1216, t = 2.18, p < .05]. However, neither of the two rooms showed a slope reliably different from zero, suggesting an elusive effect of imageability on the N400 amplitude (White Room: 95% CI [lower = .28, upper = -.02], OVO: 95% CI [lower =.06, upper = -.24]; see Figure 14.d).All other main effects or interactions in the N400 time window were not significant (all p > .08).

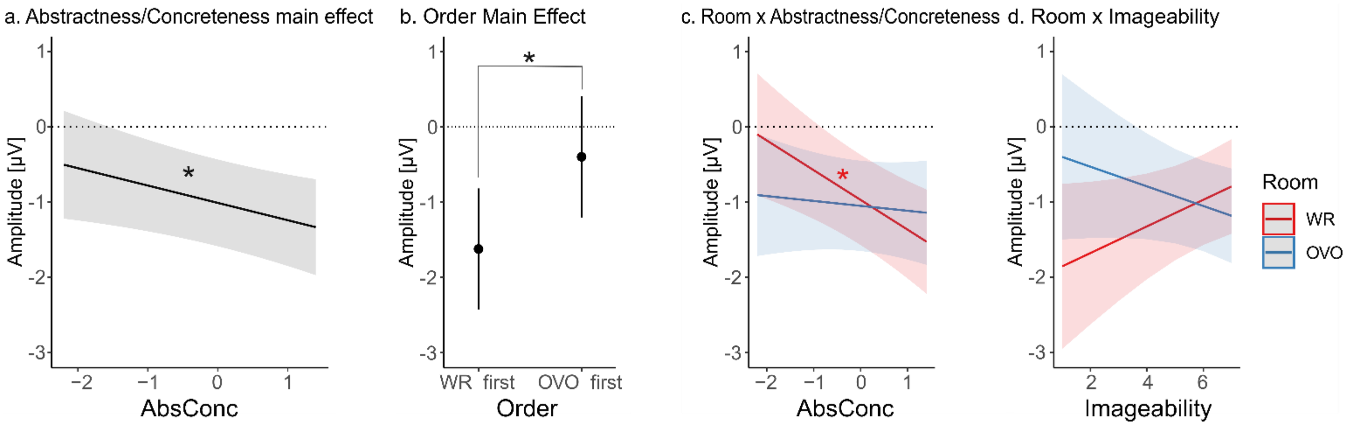

*Figure 14. Plots representing significant main effects and interactions related to the amplitude of N400. AbsConc = Abstractness/Concreteness, WR = White Room, OVO = OVO chamber. * = p < .05.*

3.3.3.2. Late N700-like component related to continuous Abstractness/Concreteness ratings

A significant Room × Abstractness/Concreteness [$\chi^2 = 6.99$, df = 1, $p < .01$] interaction have been found in the late N700-like time window. Post-hoc analysis showed that the slopes describing the N700-like amplitudes in relation to Abstractness/Concreteness for the two rooms were statistically different [$\beta_{White\ Room} = -.07$, $\beta_{OVO} = .43$, df = 1216, t = -2.64, $p < .01$]. Specifically, we observed a strong positive slope associating Abstractness/Concreteness and N700-like amplitude in the OVO chamber, suggesting that concepts rated as more abstract were associated with greater N700-like amplitude, 95% CI [lower = .16, upper = .71], while the slope related to the White Room was not reliably different from zero, 95% CI [lower = -.34, upper = .20] (see Figure 15). All other main effects or interactions in the late N700-like time window were not significant (all $p > .07$).

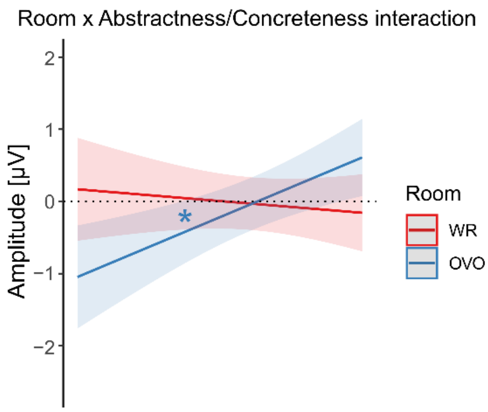

*Figure 15. Plot representing the significant Room x Abstractness/Concreteness interaction related to the amplitude of the late N700-like component. AbsConc = Abstractness/Concreteness, WR = White Room, OVO = OVO chamber. * = p < .05.*

3.3.3. HRV results

No significant differences were found comparing the RMSSD index between the two rooms ($p > .99$). No significant correlations were observed between the RMSSD index and the ΔConcreteness amplitude for what concern the N400 and the N700-like components in any of the two rooms (all $p > .31$).

3.4. Experiment 2 Discussion

The aim of the current study was to explore the effects of being immersed in an altered sensory environment on the electrophysiological correlates of spoken word comprehension. The OVO chamber employed in the current study was designed to promote relaxation and increase saliency of internal states, while stabilizing and reducing the sensory stream coming from the external environment (Ben-Soussan et al., 2019). Considering the postulated importance of interoception, internal states, and related functions (like inner speech and metacognition; Shea, 2018; Borghi et al., 2023) in the processing of Abstract concepts, we hypothesized increased ERP components related to the semantic integration during processing of Abstract words in the OVO chamber, resulting in a reduced difference of N400/N700 amplitude between Abstract and Concrete concepts in the OVO chamber. An alternative concurrent hypothesis was that the reduced salience of exteroceptive stimulation would result in a reduced amplitude in relation to Concrete concepts processing in the OVO chamber. In both hypotheses, a reduction of the difference between ERP's amplitude associated with Abstract and Concrete concepts processing was the main expected result.

