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Spatial language promotes cross-domain associations in early childhood

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Abstract

Spatial language is often used metaphorically to describe other domains, including time (a *long* sound) and pitch (a *high* sound). How does experience with these metaphors shape the associations we make across disparate domains? Here, we tested 3- to 6-year-old English-speaking children and adults with a cross-domain matching task that assessed space-time and space-pitch mappings. We tested spatial relations that are expressed in English metaphors for time and pitch, as well as metaphors that are unfamiliar to English speakers, but expressed in other languages. Participants performed a perceptual matching task, in which they matched pictures and sounds, and a linguistic matching task, in which they matched pictures or sounds to verbal labels. Adults readily matched between space and time and between space and pitch, using relations expressed by both familiar and unfamiliar metaphors. Children showed an advantage for linguistic matching compared to perceptual matching, but their performance was similarly unaffected by metaphor familiarity. Together, these results suggest that spatial language promotes the development of cross-domain associations, and that experience with particular spatial metaphors is not required to produce this benefit.

Keywords: metaphor theory; linguistic relativity; cross-modal matching

Introduction

Across languages and cultures, spatial language is frequently co-opted to describe other domains. In English, for example, we describe temporal duration as *long* or *short*, numbers as *big* or *small*, and auditory pitch as *high* or *low*. What can the prevalence of these spatial metaphors tell us about how we represent and reason about these other non-spatial domains? Previous work has demonstrated that spatial metaphors are not simply a communicative tool. Instead, they reflect our mental representations of non-spatial domains (Boroditsky, 2001; Casasanto & Boroditsky, 2008; Dolscheid, Shayan, Majid, & Casasanto, 2013). Here, we test how experience with spatial metaphors over development influences children's cross-domain associations.

Although spatial metaphors are common across languages, there is also variety in the exact spatial relations invoked. This cross-linguistic variation can be used to test hypotheses about the role of linguistic experience in the development of cross-domain associations. For example, in English, temporal durations are described in terms of two-dimensional length, whereas languages including Greek and Spanish use three-dimensional spatial terms. Likewise, though English describes pitch in terms of height, languages including Turkish and Farsi use terms related to thickness (i.e., such that thicker sounds are lower in pitch).

Linguistic experience is not required to recognize cross-domain associations. Many studies have demonstrated that prelinguistic infants are already sensitive to many types of these correspondences (de Hevia & Spelke, 2010; Lourenco & Longo, 2010; Mondloch & Maurer, 2004; Srinivasan & Carey, 2010; Walker et al., 2010). Even neonates, for example, associate longer spatial lengths with longer temporal durations and larger numerical magnitudes (de Hevia, Izard, Coubart, Spelke, & Streri, 2014). With regards to associations between pitch and space, infants appear to recognize both height-pitch and thickness-pitch mappings, even when only one of these associations is encoded in the language they are learning (Dolscheid, Hunnius, Casasanto, & Majid, 2014; Walker et al., 2010; but see Lewkowicz & Minar, 2014).

However, according to one recent study, young children may be less flexible than infants (Shayan, Ozturk, & Bowerman, 2014). This study investigated thickness-pitch mappings in 2- to 5-year-old children who spoke either German, Farsi, or Turkish, and found that while Turkish and Farsi speaking children (who speak languages that employ a thickness metaphor for pitch) can reliably map thickness to pitch, German-speaking children (who speak a language that does not employ a thickness-pitch metaphor) cannot. This finding suggests that maintenance of cross-domain associations between space and pitch may be dependent on the type of metaphorical mappings reinforced by language, at least during childhood.

In explicit matching tasks, adults appear to be more flexible than children. Adults can match pitch to both thickness and height, for example, and more generally can form mappings across innumerable domains, regardless of whether their language employs the relevant metaphors (Marks, 1978; Shayan et al., 2014) However, experience with linguistic metaphors does appear to influence the automaticity with which cross-domain associations are processed in adults. In one study, adult speakers of Dutch readily matched pitch to thickness in an explicit task, but their representations of pitch were only biased by irrelevant spatial height information and not by irrelevant thickness information (Dolscheid et al., 2013). This suggests that Dutch-speaking adults automatically process a height-pitch mapping but not a thickness-pitch mapping. The reverse pattern of results – a biasing effect of thickness but not height on pitch representations – occurs for Farsi speakers, consistent with the idea that experience with language-specific spatial metaphors influences the automaticity with which cross-domain associations are accessed. A parallel pattern of results for the case of space-time mappings has been reported from English and Greek-speaking adults. In this study, temporal duration judgments in English-speaking adults were biased by only irrelevant variation in spatial length (and not irrelevant volumetric information), and duration judgments in Greek-speaking adults were biased only by irrelevant volumetric information (and not irrelevant spatial length; Casasanto, 2008).

