Sensorimotor and interoceptive dimensions in concrete and abstract concepts

Published Version:
Sensorimotor and interoceptive dimensions in concrete and abstract concepts / Villani C.; Lugli L.; Liuzza M.T.; Nicoletti R.; Borghi A.M.. - In: JOURNAL OF MEMORY AND LANGUAGE. - ISSN 0749-596X. - ELETTRONICO. - 116:(2021), pp. 104173.1-104173.12. [10.1016/j.jml.2020.104173]

Availability:
This version is available at: https://hdl.handle.net/11585/803231 since: 2021-02-22

Published:
DOI: http://doi.org/10.1016/j.jml.2020.104173

(Article begins on next page)

Sensorimotor and Interoceptive dimensions in concrete and abstract concepts

Caterina Villani[a *], Luisa Lugli[a], Marco Tullio Liuzza[b], Roberto Nicoletti [a], Anna M. Borghi[c,d *]

[a] Department of Philosophy and Communication, University of Bologna, via Azzo Gardino, 23, Bologna, 40122, Italy.

[b] Department of Medical and Surgery Sciences, University of Catanzaro, Viale Europa (Loc. Germaneto), Catanzaro, 88100, Italy.

[c] Department of Dynamic and Clinical Psychology, Sapienza University of Rome, Via degli Apuli 1, Roma, 00185, Italy.

[d] Institute of Cognitive Sciences and Technologies, Italian National Research Council.

*Corresponding Authors:

anna.borghi@uniroma1.it (Anna M. Borghi)

caterina.villani6@unibo.it (Caterina Villani)

Abstract

Recent theories propose that abstract concepts, compared to concrete ones, might activate to a larger extent interoceptive, social and linguistic experiences. At the same time, recent research has underlined the importance of investigating how different sub-kinds of abstract concepts are represented. We report a pre-registered experiment, preceded by a pilot study, in which we asked participants to evaluate the difficulty of 3 kinds of concrete concepts (natural objects, tools, and food concepts) and abstract concepts (Philosophical and Spiritual concepts, PS, Physical Space Time and Quantity concepts, PSTQ, and Emotional, Mental State and Social concepts, EMSS). While rating the words, participants were assigned to different conditions designed to interfere with conceptual processing: they were required to squeeze a ball (hand motor system activation), to chew gum (mouth motor system activation), to self-estimate their heartbeats (interoception), and to perform a motor articulatory task (inner speech involvement). In a control condition they simply rated the difficulty of words. A possible interference should result in the increase of the difficulty ratings. Bayesian analyses reveal that, compared to concrete ones, abstract concepts are more grounded in interoceptive experience and concrete concepts less in linguistic experience (mouth motor system involvement), and that the experience on which different kinds of abstract and concrete concepts differs widely . For example, within abstract concepts interoception plays a major role for EMSS and PS concepts, while the ball squeezing condition interferes more for PSTQ concepts, confirming that PSTQ are the most concrete among abstract concepts, and tap into sensorimotor manual experience. Implications of the results for current theories of conceptual representation are discussed.

Keywords: abstract and concrete concepts - mouth motor system - hand motor system – interoception - motor interference – embodied and grounded cognition

Sensorimotor and Interoceptive dimensions in concrete and abstract concepts

Introduction

Categorizing objects and entities in the physical and social environment is fundamental for the survival of our species: categorization helps us to collect information on the world and to simplify its structure forming categories that include similar members, to predict what behavior to expect from different objects/entities, to anticipate how to interact with them etc. Concepts, i.e., the “glue” that link our past, present and future experience (Murphy, 2002), have been broadly distinguished into two main groups, i.e., concrete and abstract ones (e.g. “table” vs. “cause”). Here we do not assume a marked distinction between concrete and abstract concepts (Barsalou et al., 2018); concrete and abstract concepts can be seen more as points in a multidimensional space, the sub-kinds of which can be quite distant from each other (Crutch et al., 2013; Villani, Lugli, Liuzza & Borghi, 2019).

Compared to concrete concepts, abstract concepts have more heterogeneous members and do not possess a single object/entity as referent; they are also more detached from perceptual modalities (Barsalou, 2003), more variable both within and across participants (Borghi & Barsalou, 2014) and more flexible, since they vary more across contexts and situations (Falandays & Spievey, 2019). Previous works revealed higher contextual flexibility for abstract than concrete concepts. For example, Hoffman and colleagues (2013) found substantial variation across words in semantic diversity (*SemD*), which measures the degree of context-dependent variability in word meaning. Concrete concepts appeared in a restricted, inter-related set of contexts and consequently had low semantic diversity values; while abstract concepts tend to be used in a broad range of contexts and consequently showed high values in semantic diversity (see also Hoffman et al., 2016).

According to recent Multiple Representation Views, abstract concepts activate the sensorimotor system but also the emotional dimension (e.g. Newcombe et al., 2012; Kousta et al., 2011; Vigliocco et al., 2014), and the linguistic and social one (Borghi et al., 2019a; Dove, 2019; Glenberg, 2019). Here we focus on the WAT (Words As social Tools) theory (Borghi & Cimatti, 2009; Borghi &

Binkofski, 2014; Borghi et al., 2018a, 2019a, 2019b), according to which abstract concepts are not only grounded in sensorimotor experience, similarly to concrete concepts, but activate linguistic, social and interoceptive experiences to a larger extent than concrete concepts. The WAT view proposes that the activation of linguistic and social experience during processing and use of abstract concepts might be due to different reasons. These reasons are not incompatible, and they all stem from the basic consideration that abstract concepts are more complex than concrete ones. We consider abstract concepts as more complex than concrete ones for a variety of reasons. First, they generally do not have a single object as referent, as concrete concepts, but refer to more complex scenes and elements. For example, the abstract concept of "cause" involves an agent, a patient, an action (Pulvermüller, 2018). Second, they are more complex to learn because their members are more heterogeneous and different than those of concrete concepts - justice situations are certainly more diverse from each other than different tables. This complexity has a behavioral effect, i.e. the widely replicated concreteness effect (e.g. Paivio, 1990). Abstract concepts require generally longer times to be processed, and are recalled less accurately than concrete concept.

The first reason for the importance of the social and linguistic dimension for abstract concepts is their particular acquisition modality: linguistic inputs offered by others are crucial in order to keep together the variety of heterogeneous events and situations that characterize abstract concepts (labels as glue of heterogeneous experiences) (Lupyan, 2019). During abstract concept~~s~~ processing participants might re-enact such verbal linguistic acquisition experience. Even if further research should clarify this, this mechanism might be present also when words are in the written modality, influential especially for learning low-frequency abstract words. Indeed, evidence suggests (e.g. Topolinski & Strack, 2009) that during reading we simulate the motor responses associated with verbal stimuli. The second reason and the third reason stem from the feeling of uncertainty and the metacognitive awareness that our knowledge of abstract concepts is scarce and inadequate (see Borghi, Fini & Tummolini, under review). This awareness might lead to two different outcomes. The first is the need to rehearse and re-explain to ourselves the word meaning, possibly through inner speech. The second is the preparation to ask information to competent others (social metacognition; Borghi et al., 2018a; see also Shea, 2018; Prinz, 2014). Importantly, all these mechanisms might not only lead to the activation of linguistic and social networks, but also engage the mouth motor system more than processing of concrete concepts does. In line with an embodied account, we namely hypothesize that using both overt and inner speech implies a motor simulation that involves the mouth motor system (Topolinski & Strack, 2009; Alderson-Day, B., & Fernyhough, 2015). Consistently, a variety of studies have demonstrated that the mouth motor system is involved to a larger extent during abstract than during concrete concepts processing (review in Borghi et al., 2019a), and in particular during processing of mental states abstract concepts (Dreyer & Pulvermüller, 2018; Ghio et al., 2013). Furthermore, it is possible that "concrete" concepts may be more readily referenced through non-verbal/non-linguistic means e.g., deictic gestures, as they more likely refer to physical objects in space, while "abstract" concepts may need to be supplemented by other communicative tools (such as inner speech).

An important development in recent literature on abstract concepts relates to the recognition that they are not a unitary whole, but that subtypes of abstract concepts exist (Desai et al., 2018; Fischer & Shaki, 2018; Fingerhut & Prinz, 2018; Villani et al., 2019). In the domain of concrete concepts, instead, much research on sub-kinds of concepts has been conducted. Neuropsychological and brain imaging studies have focused in particular on the double dissociation between living and non-living entities and on their different neural representation (Warrington & Shallice, 1984; review: Forde & Humphreys, 2005), behavioral studies have investigated the roughly correspondent distinction between artifacts and natural objects and on how it develops in children (Keil, 1989). In the last few years there is growing interest for concepts such as food, that is for concepts that are neither artifact nor natural but that can be both depending on the circumstances (Rumiati & Foroni, 2016).

Our study aims to investigate the fine-grained differences in the representation of abstract and concrete concepts and to identify possible sub-kinds of both kinds of concepts. Building on previous studies (see below), we decided to use the same rating task: in the Pilot study, we asked participants to rate the difficulty and the pleasantness of different abstract words; in the Experiment, we asked participants to rate the difficulty of both concrete and abstract words. Crucially, participants were assigned to different conditions that were supposed to interfere with a specific kind of concept, thus to increase the perceived difficulty of specific kinds of words.

Pilot study

The current study builds on the method of a previous study in preparation (Borghi & Lugli, in prep; Lugli & Borghi 2017) and for the selection of materials on a recently published norming study (Villani et al., 2019).

In the study by Borghi and Lugli participants of different groups were asked to rate the degree of pleasantness and difficulty of concrete and abstract concepts while performing a concurrent task. Participants were told that their evaluations would be used to contribute to select the verbal stimuli for an experiment, and were asked to what extent they perceived the presented words as difficult and pleasant, without any further specification. We chose to avoid orienting participants toward a specific meaning of difficulty, and to use the common sense of the word. However, we think that the cover story leads them to interpret difficulty in terms of "difficulty in processing". Participants were assigned to 3 different conditions: in the ball condition they had to rhythmically squeeze a ball, in the gum condition to rhythmically chew gum, and in the candy condition to suck a candy. These conditions were designed to verify whether actively moving the mouth interfered with abstract concepts processing, and actively manipulating a ball with processing of concrete concepts. The candy condition was intended as a control one. A higher processing difficulty should lead to an increase in rated difficulty and a decrease in rated pleasantness.

