

Sensorimotor Grounding of Chinese Novel Concepts Constructed From Language Alone

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Abstract—The embodied cognitive view of language asserts that concepts are grounded in sensorimotor experience. In support of this assumption, previous studies have shown that the response times were faster when the movement direction of participants is congruent with the referent position of presented words than that under incongruent condition. This is thought to be evidence that processing these words reactivates sensorimotor experiential traces. Extrapolating from this view, this study aims to explore how concepts without direct experience can be grounded. Participants learned novel concepts related to upward or downward concepts only through a two-sentence description and learned randomly paired novel words. In both experiments, participants judged the sensibility of sentences by upward or downward movements, with the sentences containing novel concepts in Experiment 1 and containing novel words in Experiment 2. Both two experiments found the congruency effect, indicating that when understanding a sentence containing a novel concept or novel word, the sensorimotor experience of the already known concepts in description had been activated automatically, thus realizing the indirect grounding of the novel concept.

Index Terms—sensorimotor experience, grounded cognition, Chinese novel concepts, language comprehension

I. INTRODUCTION

An extraordinary and powerful cognitive skill that distinguishes humans from the vast majority of other animals is the capability to use symbols and to engage in symbolic thought. In the human mind, words serve as symbols, and the corresponding concepts are thought to be represented in the form of symbols. Language comprehension is a psychological process in which people construct meanings in their minds by processing these verbal symbols (Price, 2012). However, over the past two decades, there has been extensive debate in the field of language comprehension about the nature and format of this symbol representation.

As the most representative traditional view of language comprehension, Amodal System Theory holds that concepts are stored in our minds in an abstract, amodal, and arbitrary way. Critically, according to this theory, concepts are always defined by other concepts shared with similar features. Taking an example to illustrate: the concept CAT can be described by propositions such as IS (CAT, ANIMAL) and HAS (CAT, TAIL). Language comprehension is achieved by the collection of these abstract, amodal and arbitrary symbols, without the involvement of the sensorimotor system. However, as the experiments of Searle (1980) and Harnad (1990) have shown, this view is faced with the symbol grounding problem, that is, how to make the semantic interpretation of the symbolic system relate to the real world, not only to the meaning in our heads.

A prominent solution to the symbol grounding problem in cognitive psychology is the grounded cognition view, also known as the embodied cognition of language, emphasizing that the concept system and semantic memory needs to be grounded in sensorimotor experience with the outside world (Glenberg & Kaschak, 2002; Barsalou, 2008; Zwaan & Madden, 2005). This view puts forward the argument that conceptual representation is not independent of the bodily action and perception, and therefore is not amodal and arbitrary; Instead, it retains the experiential traces of perception and action generated when individuals interact with the real world in the process of acquiring conceptual meaning. Therefore, language comprehension is the reactivation process of these sensorimotor experiential traces, relying on the same cognitive system. Taking an example to illustrate this point: the concept CAT is a mental entity, while cats are entities in the outside world; however, this concept is very similar to our cognitive experience of real cats. For example, a child sees a kitten wagging its tail, hears it meowing, or touches it, and simultaneously the adult tells him 'This is a cat'. So when he hears or thinks about the word 'cat' in another situation, these experiences of seeing, hearing, and touching a cat will be reactivated. It is consistent with the Experiential Trace Model proposed by Zwaan and Madden in 2005: grounding is established through systematic co-appearance between linguistic stimuli (e.g., hearing the word cat) and sensorimotor experience (e.g., seeing, hearing, or touching a cat) in which linguistic stimuli act as cues to reactivate sensorimotor experience during processing. According to Gunther et al. (2019), this kind of co-occurrence is the main

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organizing principle of our conceptual system: For instance, in the above example, the concept CAT is constructed by grounding in sensorimotor experience.

In the framework of grounded cognition, a number of studies provide empirical evidence for the activation of sensorimotor experience during language comprehension. Among them, some experiments performed sentence-picture verification tasks and found that the comprehension of concrete concepts can activate visual representation in multi-dimensions, such as the implied color, orientation, shape, spatial information of objects (e.g. Öttl et al., 2017; Stanfield & Zwaan, 2001; Zwaan et al., 2002; Lachmair et al., 2011). On this basis, Glenberg and Kaschak (2002) applied the timed-sensibility judgment to discover the effect associated with language comprehension: the action-sentence compatibility effect (ACE), which is based on the idea that if participants perform mental imagery, using neural structures dedicated to motor control, then understanding action-based sentences should facilitate actually performing compatible motor actions. Specifically, when the action required to be performed is consistent with the action described in the stimulus sentence (or the representation information implied in the sentence), the speed of participant's comprehension will be accelerated.