In sum, prior research suggests that experience with one's own language's spatial metaphors affects children's explicit cross-domain associations, as well as adults' implicit cross-domain associations. This suggests that experience with spatial metaphors may have a persistent influence on cross-domain associations throughout the lifespan. Here, we expand on previous studies of the development of cross-domain associations by testing both space-time and space-pitch associations, and by directly comparing the effects of familiar versus novel metaphors in the same population. In addition, we test a large number of children between the ages of three and six years to gain insight into the fine-grained developmental trajectory of cross-domain associations. We test how children's experience with spatial metaphors influences their cross-domain associations by focusing on three critical factors.

First, we contrast cross-domain associations between space and time compared to associations between space and pitch. We focus on associations with time and pitch because while both time and pitch are frequently described using spatial language, they have different dimensional structures. Time, like spatial extent, is a prothetic dimension, meaning that it can be represented by an ordered continuum of increasing amount (Stevens, 1957). Differences in temporal duration and spatial extent are therefore quantitative. Pitch, on the other hand, is a metathetic dimension, meaning that differences in pitch are qualitative – pitches vary in frequency rather than amount. Therefore, it is possible that the shared ordinal structure of space and time may provide a specific advantage for cross-domain space-time mappings that does not extend to space-pitch mappings.

Second, we investigate the effect of experience with specific spatial metaphors by testing whether English-speaking children are better able to match domains in ways that reflect familiar spatial metaphors compared to unfamiliar metaphors. For time, we compared children's ability to map between sounds that varied in temporal durations and images that varied in either length (*long* vs. *short;* familiar relation) or in overall size (*big* vs. *small;* unfamiliar relation). For pitch, we compared children's ability to map between sounds that varied in auditory pitch and images that varied in either height (*high* vs. *low;* familiar relation) or thickness (*thin* vs. *thick;* unfamiliar relation). If experience with specific spatial metaphors constrains children's cross-domain associations, then matching performance should be higher for the familiar relations compared to the unfamiliar relations. In addition, the difference in performance between familiar and unfamiliar relations may increase with age, as children gain more experience with their language-specific spatial metaphors.

Finally, we probe whether children are better at matching across domains when the spatial metaphors are verbally labeled – even when the metaphors are unfamiliar – compared to when the task is purely perceptual. Previous research suggests that verbal labels may help children organize their representations of perceptual domains by providing cues as to how to align the endpoints of disparate domains (Smith & Sera, 1992). For example, if children understand that the word *long* in a spatial context refers to greater spatial extent, this may provide a cue for understanding that *long* in a temporal context refers to a greater temporal duration. Therefore, children's non-linguistic ability to successfully map across domains (as measured by a perceptual matching task) may be enhanced by the presence of verbal spatial labels (as measured by a linguistic matching task).

Methods

Participants

80 children aged 3 to 6 years (mean age: 4.89 years, range: 3.13-6.98 years) and 16 adults (mean age: 21.25 years, range: 18.63-27.59 years) participated in this study. All participants were native English language speakers who were not regularly exposed to or fluent in a second language. Data from an additional 17 children and 6 adults were excluded from analyses due to proficiency with another language (9 children, 5 adults), failure to complete the experiment (5 children), inattention (3 children), or performance more than 3 standard deviations below the group mean (1 adult).

Materials

Spatial stimuli consisted of pictures of cartoon aliens that varied in length (familiar space-time metaphor), overall size (unfamiliar space-time metaphor), vertical position (familiar space-pitch metaphor), or thickness (unfamiliar space-pitch metaphor). Temporal stimuli consisted of monotonic tones that varied in either duration or auditory pitch. Tones that varied in duration had a constant pitch of 384 Hz and were either 1 second or 3 seconds in length. Tones that varied in pitch had a constant duration of 2 seconds and a pitch of either 256 Hz or 512 Hz. All stimuli were presented using a laptop computer.