The rationale of our pilot experiment builds on this previous work, but with two important differences. First, we intended to test not only the effect of the mouth active movement (gum chewing) and of the hand active movement (ball squeezing) on difficulty and pleasantness ratings, but also the effects of interoceptive experience (Connell et al., 2018; Borghi et al., 2019a) and of social experience (Borghi & Cimatti, 2009; Borghi & Binkofski, 2014; Borghi et al., 2018a, 2019a) on abstract concepts processing. Hence, in the Pilot study we added to the gum and to the ball condition two further conditions, i.e., the interoceptive condition, in which participants were asked to hold an instant cold or warm pack, and the social condition, in which they were required to hold the hand of a confederate. Second, the main aim of the Pilot study was not to identify differences between abstract and concrete concepts, but more subtle differences within abstract concepts. To identify sub-kinds of abstract concepts, we relied on the study by Villani et al. (2019). In this norming study participants were asked to evaluate 425 Italian abstract words on 15 dimensions (i.e., Abstractness, Concreteness, Imageability, Context availability, Body-Object-Interaction, Modality of Acquisition, Age of Acquisition, Perceptual modality strength, Metacognition, Social metacognition, Interoception, Emotionality, Social valence, Hand and Mouth activation). We then performed a cluster analysis that led to the identification of 4 clusters of abstract concepts, i.e., Philosophical and Spiritual concepts (PS) (e.g., value, belief), Emotional and Mental State concepts (EMS) (e.g., anger), Social and Self concepts (SS) (e.g., kindness) and Physical Space Time and Quantity (PSTQ) (e.g., reflex, sum). PS concepts were more abstract than the others, i.e., acquired late (e.g. Kuperman et al., 2012) and through language, and more characterized by the tendency to ask the meaning to others (social metacognition), PSTQ concepts were more concrete, i.e., more imageable, more characterized by bodily interactions with the environment. SS and EMS were more characterized by inner grounding, i.e. interoception and emotional valence and metacognition, and by sensorimotor properties (taste, smell, etc.). Further details of four kinds of abstract concepts and their cluster distributions can be found at https://osf.io/4bztv/. As in the previous study by Borghi and Lugli (in prep.), participants were required to perform pleasantness and difficulty judgments on a 5-point scale. Both scores and response times were recorded. The reason why we choose to use pleasantness and difficulty ratings is due to the fact that, in the literature, a relationship has been found between abstraction and disfluency, and concreteness and fluency (Alter & Hoppeneyer, 2008, but see one experiment for a failure to replicate). Increased fluency augments preference for a given stimulus (Winkielman et al., 2003). For example, the increased fluency of pronunciation simulation, owing to the exposure, leads to an increase of word pleasantness (Topolinski & Strack, 2009).

Participants were assigned to 4 different conditions: ball condition (they were asked to rhythmically squeeze a softball), interoceptive condition (they were asked to hold an instant cold or warm pack); social condition (they were asked to hold the hand of a confederate); gum condition (they had to rhythmically chew gum). We predicted that judgments of difficulty would increase in the ball condition more with the more concrete PSTQ concepts than with the other abstract concepts, that the interoceptive condition would lead to an increase of difficulty and a decrease of pleasantness ratings especially with EMS and SS concepts, which are more directly related to social and emotional aspects, that the social condition would lead to an interference mostly with SS concepts, and that the gum condition would interfere mostly with judgements produced in the most abstract PS concepts.

Method

Participants

129 students (102 female, 18 left-handed; M_{age} = 24.2, SD_{age} = 3.7) of the University of Bologna participated voluntarily. All participants were recruited among the students of a Psycholinguistic course. They were randomly assigned to the four conditions, resulting in 30 participants for ball condition, 39 for interoceptive condition, 26 for social condition and 34 for gum condition. All participants assigned to each condition were tested together in a room equipped with computers.

Materials

60 concepts taken from the previously identified four clusters were selected. We considered the most representative words for each cluster (i.e., the ones with the smallest distance from the centroid; mean distance = 2.44, max. 6.75; min. 0.72) and selected them for their value of Abstractness in a range from 1 (less abstract) to 7 (more abstract). Of 60 concepts, 13 were selected from PSTQ cluster

(Mean= 2.72, SD = 0.58), 21 from PS cluster (Mean = 4.96, SD = 0.97), 11 from SS cluster (Mean = 4, SD = 0.78) and 15 from EMS cluster (Mean = 4.29, SD = 0.65).

Procedure

Participants were asked to evaluate on a 5-point Likert scale the difficulty ranging from 1 = "very easy" to 5 = "very difficult" and the pleasantness ranging from 1 = "very unpleasant" to 5 = "very pleasant" of each word presented.

Each participant was instructed to provide both difficulty and pleasantness ratings in different blocks; the order of the blocks was counterbalanced across participants. During the evaluation, they had to perform a concurrent task. They were randomly assigned to four different conditions: gum chewing (they were asked to chew gum following the rhythm of a metronome) (Topolinski & Strack, 2009; Topolinski et al., 2014), interoceptive (they were asked to hold an instant cold or warm pack, that kept the temperature until the end of the task), social condition (they were asked to hold the hand of a confederate), ball squeezing (they were required to manipulate a softball following the rhythm of a metronome). The order to the trials was fully randomized, with the exception to not repeat the same word twice in succession.

Data analysis and results

Because of the ordinal nature of the dependent variable (responses on a Likert-type format), we conducted our analyses using Cumulative link mixed models (logit link function) using the clmm function from the ordinal (Christensen, 2018) R library. We modeled participants and words as random intercepts in order to account for the dependence among observations. Ideally, we should have modeled random slopes for each participant and word in order to better control for the Type I error (Barr et al., 2013), but it led to severe convergence issues. RTs were added as a predictor in the model in order to control for the effect of speed on the pleasantness and difficulty judgments. A Model comparison through Likelihood Ratio Tests was conducted in order to test the overall effects of the Condition, the Cluster, and their interaction.

We did not find any statistically significant effect for either the Condition, the Cluster or their interaction on pleasantness ratings (see Table 1). When analyzing difficulty ratings, we did find a main effect of the cluster (see Table 2). In fact, PS words were more likely to be rated as less difficult as compared to words belonging to other clusters. We did not find any other statistically significant effect for either the Condition or for the Condition x Cluster interaction.

We expected to observe that the interference in the gum chewing condition should be stronger for PS abstract concepts, because of their high level of abstractness. However, the planned contrast on interaction between cluster PS and Condition (gum vs. social, interoceptive and ball in PS clusters > gum vs. social, interoceptive and ball in other clusters) was not significant (p = .93).

Table 1. Model comparison of the effects on pleasantness ratings. The table reports a Likelihood ratio test between models where a predictor at time was entered. AIC = Akaike Information Criterion. No.par = number of parameters of the model.

Predictors	**No.par**	**AIC**	**logLik**	**LR.stat**	**df**	**Pr(>Chisq)**
RT	7	16981	-8483	4.37	1	0.037
Condition	10	16984	-8482	2.41	3	0.492
Cluster	13	16989	-8482	1.34	3	0.721
Condition x Cluster	22	17000	-8478	7.03	9	0.634

Table 2. Model comparison of the effects on difficulty ratings. The table reports a Likelihood ratio test between models where a predictor at time was entered. AIC = Akaike Information Criterion. No.par = number of parameters of the model.

Predictors	No.par	AIC	logLik	LR.stat	df	Pr(>Chisq)
RT	7	16980	-8483	20.70	1	< .001
Condition	10	16982	-8481	3.67	3	.300
Cluster	13	16964	-8469	23.61	3	< .001
Condition x Cluster	22	16968	-8462	14.08	9	.120

Experiment

Potential problems of the Pilot study were that we had limited ourselves to consider sub-kinds of abstract concepts, and concrete words were not introduced. In addition, the social manipulation might have not been successful because touching someone you do not know could render it very difficult to concentrate on the experiment. Finally, in three of four manipulated conditions participants were asked to use their hand – this might have reduced the differences between the conditions.

The present pre-registered Experiment was designed to overcome these limitations. We confined ourselves to difficulty rating, for which the results of the previous study were more clear-cut. We selected three kinds of concrete and abstract concepts, controlled the materials, and modified two of the four conditions. The conditions to which participants were randomly assigned were: ball squeezing, gum chewing, heart beating, and articulatory suppression. For the heart beating condition we asked participants to estimate their heart beat pace and at the end of the task to report if they had noticed any change; self-estimation of heart beating within a given time is a task often used to measure interoceptive awareness (Schandry, 1981; Garfinkel et al., 2015). In order to test whether processing of abstract concepts does not only involve the mouth but implies use of inner speech, we introduced an articulatory suppression condition, since AS is often used to test involvement of inner speech (Alderson-Day & Fernyhough, 2015). In the articulatory suppression condition participants were required to rhythmically pronounce the syllable “ba ba ba”. Finally, we introduced a control condition, in which participants were asked to evaluate the difficulty of the words without performing any additional task. The control condition was introduced primarily because the conditions might differ in terms of executive demands. Conditions that capture more attention could more easily lead to interference, while conditions that involve low processing load might not affect the results (Connell & Lynott, 2012). We introduced the control condition also to better understand whether an interference or a facilitation occurred with respect to the baseline. It is worth noting that the control condition was not present in the original design and in the preregistration; we introduced it because the reviewers asked for it. Differently from the other conditions, in the control condition participants were tested online, since the lock-down due to the spread of COVID-19 did not allow us to test participants in the lab.

