Cognition 143 (2015) 77–86

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Learning novel phonological neighbors: Syntactic category matters

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ARTICLE INFO

Article history:
Received 14 December 2014
Revised 3 June 2015
Accepted 4 June 2015

Keywords:
Word learning
Lexical access
Phonetic sensitivity
Language acquisition

ABSTRACT

Novel words (like *tog*) that sound like well-known words (*dog*) are hard for toddlers to learn, even though children can hear the difference between them (Swingley & Aslin, 2002, 2007). One possibility is that phonological competition alone is the problem. Another is that a broader set of probabilistic considerations is responsible: toddlers may resist considering *tog* as a novel object label because its neighbor *dog* is also an object. In three experiments, French 18-month-olds were taught novel words whose word forms were phonologically similar to familiar nouns (noun-neighbors), to familiar verbs (verb-neighbors) or to nothing (no-neighbors). Toddlers successfully learned the no-neighbors and verb-neighbors but failed to learn the noun-neighbors, although both novel neighbors had a familiar phonological neighbor in the toddlers' lexicon. We conclude that when creating a novel lexical entry, toddlers' evaluation of similarity in the lexicon is multidimensional, incorporating both phonological and semantic or syntactic features.

1. Introduction

Many of the words young children hear are not yet in their vocabulary. As a result, in everyday conversation toddlers must often decide whether a given word-form corresponds to a word they already know, or to a word to be learned. In principle, children could accomplish this by checking to see if each utterance can be parsed entirely into a sequence of familiar words. If it cannot, perhaps the unidentified portions correspond to new words.

The problem, of course, is to define what counts as an instance of a familiar word and what does not. Different instances of a given word do not all sound the same. Talkers have different voices and varying accents (e.g., Labov, 1966); words sound different depending on the phonetic context they appear in (e.g., Holst & Nolan, 1995), and speakers routinely blend sounds together or omit completely entire sounds and even whole syllables of words (e.g., Ernestus & Warner, 2011; Johnson, 2004). Such phenomena are present in the speech parents direct to their children (e.g., Bard & Anderson, 1983). Drawing the boundary between the set of acceptable instances of a word, and the instances that cannot correspond to that word, is complex.

Traditionally, it is said to be the role of the language's phonology to define the set of phonetic differences that distinguish words, to resolve these ambiguities. If words are represented as phonological descriptions adequate for maintaining contrast, and heard utterances are converted into phonological descriptions during speech comprehension, a simple comparison procedure should be adequate for identifying new words. If a word-form in the utterance fails to line up with any word-forms in the lexicon, this means that a new word has been heard.

This might not work for children, for several reasons. Children's skills of phonetic categorization are inferior to adults' and undergo substantial refinement well into the school years, despite the rapid progress toward language-specific perception made in infancy (e.g., Hazan & Barrett, 2000; Kuhl, 2004). In many cases children may not successfully characterize utterances in phonological terms. And even when they can, it is not clear that children understand that phonological distinctions are meant to signal lexical distinctions. Although children recognize words more easily when the words are spoken with their canonical pronunciations than when spoken with deviant pronunciations (e.g., Swingley, 2009), this does not imply that the mispronunciations are interpreted as novel words (e.g., White & Morgan, 2008). Toddlers do resist interpreting some discriminable, but not phonological, differences as contrastive (Dietrich, Swingley, & Werker, 2007; Quam & Swingley, 2010), which suggests some sophistication in relating speech and the lexicon. But being wary of interpreting a non-phonological distinction as if it could distinguish words does not imply the inverse skill of readily interpreting phonological distinctions as contrastive.

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http://dx.doi.org/10.1016/j.cognition.2015.06.003
0010-0277/

One study tested whether toddlers could use a single-feature phonological distinction to assign a novel meaning to a word-form that sounded similar to a very familiar one (Swingley & Aslin, 2007). 19-month-olds were shown a novel object, which was repeatedly named using clear (hyperarticulated) speech. In some cases the novel name given was similar to a familiar word (e.g., *tog*, similar to *dog*), and in some cases it was not (e.g., *shang*, not similar to any words children knew). Children were tested using a fixation procedure in which pictures of two novel objects were presented on a screen, and one of the pictures was labeled using its novel name (e.g., "Look at the {*tog*, *shang*}". Fixation to the named picture was used to index learning of the word. In two experiments, children were able to learn words that sounded very different from the other words in their vocabularies (like *shang*), but children did not learn the phonologically similar words (like *tog*). For some of the items tested, children of the same age had previously shown discrimination of the nonce label and its familiar counterpart, so perceptual discrimination *per se* was apparently not at issue (e.g., Swingley & Aslin, 2002).

Why might this be? One possibility is that phonological competition *alone* is the problem. The lexical entry of *dog* might be activated by the phonologically neighboring form *tog*, interfering with children's considering the possibility that a new word was being offered. This explanation of the experimental results is consistent with a view that children first adopt a phonological criterion of similarity, which apparently requires a greater difference than the single phonological feature tested in the experiment, and proceed accordingly.

Another possibility is that a broader set of probabilistic considerations is responsible. Not only is *tog* phonologically similar to a well-entrenched word, but it is also syntactically and semantically similar: both *tog* and *dog* are *nouns* referring to *objects*. Considering that the 18-month-old lexicon is relatively sparse in both phonology and semantics (Swingley & Aslin, 2007; but see Coady & Aslin, 2003 for older children) the appearance of a novel word that is both phonologically similar to, and somewhat semantically close to, a familiar word, might seem implausible to children, leading them to suppose that the novel word might in fact be a rather dubious instance of the familiar word.

Adults too may, in some conditions, fail to interpret a one-feature phonological change as lexically meaningful (e.g., White, Yee, Blumstein, & Morgan, 2013). Under conditions in which the speech signal and the referential context are less clear (conditions which prevail quite generally in human communication), adults can interpret phonologically novel word forms as instances of known words (e.g., Cole, Jakimik, & Cooper, 1978). For example, upon hearing "this singer has a beautiful *foice*", listeners are more likely to misperceive *foice* as an instance of *voice*. In such a case, adults find it plausible that the word *voice* has been uttered since both the syntactic and the semantic context constrained their lexical search toward singing-related nouns. Although /f/ and /v/ are lexically contrastive in English, the difference in voicing value may plausibly be interpreted as noise rather than indicating the presence of a new word in this particular context. In arriving at an analysis of spoken sentences, adults use a diverse array of sources of information: the physical context (e.g., Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995); the prior linguistic context (e.g., Altmann & Kamide, 1999); pragmatic expectations supported by the discourse (e.g., Nieuwland & Van Berkum, 2006); and idiosyncrasies of the speaker (e.g., Creel, Aslin, & Tanenhaus, 2008). In a sense, all of these are needed while interpreting speech because speakers are aware that listeners have this information at their disposal, and frequently provide only just enough phonetic information to allow the listener to resolve the intended meaning given the context (e.g., Hawkins, 2003).

