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Abstract

This study extends the examination of the difference between abstract concepts to the Chinese language and its peculiar characteristics in word formation, where components with different semantic content might be aggregated within a word. Native Chinese speakers categorized abstract and concrete words by moving the computer mouse towards the selected choice. Stimuli with a ‘semantically simple structure’ (i.e., abstract-abstract/concrete-concrete) were compared with those with a ‘mixed structure’ (i.e., abstract-concrete/concrete-abstract) to test for an effect of the conceptual content of the stimulus’s components on its overall processing. Response time and kinematic parameters revealed that: a) the semantic content of the components affected the processing of abstract but not concrete concepts, b) concepts differed when they have a semantically mixed structure, not a simple one. We extend the concreteness effect also to logographic script and provide evidence that the presence of a concrete component within an abstract concept is elaborated and affects its processing.

Keywords Abstract concept; Semantic Categorization; Chinese Characters; Embodied Cognition; MouseTracker.

Word count: 9006

1 Introduction

Abstract and concrete concepts

According to some views, abstract concepts are not represented differently from concrete ones. Standard distributional views, indeed, propose that word meaning is given by the co-occurrence of words in big corpora (e.g., Landauer & Dumais, 1997). Thus they do not distinguish between concrete and abstract words since the meaning of both would be explained by their word associates. Likewise, standard embodied views (e.g., Glenberg et al., 2008) do not emphasize the distinction between concrete and abstract concepts: both would be grounded in sensorimotor and emotional systems (for a review and an analysis of the limits of these views, see Borghi et al., 2017).

Contemporary approaches widely agree on showing differences in how concrete and abstract words are processed and recalled: abstract concepts, like "freedom" or "justice" are more difficult to process (e.g., they take longer to process, see Fini et al., 2021; Paivio, 1990) and are generally acquired later than concrete ones, like "bottle" or "pen" (e.g., Villani et al., 2019). Also, evidence on double dissociations between deficits related to concrete and abstract concepts (Shallice & Cooper, 2013) strongly suggests that the two systems are at least partially separated. In recent years, thus, proponents of hybrid views, that combine embodied/grounded and distributional approaches, have proposed that abstract and concrete concepts have different and multiple representations. Abstract concepts would rely more than concrete ones on linguistic, social, emotional, and interoceptive experiences, while concrete concepts would evoke to a larger extent sensorimotor, and especially exteroceptive experiences (see Borghi, Barca, Binkofski & Tummolini, 2018; Borghi et al., 2019; Borghi, 2020; Desai, Desai, Reilly, & van Dam, 2018; Dove, 2019; Dove et al., 2020; Zdrazilova, Sidhu, & Pexman, 2018). Clear evidence against the idea that concrete and abstract concepts are represented in the same way comes from a well-known effect, the concreteness effect (Paivio, 1986; Schwanenflugel et al., 1992). This effect shows a disadvantage of abstract concepts: they are processed slower (e.g., in lexical decision tasks) and recalled worse than concrete ones. Differences in the processing and recall of concrete and abstract concepts can be owing to a variety of factors. First, compared to concrete concepts, abstract ones are more detached from sensory modalities (Barsalou, 2003), even if recent literature has shown that they evoke interoception more than concrete ones (Connell et al., 2018; Villani et al., 2021). Furthermore, they do not refer to single objects (as in the case of the concept "table") but to complex situations and events (as in the case of the concept "party"). Finally, differently from concrete concepts, abstract concepts generally collapse various heterogeneous exemplars; for example, the concept of "freedom" might include experiences as diverse as exiting from prison, running on grass, starting a journey, or leaving home for the first time (Borghi & Binkofski, 2014; Borghi, 2022.

As a consequence of this and because their members do not have many common traits, we can qualify them as low intensional concepts, i.e. concepts the exemplars of which do not share many characteristics (Lupyan & Mirman, 2013), or as sparse categories as opposed to dense ones (Sloutsky, 2010). Consider for example the opposition between "squirrel" and "justice": different kinds of squirrels have many similar aspects or traits – e.g., their shape, more typical color, etc.-, while experiences of justice are quite heterogeneous, differ across individuals, and do not have much in common, e.g., ranging from obtaining the right reward to having all the same worth. Activating category exemplars that are not perceptually similar and have only a few common traits involves processing costs (Lupyan & Mirman, 2013).

Recent evidence reveals that the differences between concrete and abstract concepts extend to morphology. In the English language, nouns are considered as more concrete than other parts of the speech, but mass nouns are considered as more abstract than count nouns, and words derived from French and Latin are seen as more abstract than words with other origins (Lievers et al., 2021).

The aim of the present study is to determine whether humans are sensitive not only to the broad distinction between abstract and concrete concepts but also to morphological aspects, and more specifically to the componential nature these concepts might have. Suppose that the word for a given abstract concept is composed of an abstract and a concrete component – are humans sensitive only to the overall conceptual meaning of the concept, or also to the abstractness/concreteness of each conceptual component? Does the mismatch between different components influence their processing? To answer these questions, we performed a study in a language that allows identification of the concreteness/abstractness of different components, i.e., the Chinese language.

1.1. Characteristics of Chinese language and the specificity of Chinese morphology

The main reason why we choose to focus on the Chinese language is that the components of Chinese characters and more in general Chinese morphology are quite peculiar, likely also due to the adoption of a logographic writing system that might render the role of the morphological components more salient. Because of this specificity of Chinese morphology, many studies have focused on how the acquisition of morphological competence occurs. Investigating the Chinese language thus might offer a privileged observation point to address whether participants are sensitive to the concrete or abstract character not only of entire words but also of their components.

