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To cite this version:

Lucas Raynal, Evelyne Clément, Pia Rämä, Emmanuel Sander, Louise Le Levier Goyet. Early Analogical Extensions: An ERP Study on Preschoolers' Semantic Approximations. 43rd annual meeting of the Cognitive Science Society, Jun 2021, Vienne (virtual), Austria. hal-03266957

HAL Id: hal-03266957

https://univ-paris8.hal.science/hal-03266957v1

Submitted on 22 Jun 2021

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Early Analogical Extensions: An ERP Study on Preschoolers' Semantic Approximations

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Abstract

This study investigates whether the ERPs of 4-years-olds in response to verbal overextensions reflect the encoding of actions through abstract categories. Participants were presented with images of actions (e.g. peeling an orange) while hearing a sentence containing a conventional verb (e.g. *peeling*), an approximative verb (e.g. *undressing*), a superficially related verb (e.g. *pressing*) or a pseudoverb (e.g. *rauging*). The N400 for approximative verbs significantly differed from the pseudoverb condition, but not from the conventional verb condition. In contrast, the N400 for superficially related verbs was significantly greater than for conventional verbs, but no significant difference was found with the pseudoverb condition. These results confirm our hypothesis that encoding mainly focuses on general categories (e.g. *taking of an envelope*). The implications of the findings are discussed regarding the conceptual organization of preschoolers and their analogical abilities.

Keywords: semantic approximation; overextension; analogy; abstract encoding; analogical extension; language acquisition; relational category

Introduction

When a young child says "Go on Mum, turn on your eyes", "I undress the orange" or "He breaks the book", what does it tell us about her thought (Duvignau, Fossard, Gaume, Pimenta & Elie, 2007)? It has been proposed that such *semantic approximations* denote a fundamental feature of human mind, which is to draw analogies with prior knowledge to make sense of new situations (Day & Goldstone, 2012; Hofstadter & Sander, 2013). The use of semantic approximations may reflect this process as they suggest that even very young children spontaneously encode new situations (e.g. peeling an orange) through general categories (e.g. *taking of an envelope*), allowing them to make analogies with concepts in memory (e.g. *undressing*). In this paper, we aim at providing a better understanding of the cognitive and neural processes underlying semantic approximations. To do so, we investigate the Event-Related Potentials (ERPs) associated with preschoolers' interpretation of semantic approximations.

The role of conceptual knowledge on analogy

The role of conceptual knowledge on analogical abilities has been highlighted in adults. Research on analogical encoding have shown that comparing analogs promotes the encoding of a relational category (i. e. a category mainly defined by relational properties) and enhances novices' abilities to detect relational patterns across different contexts (Goldwater & Gentner, 2015). Relational language (Jamrozik & Gentner, 2020) and prior knowledge about daily-life situations (Raynal, Clément & Sander, 2020) also play a critical role in adults' analogical abilities. Furthermore, experts have developed higher-order knowledge allowing them to detect similarities between superficially different analogs (Rottman, Gentner & Goldwater, 2012).

Relational language and analogical comparison also allows young children to learn relational categories and to apply them across superficially different exemplars (Doumas,

Sandhofer & Hummel, 2008). Gentner, Anggoro and Klibanoff (2011) presented young children with pairs of objects exemplyfing a relation (e.g. *knife : watermelon*) and tested whether they could extend the relational category to superficially different exemplars (e.g. choose the *scissors* as a *cutter for* a *piece of paper*). It was found that children both benefited from hearing a relational label (e.g. "the knife is the *dax* for the watermelon") and from being explicitly prompted to compare several category members (e.g. "You see how these [showing a knife and an ax] go with these [showing a watermelon and an evergreen tree] in the same way?"). Language and comparison may thus foster the acquisition of relational categories during childhood.

Goswami (2001) has argued that conceptual knowledge is determinant for early relational reasoning and that young children are able to make analogies as long as they are familiar with the shared relation. Children as young as 3 years of age (Goswami & Brown, 1990) performed well on solving four terms analogy tasks involving physical causal relations like *cut*, *break* or *melt*, which were supposedly very familiar to the participants (e.g. *chocolate bar : melted chocolate : : snowman : melted snowman*). A positive relation was also found between the familiarity of the relation as assessed by a control task and children's performance on the analogy task. These data show that preschoolers have a sufficient grasp of certain categories to draw analogies between superficially different exemplars.