Hypotheses

Hypothesis 1 (directional). Ball squeezing condition: if processing of more concrete concepts, and particularly of tools, involves to a larger extent the manual motor system, i) we predicted that this condition would interfere more with concrete than with abstract concepts, thus increasing the rated difficulty of the concrete concepts, compared to the other conditions. ii) The interference effect should be particularly strong for tools, increasing their perceived difficulty, and then for food items. iii) Within abstract concepts, we intended to explore whether the ball squeezing condition would create more interference with the more concrete among the abstract concepts, i.e., PSTQ.

Hypothesis 2 (directional). Gum chewing condition: if processing of abstract concepts activates the mouth motor system to a larger extent than processing of concrete concepts, then i) we predicted that the gum chewing condition would interfere more with abstract concepts than with concrete concepts of animals and tools, leading to an increase in difficulty of more abstract compared to more concrete concepts. Within concrete concepts ii) we predicted that gum chewing would modulate the food items to a larger extent, either determining a decrease or increase of difficulty (facilitation or interference), because of the relationship between food items and mouth motor system.

Hypothesis 3 (directional). Articulatory suppression condition: if processing of abstract concepts not only activates the mouth motor system but specifically involves inner speech, then i) we predicted that the articulatory suppression condition would interfere more with abstract concepts than with concrete concepts, increasing the perceived difficulty of the first with respect to the second, and in particular ii) for the more abstract concepts, i.e., PS.

Hypothesis 4 (directional). Heart beating condition: if processing of abstract concepts not only activates the mouth motor system but also the interoceptive dimension to a larger extent than processing of concrete concepts, then i) we predicted that the heart beating condition would interfere more with abstract concepts than with concrete concepts, increasing the difficulty of the first and reducing that of the second. This should occur in particular with abstract concepts that involve more the emotional and social dimension, i.e., with EMSS (see results by Connell et al., 2018, showing that interoception characterized primarily emotional concepts). Within concrete concepts, ii) we intended to explore whether the heart beating condition would create more interference with the concepts of animals, because of their animacy.

Method

Material selection.

The words were selected from both the database by Della Rosa et al. (2010) and our database (Villani et al., 2019). More specifically, the selection of concrete words was completely based on the database of Della Rosa et al. (2010). Concrete words included 10 natural objects (animals, e.g., lion, camel), 10 manipulable artifacts (tools, e.g., hammer, broom) and 10 food items (e.g., carrot, eggplant)

Concrete stimuli are shown in Table 3. We selected these three categories because these can be considered almost exhaustive of the categorical space and are used in the majority of studies on concrete concepts. Since the seminal work by Warrington and Shallice (1984), many studies on concrete concepts have focused on the distinction between artifacts and natural objects (for a review on the living/nonliving double dissociation see Forde & Humphreys, 2002). Recent studies are targeted at investigating the specificity of food concepts, which possess a special status since they are neither natural nor artifact objects (Rumiati & Foroni, 2016). Within artifacts, we focused on tools, more likely to activate the hand motor system (see Martin, 2007, for a review).

Abstract words were selected taking into consideration the two databases. Abstract words included words present in Della Rosa et al. (2010) but were selected by means of the clusters that emerged in the study by Villani et al. (2019): 10 words were selected from the cluster Philosophical and Spiritual concepts (PS, e.g., destiny, morality), 10 from the cluster Physical Space Time and Quantity (PSTQ, e.g., number, acceleration). Because the differentiation between Emotional and Mental State concepts (EMS, e.g., shame) and Social and Self concepts (SS, e.g., calm) was not clear cut, we decided to collapse the two clusters and selected 10 words from them (5 for each cluster). Abstract stimuli are shown in Table 4. Importantly, the different sub-groups of concrete and abstract words did not differ across main psycholinguistic dimensions, including the number of syllables, familiarity, absolute and relative frequency. Further characteristics of the selected concrete and abstract words in terms of dimensions and psycholinguistic variables are available in an online repository as Supplementary Materials (https://osf.io/ypx7s/).

Table 3. Selected concrete words from Della Rosa et al. (2010) database. Frequency values for each word were determined by CoLFIS, a lexical database of written Italian (Bertinetto et al., 2005).

Italian word	English word	Frequency value	Numbers of letters	Frequency absolute mean	N Letters mean
Banana	Banana	24	6		
Carota	Carrot	41	6		
Uva	Grapes	26	3		
Fragola	Strawberry	30	7		
Fungo	Mushroom	38	5		
Melanzana	Eggplant	13	9		
Peperone	Pepper	27	8		
Pomodoro	Tomato	88	8		
Torta	Cake	67	5		
Zucca	Pumpkin	33	5	*Concrete Food* = 38.7	6.2
Lampada	Lamp	76	7		
Martello	Hammer	26	8		
Scopa	Broom	12	5		
Bottiglia	Bottle	122	9		
Coltello	Knife	117	8		
Trapano	Drill	9	7		
Ombrello	Umbrella	31	8		
Forchetta	Fork	25	9		
Matita	Pencil	45	6		
Pennello	Brush	29	8	*Concrete Tool* = 49.2	7.5
Cane	Dog	328	4		
Leone	Lion	78	5		
Maiale	Pig	40	6		
Cammello	Camel	15	8		
Pecora	Sheep	56	6		
Mucca	Cow	12	5		
Piccione	Pigeon	19	8		
Gallina	Chicken	32	7		
Pappagallo	Parrott	12	10		
Insetto	Insect	76	7	*Concrete Animal* = 66.8	6.6

Table 4. Selected abstract words from Della Rosa et al. (2010) and Villani et al. (2019) database. Frequency values for each word were determined by CoLFIS, a lexical database of written Italian (Bertinetto et al., 2005).

Italian word	English word	Frequency value	Numbers of letters	Frequency absolute mean	N Letters mean
Accelerazione	Acceleration	29	13		
Inizio	Beginning	453	6		
Schema	Scheme	116	6		

Area	Area	483	4		
Numero	Number	1196	6		
Risultato	Results	902	9		
Punizione	Punishment	76	9		
Rimedio	Remedy	71	7		
Sforzo	Attempt	258	6		
Denaro	Money	337	6	*Abstract PSTQ* = 392.1	7.2
Morale	Moral	85	6		
Descrizione	Description	66	11		
Motivo	Motive	602	6		
Salvezza	Salvation	85	8		
Destino	Fate	266	7		
Paradiso	Paradise	92	8		
Enigma	Enigma	20	6		
Peccato	Pity	178	7		
Giudizio	Judgement	371	8		
Logica	Logic	117	6	*Abstract PS* = 188.2	7.3
Calma	Calm	110	5		
Gioia	Joy	235	5		
Amicizia	Friendship	212	8		
Conflitto	Conflict	186	9		
Gentilezza	Kindness	25	10		
Vendetta	Revenge	112	8		
Ansia	Anxiety	137	5		
Vergogna	Shame	101	8		
Simpatia	Liking	132	8		
Paura	Fear	698	5	*Abstract EMSS* = 194.8	7.1

Sample size rationale

We conducted a power analysis through the pwr package in R (Champley, 2018). In order to achieve a power of 80% with a critical alpha of .05 divided by the number of unpaired t-tests (.05/9 = .0055) that would allow us to test our pre-registered hypotheses, and assuming a medium effect size (Cohen's D = 0.5) (Cohen, 1988), and having a directional hypothesis we would need 93 participants per group (total N = 372). Since it would have been unfeasible to achieve that number due to objective constraints (N = 120 students enrolled in the class, and a time limited to one month), we decided to determine an effect size as the minimum amount of observations needed to have a relatively stable estimate. Based on Green (1991)'s rule of thumb for determining the smallest sample size, we would need 104 + k (where k is the number of predictors, i.e., number of groups -1 = 3). Therefore, any sample size greater than 107 would be enough to avoid overfitting.

However, since inferences based on the Null Hypothesis Significance Testing are problematic without adequately controlling for the Type I and Type II error at the same time (Dienes, 2008), we used a Bayesian approach, instead. The sample size consisted of around 100-120 participants (25-30 per condition).

Participants

130 students participated (108 female, 14 left-handed; M_{age} = 24 SD_{age} = 2.5). Participants were volunteers recruited among the students of a Psycholinguistic course; they were students of the first or second year of the Master's degree in Semiotics, Philosophy, Italian Studies, Language and Communication. Each participant was randomly assigned to one of the five groups (gum chewing, articulatory suppression, heart beating, ball squeezing, control), resulting in 26 participants for each group. All participants were tested together in a room equipped with computers, except for participants in control condition who were tested online.

Procedure

Participants were asked to evaluate the difficulty of the stimuli using a 5-point Likert scale where 1 corresponded to "very easy" and 5 to "very difficult". During the evaluation they have to perform a concurrent task depending on the condition to which they were assigned: they were asked to chew gum following the rhythm of a metronome (gum chewing), to rhythmically pronounce the syllable "ba ba ba"(articulatory suppression), to estimate their heart beat pace and in the end of the task report if they have noticed any change (heart beating), to manipulate a softball following the rhythm of a metronome (ball squeezing). In the control condition no concurrent task was introduced. In all conditions, the full list of stimuli was presented twice resulting in a total of 120 words. The order to the trials was fully randomized, with the exception to not repeat the same word twice in succession.

Data analysis

A detailed pre-registered analytic plan can be found on the Open Science Framework repository at the following link: https://osf.io/3qu7t Notice that some of the data were collected prior to pre-registration, even if we have not performed any kind of analysis on them.

We measured the evaluations provided on a 5-point scale; we also measured the response times required to respond and consider them as a covariate. Predictors: Modality of Acquisition (MoA, Wauters, 2003), abstractness and concreteness.

Given the clustered nature of our design (word categories were manipulated within participants) and to minimize any loss of information, we decided to analyze our data through a multilevel model (also known as mixed models, Pinheiro & Bates, 2000). In this way, we took into account participants and words as sources of variation. To this purpose, we modeled participants' and words' intercepts as random effects (i.e. (1|participant) and (1|word) in Wilkinson notation). Although it is recommended to keep the random structure maximal (Barr *et al.*, 2013), adding the random slopes led to convergence issues, thus we decided to model only the random intercepts.