These findings with adults highlight the importance of factors other than phonology in interpreting speech. Yet it is open to question whether toddlers identify words primarily using phonological criteria, or whether, like adults, they take into consideration a broader range of probabilities in judging the likelihood that a phonological distinction implies a novel word. In support of the latter, here we present evidence that toddlers evaluate other factors than phonological features, such as syntactic or semantic features, when evaluating the possibility that a novel sequence of sounds is a new word.

We started from Swingley and Aslin (2007)'s result that toddlers failed to learn new object labels that sounded similar to familiar object labels. In three experiments, French 18-month-olds were taught object labels that were phonological neighbors of a familiar *noun* (a noun-neighbor, as *tog* was, for *dog*), neighbors of a familiar *verb* (a verb-neighbor, like teaching *kiv*, a neighbor of *give*) or no-neighbors (such as *shang*). The noun-neighbor and the verb-neighbor were both phonologically similar to a familiar word in children's lexicon. But only the noun-neighbor was also semantically and syntactically similar to its neighbor; the verb-neighbor was not. If children take into account semantic or syntactic likelihoods when interpreting novel neighbors, verb-neighbors should be perceived as sufficiently distinct from any word in the lexicon to be easily assigned a novel object meaning – just like no-neighbor words – whereas noun-neighbors are expected to suffer from the competition with the familiar noun and be hard to learn. In contrast, if children fail to learn both noun-neighbors and verb-neighbors, this would indicate that children stake everything on phonological similarity in deciding whether a word-form is a new word.

2. Experiment 1

Experiment 1 sought to replicate Swingley and Aslin (2007)'s results showing that phonological neighbors of a familiar noun (noun-neighbors) are hard for toddlers to learn. We taught French 18-month-olds two novel object labels: a noun-neighbor (e.g., "ganard," a neighbor of "canard" *duck*) and a no-neighbor (e.g., "torba"). Word learning was then evaluated using a language-guided looking method (Fernald, Zangl, Portillo, & Marchman, 2008; Swingley, 2011). Children were presented with the two novel objects and heard sentences that named one of the pictures (e.g., "il est où le ganard?" *where is the ganard?*). An above-chance proportion of looks toward the target picture after word onset was taken as evidence that the word had been learned.

2.1. Method

2.1.1. Participants

Sixteen French 18-month-olds participated in the study, ranging in age from 17;19 (months; days) to 18;23, with a mean of 18;13 (*SD* = 0;8; 7 girls). An additional 8 children were not included in the sample because they refused to wear the sticker necessary for eye-tracking ($n = 3$), fussiness during the experiment resulting in more than 50% of trials with missing eye tracking data ($n = 3$), no increase in average proportion of looks toward the target during familiar-word trials ($n = 1$)[1] and hearing problems reported by the parents ($n = 1$). The attrition rate was somewhat higher than

[1] Following previous pilot experiments, before commencing testing here we decided on an exclusion criterion of rejecting children who looked at the target on average less than 55% of the time (from word onset until the end of the trial) over the 8 familiar-word trials. Individual time courses were inspected to be sure to not reject children who only quickly looked toward the target instead of having a sustained look; there were no such cases. This criterion was applied blind to condition performance.

expected, which we tentatively attribute to the children's having just participated in a separate study involving 10 min of active searching for toys.

2.1.2. Apparatus, procedure and design

Each child was taught two words: one novel word whose phonological form was similar to a noun they know (noun-neighbor) and one that had no phonological neighbor in their lexicon (no-neighbor). Before coming to the lab, parents filled out a questionnaire of vocabulary including all the neighbors of the test words. This was to ensure that children would be taught a novel word that neighbored a noun they already knew. Toddlers sat on their parent's lap about 70 cm away from a television screen. Their eye movements were recorded by an Eyelink 1000 eye-tracker. We used a 5-point calibration procedure. Once the calibration was judged acceptable by the experimenter, the experiment began.

The experiment was composed of two phases: a teaching phase and a testing phase. During the teaching phase, children were presented with a first introductory video and 4 teaching videos, 2 for each novel word. Which of two objects the noun-neighbor referred to was counterbalanced across toddlers. The order of presentation of the teaching video was interleaved between the two words and counterbalanced across toddlers. After presentation of the teaching videos, the test phase started as soon as children looked at a fixation cross.

The test phase was composed of 16 trials: 8 trials with familiar words and 8 test trials with novel words, 4 per novel word. Each trial started with the simultaneous presentation of two pictures on the right and left sides of the screen. Two seconds later, the audio stimuli started: ("*Regarde le [target], tu le vois le [target]?*" Look at the [target], Do you see the [target]?). The trial ended 3.5 s after the first target word onset. Trials were separated by a 1 s pause. No immediately consecutive trials presented the same pictures or words. Target and distractor pictures appeared the same number of times on the right and the left side of the screen. Target side did not repeat more than two times on consecutive trials.

The whole experiment lasted about 5 min.

2.1.3. Materials

Novel words. All novel words were bisyllabic and started with a stop consonant. We used the *Lexique* database (New, Pallier, Brysbaert, & Ferrand, 2004) to identify 4 novel words whose phonological form was similar to a common noun (noun-neighbors) and 4 novel words that had no phonological neighbor in children's lexicon (no-neighbor).