We will review below some studies with children and adults that have addressed the specific structure of the Chinese morphology, and then clarify why investigating sensitivity to abstract and concrete components of Chinese words might be relevant. Let us start comparing some examples of English, Italian and Chinese morphology. Two different English words with two morphemes are “sunset”, composed by “sun” and “set”, and “windows”, which includes the two morphemes “window” and “s”, indicating that window is represented in plural form. Consider Italian “pregiudizio”, composed by “pre” (Latin stem for *before*) and “giudizio” (*judgement*) as an example of a compound that refers to the temporal dimension of a judgment, and “automobili”, which shows two different morphological procedures: compound word formation (“auto”, *self* + “mobile”, *movable*) and inflection (in the presence of the terminal “-i” as a mark for plural, substituting the “-e” of the singular form). Differently from English and Italian, each Chinese character simultaneously represents both a syllable and a morpheme. Chinese has a unique morphological structure (Packard, 2000); it is, therefore, an interesting language to explore the role that morphological sensitivity might play in acquiring and mastering reading and writing skills and more generally in processing words.

A variety of studies have focused on Chinese morphology and its particularities. Although the importance of phonology is clearly recognized (e.g., Ho & Bryant, 1997b; McBride-Chang & Ho, 2000), others highlighted the crucial role played by morphological awareness for Chinese literacy skills development (Li, Anderson, Nagy, and Zhang, 2002; McBride-Chang, Shu, Zhou, Wat, & Wagner, 2003; Shu et al., 2006), followed by orthographic skills (e.g., Ho & Bryant, 1997a; Ho et al., 2003; Siok & Fletcher, 2001). Nagy et al. (2002) found that instruction focusing on morphological awareness increased performances of first and fourth-grade students on tasks that emphasize character-level knowledge.

McBride-Chang et al. (2003) demonstrated that morphological awareness in Chinese five and seven-year-old children is independent of phonological awareness and is able to predict reading abilities when phonological measures are held constant. Results reveal a marked improvement in a morphological construction task from kindergartners to second graders, indicating that morphological awareness is strongly related to reading ability. This is likely because, differently from language as English and Italian, the Chinese language has many characters with different orthographies but identical sounds, for example, 心，新，辛，欣，歆 all pronounce as xīn. Reading ability is, therefore, crucial to learn to distinguish among homophone characters differing in meaning.

The unique importance of morphological awareness for Chinese reading was confirmed by a study by Packard et al. (2006), who gave first graders instructions aimed to increase their knowledge of the orthographic and morphological structure of Chinese words. After two semesters, their ability to copy and write Chinese characters significantly increased. Importantly, results indicate that their performance in writing tasks is more strongly related to morphological than phonological awareness, in keeping with results by McBride-Chang et al. (2003).

Li et al. (2012) used a wide sample of 184 kindergarteners and 273 primary school students from Beijing and revealed that phonological processing and morphological awareness are crucial for very early and intermediate Chinese reading acquisition; in contrast, visual skills were associated only with very early character recognition and orthographic skills were associated with reading but only in primary school and not in kindergarten. The importance of morphological abilities for Chinese literacy acquisition is also underlined by Tong et al. (2009). In a longitudinal study with 171 Hong Kong Chinese children, they found that morphological awareness, together with orthographic knowledge, was associated with word recognition, dictation, and reading comprehension.

Moving beyond infancy, in a masked priming task, Zhou et al. (1999) showed that the components of compound Chinese characters are processed during word recognition. Semantic content appears to have a prominent role in processing Chines characters. Cao et al. (2015) showed a modulation of the attentional blink effect (e.g., the fact that the identification of the second of two targets is impaired if presented less than 500 ms after the preceding one) according to the different relationships between characters, with a gradual reduction of the effect for homophonically, morphologically and semantically related characters. This also extends to the components of compound characters, as shown by the automatic activation of semantic features of the phonetical radical (radicals that cue the pronunciation of a character) in a Stroop task (Yeh et al., 2017).

1.2 Awareness of abstractness/concreteness of morphemes

Although many studies have focused on the morphological structure of Chinese, only a paucity addressed the concrete/abstract dimension. Previous work along a similar line compared verbs and nouns that composed straightforward sentences in two alphabetic languages, i.e., Italian and German.

The authors performed a behavioral task, and then a transcranial magnetic stimulation and an fMRI task adopting a similar paradigm (Scorolli et al., 2011; 2012; Sakreida et al., 2016). In the work by Scorolli et al. (2011), participants had to judge the sensibility of German and Italian sentences, which were the combinations of one abstract/concrete verb and one abstract/concrete noun. Both the verb and the noun could be abstract or concrete (e.g., caress/grasp the idea/the dog), leading to four kinds of combinations, two compatible (i.e., A-A, C-C) and two mixed ones (A-C, C-A). Participants were required to evaluate whether sentences made sense or not; two independent groups of Italian and German participants were asked to rate aspects related to the linguistic and sensorimotor aspects of the sentences, i.e. their imageability, literal/metaphoric character, age of acquisition, and evoked quantity of motions. Results revealed that compatible combinations were processed faster, in keeping with the idea that abstract and concrete words might have different representation modalities: abstract concepts more linguistic, concrete concepts more sensorimotor, thus costs of processing within one single modality/system are the lowest. Within mixed combinations, response times were faster when the concrete word preceded the abstract one, independently of the language and of the grammatical category (in German the noun precedes the verb, in Italian, it is the opposite).

Given its characteristics, the Chinese language is ideal for determining whether the sensitivity to the characteristics of each morphological component influences the evaluation of the word overall. The salience of the morphological components might be enhanced by the fact that to convey meaning, the Chinese language uses pictures instead of letters; this might make processing of concrete components particularly salient and easier compared to that of abstract components.