Procedure

Participants' cross-domain matching ability was tested for both space-time and space-pitch pairings. Adult participants completed both the familiar (long/short for space-time and high/low for space-pitch) and unfamiliar (big/small for space-time and thin/thick for space-pitch) pairings. The order of the space-time and space-pitch blocks was counterbalanced across subjects, and the unfamiliar pairing always preceded the familiar pairing within each block. Child participants completed one block of space-time pairings and one block of space-pitch pairings, with the order of the blocks and assignment to the familiar versus unfamiliar pairings counterbalanced across participants.

All experimental sessions began with the familiarization trials. At the beginning of each block, participants were first shown pictures of both relevant aliens and listened to both types of sounds. Within each block, the perceptual matching task always preceded the linguistic matching task so as to not bias participants' responses. Adults performed 8 trials of each task type, and children performed 4 trials of each task type.

Familiarization Trials

The familiarization trials were designed to have the same structure as the test trials and involved matching pictures of animals to the appropriate sounds. In the first two trials, two animals were displayed on the screen. An animal sound was then played, and the participant was instructed to point to the animal that makes that sound. In the second two trials, one animal appeared centrally on the screen in front of two trees. The participant was told that the animal was looking for another animal just like it that was hiding in the jungle. The experimenter said that the animal was hiding behind one of the trees, and played a sound from each tree. The participant was instructed to point to the side where the animal sound that matched the visible animal was heard.

Test Trials

Perceptual Matching Task In the perceptual matching task, participants matched pictures of aliens to the types of sounds they make. Critically, in these trials verbal labels were never used to describe the stimuli. There were two trial types: *space as source* (the referent is a spatial dimension and participants chose the sound that matched in pitch or duration) or *space as target* (the referent is a sound that varies in pitch or duration and participants chose the alien with a matching spatial attribute). For the space as source trials, a single alien was presented in front of two trees and the experimenter said that the alien was looking for another alien just like it. The experimenter said that the alien could be hiding behind either tree, and pointed to each tree as the sound of the alien hiding behind it was played. The participant was asked to point to the tree that had an alien behind it that was just like the visible alien. For the space as target trials, two aliens were presented on the screen and a single sound was played. The participant was instructed to choose which of the aliens is the one that makes that sound.

Linguistic Matching Task In the linguistic matching task, a verbal label was used to describe either the appearance of an alien or the type of sound made by an alien, and the participant matched this label to one of two exemplars in the opposite dimension. In the *space as source* trials, the spatial dimension was described and participants chose one of two auditory matches (e.g., the participant is told that a long alien is looking for another long alien just like it, and the long alien is hiding behind one of two trees; the two sounds are played and the participant chooses the sound that a long alien makes). In the *space as target* trials, the type of sound was described and participants chose which of two visually presented aliens makes that type of sound (e.g., the experimenter asks the participant which of two aliens makes a long sound).

Results

Accuracy for all matches was scored as correct if the match was in the direction reflected by spatial metaphors in language (e.g., matching the long or big alien to the long tone and the short or small alien to the short tone). Children's performance was analyzed using a repeated measures ANOVA with match type (perceptual or linguistic) and match direction (space as source or space as target*)* as within-subjects factors and dimensio*n* (space-time or space-pitch), familiarit*y* (familiar or unfamiliar), and age as between-subjects factors. This model yielded a significant main effect of age ($F(3, 144) = 5.35$, $p < .005$; Figure 1A) and a significant main effect of match type ($F(1, 144) = 17.14$, $p < .001$; Figure 1B). Interestingly, neither the main effect of dimension nor familiarity was significant, indicating that overall children were equally proficient at matching across space and time compared to space and pitch, and they performed just as well for spatial relations employed by English-language metaphors compared to unfamiliar space relations.