The 4 noun-neighbors differed from their real-noun counterparts by inversion of the voicing value of the initial consonant. The four words were *pallon*, *ganard*, *gochon*, and *pateau* (/palõ/, /ganaʁ/, /goʃõ/, /pato/), neighbors of *ballon*, *canard*, *cochon*, and *bateau* (ball, duck, pig, boat) which are all likely to be known by children of that age according to CDI reports from previous studies. Frequency counts of the familiar nouns in a corpus of child directed speech (*Lyon* corpus, Demuth & Tremblay, 2008) were as follows (frequencies were calculated on the phonological forms of these words thus conflating the singular and the plural of the nouns): *ballon*, 201; *canard*, 179; *cochon*, 180; *bateau*, 105. Parents were also asked to report any other neighbors likely to be known by their children. Both *ganard and gochon* had no other phonological neighbors than the familiar noun competitor that we chose, but children knew one or two other familiar nouns close to *pallon* (*salon*, living-room) and *pateau* (*gateau*, cake; *rateau*, rattle). Thus, *ganard* and *gochon* had a phonological neighborhood density of 1 in children's lexicon; *pallon* had a phonological neighborhood density of 2 and *pateau*, on average, of 2.25. All noun-neighbors had no other neighbors in another syntactic category likely to be known by children.

The no-neighbors were generated from an *n*-phone model trained on the *Lexique* database with the constraint that they should be phonologically similar to less than 2 low frequency words in the French lexicon. Four phonotactically legal bisyllabic no-neighbor words were chosen: *prolin*, *barlié*, *torba*, *lagui* (/pʁolẽ/, /barljé/, /tɔrba/, /lagi/). To ensure that children would not learn the no-neighbors better than the noun-neighbors simply because these words were phonotactically easier (Graf Estes & Bowen, 2013; Storkel, 2001), we ensured that the sound-to-sound probabilities were on average higher for the noun-neighbors than for the no-neighbors (cumulative bigram log-probability $\log P = -7.07$ for no-neighbors; $\log P = -5.59$ for noun-neighbors; this was calculated using a *n*-phone model on the set of word types in the French lexicon, taken from the *Lexique* database; New et al., 2004).

Noun-neighbors and no-neighbors were yoked in pairs, such that each child would learn one of 4 pairs of words: (*prolin*, *gochon*), (*barlié*, *pateau*), (*torba*, *pallon*), (*lagui*, *ganard*). Children were all presented with a noun-neighbor for which they had a phonological neighbor in their lexicon according to parental report.

Novel objects. The novel objects were two unfamiliar animals. One resembled a pink white-spotted octopus with an oversized head. The other looked like a rat with bunny ears and a trunk (see Fig. 1). At the end of the experiment, parents were asked whether their child was familiar with either animal; all parents said no.

Teaching videos. Word teaching was done on a television screen. A first introductory video showed a speaker (the last author) playing with a car (*une voiture*) and labeling it several times in a short story. This video was intended to familiarize children with the procedure, showing them that the speaker would talk about the object she manipulates. The teaching phase included four short videos of about 30 s each. In each video, the same speaker talked about the novel object she was playing with and labeled it 5 times using one of the novel words. The noun-neighbor word was used in two videos, and the no-neighbor word in the other two. In total, toddlers heard each novel word 10 times.

Testing stimuli. The pictures were photographs of objects on a light gray background. For familiar trials, we chose 8 objects that children of that age are likely to know: *voiture*, *banane*, *poussette*, *chaussure*, *chien*, *poisson*, *cuillère*, *maison* (car, banana, baby-stroller, shoe, dog, fish, spoon, house). Pictures were yoked in pairs (e.g., the banana always appeared with the car). For test trials, the pictures of the two novel animals were always presented together (as in Fig. 1).

The audio stimuli consisted of the sentences "*Regarde le [target], tu le vois le [target]?*" (Look at the [target], Do you see the [target]?) or "*il est où, le [target]? Regarde le [target].*" (Where is the [target]?

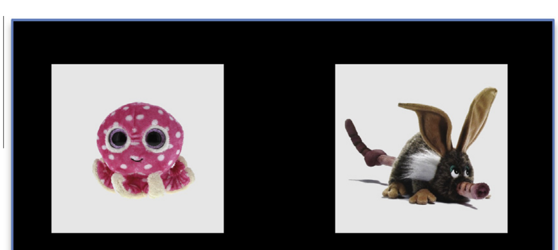

Fig. 1. Novel objects used during the experiments.

Look at the [target]!) where [target] was the target word and was pronounced two times in a given trial. All sentences were recorded by the last author (the same speaker as in the videos). The average duration of the novel words was 610 ms for the noun-neighbors and 598 ms for the no-neighbors.

2.1.4. Measurement and analysis

Gaze position on each trial was recorded via an eye-tracker with a 2 ms sampling rate. We inspected the time course of eye movements from the onset of the first occurrence of the target word (“Look at the [target].”) until the end of the trial. One recurrent problem when analyzing continuous time series is the choice of a window of analysis. Time can be made categorical by choosing a series of consecutive time windows tailor-made to the data and then performing separate analysis on each time window; or, more frequently in the infant literature, by imposing a single, large window to maximize the chances of observing a change in eye fixations. While the first option leads to a problem of multiple comparisons, the second often conflates response time and accuracy, thus resulting in a loss of information (Swingley, 2011) and both options are subject to biases inherent to window selection. Here, in order to test whether toddlers had learned each novel word we conducted a cluster-based permutation analysis (Maris & Oostenveld, 2007) to find a time window where we observed a significant increase in looks toward the target picture. This type of analysis, originally developed for EEG data, is free of time-window biases, preserves the information available in the time series and is able to cope well with multiple comparisons.[2]

The cluster-based analysis works as follows: at each time point we conducted a one-tailed[3] *t*-test on fixations to the target compared to chance (0.5). All fixation proportions were transformed via the arcsin square function to fit better the assumptions of the *t*-test. The means and variances were computed over subjects within conditions. Adjacent time points with a significant effect ($t > 2$; $p < .05$) were grouped together into a cluster. Each cluster was assigned a single numerical value measuring its size, and defined as the sum of all the *t*-values within the cluster (intuitively, a cluster is larger if it contains time-points for which the two conditions are very significantly different, and if it spans a longer time-window). To obtain the probability of observing a cluster of that size by chance, we conducted 1000 simulations where conditions (novel label, chance) were randomly assigned for each trial. For each simulation, we computed the size of the biggest cluster identified with the same procedure that was used for the real data (sum of all the *t*-values within a cluster of significant *t*-values). Clusters in the children's data were taken as significant if the probability of observing a cluster of the same size or bigger in the randomized data was smaller than 5% (that is, if a cluster that big was observed in less that 50 cases over 1000), corresponding to a *p*-value of 0.05.