Although all these empirical studies provide strong support for grounded theory, there are still some unsolved limitations to these results. First of all, previous studies of language comprehension mostly remain on the level of concrete words or sentences, but in fact, new words are often required from language alone, without specific referents in the real world and without any accompanying information of perceptual environment or sensorimotor experience. Rare studies set out to face this serious challenge of the extensibility of grounded cognition: how can the novel concepts without direct experience ground in sensorimotor experience?

What's more, as for the experimental materials, most studies on grounded cognition do not explicitly focus on the linguistic traces, but mainly consider them only in their role as cues to reactivate sensorimotor experience. As for the methodology, previous studies in embodied language comprehension to some degree were not complete and comprehensive in terms of the paradigms and the replication of experiments. First, most earlier studies employing shallower paradigms that is designed to detect low-level automatic activation, for example the color-judgment task even without requiring lexical access in the experiment given by Fischer and Zwaan (2008). Second, as the Papesch's study (2015) has shown, some experimental results of the consistency effect cannot be replicated in other experiments, that is, the experimental paradigm are not adequate to investigate sensorimotor activation under the embodied language comprehension.

In addition, previous research on embodied language comprehension, mainly focused on Indo-European languages such as English, Spanish and Dutch. So to a certain extent, the research results limit its universality. The Indo-European language belongs to the alphabetical one, characterizing with rich morphological inflections, which providing much convenience for the embodied language comprehension, especially in ACE verification. Yet Chinese, belonging to the ideographic language with its unique character system, is different from Indo-European languages. How can the new concept of Chinese which acquired purely through language ground in sensorimotor system? Is it different from other languages? This problem deserves further study. Therefore, the current study applied the paradigm in Gunther's 2020 study to perform a language comprehension task under Chinese context.

II. METHODOLOGY

A single two level design for congruency (congruent vs. incongruent) was used in the experiment. Congruent condition meant that the vertical location information (up or down) of the novel concept in the stimulus sentence was consistent with the response direction (upward or downward action) of the participants; incongruent condition refers to that the vertical location information (up or down) implied by the novel concept in the stimulus sentence is not consistent with the response direction (upward or downward action) of the participant. Secondly, to avoid the sequential effect, all participants are divided into two groups (odd and even) according to whether their experiment numbers were odd or even, and different group has different experimental instructions when they made the upward or downward movement to judge the sensibility of sentences. The independent variable of the experiment is the congruency condition and the dependent variables are the response time and accuracy.

A. Experiment 1

In the first experiment, this study aimed to test whether congruency effects occur during the processing of sentences describing an action with novel concepts learned from purely linguistic input.

1. Participants

Forty six native Chinese participants took part in the experiment for a reward of a nice gift at the end of the experiment. They were volunteer students in Dalian University of Technology (25 females and 21 males, Mage=23.3 years, SD=2.13), normal or corrected-to-normal vision and no brain damage.

2. Materials

The materials for this experiment were based on eight novel concepts shown in Table 1 which were created by combining familiar words with concrete words referring to objects (4 typically located in upper locations and 4 in lower

locations). Pretest was conducted to investigate the familiarity of these concepts to make sure that none of the concepts had an associated word in Chinese and participants had no direct experience with them. Moreover, each novel concept had a two-sentence description explaining it in more details (see Table 2). As in the study by Gunther et al. (2020), another eight novel words, which are the two-character compound non-words that had a Chinese phonemic and subsyllabic structure constructed and demonstrated by Chinese lexicon project (Sze, 2014), were adopted as labels for the novel concepts. None of them was associated with the vertical location on its own.