The literature suggests that when given an analogy involving a familiar relation, preschoolers are able to map the two representations and to find their common relational category. However, less is known about whether young children are able to make spontaneous analogies between a representation in memory and a target situation. Children's use of semantic approximations seems to be highly informative on this matter (Duvignau et al., 2007; Hofstadter & Sander, 2013; Pouscoulous, 2011).

Verbal semantic approximations

Indeed, prior research has reported that young children sometimes interchange the use of words sharing abstract semantic relations. Most research documenting this type of errors has focused on verbs, since they typically refer to relational constructs as opposed to objects names (Gentner, 2006), although other types of words are also overextended on the basis of abstract relational similarities (Bowerman, 1978; Hofstadter & Sander, 2013).

Several studies have focused on how young children and adults categorized *cutting/breaking/tearing* events. It was shown that children use different criteria as adults do when labelling events of material destruction (Bowerman, 2012; Majid, Boster & Bowerman, 2008; Pye, Loeb & Pao, 1996). For instance, young children are more prone than adults to overextend the verb *break* to tearing events.

Duvignau coined the term "semantic approximations" to refer to children's substitution errors involving concepts sharing an analogical similarity (Gaume, Duvignau, Gasquet & Gineste, 2000). Duvignau et al. (2007) asked preschoolers of age 29 to 59 months, as well as adults, to describe several video-clips showing *damage*, *remove* and *separate* actions. It appeared that children used a greater number of semantic approximations than adults, and overextended verbs of both close (e.g. "she cuts the orange", instead of "peels") and more distant (e.g. "she undresses the orange") domains from the one of the action.

Whereas the literature on semantic approximations highlights that preschoolers encode actions at an abstract level, research has also documented other types of verbal overextensions suggesting that children focus on the object involved in the action. Saji et al. (2011) studied Chinese children's uses of 13 *carry/hold* verbs distinguishing actions according to the manner of holding the object (e.g. *duan*, carry with two hands with caution, *ding*, carry on head). Interestingly, they found that children were more prone than adults to apply a similar verb to different manners of holding as long as they are typically associated to the same object (e.g. *duan* and *ding* typically appear with bowls). Indeed, young children mainly relied on the (irrelevant) type of objects being held rather than on the manner of holding when categorizing actions. Thus, overextensions may be influenced by surface similarity to a certain extent.

The present study aims at investigating how preschoolers categorize actions. More specifically, we suggest that verbal semantic approximations reflect young children ability to encode general categories allowing them to make analogies between actions and approximative concepts.

ERP studies investigating conceptual organization

The ERP method appears to be particularly suitable to investigate categorization processes in young children. Previous research has also shown that ERP responses reflect the neural and cognitive processes involved in language comprehension. Indeed, some components are known to vary as a function of whether a given statement is more or less compatible with the way a situation has been categorized.

One of the most documented ERP components associated with language processing is the N400, a negative waveform relative to a reference, which is maximal around 400 ms after stimulus onset and measured typically over centro-parietal recording sites (Kutas & Federmeier, 2011). The N400 has been associated to the violation of contextual expectancies during sentence comprehension. In this line, Federmeier and Kutas (1999) demonstrated that the final word of a sentence (e.g. "They wanted to make the hotel more like a tropical resort. So along the driveway they planted rows of …") elicits a greater N400 when it is unexpected (e.g. "tulips") than when it is expected (e.g. "palms"). Furthermore, the N400 is a relevant indicator to study how concepts are organized in memory, since it is also reduced when the unexpected word is considered as an exemplar of the same category as the expected one (e.g. "pines" instead of the expected word "palms"). Thus, this component can be used to study whether two categories are encoded through a common category, as we suggest it is the case for approximative and conventional verbs in the child's mind.