It is important to note that the criterion for including a time bin in a cluster ($t > 2$ in our study) is independent of the process which assesses cluster significance, so it does not affect the likelihood of a false positive. Yet, it does have an influence on the size of the time window that one can find. If the threshold is low then the time window will be wider. However the same low threshold will be applied to the randomized data as well, such that the chance of getting a bigger cluster will also increase under the null hypothesis, thus maintaining the rate of false positive under 0.05.

In addition, to test whether there was a significant difference between conditions (whether children found the noun-neighbor harder to learn than the no-neighbor), we conducted an additional cluster-based permutation analysis in which clusters were formed on the basis of paired two-tailed *t*-tests comparing the looking proportions between conditions at each time point.

Thus in total, we conducted three cluster-based analyses: one for each word condition (no-neighbor; noun-neighbor) comparing the average proportion of looks toward the target picture for each test word to 50%, and one comparing the looking proportions between conditions.

2.2. Results

Fig. 2 shows the average proportion of looks toward the target picture for familiar and test words (noun-neighbor and no-neighbor) from the onset of the first target word (*Regarde le [target], tu le vois le [target]?* Look at the [target], do you see the [target]?) until the end of the trial.

Children showed recognition of the no-neighbor (green curve in Fig. 2) but not the noun-neighbor (red curve in Fig. 2). The cluster-based permutation analyses revealed that they fixated the correct picture above chance when asked to look at the no-neighbor (2178–2568 ms time-window, green-shaded area in Fig. 2; $p < .05$) but stayed around chance level in the case of the noun-neighbor (no significant time window found by the cluster-based permutation analysis). The difference between the recognition of the no-neighbor and the noun-neighbor was significant in the time window ranging from 2044 to 2852 ms ($p < .01$, gray-shaded area in Fig. 2). Thus, children learned the no-neighbor but not the noun-neighbor ($p = 0.19$). We also observed that the recognition of the no-neighbor occurred with a delay of about 900 ms compared to the recognition of familiar words (gray curve in Fig. 2), a finding we will return to later in discussing subsequent experiments.

2.3. Discussion

After a brief but intensive exposure to a pair of novel words, French 18-month-olds performed better when tested on a novel no-neighbor (e.g., “torba”) than on a novel noun-neighbor (e.g., “ganard,” a novel neighbor of “canard,” *duck*) in a word recognition task. When presented with the two novel objects on the screen and hearing a sentence labeling one of them, children correctly recognized the no-neighbor but failed to recognize the noun-neighbor. This may be surprising given that children of that age can infer the meaning of a word via mutual exclusivity (e.g., Markman & Wachtel, 1988). That is, if they learnt the no-neighbor then they should be able to infer the meaning of the noun-neighbor by process of elimination during the test phase. Yet several studies have shown that mutual exclusivity effects seem to disappear when children are confronted with a novel word that is phonologically similar to a familiar word (e.g., Merriman, Marazita, & Jarvis, 1995). When children heard “Regarde le pallon!” *look at the pallon*, they may start looking for a “ballon”, the phonological competitor, and go back and forth between the two images to find the closest match.

This result replicates Swingley and Aslin's (2007) findings with English and Dutch 18-month-olds, showing that children of that age find it hard to learn a phonological neighbor of a familiar noun. We will now test toddlers' ability to learn a novel neighbor of a familiar verb.

[2] Following a reviewer's suggestion, we also compared the results of this method with more traditional methods such as the salience-corrected fixations (see Swingley, 2011, for a discussion of this measure) and the more recent growth curve analysis method (Barr, 2008). Both methods of analysis lead to the same conclusion and are available upon request to the first author.

[3] Note that we used one-tailed *t*-tests because our hypothesis was directional as we expected a higher-than-chance looking proportion when the word was recognized, yet using two-tailed *t*-test did not change the pattern of results. In particular none of the clusters of fixations below chance level passed the permutation test.

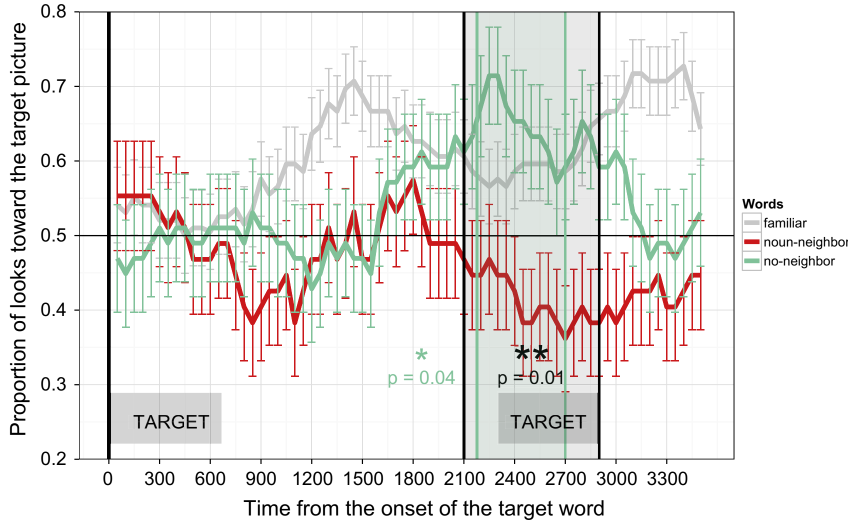

Fig. 2. Proportion of looks toward the target picture from the onset of the target word (Regarde le [target], tu le vois le [target]? *Look at the [target], do you see the [target]?*) for the noun-neighbor (red), the no-neighbor (dark green) and the familiar words (gray). Toddlers performed significantly better on the no-neighbor than on the noun-neighbor: they successfully learned the no-neighbor (green shaded time window) as shown by an increase of looks toward the correct picture, but failed to learn the noun-neighbor, staying at chance level. The gray-shaded time window corresponds to the region where toddlers were more likely to look at the target picture when asked for the no-neighbor than when asked for the noun neighbor. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3. Experiment 2

In Experiment 1, 18-month-olds failed to learn a noun-neighbor (e.g., "ganard") showing that they are sensitive to its phonological similarity to a known word in their lexicon ("canard" *duck*). In Experiment 2, we build on this failure to investigate whether toddlers are able to appreciate other factors than phonological features when deciding whether a given word-form corresponds to a novel word or is an instance of an already-known word. In the same task, we taught French 18-month-olds two novel object labels: one with a phonological neighbor from a different syntactic category (verb-neighbor; e.g., "barti" neighbor of "parti" *gone*) and one with no neighbors (no-neighbor e.g., "torba").