Furthermore, Liddle and Kruschke (2018) have recently demonstrated that treating a response measured at an ordinal level of measurement (e.g., Likert response format) like a variable measured at an interval level can lead to false alarms, misses, and even inversions. For this reason, we followed the recommendations from Buerkner and Vuorre (2019), and modeled our responses within an ordinal model, using a cumulative model with a probit or a logit link function. To decide which link function had better predictive accuracy, we fitted them both and selected the best fitting model in terms of the Watanabe-Akaike information criterion (WAIC; Watanabe, 2010).

In the first model we tested whether the difficulty ratings were affected by the interaction between the sub-kinds of concepts and the experimental conditions. We set participant-level and word-level random intercepts in order to account for non-independence among our observations.
Furthermore, we conducted our analyses within a Bayesian framework, as it provides more flexibility for parameter estimation, and allows us to make claims on the relative evidence in favor of a hypothesis (e.g., H1) compared to another (e.g., H0, Wagenmakers, 2007).

The analysis was conducted in the Bayesian framework provided by the brms (Bayesian regression models using 'Stan') library (Bürkner, 2017, 2018) in R. All the models were fit using three different priors on the coefficients, to assess the sensitivity of the analysis: uninformative (flat prior, default in brms), weakly informative (normal distribution centered on zero and with a standard deviation of 5), or a narrower prior (normal distribution centered on zero and with a standard deviation of 1).

Our hypotheses were tested through the "hypothesis" function on brms, which assesses the relative strength of evidence in favor of competitive hypotheses using the Savage-Dickey density ratio method, which compares the plausibility of a hypothesis (e.g., the null hypothesis "abstracts = concrete" under the prior *vs*. under the posterior probability distribution). Bayes factors were reported following the convention of reporting the hypothesis tested as a subscript: BF_{10} stands for relative evidence for the alternative (H_1) vs. the null (H_0), whereas BF01 stands for relative evidence for the alternative (H_0) vs. null (H_1). We also sampled from the posterior distribution for computing the posterior probability (PP) of the alternative, directional, hypothesis. We chose the best fitting link function using the WAIC (the least the best).

We interpreted the relative strength of evidence using the labels provided by Jeffreys (1961, revised by Lee and Wagenmakers,2013). Furthermore, checking the inclusion of zero within the 95% posterior credible intervals were used as additional information about the plausibility of the null hypothesis (and/or estimates of practical irrelevance) given the data.

Since Bayesian Multilevel models are relatively robust to outliers (Nezlek, 2011), especially with a relatively narrow priors as the ones used in our analysis, we did not exclude outliers. We excluded data that was incorrectly entered (e.g., age > 99, Likert scale response > 5, etc.). Missing data were dealt with using a pairwise deletion.

Results

We fit two models containing only the intercepts (fixed and random), changing only the link function for the ordinal cumulative model (logit vs. probit). We found that the ordinal cumulative model with the logit (WAIC = 29266.7) link function outperformed the ordinal cumulative model with the probit link function (WAIC = 29266.7, ΔWAIC = 7.9). We therefore used an ordinal cumulative model with the logit link function for all the following analyses (Table 5).

In the first model we modeled the variables just in terms of abstract vs. concrete words and of experimental conditions (Figure 1). The estimates for the model with uninformative and flat priors appeared to lead to similar results, but the narrow priors lead to somewhat more conservative estimates – unsurprisingly. Therefore, we reported the results when placing a narrow prior on the parameters.

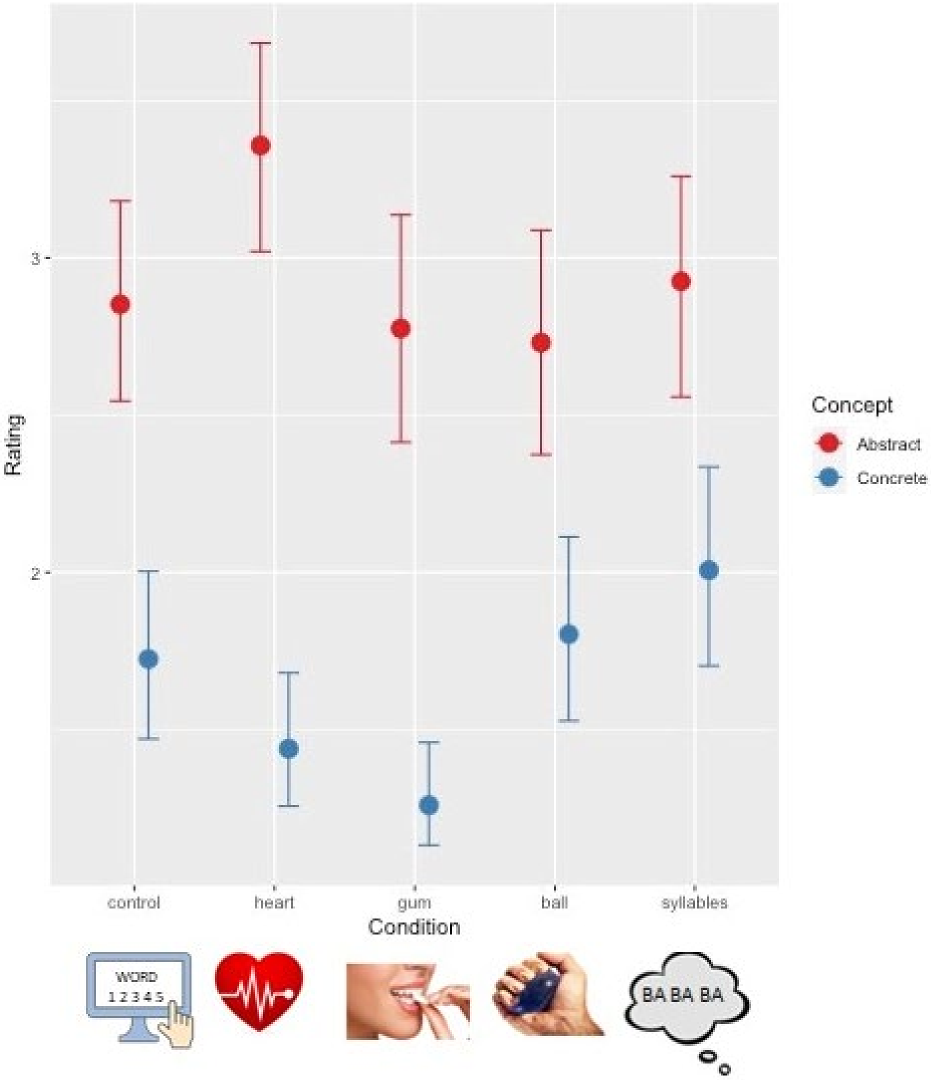


Fig.1 Interaction plot of ratings mean versus conditions (control, heart, gum, ball, syllables) for abstract and concrete concepts. Error bars indicate the 95% credible intervals.

Table 5. Estimates and 95% posterior credibility intervals (PCIs) for the estimates for the model in which we tested for the effect of concreteness (abstract vs. concrete) and experimental condition (control, heart, gum, ball, syllables) using a narrow prior (normal distribution with mean = 0 and SD = 1). Abstract concepts and heart beating conditions are set as reference variables for the concreteness and the experimental conditions, respectively. Boldfaced: the estimates whose 95% PCIs do not include the effect of zero.

	Estimate	Est.Error	l-95% CI	u-95% CI
Intercept[1]	**-2.72**	**0.33**	**-3.38**	**-2.09**
Intercept[2]	-0.62	0.33	-1.27	0.01
Intercept[3]	**1.2**	**0.33**	**0.54**	**1.82**
Intercept[4]	**3.3**	**0.33**	**2.65**	**3.93**
Condition Heart	**1.01**	**0.38**	**0.29**	**1.76**
Condition Gum	-0.16	0.39	-0.91	0.6
Condition Ball	-0.25	0.4	-1.03	0.52
Condition Syllables	0.14	0.38	-0.62	0.89
Concept Concrete	**-2.48**	**0.31**	**-3.07**	**-1.85**
Condition Heart: Concept Concrete	**-1.83**	**0.11**	**-2.04**	**-1.61**
Condition Gum: Concept Concrete	**-1.35**	**0.12**	**-1.58**	**-1.12**
Condition Ball: Concept Concrete	**0.44**	**0.11**	**0.23**	**0.65**
Condition Syllables: Concept Concrete	**0.55**	**0.1**	**0.35**	**0.75**

Hypothesis 1. i) We predicted that the ball squeezing condition would have increased the perception of the difficulty of concrete concepts (vs. abstract ones). To test this hypothesis, we tested whether the difference between abstract and concrete concepts in the ball condition was different as compared to other conditions. We found extreme evidence that this difference was smaller in the ball condition, as compared to the control, the gum and the heart beating conditions (BF_{10}s > 100, posterior probability (PP) = 100%). However, there was moderate evidence that there was no difference between the difference between abstract and concrete concepts in the ball condition as compared to the articulatory suppression condition (BF_{01} = 8.88, PP = 16%). We also tested whether the difficulty ratings for concrete concepts in the ball condition were higher than in other conditions. We found extreme evidence in favor of the hypothesis that difficulty ratings for concrete concepts in the ball condition were higher than in the gum conditions (BF_{10} > 100, PPs = 100%), and moderate evidence

that difficulty ratings for concrete concepts in the ball condition were higher than in the heart beating condition (BF_{10} = 3.4, PP = 99%). However, there was anecdotal evidence that difficulty ratings for concrete concepts in the ball condition did not differ from the articulatory suppression condition (BF_{01} = 2.25, PP = 13%). Finally, there was moderate evidence that difficulty ratings for concrete concepts in the ball condition did not differ from the control condition (BF_{01} = 3.01, PP = 68%).

ii) Next, we verified whether the interference effect was particularly strong for tools, and then for food items. We found strong evidence that the interference effect is stronger for tools (vs. the more abstract concepts, i.e. PS) in the ball condition as compared to the control condition (BF10 = 19.9, , PPs = 99 %), and extreme evidence that the interference effect is stronger for tools (vs. PS) in the ball condition as compared to the heart beating condition and to the gum condition (BFs_{10} > 100, PPs = 100%). However, there was moderate evidence that there was no difference with the articulatory suppression condition (BF_{01}= 7.80, PP = 63%). Concerning the food, we found inconclusive evidence (BF01= 1.23, PP = 96%). We also found extreme evidence that the interference effect was stronger for food items (vs. PS) in the ball condition as compared to the heart beating condition and to the gum condition as compared to the control condition (BFs_{10} > 1000, PPs = 100%). However, there was moderate evidence that there was no difference with the articulatory suppression condition (BF_{01}= 4.12, PP = 12%).

ii) We verified whether within abstract concepts the interference effect was particularly strong for PSTQ (vs. the more abstract concepts, i.e. PS). Within abstract concepts, we found moderate evidence that there was no difference with the control condition (BF01= 5.9, PP = 52%). We found extreme evidence that the interference effect was stronger for PSTQ (vs PS) in the ball condition as compared to the heart beating condition and to the gum condition (BFs_{10} > 100, PPs = 100%). However, there was anecdotal evidence that there was no difference with the articulatory suppression condition (BF_{01}= 2.23), although in terms of posterior probabilities it is plausible to assume that the effect was stronger for PSTQ in the ball condition as compared to the articulatory suppression condition (PP = 95%).