1.3 The present study

As detailed below, in our study we identified characters having only one semantic component beyond the radical, which in Chinese characters is the fundamental element. We used components that, if considered as a single character, would be classified as concrete or as abstract. In order to verify whether participants were sensitive to the different degree of abstractness/concreteness of components of abstract concepts, we selected 48 abstract terms: half of them included an abstract radical and an abstract component for both characters (e.g., 感情 “affection”, composed by 心, heart/core/center + 成, accomplished/become/developed and 忄, same as 心, + 青, blue or green/young), the other half included a concrete radical and an abstract component for both characters (e.g., 历史, “history”, composed by 厂, factory/yard + 力, strength and 口, mouth + 乂, to put in order). Furthermore, 48 concrete terms were then selected, adopting the same criterion: for half of them both characters were concrete (森林, “forest”, 木, tree/wood + 林, forest and 木 + 木), for the other half the radical was concrete, and the component was abstract (地图, “map”, 土, soil/ground + 也, also and 口, enclosure + 冬, winter/sound of a beating drum).

The task consisted of an abstract/concrete decision task. To study how the decision process unfolds over time, participants had to respond by moving the computer mouse (Freeman & Ambady, 2010), which allowed to analyze not only response times and accuracy but also the movement kinematics (trajectories, acceleration, etc.). Mouse tracking has been widely used in psychological science, successfully highlighting the dynamic nature of conflict processes occurring in the psycholinguistic domain (Barca, Benedetti, Pezzulo, 2015; Barca and Pezzulo 2012, 2015; Spivey et al., 2005), embodied cognition (Flumini et al., 2015; Lepora and Pezzulo, 2015), social cognition (Freeman and Ambady, 2009; Smeding et al., 2016), visual perception (Quétard et al., 2016; Quinton et al., 2013), decision making (McKinstry, Dale, & Spivey, 2008, Iodice et al., 2017), and affective-emotional processes (Barca et al., 2021; Pezzulo et al., 2018; Yu et al., 2021). It has a number of advantages over the classic aggregate measure of response time such as, for example, millisecond-resolution timing information (see Freeman 2018 for a thorough discussion). The analysis of the response trajectories allows studying the competition mechanisms between the response alternatives, or the attraction ‘toward a response temporally considered and not explicitly selected’ (Freeman, 2018). In the absence of competition between two responses (in the case, for example, of a lexicality decision between real words and strings of consonants), the mouse trajectory will be straight towards the correct response option (i.e., the lexical response box if a word is presented), with minimal attraction exerted by the alternative (nonlexical) response. In the case of competition between the responses (e.g., a lexicality decision with legal pseudowords), the correct (nonlexical) response can be selected but with longer timing and a mouse trajectory that reveals attraction towards the alternative-unselected (lexical) response. Notably, the 'shape' of the trajectory is informative of the structure of the underlying online decision-making process. The trajectory may indicate a continuous attraction as an indication of a gradual accumulation of evidence during the decision process, but also a sharp deviation from an initial selection (which suggests a revision process) (Barca and Pezzulo, 2015). This type of information cannot be obtained from classic aggregated measures of response times.

The present study aims to investigate whether humans are sensitive not only to the broad distinction between abstract and concrete concepts but also to the componential nature these concepts might have. Finding answers to this issue has important theoretical consequences that allow us to better understand how we represent abstract and concrete concepts. First, they will allow us to determine whether the concreteness effect, supported so far by sound evidence (Paivio, 1986; Schwanenflugel et al., 1992), holds also with words the componential structure of which does not allow us to consider them purely concrete and purely abstract. Second, and more crucially, it will allow us to test whether the processing and representation of concrete and abstract concepts rely on different modalities. If this were the case, there should be a processing cost in the case of concepts with mixed components (i.e., composed of an abstract and a concrete component) compared to concepts with homogeneous components (both abstract or both concrete), for which no modality switch would thus be required.

Overall, we predict that if a concreteness effect is present, then responses to abstract words should be slower and less accurate than those to concrete words. More specifically, if participants are sensitive to the abstractness/concreteness of the components, then we should find a reduced uncertainty in responses to characters with an abstractness/concreteness simple structure (A-A and C-C pairs) than to those with an abstractness/concreteness mixed structure (A-C and C-A pairs) (from now on, simple structure vs. mixed structure). This should result in slower RTs for A-C and C-A than for A-A and C-C pairs, and in less straight trajectories in reaching the target box. Such an effect would confirm the predictions of hybrid or multiple representation theories, according to which abstract concepts evoke both sensorimotor and linguistic representations, while concrete concepts are grounded in sensorimotor systems. Passing from one single representation modality to more modalities should increase uncertainty. We are also interested in understanding the role played by the different components. Embodied and grounded views would predict that, when a component is grounded in the sensorimotor system, the representation based on linguistic components would be more shallow.

2 Materials and Methods

2.1 Participants

Fifty-one participants (28 males and 23 females, $Mean_{age} = 18.8$; $SD_{age} = 0.75$) were recruited from the Beijing University of Chemical Technology (北京化工大学). Participants had normal or corrected to normal vision, no history of developmental disorders, and they did not report any particular educational need. Forty-nine of them were right-handed, while the remaining two were fully ambidextrous (participants self-reported their handedness). They were all Chinese native speakers. The experiment was conducted in accordance with the ethical standards laid down in the Declaration of Helsinki and fulfilled the ethical standard procedure recommended by the Italian

Association of Psychology (AIP). All participants gave their oral informed consent to participate in the study.

2.2 Materials and design

A list of 96 stimuli was used (see Appendix 1). The selection of the materials was a complex process that we will describe in detail below. Since Chinese psycholinguistics norms are not currently available, items were first selected by two Italian databases (Villani et al., 2019, Della Rosa et al., 2010). The 236 terms in common between these databases have been translated into Chinese, and subsequently scrutinized to identify the relevant Chinese parameters (see the following section for details).