Following Experiment 1, we expected children to learn the no-neighbor. If toddlers were to fail to learn the verb-neighbor, this would be evidence that phonological similarity to a known word is sufficient to prevent toddlers from considering the verb-neighbor as a novel word. On the contrary, if toddlers were to succeed in learning the verb-neighbor – just as they learn the no-neighbor word – this would indicate that children take into account not only phonological likelihood but also syntactic and/or semantic likelihood when deciding whether a given word-form denotes a novel word or not.

3.1. Method

3.1.1. Participants

Sixteen French 18-month-olds, ranging from 17;18 to 19;4 with a mean of 18;8, ($SD = 0;15$; 8 girls) took part in this experiment. Twelve additional children were replaced because of refusal to wear the sticker necessary for eye-tracking ($n = 2$), fussiness during the experiment resulting in more than 50% of trials with missing eye tracking data ($n = 6$), experimenter error ($n = 2$), no increase in the average proportion of looks toward the target during familiar trials ($n = 2$).

3.1.2. Apparatus, procedure and design

Similar to Experiment 1 except that this time children were taught two words with a phonological neighbor: one novel word whose phonological form was similar to a verb they know (verb-neighbor) and one whose phonological form was not familiar to any word they know (no-neighbor).

3.1.3. Materials

Similar to Experiment 1 except for the set of novel words used in the teaching phase.

Novel words. We chose 4 novel words whose phonological forms were similar to a common verb (verb-neighbors) and 4 novel words that had no neighbors in toddlers' lexicons (no-neighbors). Words were selected following the same procedure as in Experiment 1.

The 4 no-neighbors were the same as in Experiment 1. The 4 verb-neighbors were chosen following the same criteria as for the noun-neighbors: they were all bisyllabic words starting with a stop consonant and differing from a common verb in the voicing of that initial consonant: *barti*, *dombé*, *gassé*, *tonné* (/baʁti/, /dõbe/, /gase/, /tone/), being neighbors of *parti*, *tombé*, *cassé*, *donné* (gone, fallen, broken, given) and having no other neighbors known to children, according to parental report.[4] The verb-neighbors were modeled on the past participle forms of the verbs. This form was chosen because it is very common (the most frequent morphological form for 3 of the 4 verbs; Demuth & Tremblay, 2008) and because it is bisyllabic, Frequency counts of the familiar nouns in a corpus of child directed speech (*Lyon* corpus, Demuth & Tremblay, 2008) were as follows: *parti*, 112; *tombé*, 411; *cassé*, 263; *donné*, 252. These counts were calculated on the phonological form of the neighbor in parental input and thus included the past participle form of the verb as well as the infinitive form (except for *parti* whose infinitive form is not homophonic to the past participle).

The average duration of the novel words in the test sentences was 620 ms for the verb-neighbors and 598 ms for the no-neighbors.

[4] The word-form *parti* is a homophone and can be used as a noun meaning "political party" or "part". None of the children we tested knew these meanings, based on parental report.

3.1.4. Measure and analysis

Similar to Experiment 1.

3.2. Results

Eye movement results were analyzed as in Experiment 1. As shown in Fig. 3, toddlers started to look more toward the target picture for both the verb-neighbor (blue curve) and the no-neighbor (green curve) soon after the end of the target word. The cluster-based permutation analyses found a significant time-window where the proportion of looks to the target was significantly above chance for the verb-neighbor condition (1092–1746 ms, blue-shaded time-window; $p < .01$) as well as for the no-neighbor condition (950–1254 ms, green-shaded time-window; $p < .05$). There was no significant difference between conditions (verb-neighbor, no-neighbor) suggesting that one word was not recognized better than the other (no time window found).

3.3. Discussion

Toddlers successfully learned a verb-neighbor in Experiment 2 and failed to learn a noun-neighbor in Experiment 1, although both words had a familiar phonological neighbor in toddlers' lexicon. Performance on the verb-neighbor and the no-neighbor were not different (in Experiment 2), suggesting that the phonological resemblance to a familiar word in their lexicon did not impact their understanding of the verb-neighbor as a novel word, compared to the no-neighbor. Here, toddlers were not overwhelmed by the phonological similarity to a known word, presumably because the likelihood that the novel noun, "un barti", would be considered as a plausible variant of the familiar verb, "parti" *gone*, is low. This suggests that toddlers integrate semantic and/or syntactic likelihood in the process of creating a novel lexical entry.

Contrary to Experiment 1, where the recognition of the no-neighbor started about 1500 ms after word onset, in Experiment 2 there was no delay in the recognition of the novel words: toddlers recognized the verb-neighbor and the no-neighbor at about the same time as they recognized the familiar words (roughly 600 ms after word onset). The crucial difference between Experiment 1 and Experiment 2 is the presence of a novel word that is difficult to learn, the noun-neighbor. One possibility is thus that the presence of the noun-neighbor in the test trials hindered the recognition of the no-neighbor in Experiment 1 (cf. Swingley & Aslin, 2007). Recall that during the test trials, toddlers were presented with the two novel objects and asked to select the noun-neighbor half of the time, and the no-neighbor the other half. This may have confused toddlers, if the link between the noun-neighbor and the novel object was difficult to make for them. If the presence of the noun-neighbor is a major reason why we observe a delay in Experiment 1, then we might expect that the recognition of *any* novel word, including the verb-neighbor, should be slowed down when taught together with a noun-neighbor.

4. Experiment 3

In Experiment 3, we seek to directly compare toddlers' performance for learning a noun-neighbor versus learning a verb-neighbor in a within-subjects design. Using the same experimental materials and basic design from the prior experiments, here we taught children two novel object labels: one noun-neighbor as in Experiment 1 and one verb-neighbor as in Experiment 2. Following Experiment 1 and Experiment 2, we expected toddlers to succeed in learning the verb-neighbor, and to fail to learn the noun-neighbor.