TABLE 1
TYPE SIZES FOR CAMERA-READY PAPERS

Novel concepts	Implied location
变色头发(color-changing hair)	up-related
易容帽子(makeup hat)	up-related
暖气天花板(heating ceiling)	up-related
红外线楼顶(infrared roof)	up-related
导航车轮(guided wheel)	down-related
蓝牙袜子(Bluetooth socks)	down-related
遥控鞋(remote-control shoes)	down-related
温泉地板(hot spring floor)	down-related

Using these eight novel concepts, this study constructed 80 sentences (ten per concept) of the format “You *VERB* your *NOVEL CONCEPT*”. Among the ten sentences per concept, 5 sentences described plausible hand movements, and the other 5 sentences described implausible hand movements. Taking care that the 23 verbs (e.g., 安装, 操控) did not imply any vertical movements on their own. Furthermore, since all verbs occurred in both sensible and nonsensical sentences, participants could not rely on the verb semantics to judge the sensibility of a sentence. In addition, ten training sentences (five plausible, five implausible) were also constructed and did not describe vertical movements. And one thing to add that, none of the nouns used in the training materials appeared in the experimental block.

The experiment was conducted on a standard computer and was programmed using E-Prime 3.0 software. Stimuli in the learning phase and the test phase were presented on a 14-inch monitor screen with a screen resolution of 1366*768. Participants sat in front of the computer with his eyes 60 cm from the center of the screen and experimental stimuli were Song font size 36, displayed in white in the center of the black screen. Responses in the test phase were recorded using a vertically mounted computer keyboard which had three equal size buttons with special overlay and arranged vertically: a lower button (key “0”) overlaid with upward arrow, a middle buttons (key “1”), and an upper button (key “4”) overlaid with downward arrow.

3. Procedure

Before the test phase, participants had to go through the learning phase to learn the novel concept from language alone. The whole experiment took about 25 minutes for each participant.

a. Learning Phase

Eight different learning items were constructed for each participant by randomly pairing eight novel words with the eight novel concepts as well as their corresponding two-sentence descriptions. First, participants were instructed to learn these eight items, as shown in Table 2. These pairings were fixed within each participant, but randomized over participants. Following this initial presentation, participants were asked to recall and type in the respective novel concept paired with novel words randomly presented on the screen. Novel words were presented one at a time, in the center of the screen. Participants would receive feedback for their answers, and all items should be answered correctly two times in a row. If they gave the wrong answer, they would be tested on the novel word meanings once again. It was done to ensure that participants indeed correctly memorized the pairings for all eight novel words.

TABLE 2
EXAMPLES FOR LEARNING PHASE ITEMS

爵与(JueYu) = 蓝牙袜子(randomly paired novel concept)
爵与是一款通过蓝牙连接的高科技袜子。连接手机后即可开启按摩功能, 缓解长时间散步、购物或坐在办公室的疲劳。(JueYu is a kind of high-tech sock. JueYu can connect to your phone via Bluetooth to activate the massage function, relieving fatigue from long walks, shopping or sitting in the office.)

b. Test Phase

The experiment was divided into four blocks including two training blocks and two experimental blocks. In order to familiarize participants with the task instruction and the response device, each experimental block was preceded by a

training block consisting of ten training sentences. Then, the 80 sentences were presented in the first experimental block in random order, with the restriction that the same novel concept did not appear continuously to avoid the priming effect. The experimental procedure was shown in Figure 1.