2.2.1 Features of Chinese characters. Chinese characters can present different composition modalities and can be grouped into five sub-kinds: 1) *Pictographs*, i.e., characters that represent directly, in a stylized form, the concrete object they refer to. Some examples are 山 shān (mountain), 目 mù (eye), 鸟 niáo (bird); 2) *Ideographs*, i.e., characters where some indications are represented according to a symbolic reference system. Some examples are 一 yī, 二 èr e 三 sān (1, 2 and 3), 中 zhōng (center); 3) *Combined Ideographs*, i.e., composite characters formed by two or more simple units that together give rise to the word meaning. Some examples are 好 hǎo (good), which puts together horizontally the two units 女 nǚ (woman) and 子 zǐ (child) or 明 míng (bright), that unifies 日 rì (sun) and 月 yuè (moon). These simple units can develop horizontally, as in the previous examples, vertically (e.g., 众 zhòng, crowd, composed by three units, 人 rén, person), or according to different modalities and configurations; 4) *Determinative-Phonetic Characters*, i.e., characters which include many simple units. One or more units typically convey the meaning, while others provide indications as to the word pronunciation. Some examples are 爸 bà, (dad, more often found in the version 爸爸 bàba), composed by the unity 父 fù (father) overlapping with 巴 bā, which has the function to indicate how to pronounce the word; 洋 yáng (ocean), produced combining 水 shuǐ, (water, which appears as 氵 when it is radical) and 羊 yáng (sheep), this last component aimed at providing a phonetic suggestion. 5) *Loan Characters*, i.e., those characters that do not have a specific semantic value, but the pronunciation of which is used to build foreign terms. Some examples are 马可•波罗 Mǎkě Bōluó, (Marco Polo), 啤酒 píjiǔ, (beer), this joining the phonetic translation of the word in English and the character meaning "alcoholic beverage".

Among the aforementioned sub-types of Chinese characters, here we have focused on *Combined Ideographs* (3) and *Determinative-Phonetic Characters* (4), which are the largest groups among the whole existing sets of Chinese characters. Within these characters, it was first of all necessary to identify the radical.

The distinction between radical and component is fundamental in order to understand how Chinese characters work. Each composed character is formed by two or more components, that concur in explaining its meaning and in indicating its pronunciation. Among these components, the one defined "radical" is only one for each character. Identifying the radical is the key to the research of meaning and of the pronunciation of a character within dictionaries. The radical is the fundamental component of the character, concurring in most cases to its semantic location. The list of the 214 Chinese radicals, with their meanings, is reported in Appendix 2. Components that are not radical can be simple characters with their own meaning; alternatively, they might play either a phonetic or a semantic function within a composite character. A database including all components divided into the two categories does not exist, but for each occurrence, it is quite easy to identify the function of each component. Both the radicals and the remaining components can be distinguished for abstractness or concreteness.

2.2.2 Selection of the stimuli

The list of characters has been further reduced to obtain a final sample of 96 terms (plus four terms used for the training session). The selection process is described in Supplementary Materials, S1. The list of the terms, the description of their composition, and their division into categories is reported in the Appendix.

To control for the quality of our materials, after 18 weeks from the end of the experimental session, the same 51 participants were asked to rate the items on a 7 points rating scale Likert scale according to the psycholinguistic dimensions that are highly correlated with abstractness/concreteness, i.e., Age of Acquisition (AoA), Modality of Acquisition (MoA), imageability, contextual availability, Body-Object Interaction (BOI) and social metacognition (Villani, Lugli, Liuzza & Borghi, 2019). Furthermore, they were also asked to directly rate the abstractness and concreteness of the item, together with a preparatory question about the characters' composition mechanisms ("The character 信: is it composed by 亻 and 言?") and to evaluate the role each component was believed to play in some exemplifying given characters ("Does the sub-element 口 influence your decision on abstractness/concreteness for the word 信念?). The rating session entailed two gatherings of a total duration of about two hours. For detailed results see the Supplementary Materials S2.

To obtain a measure of the written frequency of the different characters we used an Internet search engine. We used the search engine 'Bing', which is the most frequently used by the participants of our study (as emerged from the answers to our questions). This is a procedure typically used in the event that frequency data are not available, and which has been found to be reliable (Blair et al., 2002). Abstract characters are more frequent than concrete ones but only when they have a simple morphological structure (i.e., AA-CC Pairwise comparisons using t tests p <0.001), when the morphological structure is mixed there are no differences (ns). An additional description of those measures (means and t-test comparisons) is reported in Supplementary Materials, S2. Table 1 reports the lexical characteristics of the stimuli

Table 1. Stimulus characteristics [mean (standard deviation)]

	Frequency	**Number of Strokes**	**Concreteness**
Abstract Simple (A2)	15.26 (1.24)	15.91 (5.47)	2.88 (.49)
Abstract Mixed (A3)	15.41 (1.23)	17.37 (3.93)	3.75 (.61)
Concrete Simple (C2)	13.66 (1.59)	19.60 (3.31)	6.22 (34)
Concrete Mixed (C3)	14.69 (1.24)	21.43 (3.87)	6.32 (.28)

Frequency: written frequency gathered from the Internet search engine Bing; *Number of Strokes*: Number of character stokes; *Concreteness*: rating with scale ranging from 1 (low concreteness) to 7 (high concreteness)

2.3 Procedure

To begin each trial, participants clicked on the /START/ button located at the bottom-center of the PC screen. Then a fixation cross appeared at the center of the screen, which was replaced by an experimental stimulus after 300ms. The stimuli remained on the screen for 500ms. Participants had to respond within 2000ms; otherwise, a /TIME OUT/ message appeared. Stimuli were presented in black print on a white background. Participants were instructed to use the mouse to move the cursor to the appropriate response (i.e., top-left button for abstract stimuli, top-right button for concrete stimuli)[1] and to click it to indicate their response. Categorization errors and reaction times (i.e., from

[1] In studies that require a motor response (button press or mouse tracker) with two response options, their position is usually counterbalanced. Here, the 'abstract' response was always on the left, the

when participants pressed /START/ until they reached and pressed the response button) were recorded automatically. In the case of errors, a feedback message (red cross) appeared after the response.

During participants' responses, the x and y coordinates of the mouse trajectories were recorded (sampling rate of approximately 70Hz) using MouseTracker. This package was used to record, process, and analyze mouse movements (Freeman & Ambady, 2010). Experimental data acquisition was preceded by a practice session of four items (two abstract and two concrete stimuli) to become familiar with the procedure. The 96 experimental stimuli were presented in two blocks of 48 items each. The order of stimuli within blocks was randomized. The experimental session lasted about eight minutes.