4.1. Method

4.1.1. Participants

Sixteen French 18-month-olds were tested (ranging from 17;26 to 18;29 with a mean of 18;8, $SD = 9$, 7 girls). An additional 8 children were not included in the final sample because of refusal to wear the sticker necessary for eye-tracking ($n = 3$), fussiness during the experiment resulting in more than 50% of trials with missing eye tracking data ($n = 2$), no increase in average proportion of looks toward the target during familiar trials ($n = 2$), or no knowledge of the phonological neighbors ($n = 1$).

4.1.2. Apparatus, procedure and design

Similar to Experiment 1 except that this time children were taught two words with a phonological neighbor: one novel word whose phonological form was similar to a verb they know

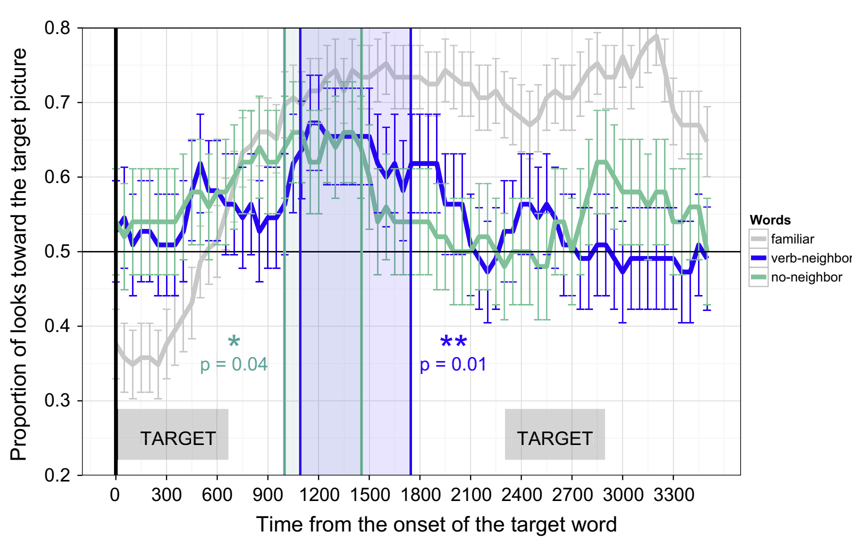

Fig. 3. Proportion of looks toward the target picture from the onset of the target word (Regarde le [target], tu le vois le [target]? *Look at the [target], do you see the [target]?*) for the verb-neighbor (blue), the no-neighbor (green) and the familiar words (gray). Toddlers successfully learned both the verb-neighbor (blue-shaded time window) and the no-neighbor (green-shaded time window). There was no significant difference between the verb-neighbor and no-neighbor conditions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(verb-neighbor) and one whose phonological form was similar to a noun they know (noun-neighbor).

4.1.3. Materials

The materials were similar to those of Experiment 1 except for the set of novel words used in the teaching phase.

Novel words. We used the 4 noun-neighbors used in Experiment 1 (novel words whose phonological form was similar to a noun) and the 4 verb-neighbors from Experiment 2 (novel words whose phonological form was similar to a verb). All 4 verb-neighbors had only one phonological neighbor known to the children, the two noun-neighbors, *ganard and gochon* had exactly one phonological neighbor and the two other noun-neighbors, *pallon* and *pateau* had on average 1.75 phonological neighbors in children's lexicon. The noun-neighbors' cumulative bigram log-probability was slightly lower than the one of the verb-neighbors ($\log P = -5.59$ for noun-neighbors; $\log P = -6.21$ for verb-neighbors). Verbs were, on average, 56% more frequent than the nouns, based on counts from the Lyon corpus of French child-directed speech (Demuth & Tremblay, 2008).

Verb-neighbors and noun-neighbors were yoked in pairs, such that each child would learn one of 4 pairs of words: (*pallon*, *gassé*), (*ganard*, *tonné*), (*gochon*, *barti*), (*pateau*, *dombé*). Children were taught a verb-neighbor and a noun-neighbor for which they knew the phonological neighbors, according to parental report.

The average duration of the novel words in the test sentences was 620 ms for the verb-neighbors and 610 ms for the noun-neighbors.

4.1.4. Measure and analysis

Similar to Experiment 1.

4.2. Results

As can be seen in Fig. 4, we replicated the pattern of results observed in Experiment 1 and 2. Toddlers successfully learned the verb-neighbor: they looked toward the correct picture at above-chance rates for the verb-neighbor (1660–2930 ms, blue-shaded time-window; $p < .01$) but resisted learning the noun-neighbor, showing no recognition of the novel word (no significant time-window found; $p = 0.80$). As a result, toddlers recognized the verb-neighbor significantly better than the noun neighbor (2024–2662 ms, gray-shaded time-window; $p < .05$), showing that toddlers' processing of these phonological neighbors is significantly different, depending on the syntactic category of the neighboring word.

Note that toddlers recognized the verb-neighbor at about 1500 ms after target word onset, a delay comparable with the time course of recognition of the no-neighbor in Experiment 1. This suggests that the presence of the noun neighbor in these two experiments slowed down the recognition of the other novel word.

4.3. Discussion

Children failed to learn an object label when it was a phonological neighbor of a noun they knew (as in Experiment 1) but succeeded when it was a phonological neighbor of a verb they knew (as in Experiment 2). Experiment 3 replicated this phenomenon within children, ruling out variation among children as a possible explanation of the difference between the results of Experiments 1 and 2. The failure to learn a noun-neighbor cannot be attributed to phonological competition alone, because both the noun-neighbor and the verb-neighbor had a frequent phonological neighbor in the children's lexicon. The most likely explanation, then, is that children take into account semantic and/or syntactic likelihood when interpreting a novel word.