Hypothesis 2. i) We predicted that the gum chewing condition would interfere more with abstract concepts than with concrete concepts of animals and tools, determining an increase in difficulty at the increase of the abstractness level. To test this hypothesis, we tested whether the difference between abstract and concrete concepts of animals and tools in the gum condition was different, as compared to the other conditions. When tested against the heart beating condition, we found inconclusive evidence in support of this hypothesis (BF_{10} = 2.9), and actually it was more plausible that the difference was in the opposite direction as compared to the predicted one (PP = 0.33%). However, when compared with the control, ball and articulatory suppression conditions, we found extreme evidence in support of our hypothesis (BF_{10}s > 100, PPs = 100%). ii) We also predicted that the gum condition would modulate more the food items, either determining a facilitation or an interference. Thus, we compared the difference between the food items and the rest of sub-categories in the gum condition against the same difference in all the other conditions. We found inconclusive evidence for a difference that food items were affected as compared with the control condition (BF10= 1.1, PP = 2%). However, we found strong evidence for this hypothesis, when comparing the interference effect on food with the heart condition (BF10 = 84 because the interference was greater (PP = 100%).When compared to the ball condition, however, we found moderate evidence for this hypothesis (BF_{10} = 3.89), but in the opposite direction (PP = .03%), as the interference on food was greater in the ball condition. The same was true in the comparison with the articulatory suppression condition (PP = 0.03%), although in this case the evidence for an effect was extreme (BF10 > 100).

Hypothesis 3. We predicted i) that the articulatory suppression condition would interfere more with abstract concepts than with concrete concepts, and in particular ii) for the more abstract concepts, i.e. PS). It is clear from a simple visual inspection of the results that hypothesis 3 was not supported by our data (Figure 1), indeed the articulatory suppression condition seems to produce less interference with the abstract concepts, and it was indeed quite similar to the ball condition, as emerged in our analyses related to Hypothesis 2. Ii) The same applies to our second sub-hypothesis concerning the more abstract concepts (PS) that did not appear to be judged as more difficult in this condition, as compared to the other experimental conditions (Figure 2).

Hypothesis 4. i) We predicted that the heart beating condition would interfere more with abstract concepts than with concrete ones. To test this hypothesis, we tested whether the difference between abstract and concrete concepts was bigger in heart beating condition, as compared to other conditions. We found extreme evidence that the difference in the heart condition was bigger than in all the other conditions, including the control condition (BF_{10}s > 100, PPs = 100%). ii) Furthermore, we tested in particular if the effect was bigger for the abstract concepts that involve more the emotional and social dimension. We found extreme evidence for a greater difference between EMSS and PSTQ concepts (PS is the reference level) in the heart beating condition as compared with the ball, the articulatory suppression and the control conditions (BF_{10}s > 100, PPs = 100%), moderate evidence for a greater difference between EMSS and PSTQ concepts in the heart condition as compared with the gum condition (BF_{10} = 7.85, PP = 99%). ii) Finally, we explored whether the heart beating condition could create more interference with the concepts of animals, because of their animacy. However, even from a simple visual inspection of the results this does not seem to be the case (Figure 2).

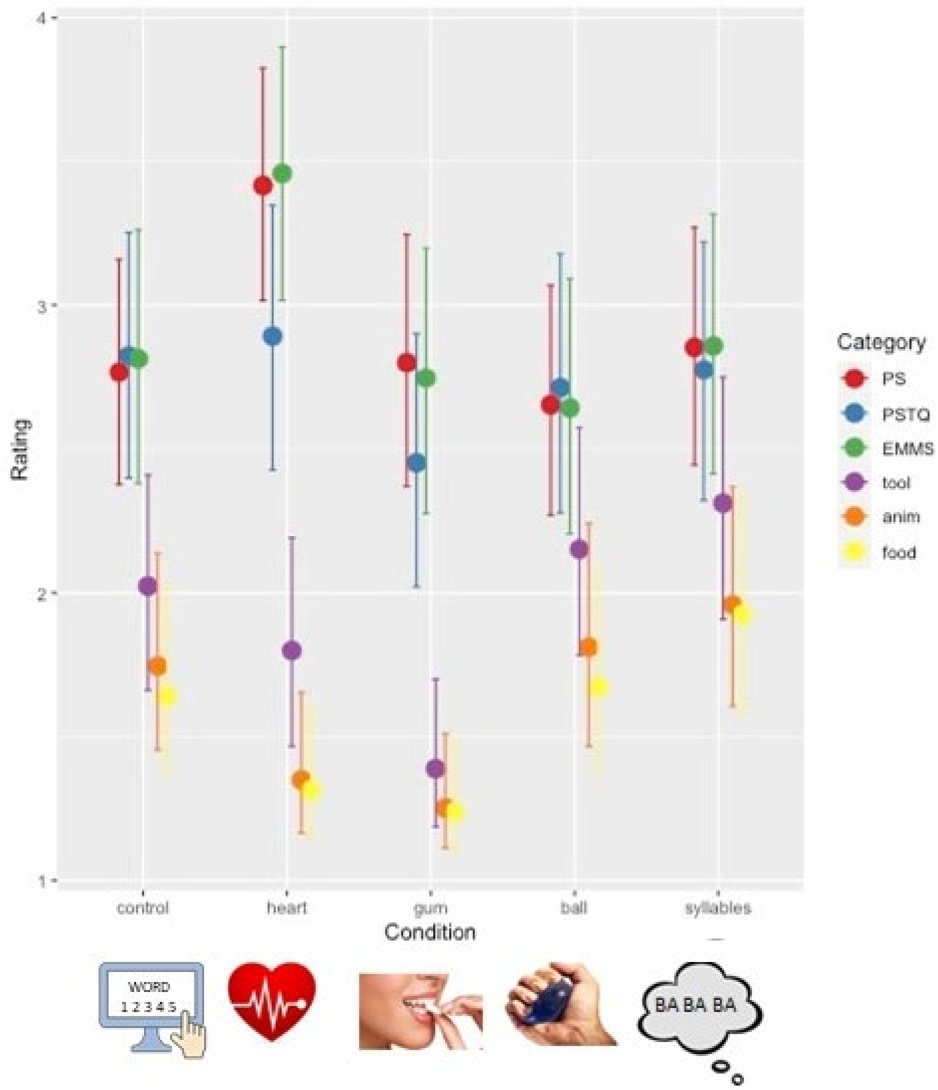


Fig.2 Interaction plot of ratings mean versus conditions (control, heart, gum, ball, syllables) for the sub-kinds of abstract (Philosophical and Spiritual concepts, PS; Physical Space Time and Quantity concepts PSTQ; Emotional, Mental State and Social concepts, EMSS) and concrete concepts (Tools, Animals, Food). Error bars indicate the 95% credible intervals.

Exploratory analyses

To better interpret how dual-tasks modulated the differences in ratings between the two kinds of concepts and their sub-kinds, we decided to run further exploratory analyses on our data.

Specifically, we tested whether the difficulty rating for abstract concepts in each condition differed from the rating for abstract concepts in the control condition. The same analysis was conducted for the concrete concepts.

We also tested whether, when compared to the control condition, the difficulty rating in the gum and heart condition was higher for the more abstract concepts, PS and EMSS, than for the most concrete among the abstract concepts, PSTQ.

Finally, we tested whether the perceived difficulty of tools compared to other concrete concepts decreased more in the gum condition than in the control condition.

Exploratory analyses results.

Concrete concepts. We found very strong evidence (BF_{10}= 61.48) that concrete concepts were judged as less difficult in the gum condition, as compared to the control (PP = 100%). We found only inconclusive evidence ($0.33 < BFs_{10} < 3$) in favor of a difference in the difficulty ratings provided to the concrete concepts between the control condition and the other conditions (4% < PPs < 98%).

Abstract concepts. We found strong evidence (BF_{10}= 15) that abstract concepts were judged as more difficult in the heart condition, as compared to the control condition (PP = 100%). We found only inconclusive evidence ($0.42 < BFs_{10} < 0.47$) in favor of a difference in the difficulty ratings provided to the abstract concepts between the control condition and the other conditions (4% < PPs < 34%).

Differences within abstract concepts. We found extreme evidence ($BFs_{10} > 100$) that PSTQ concepts were considered as less difficult, compared to other abstract concepts, in the heart condition and in the gum conditions as compared to the control condition (PPs = 100%). We found moderate evidence (BF_{01} = 6.9) that PSTQ concepts were not rated differently from other abstract concepts, in the ball condition as compared to the control condition (PPs = 32%). We found only inconclusive evidence (BFs_{01} = 1.93) in favor of the absence of a difference in the difficulty ratings provided to the PSTQ concepts compared to other abstract concepts between the control condition and the other conditions (PPs = 96%).