A first analysis showed a significant main effect of Concreteness with Concrete concepts showing greater negativity compared to Abstract ones over frontocentral electrodes at 500~550 ms from stimulus onset. This N400 was similar in terms of latency to the one reported by other studies exploring spoken word recognition (Dufour et al., 2013; Winsler et al., 2018). Also, a greater late negative deflection for Abstract concepts compared to Concrete concepts in the OVO chamber in a late time-window ranging from 1700 to 1800 ms post-stimulus onset. Such late centroparietal component appeared to arise at around 1000 ms after stimulus onset and it became significant in a much later time-window. This component resembled the negativity observed in other studies (e.g., Barber et al., 2013; Winsler et al., 2018) even though in a later time window and so we called it late N700-like.

The subsequent analysis adopting linear mixed modeling of multiple continuous variables as factors showed the classical concreteness effect in the N400 time-window appearing both as a main effect (as previously observed) and in interaction with room. In detail, the N400 effect for Abstractness/Concreteness was found only in the White Room while it resulted not significant in the OVO. Similarly, we have found a modulation of the late N700-like activity related to Abstractness/Concreteness variable in the OVO with words close to the Abstract end of the continuum eliciting a larger negativity compared to words on the Concrete pole of the continuum, mirroring what observed in the first analysis.

Interestingly, we further observed a modulation of the N400 in relation to imageability. In detail, we observed a difference between rooms concerning the N400 amplitude in relation to the imageability, as words with low imageability showed a lower N400 in the OVO chamber and a greater N400 in the White Room, while, on the other hand, words with high imageability showed similar amplitudes across rooms (see Figure 3). The effect observed in our study was not particularly robust as the single slopes representing the N400 modulation in each room were not reliably different from a null slope, despite their difference was observed to be significant. However, this was an unexpected result since words with high imageability have been usually reported to elicit a larger N400 compared to words with low imageability (e.g., Nittono et al., 2002; Swaab et al., 2002). At the best of our knowledge, one study reported a result similar to what we observed. Specifically, words with low cohorts (i.e., words whose first syllable make their processing easier as few other words that starts with the same syllable) were found to elicit stronger activation in the left

Superior and Medial Temporal Gyrus during processing of words with low imageability compared to highly imageable words (Zhuang et al., 2011). This effect was associated with the fact that the lower competition associated with the phonological word form reduced the need for a deeper activation of visual imagery for their processing in a lexical decision task. In the current study, we controlled our stimuli for Phonological Neighborhood Density and Phonological Levenstein Distance but not for cohort competition. Further studies are needed to explore whether the other psycholinguistic variables such as the cohort dimension or other measures of ease of processing could affect the direction of the N400 imageability effect in tasks involving spoken word comprehension.

3.4.1. N400 results

In line with our hypothesis, we observed a classic N400 concreteness effect in the white room, while such effect disappeared in the OVO chamber. Specifically, we found a strong reduction of the N400 amplitude for Concrete concepts comparing the two rooms. The flattening of the N400 for Concrete concepts in the OVO could be interpreted in terms of an increased attention on inner states and a contextual reduction of saliency of exteroceptive modality. As previously stated, the N400 is thought to reflect a process of integration of sensorimotor information retrieved to activate meanings during lexical recognition (Kutas and Federmeier, 2000; Chwilla and Kolk, 2005; Barber et al., 2013). The direction of attention towards the external environment is less demanding in terms of attentional effort than directing attention towards internal states to collect interoceptive sensations (Garcia-Cordero et al., 2017). We suggest that the immersion in the OVO chamber promotes effortless internally directed attention, thus increasing the saliency of inner states (e.g., interoceptive sensations, self-generated multimodal imagery, and metacognitive processes). One could argue that increasing the saliency of inner states, including interoceptive sensations, would determine a reversed N400 concreteness effect with Abstract concepts showing greater amplitude over Concrete ones. However, Barber and colleagues observed that the amount of affective and linguistic features did not influence the N400 amplitude, even when other features (e.g., imageability and context availability) were controlled (Barber et al., 2013). This observation was found together with improvements in behavioral performance in processing Abstract words, suggesting that the N400 could reflect a specifically perceptually oriented process of semantic integration which do not capture other semantic dimensions like the activation of situational, affective, and linguistic representation of words meaning. On the other hand, we interpret the observed reduction of N400 for Concrete concepts as a result of attentional disengagement from exteroceptive information which is thought to operate through inhibition of sensorimotor cortices (Cooper et al., 2003; Harmony, 2013). Considering the prevalently sensorimotor nature of the information required to process Concrete words, the disengagement from perception coming from exteroceptive modalities could reduce the saliency of perceptual features retrieval during words processing. This would in turn favor the retrieval of other experiential dimensions overarching the sensorial domain, like complex multimodal situational simulation (Barsalou et al., 2008).