Developmental studies have shown that the neural and cognitive processes indexed by the N400 component are already mature in very young children. Indeed, 19-months-olds, like adults, show a N400 effect when incongruous words or nonsense word that are phonotactically legal (pseudowords) are acoustically presented following the introduction of the image of an object (Friedrich & Friederici, 2005). Several studies have further used the ERP technique to determine whether the lexical-semantic language system of young children is organized by taxonomic categories (e.g. *animals* and *furnitures*, Rämä, Sirri & Serres, 2013) as well as whether basic-level categories (e.g. *dogs* and *horses*) are discriminated by toddlers, who are known to overextend these categories (Torkildsen et al., 2006). In Torkildsen et al. (2006), a picture-word match experimental paradigm was used in which acoustically presented words were either a congruous term (e.g. "dog"), a within-category violation (e.g. "cat") or a between category violation (e.g. "car"). A strong N400 incongruity effect was found for the between-category violation. A N400-like incongruity effect was also found for the within-category violation, but it was smaller, later and less distributed than the latter one. The presence of the N400 effect for within-category violations indicates that toddlers discriminate basic-level categories. The fact that the within-category effect was reduced compared to the between-category violation shows that very young children have organized their lexical-semantic system by taxonomic categories (see also Rämä et al., 2013).

These data suggest that the N400 component is well-suited to study how actions are categorized (Maguire, Magnon, Ogeila, Egbert & Sides, 2013). More specifically, the processing of approximative verbs should reflect a reduced N400 if the general category that it shares with the action is encoded. In contrast, the processing of verbs sharing only the object type (i.e. superficially related verbs) with an action should elicit a reduced N400 if the encoding is mainly focused on objects (Saji et al., 2011).

The present study

In the current experiment, we tested the hypothesis that semantic approximations reflect the encoding of a general category which is common between the approximative and the conventional term. In order to test this prediction, we used a picture-word match experimental paradigm in which sentences containing one of four types of verbs were acoustically introduced during the presentation of pictures describing actions (e.g. repairing a car). Sentences contained either a conventional verb (e.g. "he is *repairing* the car"), an approximative verb (e.g. "he is *healing* the car"), a superficially related verb (e.g. "he is *driving* the car"), or a pseudoverb (e.g. "he is *trunting* the car", see Tab. 1). Based on previous research (Friedrich & Friederici, 2005), it was predicted that pseudoverbs elicit a more pronounced N400 response in comparison to conventional verbs. Most importantly, the amplitude of the N400 elicited by approximative verbs and superficially related verbs relatively to the N400 provoked by conventional verbs and pseudoverbs will reveal how preschoolers encode actions. If encoding is mainly focused on an abstract category (Hofstadter & Sander, 2013), approximative verbs should elicit smaller N400 than pseudoverbs, whereas superficially related verb would evoke greater N400 than conventional verbs. Indeed, approximative verbs, but not superficially related verbs, should be compatible with preschoolers' encoding of actions. In contrast, if encoding is dominated by objects (Saji et al., 2011), the N400 should be smaller in the superficially related verb condition than in the pseudoverb condition, and greater in the approximative verb condition than in the conventional verb condition. Under this assumption, superficially related verbs, but not approximative verbs, are compatible with young children's encoding.

Table 1: Examples of stimuli (translated from French).

Images	Verb types
	He is [*reparing / healing / driving / trunting]* the car
	She is [*peeling / undressing / pressing / rauging]* the orange
	The house has been [*destroyed / killed / built / sedered]*
	He is [*tearing / breaking / reading / federing*] the book

Note: the first verb in italics is the conventional verb, the second one is the approximative verb, the third one is the superficially related verb, and the last one is the pseudoverb

Methods

Participants

Thirty-five 4-year-old children (*M* = 4. 0 years, *SD* = 1. 8 months, 18 girls and 17 boys) from monolingual French-speaking families took part in the study. All the children were born full-term and none of them suffered from hearing or language impairments. Thirty other children came to the lab but their data could not be analyzed either because they refused to wear the cap (*N* = 1), because of an early interruption of the experiment following the child's will (*N* = 6) or due to noisy data[1] (*N* = 23). The parent gave an informed consent for the participation of their child to the experiment before it started.