Differences within concrete concepts. We found strong and extreme evidence (BF_{10} = 94.6 and BF_{10} > 100) that tools concepts were considered as more difficult, compared to other concrete concepts, in the heart condition as compared to the control condition (PP = 99%). We found moderate evidence (BFs_{01} > 4) that tool concepts were not rated differently from other concrete concepts, in the gum (PP = 13%), in the ball (PP = 86%), and in the syllables condition (PPs = 59%) as compared to the control condition.

Discussion

The results clearly show that the different conditions modulate the ratings of abstract and concrete concepts, and of sub-kinds of abstract and concrete concepts. In many cases they supported the hypotheses we had advanced, with some exceptions that we will discuss later. We will summarize and discuss the implications of our results below.

We assume that the increase of difficulty ratings in one condition with respect to the others signal the presence of an interference. We will focus first on abstract and concrete concepts as a whole, and then on the sub-kinds of abstract and concrete concepts. Notice that the conditions might differ in terms of executive demands, but the introduction of a control condition allowed us to have a useful baseline. While we cannot completely exclude that the comparison between the different conditions might be impacted by the differences in difficulty between the secondary tasks, we do not think it is the case. The various conditions differently influenced the ratings on concrete and abstract concepts, hence we believe that their effect is due to the different dimensions they tackle, and not to the different level of task difficulty.

Abstract and concrete concepts as a whole.

In line with hypotheses 1, 2, and 4, when compared to concrete concepts abstract concepts elicited more interference with the gum chewing and the heart beating condition than with the ball squeezing condition. Results indeed showed that the difference between difficulty ratings in concrete and abstract concepts is larger in the heart beating than in all the other conditions, followed by the gum chewing condition which is larger than in all other conditions with the exception of the heart beating one. This supports the hypothesis that interoceptive experience is crucial for the representation of abstract concepts, and also suggests that processing of more abstract concepts involves the mouth motor system. Exploratory analyses allowed us to determine that the heart beating condition rendered abstract concepts more difficult with respect to all other conditions. The gum chewing condition, instead, rendered concrete concepts easier compared to all the other conditions.

As to a possible role of inner speech, our hypothesis that the articulatory suppression interfered more with abstract concepts than with concrete ones was instead not supported.

If we focus on concrete concepts, we found that the ball squeezing condition rendered the difference between concrete and abstract concepts smaller compared to the differences in the control, gum, and heartbeat conditions, but not to the articulatory suppression condition. Specifically, the ball squeezing condition rendered concepts more difficult with respect to the gum chewing and to the heart beating conditions, in keeping with our hypothesis that manual activity would interfere more with more concrete concepts. However, there is absence of significant evidence that ball condition renders concrete concepts more difficult than the control and articulatory suppression condition. The difference in difficulty with the control condition is however present when we consider tool concepts, for which manual experience is clearly crucial.

In sum, most results confirm our predictions, testifying that abstract concepts are grounded in interoceptive experience and that they evoke the mouth motor system, and that concrete concepts and particularly tools are more grounded in sensorimotor experience and activate the hand motor system.

However, with respect to our predictions one result strikes us as novel, and another as unexpected. The novel result is the pivotal role of interoceptive experience, that strikes us as more crucial than other dimensions for the representation of abstract concepts.

The unexpected result is the scarce modulation of articulatory suppression depending on the abstractness of stimuli. It is mainly unclear from the results whether articulatory suppression elicited a selective interference in processing of abstract concepts or instead on both abstract and concrete ones. In the articulatory suppression condition the disadvantage of abstract over concrete concepts is slightly larger than in the ball condition, in line with our predictions, but the evidence is inconclusive. It is therefore possible that the effect of suppression increases the difficulty of all linguistic stimuli, irrespective of their abstractness level. The result contrasts with recent evidence (Zannino, Fini, Benassi, Carlesimo, Borghi, under review) in which we found a selective interference of articulatory suppression on abstract concepts processing, in a task in which we asked participants to judge whether words were concrete or abstract and we measured response times. It is therefore possible that the absence of a selective interference due to articulatory suppression is owing to the specific task we selected, that required participants to explicitly evaluate conceptual difficulty and did not consider their online performance. Further studies are necessary, to investigate more in depth the role of articulatory suppression in abstract concepts processing across different tasks.

Sub-kinds of abstract and concrete concepts

PSTQ abstract concepts. As predicted (exploratory hypothesis), we found that the ball squeezing condition increased difficulty judgments of PSTQ concepts to a larger extent than the heart and gum conditions, but not than the control condition. Furthermore, as predicted EMSS (together with PS) differed from PSTQ concepts more in the heart condition compared to all the other conditions. This result confirms that PSTQ are the most concrete among the abstract concepts, and tap on sensorimotor (exteroceptive) rather than on interoceptive experience.

EMSS abstract concepts. As predicted (directional hypothesis), the heart beating condition interfered in particular with abstract concepts that involve more the emotional and social dimension, i.e., with EMSS, compared with the more concrete PSTQ concepts (but not with PS concepts).

Tools concrete concepts. Within concrete concepts, as predicted (directional hypothesis) the ball condition interfered more with judgments on tools when compared with all other conditions except the articulatory suppression one.

Food and animals concrete concepts. As predicted (directional hypothesis), compared with the ball squeezing and the suppression condition the gum chewing condition interfered more with abstract concepts than with animal and tool concepts (mouth activation), but also with food ones. Surprisingly, we did not find a clear effect of mouth chewing on food stimuli; instead, concrete concepts were differentiated into the two classical categories of living (food and animals) and nonliving (tools) entities. Interestingly, compared to PS abstract concepts food concepts were considered more difficult in the ball than in the gum and heartbeat condition (but not than in the control and articulatory suppression one), likely because of their graspability. Hence, it appears that food was represented more as graspable, hence more in relation to the hand than to the mouth effector.

PS abstract concepts. Our prediction that, because of their higher abstractness level, PS concepts would be mostly interfered in the articulatory suppression condition was not confirmed. This however depended on the fact that, overall, articulatory suppression did not seem to interfere more with abstract concepts than with concrete ones, if not for a slight tendency that requires further studies to be investigated. Interestingly, PS abstract concepts differed from PSTQ ones in interoception, likely because of their higher abstractness level.

Conclusion

The study was aimed to test a general claim and more specific claims deriving from the WAT proposal (Borghi et al., 2018b, 2019a) and from other proposals on abstract concepts representation. According to the general claim of the WAT proposal abstract concepts are more characterized than concrete ones by linguistic experience (see also Dove, 2019, LENS proposal), hence mouth activation, and by inner grounding and interoceptive experience (see also Connell et al., 2018), and less characterized than concrete ones by sensorimotor experience related to hand experiences. This general claim was supported by our results: perceived difficulty of abstract concepts selectively increased when participants were required to perform a task requiring interoceptive awareness (heart beating condition). Furthermore, when their mouth active movement was not allowed the processing of concrete concepts and of the more concrete within abstract concepts, PSTQ, was facilitated, suggesting the presence of a higher difficulty at the increase of the abstractness level of concepts (gum chewing condition). Finally, perceived difficulty of concrete concepts, and particularly of tools, increased when participants had to manipulate an object (ball squeezing condition). Notice that, even if the instructions we gave did not specify what we intended with "difficulty" of the word, our results suggest that this was interpreted as difficulty of processing: the words perceived as easier were "dog" (cane), "grapes" (uva), and "banana" (banana), while the words perceived as more difficult across conditions were "acceleration" (accelerazione), "enigma" (enigma) and "salvation" (salvezza) (see supplementary materials).

This study was also aimed to test more specific claims concerning the way in which different kinds of abstract and concrete concepts were represented. Our results demonstrated that abstract concepts cannot be considered as a whole (Villani et al., 2019), and that different mechanisms underline their representation. Within abstract concepts, EMSS and PS concepts are more characterized by interoceptive experience than PSTQ, the more concrete among abstract concepts. Within concrete concepts, the major differences concerned tools, more grounded in sensorimotor experience (ball experience) than animals and foods: our results thus confirmed the classic distinction between living and nonliving entities. Surprisingly, this distinction did not emerge only in the ball squeezing condition, in the direction we expected, but also in the heart beating and articulatory suppression condition.

What diverged from our initial predictions was the pattern elicited by the articulatory suppression condition, which we expected to provoke selective interference with abstract concepts processing. Can we conclude that articulatory suppression, typically used to access inner speech (Alderson-Day & Fernyhough, 2015), has not a selective influence on abstract concepts? Given the discrepant results found elsewhere with response times (Zannino et al., under review), we are inclined to think that this condition did not lead to the expected results because of the task, which required an explicit evaluation and did not have any specific time constraints.

Another possibility we can speculate on concerns the mechanisms underlying the mouth motor system activation. We hypothesized that three mechanisms are at play: a re-enactment of the linguistically mediated acquisition experience, an inner re-explanation of the word meaning, occurring through inner speech, and a social metacognitive mechanism, aimed at asking others information to fill our knowledge gaps. The mechanism for which inner speech is more required is likely the internal re-explanation of the word meaning. It is possible that this mechanism is less powerful than the others, at least in the present task. Further studies are needed to investigate this issue.

Overall, our study reveals that abstract concepts, compared to concrete ones, are more grounded in interoceptive and linguistic (mouth motor system) experience, and that abstract concepts are not a unitary block but that the experiences they rely on widely differ.

Acknowledgments and funding information.

We thank Fabrizio Campanile for his collaboration with data collection of the pilot study. We would like to thank Laura Barca, Chiara Fini, Claudia Mazzuca and Luca Tummolini for comments and discussions. Funds: Sapienza University of Rome, Progetti medi, “Inner grounding of abstract concepts: the role of interception and social metacognition” to the last author.

Compliance with ethical standards

Ethical standards: The local ethics committee approved the study and it has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Informed consent: Informed consent was obtained from all individual participants included in the study.

Conflict of Interest: The authors declare that they have no conflict of interest.

References

Alderson-Day, B., & Fernyhough, C. (2015). Inner speech: development, cognitive functions, phenomenology, and neurobiology. *Psychological bulletin*, *141*(5), 931.