An unexpected observation was that toddlers were slowed down in their recognition of newly-taught words which were tested at the same time as noun-neighbors: no-neighbors in Experiment 1, and verb-neighbors in Experiment 3. Given that both no-neighbors and verb-neighbors were observed to be recognized quickly in Experiment 2 (in the absence of the noun-neighbor), this suggests that the presence of the object the noun-neighbor referred to was sufficient to delay recognition of the other object in Experiments 1 and 3. To our knowledge, no prior study has reported a delay in novel word recognition while learning phonological noun-neighbors, though Swingley and Aslin (2007) did find that performance on familiar nouns was affected by children's (unsuccessful) exposure to novel noun-neighbors. The confusion triggered by noun-neighbors is consistent with our interpretation in terms of toddlers estimating

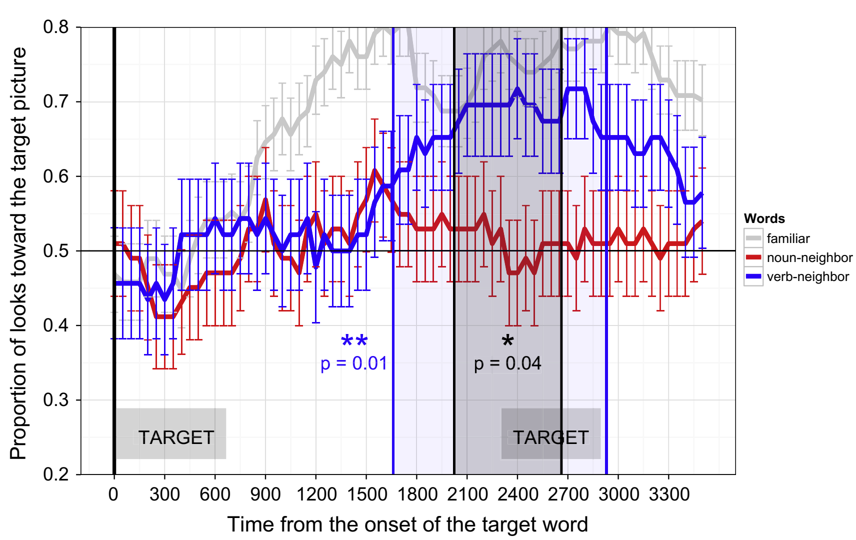

Fig. 4. Proportion of looks toward the target picture from the onset of the target word (Regarde le [target], tu le vois le [target]? *Look at the [target], do you see the [target]?*) for the verb-neighbor (blue), the noun-neighbor (red) and the familiar words (gray). Toddlers recognized the verb-neighbor significantly above chance level (blue-shaded time window) but failed to recognize the noun-neighbor. As a result, their performance was significantly better for the verb-neighbor than for the noun-neighbor within the time region shaded in gray. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the likelihood that a given word-form corresponds to a novel lexical entry or an existing one: When the odds are against the creation of a novel lexical entry – because the phonological and semantic/syntactic similarity appear too great to be coincidental – children attempt to reconcile the deviant phonological form with the existing lexical entry. This process might involve trying to figure out in what circumstances the observed phonological change may be licensed by the native language, as well as what extension of the word's meaning may encompass both the familiar referent and the novel referent. Whatever the exact nature of this process, it may contribute to the confusion that is observed.

5. General discussion

A simple rule for determining whether a spoken word corresponds to a word in the lexicon is to compare the phonological form of this word to the phonological forms in the lexicon. When the forms match, the word's identity is known; if the heard form matches no known words, it may be a candidate for entry into the lexicon as a new word. Part of the function of a phonological system is to ensure that this matching process can work, at least when the signal itself is carefully produced and clearly heard.

Young children apparently have some difficulty in operating with their developing phonology in this way. For example, they have some trouble learning similar-sounding words (e.g., Stager & Werker, 1997). Swingley and Aslin's (2007) finding, in which the proximity of a novel word like *tog* to the familiar word *dog* made the novel word hard to learn, showed that lexical activation processes, whose function is to account for the sounds in an utterance in terms of the correct string of words (and possibly in spite of mispronunciation or misperception), can conflict with word learning processes. In that study, the novel object intended as the referent for the novel word (e.g.) *tog* had no real resemblance to its familiar counterpart (*dog*). Similarly in the present experiments, the plush pink octopus object labeled here as *pateau* is not a reasonable member of the category of boats (*bateaux*). Such considerations suggest that children's difficulty might be purely a matter of phonological proximity: *tog* (or *pateau*) is simply too close to a familiar word to permit ready detection as a novel form.

The present work shows that this is not the case. In fact similarity of the novel referent to its competitor's denotation matters. The similarity of a *pateau* (plush octopus) to a *bateau* (boat) is not great, but it is greater than the similarity of the same octopus to the meaning of *parti* or *cassé* (gone, broken) because it shares the same syntactic category (nouns) and the same broad semantic category (toys).

With the present data we cannot determine whether it is the *syntactic* difference that is most important, or the *semantic* one, or both; but to get some purchase on this question we looked for potential item differences within the experiments. Recall that two of our familiar nouns were animals (*canard*, duck, and *cochon*, pig) and two were artifacts (*ballon*, ball, and *bateau*, boat). Given how fundamental the distinction between animals and artifacts is, even to infants (e.g., Setoh, Wu, Baillargeon, & Gelman, 2013), our items *ganard* and *gochon* (as plush animals) were probably semantically much closer to their competitors *canard* and *cochon* than *pateau* or *pallon* (as plush animals) were to *bateau* or *ballon*. If semantic similarity were the main driving force behind our results, we would expect children to learn *pateau* and *pallon* more easily than *ganard* and *gochon*. Indeed, inspection of the results revealed a nonsignificant trend toward better performance on *pateau* and *pallon* than *ganard* and *gochon* for participants in Experiment 1 and 3. It could be interesting to vary this similarity systematically with more items; here, there are confounding features of the words, such as uneven phonotactic probability and neighborhood density, that make interpreting this trend difficult. At any rate, although the present result cannot tells us whether the semantic or the syntactic difference between the neighbors and their familiar competitors play a role, it is clear that 18-month-olds take more into consideration than the sounds alone.

Might some unmeasured difference between our noun and verb neighbors be responsible for our effects? For example, frequent words are generally recognized more readily than infrequent words (e.g., Solomon & Postman, 1952). Could it be that the interfering effect of noun neighbors derives from stronger activation of those words, and not from the direct consequences of semantic or syntactic distance from the novel objects? This might happen if the phonological form of nouns were more strongly established in children's lexicons than the phonological form of verbs: indeed, verbs in French occur in more varied phonological forms than nouns, due to morphology. However, as we reported, the exact phonological forms of the verbs we used were, on average, 56% more frequent than the nouns in parental input, and as frequent as the nouns in children's production, based on counts from the Lyon corpus of French child-directed speech (Demuth & Tremblay, 2008), and parents in each experiment reported that their children knew the neighboring words.