In fact, the reduction of N400 for Concrete concepts in the OVO chamber could be further explained in terms of a mechanism called "cognitive dedifferentiation" (Werner, 1978). Recently, experience of immersion in the OVO chamber has been also associated with altered perceptual experiences, like synesthesia (Pellegrino et al., 2023). The altered sensory environment inside the OVO would promote a state that causes the merging of environmentally gathered and internally generated sensory information in multimodal representations in a process of cognitive dedifferentiation. Cognitive dedifferentiation refers to a state in which one can experience less detailed and blurred perception of time and space, as well as merged perception of: (3) sight and sound (i.e., synaesthetic experience); (4) imagination and apprehension (5) affect and perceptual information and (6) mental and bodily experiences (Werner, 1978). This mechanism could be of particular interest during the elaboration of complex multimodal concepts like Abstract ones and, as observed in our data, reduce the amount of available modality-specific perceptual information required to process Concrete concepts.

3.4.2. Late N700-like negative component results

We observed significant increased late negative N700-like deflection during the processing of Abstract concepts in the OVO chamber, while no differences related to Abstractness/Concreteness were observed in the White Room. The significant difference in the OVO chamber was found specifically in the time-window ranging from 1700 to 1800 milliseconds after words' onset. However, visual inspection of ERPs waveform shown a long-lasting sustained negativity for Abstract that had its onset at around 1000 ms and lasted until the end of the trial suggests an involvement of post-lexical processes of imagery. We can argue that immersion in the OVO would facilitate the emergence of complex multisensory imagery processes following access to words' meaning. Different studies suggested that such a late negative activity would be particularly associated with imagery in the visual domain (Farah et al., 1988; Welcome et al., 2011). The involvement of visual imagery during the processing of Abstract concepts has different implications. As already suggested, this would support the idea that the altered sensory environment could affect how words are processed by suppressing exteroceptive modality-specific saliency and favoring the merging of multimodal information in working memory at a post-lexical stage. However, it is important to note that the participants involved in this study rated some Abstract concepts with very high imageability ratings (e.g., *Happiness*, or *Love*), underlining that imageability and Abstractness/Concreteness reflect different constructs (Dellantonio et al., 2014). Interestingly, the fact that we did not find a modulation of the late N700-like component by Imageability could be furtherly related to the fact multiple regression analysis showed that Imageability ratings were strongly associated with Vision and Touch modalities only, while Abstractness/Concreteness ratings revealed to be associated with Vision and Touch, plus Interoception. Thus, we argue that

Abstractness/Concreteness ratings reflect a complex construct that captures aspects of sensorimotor information that are not captured in other variables, like Imageability.

Most of the Abstract words included in the study represented socially relevant concepts, emotion-laden words, and mental state concepts, all concepts that easily relate to first-person subjective relevant experiences. The increased saliency on internal state operated by the OVO chamber immersion could enhance the saliency of affective information carried by Abstract concepts, thus facilitating the automatic retrieving of personal memories associated with their meaning in a vivid manner. In fact, semantic memory and autobiographical memory are thought to be tightly related (Renoult et al., 2019), and this interpretation is furtherly in line with studies on the effect of emotion-laden stimuli in memory retrieval tasks (Buttafuoco et al., 2018; Ballot et al., 2022).

Noteworthy, we haven't found any significant direct modulation of ERP components in relation to psycholinguistic variables (e.g., Phonological Distance or Phonological Neighborhood Density) or affective components (e.g., Arousal, Valence, or Interoception ratings), as other research evidenced. This could be due to the fact that we used a small set of words aimed at exploring mostly the abstract – concrete distinction. Studies designed to address specific differences related to linguistic and/or emotional dimensions should adopt set of words targeted at exploring these particular aspect (e.g., Imbir et al., 2023), or very large set of words providing a good sampling of the words' psycholinguistic features of interest (Winsler et al., 2018).

3.4.3. Vagal tone and electrophysiological correlates of words comprehension

Another aim of the current study was to observe whether an objective measurement of vagal activity would show differences between rooms and correlations with electrophysiological activity. We did not observe significant differences between the two rooms in terms of RMSSD, nor a correlation of RMSSD with the electrophysiological correlates of Abstract vs Concrete word processing. We suggest that increase of the sample size would be crucial to obtain reliable results in relation to HRV as a well-powered study (80%) designed with medium expected effect size would require at least 61 participants (Quintana, 2017), which is the triple of the current sample.

3.4.4. Novelty of the current study

The results observed in the current study are of particular importance for two main reasons. The first is that results point out that the electrophysiological activity related to Abstract and Concrete concepts processing is both environment- and content-dependent. Environment-dependent features of words processing include bodily states and modulation of attentional resources, while content-dependent features include the source of experiences underlying words' meaning, either sensorimotor, social, affective, or linguistic.

The second particularly important result is that we provided some hints on the possibility to manipulate the interoception-cognition coupling through manipulation of environmental features. Recent scientific efforts have been made in the direction of finding ways to manipulate interoceptive states with the aim of exploring effects on cognition (Weng et al., 2021). However, the proposed interventions aimed at modulating interoception would require voluntary efforts from participants (as in the case of meditative trainings suggested by Weng and colleagues), somatosensory interfaces (Schoeller et al., 2019), or vagal nerve stimulation (Paciorek and Skora, 2020) which could be invasive and/or harmful. The modulation of interoception using specifically designed room, like the OVO chamber involved in the current study, is a non-invasive and effortless methodology that, considering our current results, could be used to explore the relationship between interoception, cognition and emotional experiences.