Alter, A. L., & Oppenheimer, D. M. (2008). Effects of fluency on psychological distance and mental construal (or why New York is a large city, but New York is a civilized jungle). Psychological Science, 19(2), 161-167.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing: Keep it maximal. *Journal of memory and language*, *68*(3), 10.1016/j.jml.2012.11.001. doi:10.1016/j.jml.2012.11.001

Barsalou, L. W. (2003). Abstraction in perceptual symbol systems. Philosophical Transactions of the Royal Society B: Biological Sciences, 358(1435), 1177-1187.

Barsalou, L.W., Dutriaux, L., Scheepers, C. (2018). Moving beyond the distinction between concrete and abstract concepts. *Phil. Trans. R. Soc. B* **373**, 20170144. (doi:10.1098/rstb.2017.0144)

Bertinetto, P. M., Burani, C., Laudanna, A., Marconi, L., Ratti, D., Rolando, C., & Thornton, A. M. (2005). CoLFIS (Corpus e Lessico di Frequenza dell’Italiano Scritto). Available on Http://Www. Istc. Cnr. It/Material/Database.

Borghi, A. M., Barca, L., Binkofski, F. & Tummolini, L. (2018a). Abstract concepts, language and sociality: from acquisition to inner speech. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 373 (1752). doi.org/10.1098/rstb.2017.0134

Borghi, A. M., Barca, L., Binkofski, F. & Tummolini, L. (2018 b). Varieties of abstract concepts: development, use and representation in the brain. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 373 (1752). doi.org/10.1098/rstb.2017.0121

Borghi, A.M., Barca, L., Binkofski, F., Castelfranchi, C., Pezzulo, G., & Tummolini, L. (2019a). Words as social tools: Language, sociality and inner grounding in abstract concepts. *Physics of life reviews,* 29, 120-153. doi: 10.1016/j.plrev.2018.12.001.

Borghi, A.M., Barca, L., Binkofski, F., Castelfranchi, C., Pezzulo, G., & Tummolini, L. (2019b). Words as social tools: Flexibility, situatedness, language and sociality in abstract concepts. Reply to comments on Words as social tools: Language, sociality and inner grounding in abstract concepts. *Physics of life reviews,* 29, 178-184. doi: 10.1016/j.plrev.2019.06.004.

Borghi, A. M. & Binkofski, F. (2014). *Words as social tools: an embodied view on abstract concepts*. New York; Springer.

Borghi, A.M., Cimatti, F. (2009). Words as tools and the problem of abstract words meanings. In N. Taatgen & H. van Rijn (eds.). *Proceedings of the 31st Annual Conference of the Cognitive Science Society* (pp. 2304-2309). Amsterdam: Cognitive Science Society.

Borghi, A.M., Fini, C., Tummolini, L., (under review). Abstract Concepts and metacognition: searching for meaning in self and others.

Borghi, A.M., & Lugli, L. (in prep) Abstract concepts and mouth motor system: evidence with an interference paradigm.

Bürkner, P.-C., & Vuorre, M. (2019). Ordinal Regression Models in Psychology: A Tutorial. *Advances in Methods and Practices in Psychological Science*, *2*(1), 77–101. https://doi.org/10.1177/2515245918823199

Bürkner, P.C. (2017). brms: An R Package for Bayesian Multilevel Models using Stan. *Journal of Statistical Software*. 80(1), 1-28. doi:10.18637/jss.v080.i01

Bürkner, P.C. (2018). Advanced Bayesian Multilevel Modeling with the R Package brms. *The R Journal*. 10(1), 395–411. doi:10.32614/RJ-2018-017

Champely, S. (2018). pwr: Basic functions for power analysis (ver.1.2-2.). Retrieved from https://CRAN.Rproject. org/package=pwr.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed). Hillsdale, N.J: L. Erlbaum Associates.

Connell, L., & Lynott, D. (2012). When does perception facilitate or interfere with conceptual processing? The effect of attentional modulation. Frontiers in Psychology, 3, 474.

Connell, L., Lynott, D., & Banks, B. (2018). Interoception: the forgotten modality in perceptual grounding of abstract and concrete concepts. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *373*(1752). https://doi.org/10.1098/rstb.2017.0143

Christensen, R. H. B. (2019). ordinal - Regression Models for Ordinal Data. R package version 2019.4-25. http://www.cran.r-project.org/package=ordinal/.

Crutch, S.J., Troche, J., Reilly, J., Ridgway, G.R. (2013). Abstract conceptual feature ratings: the role of emotion, magnitude, and other cognitive domains in the organization of abstract conceptual knowledge. *Front Human Neurosci*; 7:186. https://doi .org /10 .3389 /fnhum .2013 .00186.

Della Rosa, Pasquale A., Catricalà, E., Vigliocco, G., & Cappa, S. F. (2010). Beyond the abstract concrete dichotomy: mode of acquisition, concreteness, imageability, familiarity, age of acquisition, context availability, and abstractness norms for a set of 417 Italian words. *Behavior Research Methods*, 42(4), 1042–1048. https://doi.org/10.3758/BRM.42.4.1042

Desai, R. H., Reilly, M., & van Dam, W. (2018). The multifaceted abstract brain. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *373*(1752). https://doi.org/10.1098/rstb.2017.0122

Dienes, Z. (2008). *Understanding Psychology as a Science: An Introduction to Scientific and Statistical Inference*. Palgrave-Macmillan.

Dove, G., (2019). More than a scaffold: Language is a neuroenhancement. *Cogn Neuropsychol*, 4:1-24. doi: 10.1080/02643294.2019.1637338

Dreyer, F. R., & Pulvermüller, F. (2018). Abstract semantics in the motor system?–An event-related fMRI study on passive reading of semantic word categories carrying abstract emotional and mental meaning. Cortex, 100, 52-70.

Falandays, J.B., & Spivey, M. J. (2019). Abstract meanings may be more dynamic, due to their sociality: Comment on" Words as social tools " by Borghi et al. Physics of life reviews, 29, 175-177.

Fingerhut, J., Prinz, J.J., (2018). Grounding evaluative concepts. *Phil. Trans. R. Soc. B* 373, 20170142. (doi:10.1098/rstb.2017.0142)

Fischer, M.H., Shaki, S., (2018). Number concepts: abstract and embodied. *Philos Trans R Soc Lond B, Biol Sci* 2018; 373 (1752). https://doi .org /10 .1098 /rstb.2017 .0125.

Forde & Humphreys, (2005). *Category specificity in brain and mind*. Hove, East Sussex: Psychology Press; New York: Taylor & Francis.

Garfinkel, S. N., Seth, A. K., Barrett, A. B., Suzuki, K., & Critchley, H. D. (2015). Knowing your own heart: distinguishing interoceptive accuracy from interoceptive awareness. *Biological psychology*, *104*, 65-74.

Ghio, M., Vaghi, M. M. S., & Tettamanti, M. (2013). Fine-grained semantic categorization across the abstract and concrete domains. PloS one, 8(6).

Glenberg, A. M. (2019). Turning social tools into tools for action. Comment on" Words as social tools " by Borghi et al. Physics of life reviews, 29, 172-174.

Green, S. B. (1991). How many subjects does it take to do a regression analysis. *Multivariate behavioral research*, *26*(3), 499-510

Hoffman, P. (2016). The meaning of 'life' and other abstract words: Insights from neuropsychology. Journal of Neuropsychology, 10, 317-343.

Hoffman, P., Lambon Ralph, M. A., & Rogers, T. T. (2013). Semantic diversity: A measure of semantic ambiguity based on variability in the contextual usage of words. Behavior Research Methods, 45, 718–730.

Jeffreys, H. (1961). *Theory of Probability*. 3rd Edition, Clarendon Press, Oxford.

Keil, F.C. (1989). *Concepts, kinds and cognitive development,* MIT Press, London.

Kousta, S. T., Vigliocco, G., Vinson, D., Andrews, M., & Del Campo, E. (2011). The motor and pre-motor cortex. Neuron, 41, 301–307. doi: 10.1016/s0896-6273(03)00838-9

Kuperman, V., Stadthagen-Gonzalez, H. & Brysbaert, M. Age-of-acquisition ratings for 30,000 English words. Behav Res 44, 978–990 (2012). https://doi.org/10.3758/s13428-012-0210-4

Lee, M. D., & Wagenmakers, E.J. (2013). *Bayesian cognitive modeling: A practical course*. Cambridge University Press.

Liddell, T. M., & Kruschke, J. K. (2018). Analyzing ordinal data with metric models: What could possibly go wrong? *Journal of Experimental Social Psychology, 79,* 328-348. http://dx.doi.org/10.1016/j.jesp.2018.08.009

Lugli, L., & Borghi, A.M. (2017). Chewing a gum interferes with abstract concepts' processing. *20th Conference of the European Society for Cognitive Psychology* (ESCOP 2017). Postdam, Germany, 3-6 September 2017.

Lupyan, G. (2019). Language as a source of abstract concepts: Comment on "Words as social tools: Language, sociality and inner grounding in abstract concepts" by Anna M. Borghi et al. *Physics of Life Reviews, 29*, 154-156. doi: 10.1016/j.plrev.2019.05.001. Epub 2019 May 13.

Martin, A. (2007). The representation of object concepts in the brain. *Annu Rev Psychol*, 58:25-45.

Murphy, G. (2002). *The Big Book of Concepts*, Cambridge, MA: MIT Press.

Newcombe, P.I., Campbell, C., Siakaluk, P.D., & Pexman, P.M. (2012). Effects of emotional and sensorimotor knowledge in semantic processing of concrete and abstract nouns. Frontiers in human neuroscience, 6, 275.

Nezlek, John B.(2011) Multilevel modeling for social and personality psychology. SAGE Publications Ltd.

Pinheiro, J. C., & Bates, D. M. (2000). *Mixed-effects models in S and S-PLUS*. New York: Springer.

Prinz, J. J. (2014). *Beyond human nature: How culture and experience shape the human mind*. WW Norton & Company.

Pulvermüller, F. (2018). The case of CAUSE: neurobiological mechanisms for grounding an abstract concept. Philosophical Transactions of the Royal Society B: Biological Sciences, 373(1752), 20170129.