3 Results

3.1 Data processing

Following the procedure established by previous studies (Barca and Pezzulo, 2012; 2015; Barca, Pezzulo, Ouellet & Ferrand, 2017; Freeman & Ambady, 2010) response trajectories were first rescaled into a standard coordinate space. Then the duration of the trajectory movements was normalized by re-sampling the time vector into 101 time-steps using linear interpolation to allow averaging across multiple trials.

'concrete' response always on the right. This is a potential flaw in the study. However, to the best of our knowledge, there are no studies that have precisely measured motion bias due to the position of the responses. In Wirth et al. (2020) it is recommended to place the answers as far as possible from the starting position of the mouse (i.e., top right and top left corners of the screen), but no information is provided on the difference between the left and the right positions. Additionally, the potential bias (if any) might affect the main effect of the semantic category, with reduced influence on the main effect of the morphological category and the interaction between the two. Given all the above, we consider our results reliable.

Responses exceeding the 2000ms deadline, which accounted for .84% of the total data, were discarded from response time analysis, as were categorization errors, which accounted for 12% of the total data, and were subsequently analysed. Thus, a total of 13% of the data points were discarded from subsequent analysis of the reaction times parameter and trajectories.

We applied Linear Mixed-Effects Modelling (LMMs) to assess the impact of Concept type (Abstract vs. Concrete) and Morphological Structure (Simple vs. Mixed) on the response variables. Subjects and Items were considered Random-effects factors; Concept type, abstractness/concreteness Structure and their interaction as fixed factors (Barr et al., 2013). As this model was found to have singularity problems (i.e., variances of one or more linear combinations of effects are (close to) zero) we reduced its' complexity by removing by the random effects the slope by item (based on the reduction of the AIC value). Details on the LMMs model and the model selection procedure are given in Supplementary Materials S3. Separate models were run for the different dependent variables, namely Response Time, trajectories Maximum Deviation Time, and Area Under the Curve. The Area Under the Curve (AUC) of a trajectory is calculated as the geometric area between the actual trajectory and an idealized trajectory (i.e., a straight line between each trajectory's start and endpoints). Therefore, higher scores reflect participants' overall attraction to the unselected choice across all time-steps. Analyses were run with the 'lmerTest' package for R (Kuznetsova, Brockhoff, & Christensen, 2016), with backward elimination of non-significant effects performed with the step function (backward elimination of the random part is performed first, followed by backward elimination of the fixed part). The p-values for the fixed effects were calculated from an F test and t-test based on Sattethwaite's approximation.

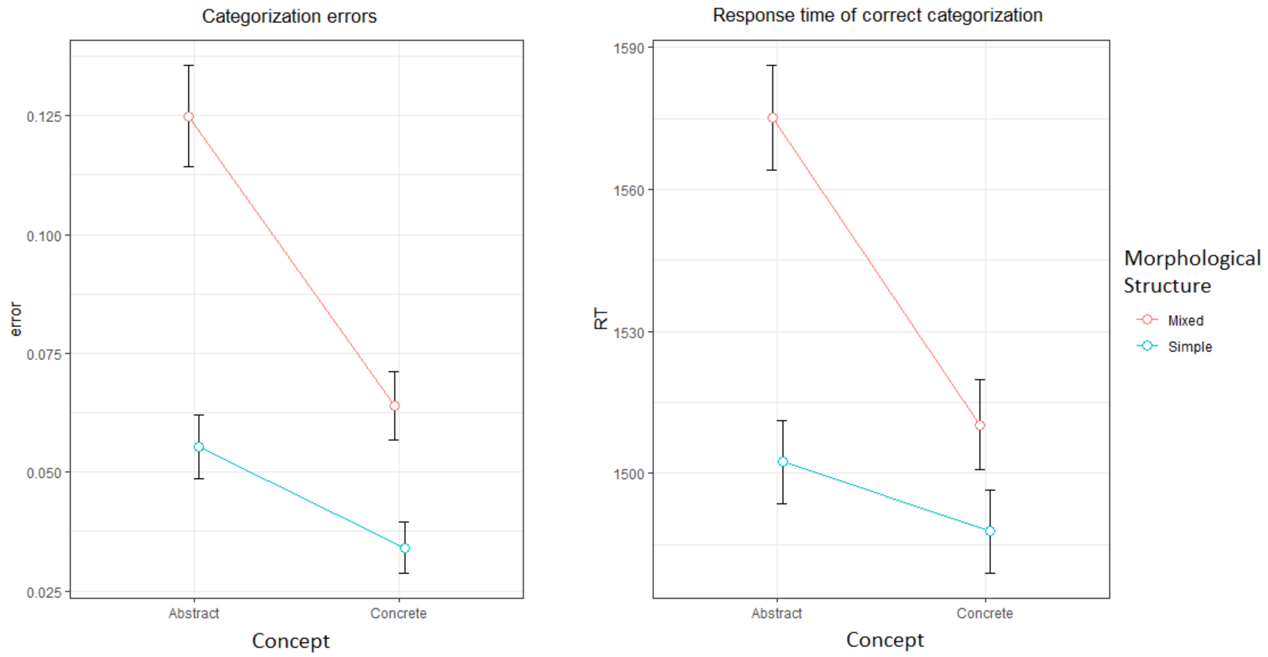
Accuracy data (i.e., number of erorrs) were analyzed using the Generalized linear mixed-effects model (GLMM) (Baayen et al., 2008; Bolker et al., 2009). GLMM fit by maximum likelihood

(Laplace Approximation) was implemented in R with the ‘lme4’ package, with parameter family ‘binomial’ to account for categorical data (Bates and Maechler, 2009; Jaeger, 2008).