[1] The criterion for considering data as noisy is presented in the section "EEG recording and analysis"

Materials

The acoustic stimuli were sentences pronounced by a French female speaker. Forty sentences containing a conventional verb, an approximative verb, a pseudoverb or a superficially related verb were presented to each participant for a total of 160 sentences. The semantic approximations presented in this experiment were taken from a corpus of spontaneous productions from 2 to 4 years old children (Duvignau, 2002). The mean duration of the spoken verbs presented in the experiment was 473.7 ms A questionnaire was administered to the parents in order to assess their child's comprehension of each verb that was presented. In addition, a French adaptation of the McArthur Communicative Development Inventory for Words and Sentences (Kern, Langue, Zesiger, & Bovet, 2010) was distributed to the parents at the end of the experiment with a stamped envelope so that they could send it back to us. However, these data could not be analyzed due to an insufficient return rate. Four images of action corresponding to each conventional verb (one for each of the four conditions) were selected from the internet or were created to match the requirement of the task, constituting a total set of 160 images. In this way, a given image was only presented once during the experiment. Four sets of 160 picture/sentence associations were created by associating each type of sentence (the one containing the conventional verb, the approximative verb, the pseudoverb and the superficially related verb) to a different picture (one of the four different pictures describing the same action).

Procedure

The experiment lasted about 20 minutes and took place in a soundproof chamber. According to their wish, children were seated on their parent's lap or on their own in front of a computer screen. Parents were asked to avoid communicating verbally or non-verbally to their child during the experiment. The interstimulus interval (ISI) between the presentation of the prime picture and the sentence varied between 750 ms and 1250 ms. The experimenter followed the experiment's progression through a webcam and triggered each stimulus while making sure the child was attentive. An attention getter (a colored screen with an indistinct animation) was used if necessary so as to focus the child on the screen. The webcam system was presented to the child before the experiment and he or she was told to use a hand signal to put an end to the experiment.

EEG recording and analysis

A 128 captors Geodesic Sensor Net (GSN, NetStation EGIS V2.0) referenced to the vertex was used to record continuous electroencephalogram (EEG, sampling rate: 500 Hz and Band-Pass = 0. 1 – 100Hz). The experiment started when impedances were below 50 Ω. The recorded signal was filtered (0.3 – 30 Hz) and segmented (-100 ms – 1000 ms before/after the verb onset). The 100 ms pre-stimulus period was used as the baseline for amplitude measures. The epochs including ± 150 μv (eye movement, eye blink, etc) were rejected, and trials with more than 40 noisy channels were excluded. Below this threshold, individual bad channels were replaced using spherical spline interpolation. Trials were excluded from further analyses when they corresponded to verbs that the parent indicated as not understood by their child (M = 12. 1, SD = 7, 6). Epochs were first averaged separately for each participant and condition. Then, data was re-referenced to the average of all electrodes. Lastly, the epochs were grand-averaged across all participants for each condition. Data from participants who retained less than 10 artifact-free trials per condition were excluded from the grand average and the statistical analysis.

All statistical analyses were performed on the mean ERP amplitude in the four experimental conditions. Considering that the N400 is typically peaking at 400 ms over centro-parietal sites (Kutas & Federmeier, 2011), and following a visual inspection of the waveforms, the statistical analyses focused on activities recorded on posterior sites during the 300-500 ms temporal window. As illustrated in Fig. 1, we constituted a cluster over the posterior left site (60, 66, 70, 73,69, 65, 59,58, 64, 68), over the posterior middle site (61, 78, 77, 76, 82, 74, 75, 71, 67, 72) and over the posterior right site (85, 91, 96, 95, 94, 89, 88, 83, 84, 90). According to the 10-10 international electrode position system, the electrode placement 58 over posterior left site was located around electrode P7 position, the electrode placement 75 over posterior middle site around Oz position, and the electrode placement 96 in posterior right site around P8 position. The analysis of variance (ANOVA) included two factors: condition (conventional verb / approximative verb / superficially related verb / pseudoverb) and recording site (posterior left / posterior middle / posterior right). The Greenhouse-Geisser sphericity correction was applied when necessary.