3.4.5. Limitations and future studies

Different limitations of the current study can be identified. The first limitation is that in order to promote a fully immersive experience in the OVO chamber, participants should theoretically focus on their inner state without the influence of any external stimulation or task performance. However, we were forced to disrupt the experience of absorption in the OVO chamber to provide experimental stimuli. For the same reason, we tested the differences between types of concepts using a very simple and shallow test. In fact, the adoption of a decision task requiring deeper semantic processing would have had a negative impact on the immersion in the experience of the OVO chamber. Future studies could be designed to address the effect of deprivation room on deeper aspects of semantic processing with different paradigms.

Further limitation occurred in the study is that we had to calibrate the number of words and repetitions in order to have a sufficient number of trials in both rooms without making the data collection too exhausting. In fact, the recording in the two rooms had to be done in one single session to avoid the risk of dropout from participants, thus forcing us to reduce the number of trials. The recruitment was particularly challenging partially because of the pandemic ongoing and partially because the OVO chamber could not be moved, thus forcing participants to come to the laboratory which is located far from big cities or universities. This of course affected the sample size, which should be increased to generalize and strengthen the observed results. Also, the adoption of a larger number of words would be of particular importance as it would allow a more fine-grained characterization of the features underlying conceptual processing. A larger set of words would further allow the possibility to explore a reliable identification of subtypes of concepts on the basis of their electrophysiological activity. Given the high inter-participants variability for what concerns the physiological measurements, we suggest that a larger sample size would improve reliability and precision of Heart Rate Variability indexes. Another limitation is that despite our effort to make the two experimental conditions as similar as possible in terms of comfort and posture, the two chairs adopted in each room were different enough to be noted, as reported by a few participants.

Future studies will utilizing a larger cohort of participants will be necessary to collect reliable HRV measurements and deepen the preliminary results shown in the current study. Moreover, it would be interesting to take in consideration the involvement of electrophysiological abnormalities on delta-to-alpha power associated with neurodegenerative diseases such as Alzheimer or Semantic Variant of Fronto Temporal Dementia (Yener et al., 2016; Babiloni et al., 2018; Caso et al., 2012). The exploration of how interventions aimed at integrating bodily states may affect slow frequencies power and, contextually, facilitates retrieval of personally relevant semantic knowledge during language processing could be of particular interest for the design of noninvasive treatments with patients showing impaired access to semantic knowledge and autobiographical memory.

5. Conclusions

In the current experiment, we observed that immersion in the OVO chamber, an altered sensory environment aimed at increasing the saliency of internal states, affected the electrophysiological correlates of Concrete and Abstract concepts. Specifically, we observed a decrease of the N400 associated with concreteness which we interpreted as a reduction of sensorial components gathered to process words' meaning, and a greater late negativity associated with post-lexical imagery processes for Abstract rather than Concrete concepts. The modulations of N400/late N700-like components observed in the current study suggest that increasing the salience of internal states would 1) detach from sensorimotor exteroceptive information, and 2) facilitate the processing of Abstract words by favoring the retrieval of multimodal subjective relevant memories associated with words' meaning. Taken together, our results show that artificial manipulation of bodily states through control of environmental characteristics of the room could open a window on the interoception-cognition coupling with important implications for future research.

4. General Discussion

In the current dissertation, results from two experiments have been shown and discussed. The two experiments revolved around the idea that words processing involves the retrieval of sensorimotor features that constitute the experiential component of conceptual representations, in line with propositions from Embodied Theories of Language (Foglia and Wilson, 2013; Horchak et al., 2014). Both experiments were focused on the differences between Abstract and Concrete concepts in terms of the sensorimotor features involved in their comprehension, with a special focus on interoception. The two experiments have been designed to enlarge current knowledge of how interoception is related to conceptual processing by directly comparing different languages (Experiment 1) and exploring how manipulation of interoceptive experience through immersion in an altered sensory environment could affect conceptual processing (Experiment 2).

In the first experiment, we showed that interoception is particularly important in defining the perceptual contents of Abstract concepts and, to a much lesser extent, Concrete concepts. On the contrary, Concrete concepts are mostly characterized by experiences in exteroceptive modalities (e.g., Vision, Touch, Taste, and Smell in particular). This pattern of Abstractness-Interoception vs Concreteness-Exteroception has been found to be robust across the different languages included in the study, namely Italian, Hebrew, and English. Overall, the current study showed that Perceptual Strength ratings are good predictors of the categorization of concepts as belonging to the Abstract or Concrete category, as well as providing sufficient information to identify subtypes of concepts with good consistency across languages. Furthermore, Interoception ratings were found to predict bodily awareness scores in all languages. On the other hand, empathy and bodily reactivity (which are indexes associated directly or indirectly to regulation of social behavior) were found to be consistently associated with interoception only in the Hebrew native speaker sample, while we observed mixed and less robust associations in the other two languages samples. These results suggest that the information carried by interoception in relation to bodily experiences is important to provide a bodily basis for conceptual representations of Abstract concepts. However, its further involvement in higher order functions (e.g., prosocial behaviors) turned out to be, at least partially, modulated by the linguistic and cultural milieu. These results are in line with what is reported in literature regarding the importance of interoception in embodiment of Abstract concepts and enlarged it by directly comparing for the first time perceptual ratings and implications for prosocial behavior across different languages.