Another possibility is that independently of frequency, the *meanings* of the noun neighbors were better entrenched in children's lexicons than the meanings of the verb neighbors, leading to greater interference. Yet if more entrenched representations lead to greater interference, we would also expect that verb-neighbors should lead to more interference than a word with no neighbor. That's not what we observe: children learnt verb-neighbors just as well as no-neighbors in Experiment 2. So while we cannot dismiss the possibility that more entrenched representations of the familiar nouns over the familiar verbs plays a role in children's interpretation of novel neighbors, our data provide little support for this hypothesis. Thus our main point would still hold, namely that semantic or syntactic similarity plays a role in children's interpretation of novel neighbors.

Thus, we propose that young toddlers' evaluation of similarity in the lexicon in the context of word learning is multidimensional, incorporating both phonological and semantic and/or syntactic features. The plausibility of a syntactic contribution to the results is supported by prior studies showing that children, like adults, use the sentence context to build on-line expectations about the syntactic category of an upcoming word (e.g., Bernal, Dehaene-Lambertz, Millotte, & Christophe, 2010). Toddlers as young as 14 to 18 months expect a noun to follow a determiner and expect a verb after a personal pronoun (Cauvet et al., 2014; He & Lidz, 2014; Kedar, Casasola, & Lust, 2006; Shi & Melancon, 2010; Zangl & Fernald, 2007). For instance, Cauvet et al. (2014) showed that French 18-month-old toddlers trained to turn their head for a known target noun ("la balle" *the ball*), responded more often to the word "balle" when it appeared in a noun context ("une balle" *a ball*) than when it appeared (incorrectly) in a verb context ("on balle" *they ball*). In fact, in that last case, they did not turn their head more often than for control sentences which did not contain the target word at all. In our study, when children were processing the syntactic context of our sentences, they should have expected a noun at the point where the verb-neighbor, *barti*, was heard. Since *barti* occurred in a context where the familiar verb *parti* was not expected, one possibility is that children did not access the familiar verb *parti* at all, and therefore that they did not even notice the similarity with a word present in their lexicon. Another possibility is that children may have accessed *parti* despite the nominal context because the integration of contextual cues is limited by toddlers' developing executive function abilities (e.g., Khanna & Boland, 2010, but see Rabagliati, Pylkkänen, & Marcus, 2013) Yet the presence of additional cues provided by the learning situation (i.e., repetition of the verb-neighbor in a noun context, presence of a novel object and contingent gaze cues from the speaker whenever the verb-neighbor was used) may render the possibility that the verb-neighbor *barti* is a novel word a more plausible alternative than for the noun-neighbor.

Children process words in context, just as adults do. In particular, the linguistic context plays a prominent role in constraining lexical access and thus in estimating the likelihood that a novel phonological word-form is a novel lexical entry rather than a variant of a known word. Manipulating the linguistic context by placing a verb-neighbor in a noun syntactic frame indicated to children that a new meaning was appropriate for the novel word-form. We would expect the same result to be found using other syntactic frames (e.g., pronouns) or by doing the symmetric manipulation (i.e., presenting a noun-neighbor in a verb syntactic frame). This suggests also that the linguistic context may play a role in learning several meanings for perfectly identical word-forms (homophones; see also Casenhiser, 2005), a possibility that we are currently exploring.

Learning neighbors of familiar words is difficult for toddlers, but as we showed, this difficulty disappears when the novel words appear in contexts that are sufficiently different from their known neighbors (either syntactically or semantically or both). If learnability influences language changes, then this constraint on early lexical acquisition might have a long-lasting impact on the overall structure of the lexicon. Do lexicons avoid similar-sounding words? And when similar-sounding words do occur, are they preferentially distributed across syntactic or semantic categories to improve their learnability (and their recoverability)? Recent studies observed that not only do mature lexicons contain many similar-sounding words, perhaps even more than would be expected by chance (Dautriche et al., 2014), but there is also a tendency for phonologically similar words to be more semantically similar than phonologically distinct words (Monaghan, Shillcock, Christiansen, & Kirby, 2014; Dautriche et al., 2014). In sum, lexicons appear to favor similar-sounding words which are semantically related.

At first sight this might appear at odds with the present study, yet there are two ways to resolve this apparent inconsistency. First, a rich literature suggests that similar-sounding words display a range of advantages for language use: they are easier to remember, produce and process for adults (e.g., Vitevitch, 2002; Vitevitch, Chan, & Roodenrys, 2012; Vitevitch & Stamer, 2006) and preschoolers (e.g., Storkel & Lee, 2011; Storkel & Morrisette, 2002). Also, greater systematicity of form-to-meaning mappings could facilitate the grouping of words into categories (Padraic Monaghan, Christiansen, & Fitneva, 2011). Overall, the processing benefits for similar-sounding words might outweigh an initial learning disadvantage. Second, an early disadvantage for learning similar-sounding words may not actively exert a selective pressure for words that are more phonologically dissimilar because children may eventually manage to learn neighbors through repeated exposure. Thus, instead of being reflected in the static organization of the lexicon, the constraint we uncovered may be reflected in the dynamics of early lexical growth: early in children's lexical development, novel words may preferably be added whenever they can be easily distinguished from already existing words along at least one dimension (phonological, syntactic, and/or semantic). Previous work looking at the growth of the lexicon focused on how either phonological similarity or semantic similarity influences word learning, but not on potential interactions between several dimensions (Carlson, Sonderegger, & Bane, 2014; Hills, Maouene, Maouene, Sheya, & Smith, 2009; Steyvers & Tenenbaum, 2005; but see Regier et al., 2001).

In sum, our work shows that 18-month-old children process words in context, using multiple sources of information. Phonological similarity alone does not serve as a kind of filter that collapses phonological neighbors in advance of meaningful analysis. Rather, 18-month-olds appear to evaluate simultaneously the phonological, syntactic and/or semantic likelihood of this sequence of sounds being a new word.

Acknowledgements

This work was funded by grants from the Région IIe-de-France, Fondation de France, LabEx IEC (ANR-10-LABX-0087), IdEx PSL (ANR-10-IDEX-0001-02), the ANR 'Apprentissages' (ANR-13-APPR-0012) to AC, NIH grant R01-HD049681 to DS, and a PhD fellowship from DGA to ID.

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