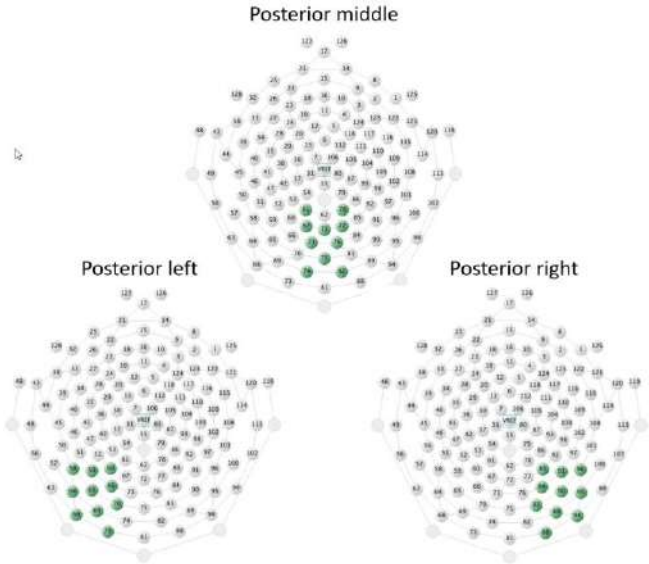

Figure 1: The three clusters of electrodes selected for the N400 analyses

Results and discussion

Grand average waveforms for the verbs in each condition at the three posterior clusters are displayed in Fig. 2. The main effect of condition was significant (F (3, 34) = 4. 83, p < .01), but the effect of recording site was not significant (F (2, 34) = 1. 66, p = .21), and there was no significant interaction between conditions and recording site (F (6, 34) = . 42, p = . 86).

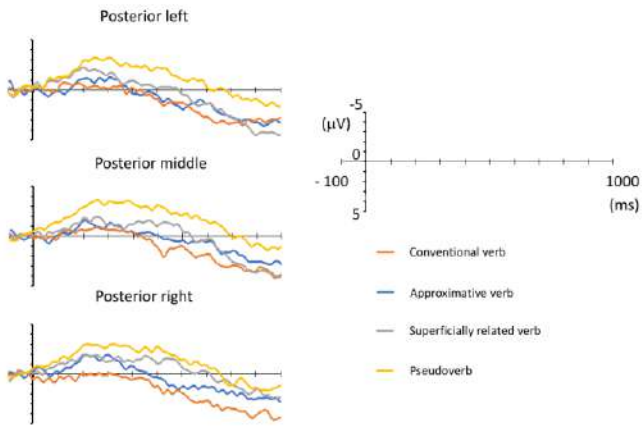

Figure 2: Grand average ERP waveforms recorded at 30 electrodes sites grouped into three clusters.
Note: Vertical lines indicate word onsets.

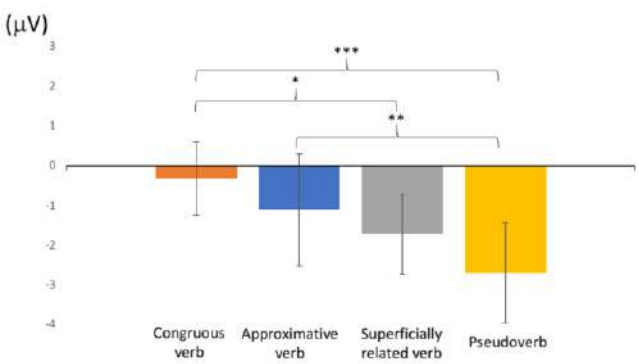

Figure 3: Amplitude means of the N400 in the four experimental conditions [300-500 ms temporal window]

Post hoc comparisons between conditions combined over the three clusters (see Fig. 3) showed that the amplitude of the N400 was significantly larger for pseudoverbs than for conventional verbs (t (34) = 3. 58, p = .001). Second, supporting our main hypothesis, the amplitude of the N400 was smaller in the approximative verb condition than in the pseudoverb condition (t (34) = 2. 16, p < .05). The N400 elicited by the approximative verb did not significantly differ in amplitude from the one provoked by the conventional verb (t (34) = 1. 05, p = .30). In contrast, the N400 amplitude elicited by superficially related verbs was significantly greater than the one provoked by conventional verbs (t (34) = - 2, 74, p = 0. 01). Finally, the N400 was not significantly different in the superficially related verb condition and the pseudoverb condition (t (34) = 1. 38, p = .18).

The differences in amplitude of the N400 between the approximative verb and the pseudoverb conditions, as well as between the superficially related verb and the conventional conditions, confirm our main hypothesis that abstract categories are encoded by preschoolers and fail to support the possibility that action are superficially encoded.