Rumiati, R.I. & Foroni, F. (2016). We are what we eat: How food is represented in our mind/brain. *Psychon Bull Rev*, 23: 1043. https://doi.org/10.3758/s13423-015-0908-2

Schandry, R. (1981). Heartbeat perception and emotional experience. *Psychophysiology*, 18(4), 483–488.

Shea, N. (2018). Metacognition and abstract concepts. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *373*(1752). https://doi.org/10.1098/rstb.2017.0133

Topolinski, S., & Strack, F. (2009). Motormouth: mere exposure depends on stimulus-specific motor simulations. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 35(2), 423–433. https://doi.org/10.1037/a0014504

Topolinski, S., Lindner, S., & Freudenberg, A. (2014). Popcorn in the cinema: Oral interference sabotages advertising effects. *Journal of Consumer Psychology*, 24(2), 169–176.

Vigliocco, G., Kousta, S.T., Della Rosa, P.A., Vinson, D. P., Tettamanti, M., Devlin, J.T., & Cappa, S. F. (2014). The neural representation of abstract words: the role of emotion. Cerebral Cortex, 24(7), 1767-1777.

Villani C., Lugli L., Liuzza MT., Borghi AM. (2019). Varieties of abstract concepts and their multiple dimensions, *Language and Cognition 11*(3), 403-430. doi:10.1017/langcog.2019.23

Wagenmakers, E. J. (2007). A practical solution to the pervasive problems of p values. *Psychonomic bulletin & review*, *14*(5), 779-804.

Warrington, E. K., & Shallice, T. (1984). Category specific semantic impairments. *Brain*, *107*(3), 829–27 853.

Watanabe, S. (2010). Asymptotic equivalence of Bayes cross validation and widely applicable information criterion in singular learning theory. *Journal of Machine Learning Research*, *11*(Dec), 3571-3594.

Wauters LN, Tellings AE, Van Bon WH, Van Haaften AW. (2003). Mode of acquisition of word meanings: the viability of a theoretical construct. Applied Psycholinguistics 24(03):385406 DOI 10.1017/S0142716403000201.

Winkielman, P., Schwarz, N., Fazendeiro, T., & Reber, R. (2003). The hedonic marking of processing fluency: Implications for evaluative judgment. In J. Musch, K.C. Klauer (ed.) The psychology of evaluation: Affective processes in cognition and emotion, 189, 217.

Zannino, GD., Fini, C., Benassi, M., Carlesimo G.A., Borghi, A.M. (under review) Articulatory suppression and processing of abstract concepts: the role of inner speech.

Figure captions:

Fig. 1: Interaction plot of ratings mean versus conditions (control, heart, gum, ball, syllables) for abstract and concrete concepts. Error bars indicate the 95% credible intervals.

Fig. 2: Interaction plot of ratings mean versus conditions (control, heart, gum, ball, syllables) for the sub-kinds of abstract (Philosophical and Spiritual concepts, PS; Physical Space Time and Quantity concepts PSTQ; Emotional, Mental State and Social concepts, EMSS) and concrete concepts (Tools, Animals, Food). Error bars indicate the 95% credible intervals.

Fig. 1

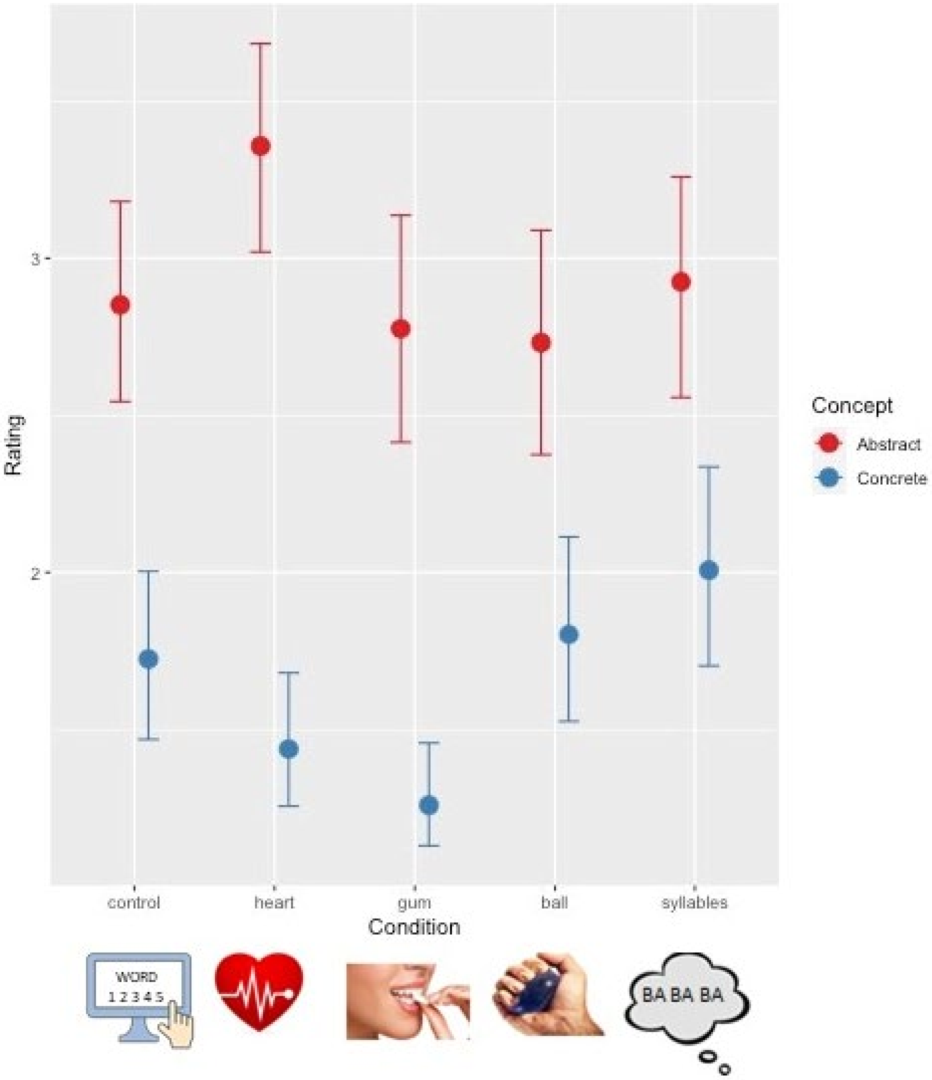
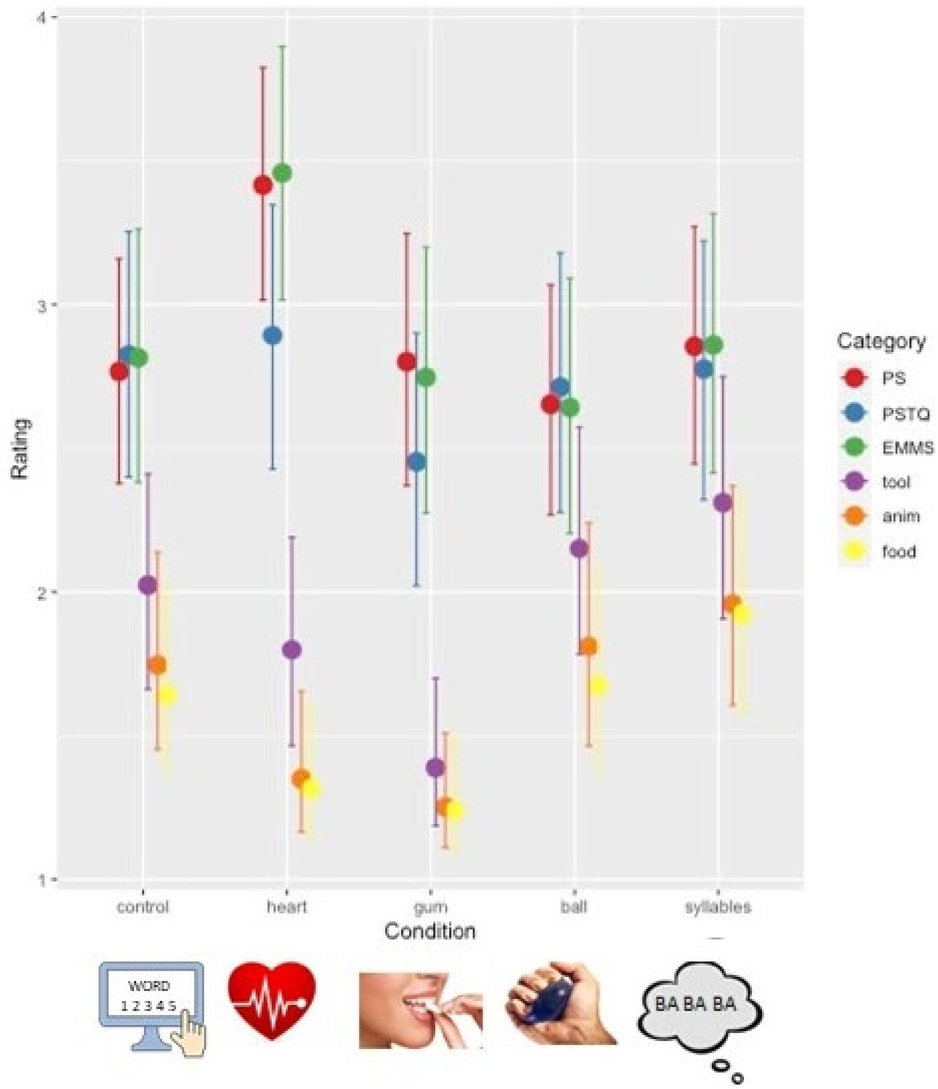

3
2
Rating
control
heart
gum
ball
syllables
Condition
Concept
Abstract
Concrete
WORD
1 2 3 4 5
BA BA BA

Fig.2


4
3
2
1
Rating
control
heart
gum
ball
syllables
Condition
Category
PS
PSTQ
EMMS
tool
anim
food
WORD
1 2 3 4 5
BA BA BA

900