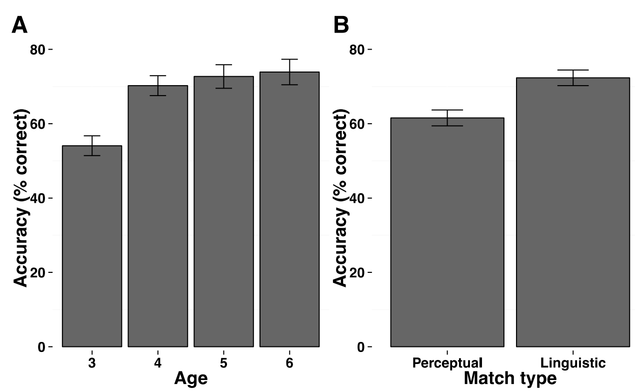

Figure 1: Children's cross-domain matching performance by age group (A) and by match type (B). Error bars indicate SEM.

Planned post-hoc comparisons revealed that 3-year-olds performed worse than the older age groups, all of whom performed at similar levels (3-year-olds: M = 54.08, SEM = 2.67; 4-year-olds: M = 70.24, SEM = 2.68; 5-year-olds: M = 72.70, SEM = 3.16, 6-year-olds = 73.9, SEM = 3.42; all *ts* for 3-year-olds vs. older children > 3.9, *ps* < .001; all *ts* between 4-, 5-, and 6-year-olds < .7, *ps* > .5). In addition, performance was better for the linguistic matching trials compared to the perceptual matching trials (linguistic matching: 72.34, SEM: 2.09; perceptual matching: 61.56, SEM: 2.13, $t = 3.12$, $p = .002$).

This analysis also revealed a significant interaction between match type and match direction ($F(1, 144) = 5.17$,

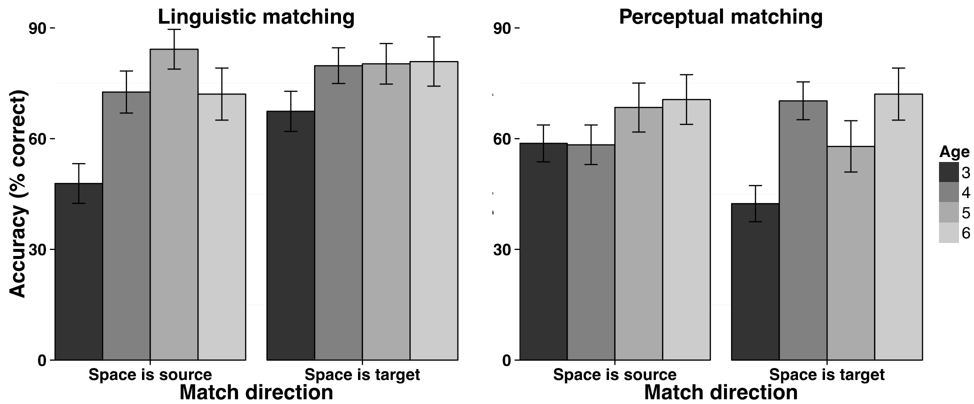

Figure 2: Children's matching performance on the linguistic and perceptual matching tasks, grouped by age and match direction. Error bars indicate SEM.

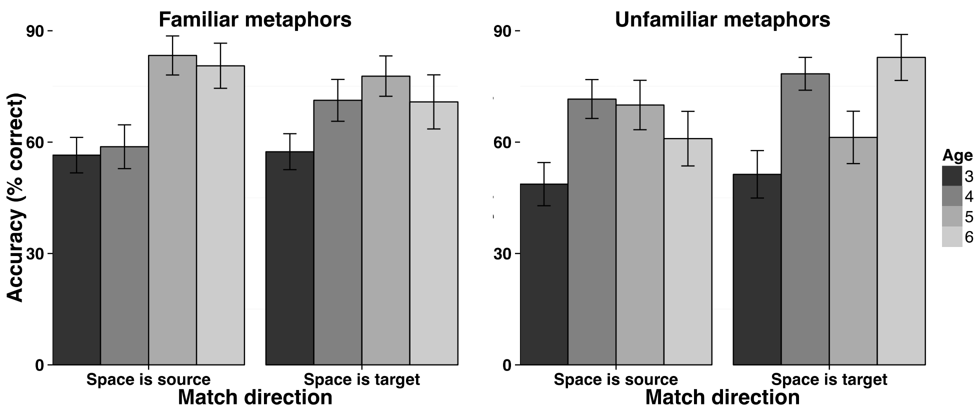

Figure 3. Children's matching performance for familiar and unfamiliar metaphors, grouped by age and match direction. Error bars indicate SEM.