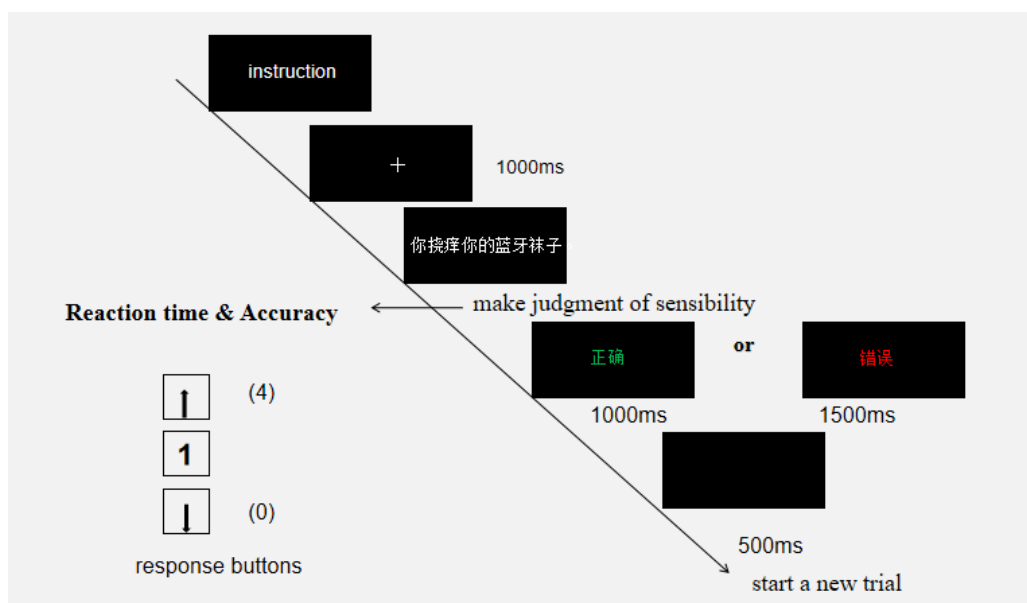


Figure 1. The Procedure of One Trail in Experiment

As shown in Figure 1, participants started each trial by holding down the middle button of the keyboard after the instruction sentence “请用右手食指按住 1 键” (Please hold down the key “1”). Pressing the button lead in a white fixation cross on the black background for 1000 ms. Then, one of the experimental sentences (e.g. 你按摩你的蓝牙袜子) appeared in the center of the screen in white letters on black background. Participants were instructed to judge whether the sentences presented to them described a sensible action or not. Participants were divided into two groups: Participants in the odd group were instructed to release the middle button and to press the upper button when judging a sentence as plausible, and to release the middle button and to press the lower button when it is implausible; while the other half participants who in the even group performed the opposite action instruction. All responses to sensible sentences were to be made with the dominant hand. The time from the presentation of the stimulus to the release of the middle button was recorded as the reaction time. According to their response, feedback was given on the screen: 正确 (correct) in green letters for 1000 ms or 错误 (error) for 1500 ms in red letters. After the presentation of a blank black screen for 500 ms, a new trial started.

Before initiating the second experimental block, the response instruction would be reversed: Participants in the odd group were instructed to release the middle button and to press the lower button when judging a sentence as plausible, and to press the upper button when the sentence was implausible; while participants in the even group performed the opposite action instruction. Participants were also asked to practice 10 training sentences in the second training block.

B. Experiment 2

The critical second experiment was set up to rule out that the congruency effect in the first experiment was a surface-level effect merely caused by the basic concepts implied up or down vertical information in the sentence. Furthermore, the Experiment 2 was designed to test whether novel concepts, whose novel labels were learned from language alone, could be indirectly grounded in sensorimotor experience.

1. Participants

43 native Chinese students in Dalian University of Technology (31 females and 12 males; mean age =22.95 years, SD=2.25), with normal or corrected-to-normal vision, volunteered to take part in the second experiment. None of the participants had taken part in Experiment 1.

2. Materials and Procedure

Experiment 2 was identical to Experiment 1, except for the experimental sentences: As mentioned in the learning phase, participants learned the pairs of novel words and novel concepts. Experimental sentences in Experiment 2 were modified by replacing the novel concepts in the sentences in Experiment 1 with its corresponding novel words as labels.

III. RESULTS ANALYSIS

SPSS 25.0 software was adopted to analyze the behavioral measures including the reaction time of releasing the middle button and accuracy of pressing the upper or lower button.

A. Analysis of Experiment 1

First, all implausible and practice trials were excluded from the data set. Then further omitted the data from three participants with high error rates (defined as higher than 30% error rate of reasonable or unreasonable sentences) and all data for a high-error sentence (less than 65% correct answers). All error trials (11.2% of trials) were eliminated from the data set in the analysis of reaction time. Secondly, the quantile method was used to eliminate the absolute outliers with extremely long or extremely short reaction times (faster than the 0.01-quantile, 596 ms, or slower than the 0.98-quantile, 6697 ms), and the relative outliers (3% of trials) of each participants deviating more than 2.5 SDs from the mean value under each condition.

Using these data, this study opted for the more stable option of modelling a single two-level congruency effect instead of the interaction models between response direction and sentence direction. F_1/F_2 -ANOVA analysis was did with repeated measurement in the by-participants analysis (F_1) and repeated measurement on response direction in the by-items analysis (F_2). Here, items refer to the 20 random pairs among 80 different experiential sentences, and one item pair includes a congruent sentence and an incongruent sentence.