General discussion

The main goal of this study was to determine whether preschoolers encode situations through general categories in a way that induces semantic approximations. We also tested alternative accounts according to which young children would tend to substitute superficially related verbs due to a focus on objects involved in actions. A picture-word match experimental paradigm was used where images of actions were presented together with a sentence containing either a conventional verb, an approximative verb, a superficially related verb, or a pseudoverb. The results showed that the N400 elicited by semantic approximations was smaller in amplitude than the one evoked by pseudoverbs, but not significantly different from the one evoked by conventional verbs. Further, superficially related verbs elicited a N400 that was higher than the one provoked by conventional verbs and that did not significantly differ from the one evoked by pseudoverbs. Together, these findings support our main hypothesis that young children encode actions through general categories rather than at a surface level.

Our results have important implications for category development. Indeed, prior research has documented that learning verbs and other relational terms may be challenging for young children because, contrary to nouns referring to objects, they are mainly defined by relations (Gentner, 2006). In line, Maguire et al. (2013) investigated the ERP responses elicited by incongruities between object and nouns or between actions and verbs in 8-9 years old children and adults. They found that the N300 component - an ERP response associated with a rapid matching between visual input and stored semantic knowledge – was provoked by objects-nouns incongruities in both adults and children, but by actions-verbs incongruities only in adults. The authors concluded that children's conceptions of verbs are less abstract and flexible than the ones of adults. The results from the present study demonstrate that children as young as 4 years of age grasp abstract relations defining verbs. Indeed, they were able to apply familiar verbs on the basis of abstract relational similarity.

Furthermore, our ERP results failed to support previous findings by Saji et al. (2011) showing that young children mainly focus on object type when applying familiar verbs to actions. One possible account for this apparent discrepancy is that participants in the previous study were influenced by both surface similarity and abstract similarity since the superficially related verbs still shared a *carry/hold* meaning in common. In contrast, the superficially related verbs in the

present study shared only the object type and did not possess a relevant meaning in common (e.g. *repair* versus *drive*). Our data suggest that preschoolers mainly focus on abstract relational similarity rather than only on surface similarity when extending familiar verbs.

Some authors have conveyed the status of metaphors to young children's non-conventional uses of words by arguing that they reflect pragmatic strategies rather than conceptual errors (Bloom, 1973; Hudson & Nelson, 1984; Walaszewska, 2011). Others have underlined that overextensions may originate in overly broad categories (Bowerman, 1978, 2005; Duvignau et al., 2007; Gentner & Bowerman, 2009; Saji et al., 2011). Our results precludes that superficially related verbs would be merged, since these verbs elicit greater N400 than conventional verbs. However, the absence of difference between the N400 in the approximative verb condition and the conventional verb condition leaves open the possibility that verbs sharing an abstract similarity are not well discriminated. If this is the case, it would imply that children are like adults to the extent that they can grasp abstract similarities, but also different from them in that they initially rely on overly general categories when extending familiar words. A more unifying view concerning the pragmatic and the conceptual accounts for overextensions could be that young children start by making overextensions unwittingly, but progressively start using them on purpose while realizing their pragmatic interest (Pouscoulous, 2011). Further studies comparing adults' and preschoolers' ERP responses to semantic approximations may help distinguishing between the pragmatic and the conceptual immaturity accounts. Moreoever, it would also be essential to conduct ERP studies exploring whether factors such as the diversity of objects to which a verb applies (Bowerman, 2005), the degree to which a categorical distinction is culturally shared (Gentner & Bowerman, 2009), or the number of synonyms a concept has (Saji et al., 2011), modulates preschoolers' ERP responses to an overextension.

Semantic approximations are especially meaningful for theories of analogy as they invite researchers to broaden the scope of intervention of this mechanism. Whereas studies have extensively documented the efficiency of the explicit mapping process (Gentner et al., 2011; Goldwater & Gentner, 2015; Goswami & Brown, 1990), less is known about how analogies are spontaneously implemented. Investigating spontaneous analogies may be a promising route for further research, since they indicate that analogical thinking may be even more prevalent than it was supposed to (Raynal et al., 2020). Semantic approximations witness that analogies are used to interpret new situations through prior knowledge from an early age (Day & Goldstone, 2012; Hofstadter & Sander, 2013).

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