3.2 Results on Accuracy and Categorization time

The first observation of the data revealed a high percentage of errors on eight items, suggesting a wrong attribution to the conceptual categories. For these items, the error rate was greater than 50% (indicating random responses) up to 84% (indicating incorrect attribution to the category). Specifically, we excluded the following items: 'marriage' of category a2 (84% of errors); ‘drama’ (78.45%), ‘gambling’ (70.59%), ‘money’ (88.24%), ‘scheme’ (58.82%) and ‘symbol’ (54.90%) of category a3; ‘compartment’ (96.8%) of category c2; and ‘explosion’ (66.67%) of category c3. These items (marked with an asterisk in the Appendix) were not included in the subsequent analyses, which were then carried out on a sample of 88 items. Mean accuracy rates and total response time were computed for each participant by averaging trials across each condition (see Figure 1).

Fig. 1. Average number of categorization errors and mean Response Times of correct categorization for mixed and simple abstract and concrete concepts



Legend: Abstract Mixed (Abstract-Concrete) and Simple (Abstract-Abstract) Combinations, Concrete Mixed (Concrete-Abstract) and Simple (Concrete-Concrete) Combinations

Inspection of the figures shows that, as predicted, a concreteness effect was present, i.e., abstract words elicited a higher percentage of errors and were responded to slower than concrete words. In addition, as predicted, items with a simple structure were processed more accurately and faster than items with a mixed one.

Number of errors were analyzed with GLMM for binomial distribution. The analysis showed a significant effect of the type of concept ($\beta_{\text{Intercept}} = -2.13$, Z value = -14.33, $p<.0001$; $\beta_{\text{conceptConcrete}} = -.69$, Z value = -3.24, $p<.001$), and its morphological structure ($\beta_{\text{StrSimple}} = -.99$, Z value = -5.18, $p<.001$). The interaction was not significant ($\beta_{\text{Interaction}} = .26$, Z value = .88, ns).

Results of the LMM applied to correct response time are presented in Table 2. To establish which variables to include as covariates in the model we performed a comparison procedure between models with varied complexity (see Supplementary materials S3 for details). The final model includes as covariates the BING written frequency, AOA, and MoA.

The analysis showed a significant effect of the type of concept ($\beta_{Intercept}$ = 1395.71, *T* value = 26.28, *p*<.0001; $\beta_{conceptConcrete}$ = -40.8, *T*value = -2.69, *p*<.001), morphological structure ($\beta_{StrSimple}$ = -48.55, *T* value = -5.14, *p*<.001), and their interaction ($\beta_{Interaction}$ = 37.59, *T* value = 2.92, *p*<.005). Written frequency and AoA were not significant, and were eliminated from the model with the backward procedure. MoA was significant (β_{MoA} = 22.92, *T* value = 2.4, *p*<.05) and kept in the model.

Table 2. Linear Mixed Model statistics on Response Time data

(significant effects are marked in bold)

	RT		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	1395.71	1291.62 – 1499.81	<**0.001**
concept	-40.91	-70.66 – -11.15	**0.007**
morp_structure	-48.55	-67.04 – -30.07	<**0.001**
LN_Bing	3.77	-1.11 – 8.65	0.130
AoA	-2.00	-24.74 – 20.73	0.863
MoA	22.92	4.23 – 41.61	**0.016**
concept * morp_structure	37.59	12.32 – 62.86	**0.004**
Random Effects			
σ^2	36111.33		
$\tau_{00\ trial}$	714.17		
$\tau_{00\ subject}$	16255.54		
$\tau_{11\ subject.concept}$	6151.23		
$\tau_{11\ subject.morp\_structure}$	134.71		
$\rho_{01\ subject.concept}$	-0.44		
$\rho_{01\ subject.morp\_structure}$	0.75		
ICC	0.31		
$N_{subject}$	51		
N_{trial}	96		
Observations	3933		
Marginal R^2 / Conditional R^2	0.018 / 0.325		

Pairwise comparison showed that response times were faster for simple than mixed items for abstract stimuli (*estimate* = 48.6, *SE* = 9.43; *z* ratio = 5.15, *p*<.0001), but not for concrete ones (*estimate* = 11, *SE* = 9.05, *z* ratio = 1.21, *ns*). Faster categorization of concrete than abstract items occurs when they have a mixed structure (*estimate* = 40.91, *SE* = 15.2; *z* ratio = 2.69, *p*<.01), not when their structure is simple (*estimate* = 3.31, *SE* = 14.4; *z* ratio = .23, *ns*).

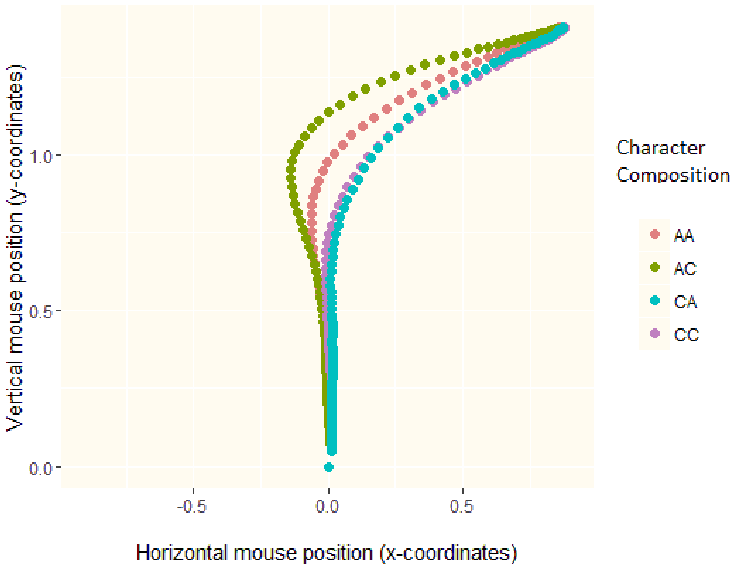
Considering Trajectories Maximum Deviation time, the main effect of the type of concepts was not significant ($\beta_{\text{Intercept}}$ = 773.24, *T* value = 13.03, *p*<.0001; $\beta_{\text{conceptConcrete}}$ = -11.57, *T* value = -.72, *ns*). The morphological structure ($\beta_{\text{StrSimple}}$ = -44.78, *T* value = -3.80, *p*<.001), and the interaction were significant ($\beta_{\text{Interaction}}$ = 27.74, T value = 1.89, p<.05). Written frequency and MoA are significant ($\beta_{\text{WrittenFreq}}$ = 7.32, T value = 5.15, p<.005; β_{MoA} = 26.93, T value = 2.46, p<.05). AoA was not significant (β_{AoA} = -11.72, T value = -.89, *ns*) and elimitaed with backward reduction. Pairwise comparison showed that Maximum Deviation time occurs earlier for abstract stimuli with simple than mixed structure (*estimate* = 44.8, *SE* = 11.8; *z* ratio = 3.8, *p*<.001), but not for concrete ones (*estimate* = 17, *SE* = 11.4, *z* ratio = 1.49, *ns*). No difference emereged when directly comparing abstract and concrete stimuli with mixed structure (*estimate* = 11.6, *SE* = 16; *z* ratio = .72, *ns*) or simple structure (*estimate* = -16.2, *SE* = 15.2; *z* ratio = -1.07, *ns*). Thus in the case of abstract characters, the maximum deviation of the trajectory occurs later in time when they have a mixed structure than when they have a simple structure (suggesting that an information competition mechanism might be in place).