TABLE 3
 F_1/F_2 -ANOVA OF REACTION TIMES IN EXPERIMENT 1

	MEAN. RT(MS)		F	SIG.	PARTIAL η^2
	CONGRUENT	INCONGRUENT			
WITHIN-PARTICIPANTS	1796±558	1884±633	8.162	0.007	0.163
WITHIN-ITEMS	1784±115	1877±103	12.956	0.002	0.419

The results are as follows: In the by-participants analysis, release times in the congruent condition (1796ms) were faster than in the incongruent condition (1884ms), amounting to a congruency effect of 88 ms; in the by-items analysis, reaction times in the congruent condition (1784ms) were also faster than in the incongruent condition (1877ms), resulting in a congruency effect of 93 ms. What's more, the congruency effects of both analysis are significant ($F_1(1, 42) = 8.162, p = 0.007 < 0.05$, partial $\eta^2 = 0.163$; $F_2(1, 19) = 14.207, p = 0.001$, partial $\eta^2 = 0.428$).

In summary, the well-above results demonstrate that people can learn the novel concepts from language alone and use them in reading tasks. Furthermore, the results demonstrate that the congruency effect was found during language comprehension task, even when the experimental sentences include novel concepts, indicating that the experimental setting was suitable.

B. Analysis of Experiment 2

The data processing of Experiment 2 was consistent with that in Experiment 1. First, all implausible and practice trials, and all data for a high-error item (你打开你的易容帽子, You open your makeup hat) were excluded from the data set. Here, an item is defined at the meaning level of the original sentence. That means, all trials in the meaning of 'You open your makeup hat' were excluded from the analysis, regardless of which novel words were paired with the novel concept 'makeup hat'. Then, following the same method used in the first experiment, all error trials (13% of the data), the absolute outliers trials and the relative outliers trials were eliminated from the data. The F_1/F_2 -ANOVA analysis with repeated measurement in the within-participants analysis (F_1) and repeated measurement on response direction in the within-items analysis (F_2) were also conducted in Experiment 2.

TABLE 4
 F_1/F_2 -ANOVA OF REACTION TIMES IN EXPERIMENT 2

	MEAN. RT(MS)		F	SIG.	PARTIAL η^2
	CONGRUENT	INCONGRUENT			
WITHIN-PARTICIPANTS	2970±794	3105±875	7.96	0.007	0.159
WITHIN-ITEMS	2938±195	3127±239	18.315	0.000	0.504

From the results of Table 4, we also can observe a significant congruency effect in the within-participants analysis ($F_1(1, 42) = 7.96, p = 0.007 < 0.01$, partial $\eta^2 = 0.159$), for which the reaction time in the congruent condition (2970 ms) were 135 ms faster than that under the incongruent condition (3105 ms). In the within-items analysis, the releasing time in the congruent condition (2938 ms) were also faster than that under the incongruent condition (3127 ms), and the effect was extremely significant ($F_2(1, 18) = 18.315, p = 0.000 < 0.001$, partial $\eta^2 = 0.504$).

Note that the mean response times in Experiment 2 were more than 1000 milliseconds slower than in Experiment 1, indicating that the task was more difficult. Moreover, the accuracy rate of participants in the congruent condition (86.5%) was higher than that in the incongruent condition (85.9%), suggesting that the consistency effect was not the result of a trade-off between speed and accuracy. Taken together, the congruency effect observed in Experiment 2 suggests that comprehension of non-vertically related novel words used to name novel concepts is grounded in sensorimotor experience.