The second experiment showed that being immersed in a sensory deprivation chamber, which is an environment that promotes the saliency of internal states (e.g., interoceptive sensations and internal dialogue) while detaching one's experience from the flow of exteroceptive information, can affect electrophysiological correlates of Concrete and Abstract words comprehension. No study we are aware of explored the processing of words during the immersion in an altered sensory environment designed to artificially manipulate interoceptive states. Main results of the current study showed that the N400 component involved in semantic integration of sensorimotor information was modulated by Abstractness/Concreteness with greater amplitude for Concrete compared to Abstract concepts in the White Room, but, in line with our hypothesis, we observed it to be significantly reduced in the OVO deprivation chamber. On the same line, a late negative component (N700-like), which is associated with imagery and associations of multimodal information in working memory, was found to be larger for Abstract concepts compared to Concrete ones, selectively in the OVO chamber. Taken together, results of Experiment 2 suggest that 1) being immersed in an altered sensory environment that is thought to enhance the saliency in experiencing bodily and internal states could affect conceptual processing reducing the differences in ERP amplitudes between Abstract and Concrete concepts through disengagement of exteroceptive modalities, and that 2) this kind of intervention aimed at increasing saliency of internal states can facilitate the effortless emergence of multimodal imagery processes selectively during processing of Abstract concepts. This study provided further evidence in favor of the active involvement of bodily states in the processing of Abstract concepts.

4.1. Bidirectionality of embodied language processing

The two studies presented in the current dissertation differed in methodology and in the kind of processes subtending comprehension of linguistic materials but shared a common thread: the exploration of the extent to which bodily states are involved in Abstract words' meaning processing. This involvement can be interpreted in terms of the directionality of body-words interaction. In fact, the first experiment was based on a process of retrieval of experiential components in relation to target words. Thus, this specific task was based on a cued retrieval of perceptual features stored in long term semantic memory (Prince et al., 2005). In this case the retrieval of the perceptual components was voluntary, it was cued by word presentation, and it required an active effort from participants.

On the other side, the task we adopted in the second experiment was based on the mere categorization of target words as meaningful words or meaningless pseudowords. Thus, the direct retrieval of semantic information was not part of tasks instruction. Nonetheless, we observed not only electrophysiological modulation of brain activity compatible with the use of multimodal imagery, but participants further reported that the adoption of such imagery processes emerged spontaneously during the lexical decision task. This happened especially in the sensory deprivation room which was consistently reported as an immersive environment in which bodily and internal states were enhanced. This suggests that the retrieval of information from long term memory associated with words' meaning was automatic and effortless, as opposed to the mechanisms required by the task in the first experiment.

Considering these results, we argue that the recollection of semantic information associated with conceptual representations was observed to be important in a bidirectional manner. As it was the core of the presented projects, in this discussion we will focus on bodily sensations and Abstract concepts. In fact, we can think of the mechanism involved in the first experiment as an attribution of interoceptive perceptual experiences to target concepts with a language-to-body mapping direction in which past bodily experiences represent the information gathered and associated to target concepts according to one's experience. In the second experiment the retrieval of Abstract words meaning was facilitate by the altered sensory environment, suggesting a body-to-language mapping in which bodily states favored the emergence of memories and vivid multimodal imagery associated with words meaning, even when this was not necessary for the task. The attentional effort spent to focus on interoceptive or exteroceptive modalities appeared to be a crucial aspect of words processing since directing the attention towards interoceptive sensations has been often reported to be particularly effortful in comparisons to directing attention on exteroception (García-Cordero et al., 2017).

We are constantly immersed in a sensory environment that does not facilitate the focusing on our internal states and we are usually not trained to direct our attention without high attentional costs. With the current results, we suggest that being more focused on our bodily and internal sensations could influence how we process Abstract words meaning and potentially exert positive effects on prosocial behavior and emotional regulation. The influence of bodily states on language processing is important since the mechanisms that are thought to underlie access to words' meanings are prone to flexible adaptation to available attentional resources and engagement of the sensorimotor system, thus making the retrieval of first-person bodily experiences a bidirectional mechanism that affect both the encoding and the retrieval of conceptual representations (see Figure 16).