$p < .05$) and significant three-way interactions between age, match direction, and match type ($F(3, 144) = 3.62$, $p < .05$), and between age, match direction, and familiarity ($F(3, 144) = 3.12$, $p < .05$). We analyzed the three-way interaction between age, match direction, and match type with separate ANOVAs for the linguistic and perceptual match trials (Figure 2). For the linguistic matching trials, the effects of both age and match direction were significant (*Fs* > 5.6, *p*s < .05). Overall, three-year-olds performed worse than older children, and performance was higher when space was the target dimension compared to the when space was the source dimension. For the perceptual matching trials, the main effect of age and the interaction between age and match direction were significant (*Fs* > 2.8, *ps* < .05), indicating that older children outperformed younger children, and particularly so when space was the target dimension.

We analyzed the three-way interaction between age, match direction, and familiarity with separate ANOVAs for familiar versus unfamiliar metaphors (Figure 3). For familiar metaphors, there was a significant main effect of age and a significant interaction between age and match direction (*Fs* > 3.6, *ps* < .05), indicating that older children performed better than younger children, and the age effect was particularly pronounced when space was the source dimensions. For unfamiliar metaphor trials, there were no significant main effects, but the interaction between age and match direction was significant ($F(3, 54) = 3.11$, $p < .05$), suggesting that the effect of age was more pronounced when space was the target dimension.

Adults' performance across all conditions was near ceiling (mean = 96.19, SEM = .51). Performance was analyzed using a repeated measures ANOVA with dimension (space-time or space-pitch), familiarity (familiar or unfamiliar), match type (perceptual or linguistic) and match direction (space as source or space as target) as within-subject factors. This analysis revealed no significant effects (*Fs* < 2.2, *ps* > .16), nor any significant interactions (*Fs* < 3.1, *ps* > .1). Therefore, adults performed equally well in all conditions.

General Discussion

The present work explored cross-domain associations between space and time and between space and pitch, and the role that experience with spatial metaphors may play in shaping these representations. English-speaking children and adults performed perceptual and linguistic cross-domain matching tasks for pairs of stimuli that varied in spatial extent and either temporal duration or auditory pitch. For both types of cross-domain pairings, we assessed matching performance for pairs that reflected familiar English-language spatial metaphors (length for time, height for pitch) or that reflected novel spatial metaphors not used in English (size for time, thickness for pitch). Consistent with previous work (e.g., Marks, 1978; Shayan et al., 2014), we found that adults readily matched time and pitch to both familiar and unfamiliar spatial attributes. Children's matching performance, however, revealed a nuanced developmental trajectory for these cross-domain associations, which we describe below.

Most notably, children's cross-domain matching performance was better for the linguistic matching task compared to the perceptual matching task. In the linguistic task, participants were provided with a verbal label that described a stimulus in terms of its spatial attributes, auditory pitch, or temporal duration, and needed to choose an exemplar from the other domain to match it. By comparison, in the perceptual matching task, participants matched the exemplars in the absence of a verbal label. This suggests that the presence of a verbal label conferred an advantage for cross-domain matching above and beyond matching the exemplars themselves.

Strikingly, we found that the verbal label provided an advantage even when it labeled a spatial relation not employed by English-language metaphors. In contrast to previous work (Shayan et al., 2014; but see Dolscheid, Hunnius, & Majid, 2015), we found no significant effect of metaphor familiarity on children's matching performance. Children were equally proficient at matching spatial relations across domains that reflected both familiar and novel metaphors. Although English-speaking children presumably have little experience with thickness metaphors for pitch, they matched thickness onto pitch just as readily as they matched vertical height onto pitch. Likewise, they matched overall size onto duration just as readily as they matched spatial length onto duration. Given that previous findings have provided mixed results as to whether familiarity with specific spatial metaphors is required for children's success in space-pitch matching tasks, it is unclear whether these contrasting outcomes should be ascribed to differences in procedure or population. In addition, familiarity in the present experiment was defined based on the presence or absence of specific spatial metaphors in the English language. Therefore, it is possible that individual differences in children's experience with these metaphors may influence their matching performance. Regardless, the present results suggest that young children, like infants and adults, can flexibly map abstract domains onto multiple spatial reference frames. We also found no significant effect of dimension on children's mapping performance, which indicates that the shared ordinal structure between space and time did not confer an advantage for mapping between these dimensions compared to mapping between space and pitch.