The MuMIn R package (Barton, 2017) was used to compute a PseudoR2 (see also Nakagawa, Schielzeth, 2013), which indicates that our statistical model explained 20% of the variance with a medium to large effect size (*f2* = .24) according to Cohen's conceptualization (1992). To verify the adequacy of the sample size we performed a post-hoc power calculation test with the *pwr.f2.test* function in R, within the *pwr* package. According to such calculation, our sample of 51 participants is enough to have a statistical power of .85.

3.3 Analysis of trajectories - Spatial attraction

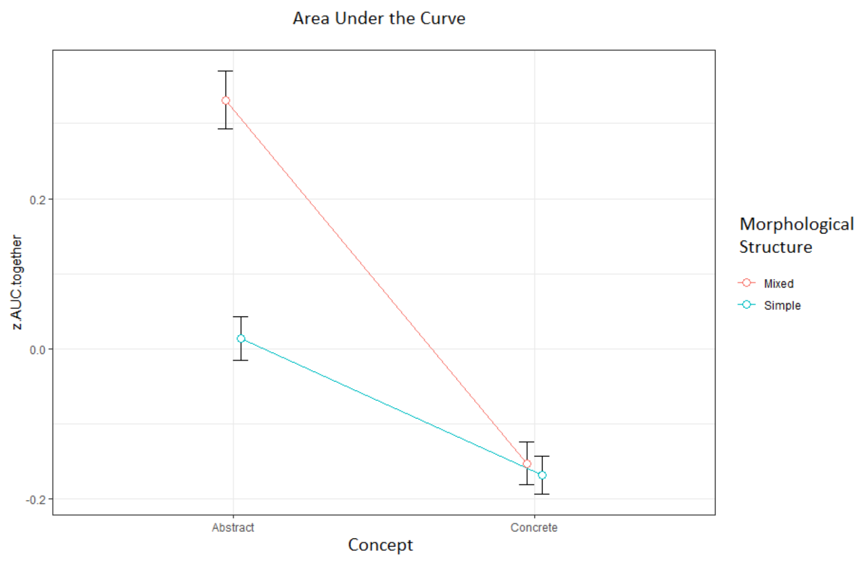
Average movement trajectories for correct categorizations are presented in Figure 2. The Figure shows that movement trajectories for Abstract concepts with a mixed structure (AC) are pulled toward the competing (concrete) response box, more than the trajectories for Abstract concepts with a simple structure (AA) and the other type of stimuli. The trajectories for Concrete concepts (either with a mixed or simple structure) do not show such attraction.

Fig.2. Movement trajectories for correct categorizations



Mean values of Area Under the Curve (AUC) for the different conditions are presented in Figure 3. LMMs on the AUC measure (z-scored for different conditions calculated together) confirmed effects of Concept type ($\beta_{\text{Intercept}}$ = .44, *T* value = -1.85, *p*=.06; $\beta_{\text{conceptConcrete}}$ = -.38, *T* value = -4.52, *p*<.001), and morphological structure ($\beta_{\text{StrSimple}}$ = -.31, *T* value = -6.95, *p*<.001), and their interaction ($\beta_{\text{Interaction}}$ = .29, *T* value = 4.9, *p*<.001) on mouse trajectories. Written frequency and MoA significantly contributed to the model ($\beta_{\text{WrittenFreq}}$ = .04, *T* value = 3.28, *p*<.001; β_{MoA} = .11, *T* value = 2.4, *p*<.05), not Aoa (β_{AoA} = -.04, *T* value = -.76, *ns*) which was removed with backfitting.

Fig. 3. Area Under the Curve (z-score values) for correct categorizations



Legend: Abstract Mixed (Abstract-Concrete) and Simple (Abstract-Abstract) Combinations, Concrete Mixed (Concrete-Abstract) and Simple (Concrete-Concrete) Combinations

Pairwise comparison showed greater AUC values for mixed than simple abstract stimuli (*estimate* = .31, *SE* = .05; *z* ratio = 6.65, *p*<.001), but not for concrete ones (*estimate* = .01, *SE* = .04; *z* ratio = .33, *ns*). The difference between abstract and concrete items is significant when they have a mixed structure (*estimate* = .38, *SE* = .08; *z* ratio = 4.52, *p*<.001), and is not significant when they have a simple structure (*estimate* = .08, *SE* = .08; *z* ratio = 1.02, *ns*).

Thus in the case of abstract characters with mixed structure, the trajectories of the mouse (indexed here by AUC values) reflect some dynamically weighted coactivation of both the abstract and concrete components during the choice.