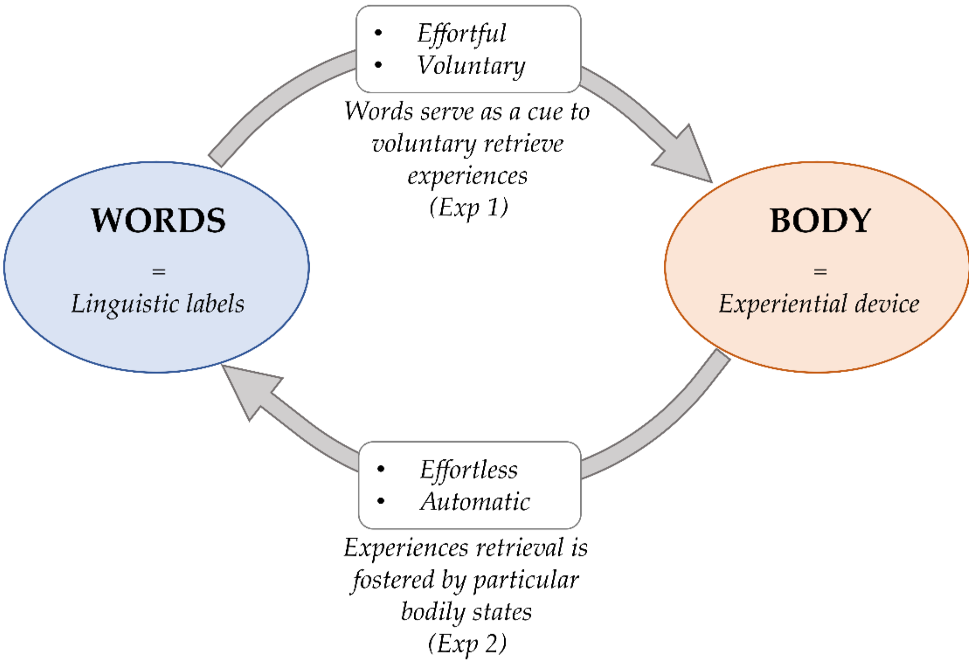

Figure 16. Diagram describing the bidirectional relationship between words and body according to the results of Experiment 1 and 2.

4.2. Abstract-Concrete concepts distinction versus Internal-External situational elements

Taken together, our results also open the discussion on the Abstract-Concrete dichotomic distinction. As observed in the literature review and in our results, relevant experiences for embodiment of Abstract concepts do not just refer to the collection of visceral bodily information from interoception, but it also includes the involvement of other experiential dimensions including emotional and mental states that accompany the experiences that are eventually represented and labeled as Abstract concepts (Buccino et al., 2016). All these experiences are condensed in *situated simulations*, which are neural reactivation aimed at reconstructing past experiences by retrieving traces of perceptual, motor, emotional, social, cognitive, linguistic, and contextual features clustered in multifaceted representations (Barsalou, 2015). We argue that each concept, either ascribable to the Abstract or Concrete typology, can be conceived as a dense situated representation composed by multimodal components having different levels of modality-specificity features according to the salient features characterizing the original associated experience. This formulation of conceptual representation emerged from our data in both experiments: in the first experiment we observed that some subtypes of abstract concepts obtained overall high perceptual ratings beyond the mere interoceptive experience (e.g., concepts like *love*, *nostalgia*, and *happiness* belonging to a cluster characterized by high perceptual features in all languages); and in the second experiment we observed that Abstract concepts were sometimes reported to be imagined in specific situations accompanied by strong vivid sensorial imagery depicting events occurred in real life, especially for those concepts referred to social interactions or with high emotional contents (e.g., *love* or *happiness*).

The results presented here can be interpreted in the light of the Brain As a Situation Processing Architecture proposal (Barsalou et al., 2018), in which conceptual processing would be implemented in networks carrying out two main functions: 1) the processing of situational elements, which represents entities like objects, action, settings, emotions, values, and all those single elements that can be experienced and identifies as single entities; 2) the processing of situational integration, which represents integrative concepts used to associate single situational elements in broader contexts. According to this view, the distinction between Abstract and Concrete concepts in terms of their perceptual components is no longer informative as the most important feature is their functional significance. Barsalou and colleagues further identify two main categories of situational elements, namely elements related to internal experiences and elements related to external experiences. These two categories interact to build complex representations that are imbued with both internal and external experiences. For example, the meaning of the Abstract concept "*happiness*" entails the involvement of internal experiences of motivations, cognitive evaluations, and affection as well as external experiences related to specific places, activities, objects, or agents that can be associated with the experience of *happiness*. The retrieval of relevant experiences defining semantic representations would be recalled in the form of situated simulations of the original experiences in a context- and content-dependent nature.

5. Future studies

Future studies are needed to address the generalization of our conclusions by exploring the effects of directing attention towards internal states enrolling native speakers of languages that showed greater impacts of bodily states on conceptual representations and higher-order functions (e.g., Hebrew native speakers as observed in Experiment 1).

More studies designed to explore the state of sensorimotor cortices through the coupling of event-related synchronization or desynchronization with language-related ERPs would provide a deeper understanding of the mechanisms underlying semantic processes. In fact, some frequency bands are thought to support integration of multimodal information (Von Stein and Sarnthein, 2000; Harmony, 2013) and provide information about the inhibition or excitability of sensorimotor cortices (Neuper et al., 2006), thus potentially carrying interesting information on how modality-specific sensorimotor cortices are recruited in language processing.