We found that verbal labels were most likely to improve performance for the youngest children when space was the target domain. On these trials, children were presented with two aliens and were asked to choose which one made a labeled sound (e.g., which alien makes a thick sound). Therefore, to match correctly, children could simply choose the alien whose visual appearance matched the label (e.g., a thick alien), without needing to represent the labeled sound (e.g., a thick sound). These were the trials on which three-year-olds performed the best, suggesting that understanding the spatial meaning of these words precedes understanding of the metaphorical meaning. Indeed, with regards to spatial metaphors for time, children typically produce the spatial meaning of the word earlier than the temporal meaning (Clark, 1973). However, for older children the performance benefit for linguistic trials held both when space was the target domain and when space the source domain. Therefore, it was not solely the trials on which children could match a label to a spatial attribute that drive this effect because there was also improved performance when children mapped the label to a sound. Instead, it seems that the presence of labels themselves improves children's cross-domain matching performance.

The finding that children perform better on the linguistic matching task compared to the perceptual matching task is consistent with previous work suggesting that language is a facilitating factor in the development of cross-domain associations. This work suggests that children may initially form mappings between the labels for two domains, such that the association between the labels then drives the perceptual mapping. For example, when forming an association between size and auditory volume, children may initially map the word *big* onto the word *loud* and the word *small* onto the word *quiet*, and this linguistic association may lead children to think of *loud* as being more than *quiet* and lead to an association between the perceptions of size and volume (Smith & Sera, 1992). This explanation can be logically extended to associations between space and time as well, with the common labels of *long* and *short* providing ordinal cues to children as to how to align and map these domains. However, it is less clear how this explanation applies to pitch, as the spatial metaphors used to describe pitch seemingly ascribe opposite ordinal anchors to the spectrum of pitch: both *thick* and *low* refer to low-frequency pitches, yet *thick* typically corresponds to *more* whereas *low* typically corresponds to *less*. Therefore, it seems that in the present task, labels must be providing an additional cue beyond an ordinal reference frame.

Another advantage that labels may provide is by clarifying what is otherwise an ambiguous task. When children are initially mapping between the pictures and the sounds, they may not spontaneously focus on the spatial attributes that are varying. However, labeling a particular dimension likely makes that dimension more salient, thus clarifying the goal of the task. For example, when shown a thick alien and asked which of two sounds that type of alien would make, children may not immediately recognize that they could consider the width of the alien when making their choice. However, when asked which of two sounds a *thick* alien makes, children may perceive thickness as a relevant attribute. Therefore, the act of labeling itself may provide an additional cue for mapping that is not present in the perceptual matching task.

Although our results suggest that children's matching performance increases with age, the largest change in performance occurred between ages three and four. Overall, three-year-olds performed at chance, whereas four-, five-, and six-year-olds all performed at similar levels above chance. From the present data it is difficult to determine whether this jump in performance reflects improvements in cross-domain mapping ability, or whether the demands of our matching task may be too taxing for three-year-olds. Given that cross-domain associations have been demonstrated in infants using more implicit tasks, additional work is needed to trace the development of these associations between infancy and early childhood. Further, the present study involved making explicit matches between domains. Although adults can form explicit mappings across a multitude of domains (Stevens, 1957), there are constraints on the types of cross-domain associations that occur implicitly (e.g., Casasanto, 2008; Dolscheid et al., 2013; Srinivasan & Carey, 2010). Therefore, it remains an open question whether children spontaneously associate space and time and space and pitch, and whether experience with particular spatial metaphors may influence the automaticity with which these associations are accessed. Reaction time measures may be useful for addressing this question, because implicit matching processes should proceed more rapidly than explicit matching processes.

Taken together, these findings suggest that spatial language promotes cross-domain associations in early childhood. Critically, this process appears to be equally accessible for spatial metaphors that are both familiar and novel, suggesting that experience with specific spatial metaphors is not necessary for forming these associations. Instead, spatial language may promote the perceptual organization of other domains by providing a reference frame for aligning these domains, as well as by highlighting relevant spatial attributes.

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