4. Discussion

The role of morphological structure has been extensively studied in languages with an alphabetic script. In Italian, for example, there is an advantage in processing words' morphological structure, both in typical (Burani, Marcolini, Stella, 2002) and atypical development (Burani, Bimonte, Barca, Vicari, 2006). However, it is not clear if such an advantage of the morphological structure is linked only to the statistical co-occurrence of orthographic aspects of the two morphological elements, or to the processing of the semantic features of the components (and specifically to the abstract/concrete dimension). The present study suggests that semantic aspects might play an essential role.

Here, we explored if Chinese readers are sensitive to the componential nature of abstract and concrete concepts. They were asked to categorize as abstract or concrete a list of stimuli with varied morphological structures, that is, Chinese characters made of either abstract-abstract, abstract-concrete, concrete-concrete, or concrete-abstract conceptual components. To the best of our knowledge, this is the first study that analyzes not only the response time but also the kinematics of the movement in selecting the response by moving the computer mouse, which enriches the parameters to be examined, including also measures of uncertainties.

The results across the different measures (accuracy, response times, Trajectories Maximum Deviation Time, and Area Under the Curve analyses) are very consistent and clear.

First, we found an extension of the concreteness effect (Paivio, 1986; Schwanenflugel et al., 1992) using a new task, i.e., asking participants to distinguish stimuli into abstract/concrete ones (instead of using lexical decision or recognition tasks). Responses to concrete concepts are more accurate than responses to abstract ones, and responses to concepts with a simple composition are more accurate than responses to concepts with mixed composition. We did not find any interaction.

More crucially, we found that Chinese participants are sensitive to the componential structure of words, and the abstractness/concreteness of the morphemes. Behavioral and kinematic measures are influenced by the concreteness effect, which is more marked with concepts with a mixed composition (AC, CA pairs). When abstract concepts have a concrete component, response times slow down, and trajectories are more attracted from the competing alternative response than when they have a simple structure. The same does not hold for concrete concepts, for which the difference between simple and complex structure is not significant. Thus, response times analyses indicate that the effect of morphological structure is present for abstract, but not for concrete stimuli and that abstract and concrete concepts differ when they have a mixed structure, not when they have a simple one.

The same result obtained with Trajectories Maximum Deviation time reveals the consistency of the data pattern, which is also confirmed by the analysis of mouse trajectories. Response trajectories of abstract concepts with a mixed structure are attracted more to the competing (concrete) response box than trajectories of abstract concepts with homogenous abstract content, while the trajectories for concrete concepts (either with a Mixed or Simple structure) do not reveal such attraction. Likewise, AUC analyses reveal a higher uncertainty for abstract than for concrete concepts (i.e., a higher value of AUC for abstract than concrete stimuli), and a difference between abstract concepts with different morphological structure (i.e., higher value of AUC for abstract mixed than abstract simple stimuli). This means that, when processing abstract concepts, the presence of a concrete element strongly attracts attention, and this consistently slows down response times and pulls the response toward the competing stimulus. This does not happen when processing concrete radicals combined with an abstract component: the presence of an abstract component does not seem to influence much response times. Results on mixed combinations confirm the critical role of the radical in Chinese stimuli, which plays a major role, especially for concrete stimuli.

Importantly, the asymmetry we found is in line with what a grounded approach to cognition would predict (Barsalou, 2016). It is also in line with recent data on language evolution, suggesting that over the years languages evolve toward concreteness: more concrete words of different word classes (nouns, verbs, and prepositions) are preferred over more abstract ones, likely because the meaning of the first is easier to access and process (Hills & Adelman, 2015). When participants are processing an abstract concept with an embedded concrete element (which is grounded in the sensorimotor system), their decision time increases. When processing abstract concepts, participants are both slower and more sensitive to the morphological structure of the concept (these results are in line with Scorolli et al., 2011). Whether this sensitivity concerns morphology in general or only the presence of a concrete component, as we suspect, should be investigated by future research.

Our results have a further implication: concrete concepts seem to be better defined and to have more definite boundaries than abstract concepts. Hence, they suggest that, beyond morphology per se, the grounded characteristics of morphemes are crucial for fast access to meaning.

Finally, our study extends current evidence on the role of Chinese morphology, indicating that participants take into account the concrete or abstract character of words' components. It remains an open issue, whether and to what extent these results occur because meaning in Chinese is conveyed through pictures rather than alphabetic letters and whether this might render the role of the single components, and particularly of concrete ones, more salient. Further studies are needed, to investigate whether the sensitivity to abstract and concrete components holds across other languages.

To conclude, the present findings demonstrated, for the first time, that individuals are sensitive not only to the broad distinction between abstract and concrete concepts but also to the componential nature of these concepts. More specifically, Chinese language users are sensitive to the abstractness/concreteness of each conceptual component since the mismatch between different components influences their processing. Furthermore, our results confirm and extend the views that do not emphasize the marked differences between abstract and concrete concepts (e.g., Barsalou et al., 2018). Indeed, they show that each word might have different components and that also the abstractness/concreteness of a single component can influence the concept processing and categorization. At the same time, however, they suggest that different mechanisms and kinds of grounding (one more related to the sensorimotor system, one to the linguistic one) might subtend the processing of concrete and abstract concepts. It is important to notice that different varieties of Chinese language exist – for example, Cantonese and Mandarin Chinese differ in many respects. Despite these differences, we believe that our results can hold across the varieties of Chinese languages since all different kinds of Chinese are graphematic languages and possess a similar morphological structure.

Further research is needed to understand whether the sensitivity to the componential structure of concrete and abstract concepts is present also in tasks that do not involve an abstract/concrete categorization, and also during everyday verbal interactions.

Declaration of Interest statement

No potential conflict of interest was reported by the author(s).

Data deposition

The dataset and ratings are available in the Open Science Framework repository at the following link https://osf.io/dcwt8/

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