Furthermore, we suggest that it could be of particular interest to collect neuroimaging data employing fMRI or high-density electrodes EEG systems to address whether the proposed internal vs external situational elements distinction could be detected adopting a multivariate pattern analysis approach (Grootswagers et al., 2017). In fact, this kind of analysis revealed to be particularly powerful in exploring patterns of activity reflecting distributed semantic representations with good accuracy (see for example Ghio et al., 2018; Alizadeh et al., 2017). These approaches would moreover open the possibility to explore exploration of similarities and differences between different types of representations by adopting Representational Similarity Analysis. In the specific context, we could explore whether pattern of neural activation related to concepts categorized as internal vs external situational elements could show similarities with experiential ratings associated with bodily, social or affective experiences with greater accuracy compared to the Abstract vs Concrete concepts categorization.

Another possible future direction that deserves deeper exploration regards the implications of Heart Rate Variability indexes in revealing objective and direct measures of bodily states in relation to conceptual representations. Our approach was a first step taken in this direction but further studies with increased sample size and the adoption of additional physiological measurements (e.g., respiration sensors or galvanic skin responses) in relation to the processing of different concepts would be a great advance in disentangling the embodiment mechanisms underlying language processing.

Finally, we suggest that adoption of novel approaches aimed at manipulating interoceptive functions and internal states using noninvasive and safe instruments, like for example perceptual deprivation chamber like the one adopted in the current study or body-oriented activities that increases one's attentional focus on bodily states, would be of main interests for the establishment of neuroscientific research endeavors oriented at exploring the complexity of body-brain coupling. Another step that we suggest would be useful in this direction is the adoption of a neurophenomenological perspective that could shed some new lights on the qualitative analysis of first-person experiences reintroducing introspection and subjective appraisals of experiences in scientific inquiries.

6. Conclusions

The results of the studies presented in the current dissertation showed that interoceptive modality is an important experiential source in the embodiment of conceptual representations, with a particular focus on Abstract concepts. In Experiment 1, cross-linguistic comparisons showed that the prominent role for Interoception in Abstract concepts is robust across languages. In Experiment 2, we showed that increasing saliency on interoception and internal states would reduce the differences in electrophysiological correlates of Abstract and Concrete concepts processing. Moreover, Abstract concepts were found to elicit a significantly stronger centroparietal late negativity which reflects post-lexical multimodal imagery, selectively in the perceptual deprivation room. Results from this experiment showed that the state of the sensorimotor system can affect how we retrieve information from long term semantic memory and shed new light on the relationship between bodily states and words comprehension. Results from the two experiments were then discussed in light of the bidirectional relationship between bodily states and language and expanded to the current and possible future formulation of the Abstract vs Concrete concepts distinction.