IV. DISCUSSION

This experiment explores the sensorimotor grounding process of Chinese novel concepts in sentence comprehension. With the help of Stroop-like paradigm, and through statistical analysis of participants' reaction times under congruent and incongruent conditions, this study researched the influence of sensorimotor experience on sentence comprehension and how can concepts without direct experience ground in sensorimotor experience, implemented experimentally through novel concepts learned only from language. The main findings of the experiment are as follows:

(1). This study observed the congruency effect in both experiments: Reactions were faster when the implied vertical location of novel concepts matched the direction of the hand movement. Specifically speaking, upwards-reactions were faster for the sentences with up-related novel concepts that were learned from up-related context than downward-reactions, and vice versa. It is indicating that the novel concepts were indirectly grounded via the experiential traces of the already-known concepts they were learned from the descriptions. These experiential traces were reactivated automatically upon encountering the novel concepts in the plausible or implausible sentences. It's important to emphasize that this is the crucial difference between the current study and previous studies without demanding comprehension tasks. What this paper found is in line with grounded theory, holding that conceptual system need to be grounded in sensorimotor experience, and in line with embodied cognitive view that language comprehension is a simulated process in which sensorimotor experience is reactivated.

(2). Another important findings in this study was that the direct sensorimotor experience is not a necessary condition for conceptual grounding, for which the participants had no direct experience with the novel concepts and novel words, but the consistency effects were still found in both experiments of this study. Therefore, concepts without direct experience can be indirectly grounded through existing sensorimotor experience, greatly contributing to broadening the boundaries of grounded theory and highlighting the important role played by the experience with linguistic stimuli in the experiential trace model. In previous cognitive studies, language traces were mostly served as cues to reactivate sensorimotor experience. However, the present study further found that these language traces play another vital role, that is, they serve as a bridge for indirect grounding of new concepts and novel words. As put by Harnad in 1990 that grounding can be achieved by relying on the existing conceptual system and semantic representations, and combining the congruency effects found in this study, it can be concluded that language plays a crucial role in expanding our conceptual system.

(3). The third finding is that: The sensorimotor activation occurs automatically, as it is in no way required to perform the task at hand. In other words, the sensibility of an action described in the test sentence does not depend on the vertical location of the object. Instead, it depends on whether the collocation of neutral verbs and novel concepts makes sense. Therefore, it would also suggest an actual motor simulation of the described action, rather than just a re-enactment or the re-activation of past experience: The specific actions described in the experimental sentences have never been performed before, since these objects are novel concepts.

(4). In addition, there was another surprise finding in this study: the experimental findings were consistent with the previous research results, but compared with the effect size of the original experiments with German as the stimulus (44ms and 56ms), the difference of response time in both two experiments under different conditions was greater in the current study (88ms and 135 ms). This may have something to do with the difference between Chinese and Indo-European languages: Chinese native speakers tend to perceive things in the real world through vertical space. The interaction between language comprehension and spatial perception has attracted the attention of many researchers: human recognition and action of objects in the environment depend on the ability of spatial representation. Li Heng's research in 2013 also found that even infants already have spatial experience in their mother's womb, so spatial representation is of great significance to human survival and development. In particular, many abstract concepts in Chinese are grounded through vertical spatial experience, such as grounding abstract concepts of emotions (e.g. “高兴 happy” and “低落 sad”) via space (e.g. Li, Ma & Ye, 2012; Lv & Lu, 2013), grounding abstract concepts of morality (e.g. “noble” and “indelicate”) via space (e.g. Wang et al, 2020), grounding abstract concepts of power (e.g. “高官 dignitary” and “平民 civilian”) via space (e.g. Zhang et al, 2013), grounding time (e.g. “上午 morning” and “下午 afternoon”) via space (e.g. Wang et al, 2006) and so on. Therefore, this study suggests that spatial representation plays an important role not only in low-level perceptual and motor processing, but also in high-level cognitive processing such as language comprehension.

This is a major stepping stone in scaling up sensorimotor grounding to the non-experienced parts of the conceptual system. And it offers a perspective on the role of linguistic stimulus in the activation of sensorimotor experience. In addition, the obtained consistency effects further prove the reliability of embodied cognition theory and the replicability of experimental paradigm of grounded cognition in Chinese context. However, the role of sensorimotor information in language comprehension is not clear. In other words, this study does not provide a clear answer to the question of how perceptual processing interacts with language comprehension. Therefore, future research can explore the interaction mechanism between the two.

V. CONCLUSION

In summary, using Chinese novel concepts and Chinese two-character novel words as experimental materials, this study obtained the same discovery as the experiment of Gunther et al. (2020), that is, novel concepts without direct

experience can be indirectly grounded in sensorimotor experience. This further confirms and expands the grounding theory, showing that our conceptual systems are based on our bodies and experiences.

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