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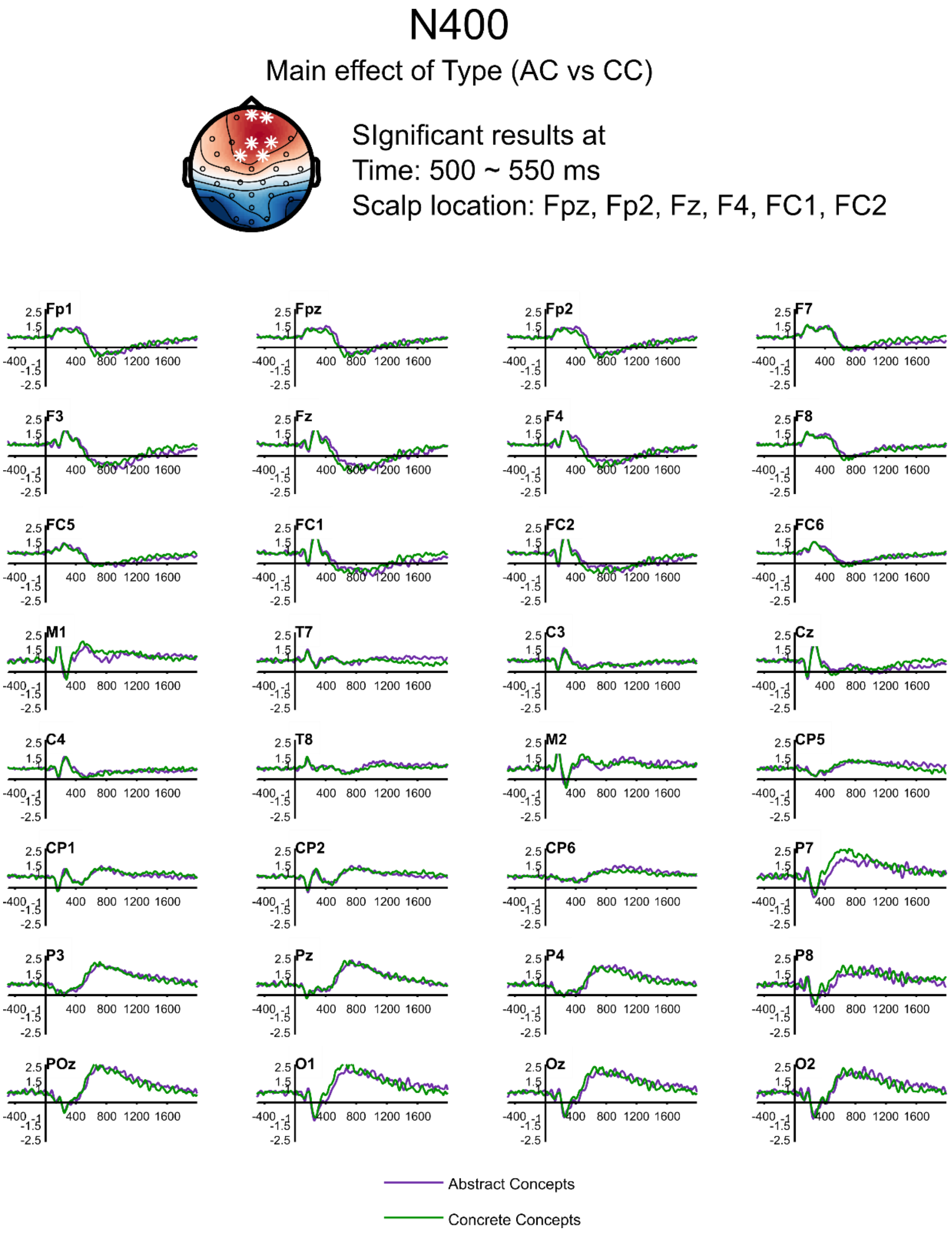
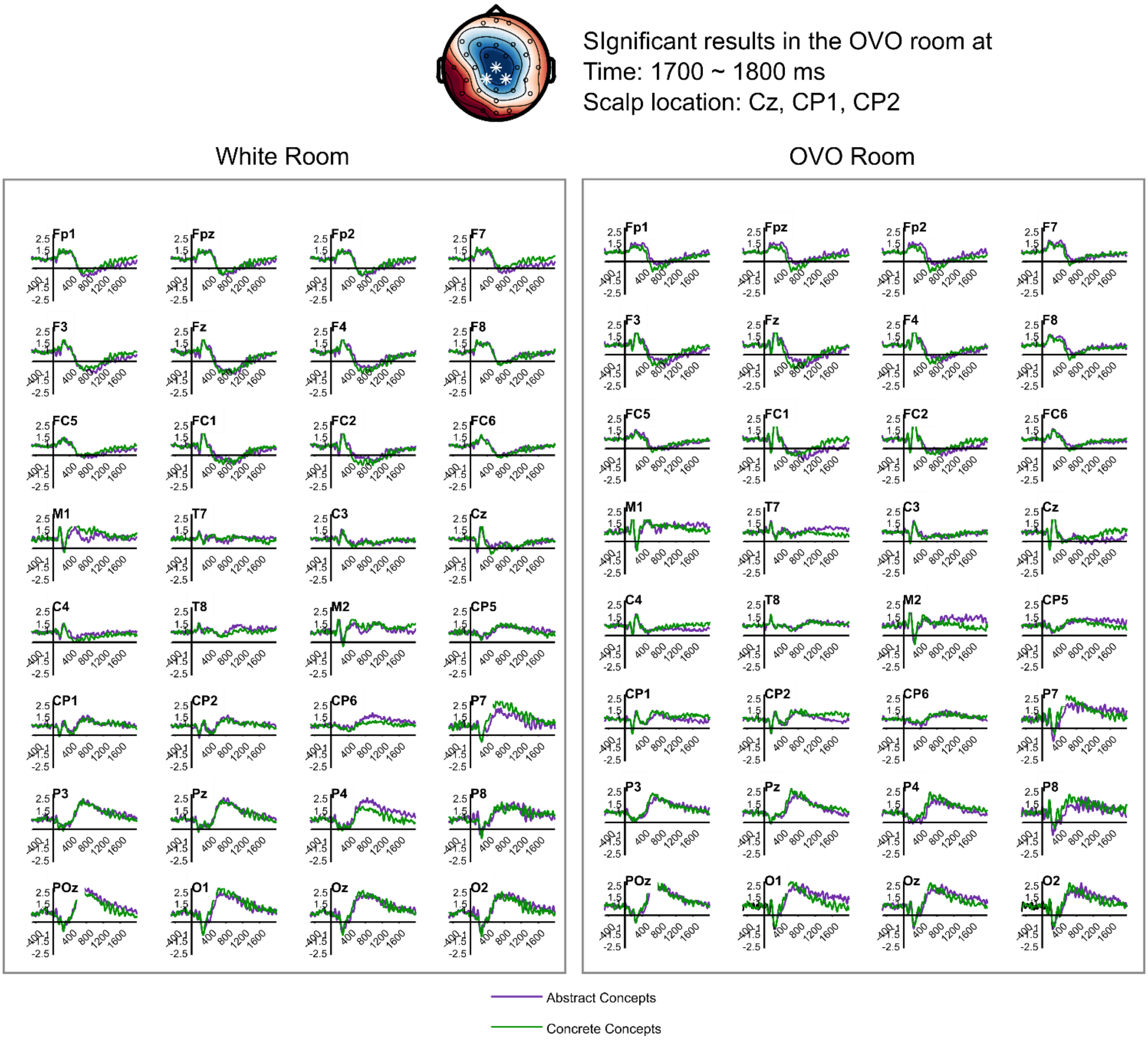
Supplementary Figures



Supplementary Figure1: Plot of time course for Abstract and Concrete concepts in each single channel

N700-like

Type x Room (AC vs CC in OVO room and White Room)



Supplementary Figure 2: Plot of time course for Abstract and Concrete concepts in the White Room (left panel) and the OVO Room (right panel) in each single channel