Processing of Morphological Variations in Toddlers

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1. Introduction

A crucial step in word learning is to map word forms to meanings. Infants' word learning is associated with a number of other perceptual capabilities. Word-size units must be segmented from input speech and encoded as candidates to which meaning can be mapped. A large body of literature starting from the work of Jusczyk and Aslin (1995) has shown that infants begin to segment and store word forms before one year of age. In addition to this step, infants must learn that perceived word units must be distinguished from one another in a phonologically significant way in order to receive different meanings. For example, words such as *bit* versus *bat*, which differ in one phoneme, are distinct in meaning, as are words differing in more phonemes or in other phonological structures (e.g., number of phonemes, number of syllables), such as *bee* versus *paper*. There is evidence that infants distinguish native and non-native phonetic contrasts very early and gradually become attuned to phonemic contrasts towards one year of age (e.g., Werker & Tees, 1984). They treat minimal pairs as different word forms in word segmentation tasks from the preverbal stage (e.g., Bortfeld, et al., 2005; Shi & Lepage, 2008). During word learning infants map novel minimal-pair forms to different meanings by 17 months of age (Werker, Corcoran, Fennell & Stager, 2002). Novel word forms with larger phonological differences such as *lif* versus *neem* are assigned to different meanings at an earlier age (Stager & Werker, 1997).

Embedded word forms represent an interesting situation. Word pairs such as *sock-soccer* and *king-kingdom* overlap partially in form while still exhibiting other phonological differences, e.g., more segments or an added syllable. Jusczyk, Houston and Newsome (1999) showed that during initial segmentation preverbal infants treat cases such as *king* and *kingdom* as different word forms, i.e., perceiving the two words as unrelated forms.

The above literature therefore suggests that words differing in phonological structures generally have different meanings, and infants do treat them as different words, as shown in studies of word form perception and word learning. In this paper we address a potential problem for word learning. Despite the need for meaning contrasts for phonemically different words, human languages often have word forms which contain phonemic distinctions but share the same core meaning. In cases of morphological variations, a word pair such as *sit-sat* or *walk-walking*, denote the same core meanings although phonemic differences are involved. We therefore have a situation where the grammar contains conflicting linguistic demands: word forms with distinct phonological structures

generally differ in meaning, but morphology may require phonologically different words to share the same meaning. How do children resolve the competing needs and learn both linguistic requirements?

The solution that we propose to this learning problem lies in the rule-governed nature of morphological variations. In the English examples of *walk-walking* or the French example *marche-marcher* (/marʃ/-/marʃe/), the suffix *–ing* and *–er* are highly frequent and regular. The two suffixes both occur with vast number of verb stems, which strengthens the segmentation cue for these two units by lowering their transitional probability. It is known that preverbal infants use transitional probability for segmentation (Saffran, Aslin & Newport, 1996). Thus, the suffixes are likely to be recognized by infants as independent units. On the other hand, such suffixes are bound morphemes and are often sub-syllabic, and do not have strong phonological prominence as independent word-like units. For example, the word form *marcher* in French contains a highly frequent suffix /e/ (infinitive marker), which is resyllabified with the preceding /ʃ/ of the stem to form the syllable /ʃe/. Phonological characteristics such as resyllabification or stress patterns (e.g., the trochaic stress in the English word *walking*) provide support for word integrity that conjoins the stem and suffix. Therefore, infants may treat *walking* and *marcher* as a word at one level and parse them into stem+suffix (/marʃ-e/) at a lower level. Since the parsed /marʃ-/ from /marʃe/ is similar in form as the variant verb *marche* (/marʃ/) in the *marche-marcher* alternation, we suggest that this serves as a basis for infants to treat the two words as sharing the same meaning. Note that this approach would predict that infants should not treat embedded word pairs such as *king-kingdom* as having the same meaning because there is no frequent, regular suffix in *kingdom* that supports a sub-lexical parsing of stem+suffix.

Our proposal therefore centers on the idea that word forms are interpreted by infants as sharing the same meaning due to the highly frequent and regular parsable subsyllabic affix elements. Morphologically alternating forms such as *marche-marcher* are good candidates for assigning the same word meaning. Consistent with our proposal, there is evidence that before one year of age, infants not only begin to perceive free-morpheme function words (e.g., Hallé, Durand & de Boysson-Bardies, 2008; Höhle & Weissenborn, 2003; Shady, 1996; Shi, Cutler, Werker & Cruickshank, 2006; Shi, Werker & Cutler, 2006; Shi & Lepage, 2008), but also perceive bound functional morphemes. In a study by Santelmann and& Jusczyk (1998), 18-month-old infants tracked non-adjacent dependencies such as *is_-ing* in sentences (e.g, *She is washing the car*), suggesting that infants were sensitive to the *–ing* bound morpheme. Comparable results were shown by Höhle, Schmitz, Santelmann & Weissenborn (2006) with 19-month-old German children. Three studies directly addressed the question of bound morpheme segmentation (Mintz, 2004; Marquis & Shi, 2009; Shi & Marquis, 2009). Mintz (2004) familiarized 15-month-old English-learning infants with pseudo-words ending with the English inflection *–ing*, versus those ending with a nonsense suffix *–dut*. During the test phase infants listened more to isolated stems that had occurred with *–ing* during familiarization, more than

to the materials stripped out of the pseudo-bound morpheme *–dut*. In the Shi and Marquis (2009) study, morphological parsing cues were pitted against syllabic boundary cues. After being familiarized with the pseudo-verb *glater* (/glate/), 14-month-old French-learning infants preferred the stem parsed according to morphological operations (/glat/) than to a parsing according to the syllabic boundary (/gla/). Similar results were shown in Marquis and Shi (2009), who found that by 11 months, infants can segment verb stems from suffixed verb forms. These studies demonstrate that infants do attend to bound morphemes and can segment the stem from the affix at an early age. The stem constitutes what the different morphological variants share in common. Recognizing the stem is therefore a crucial step for mapping meaning.

Although previous studies showed that children can segment inflected word forms into the stem and the suffix, no direct word learning study has tested whether children can map morphological variants to the same concept.

In the present study we inquired whether infants during early vocabulary learning encode morphological regularities. We decided to examine infants' mapping of meanings to verbs because morphological variations are prevalent for verbs in French. Specifically, our goals were to examine 1) whether infants can map an action to a novel verb form, and 2) how they interpret variants of a novel verb. Considering that in French, verb learning is late compared to noun learning (Bassano, 2000), we decided to examine infants aged 20-24 months.

In our study we were also interested in a more complex form of morphological variations – those that involve morphophonemic alternations. For example, verb forms like /repete/-/repɛt/, not only involve the suffix /e/ (in /repete/) and the resyllabification of /t/, but also a vowel phonemic change between the variants (/repɛt/), i.e., /e/-/ɛ/ alternation. Due to the greater changes in the stem, it may be more complex to assign meaning to the two verb variants. Nevertheless, since this kind of morphophonemic alternation is also rule-governed and tied to suffix operations, we predicted that infants should be able to assign the same meaning to forms containing such morphophonemic alternations.

2. Method

2.1. Participants, Stimuli and Design

Thirty-three monolingual Quebec-French-learning infants aged 20 to 25 months (Mean age: 726.64 days, SD: 53.95; range: 609-771) completed the study. The stimuli were sentences with pseudo-verb forms (table 1). The pseudo-verb has an /e/ ending when it is in its infinitive (*-er*) and past participle forms (*-é*). The /e/ ending verbs are highly frequent and regular in French. The pseudo-verb form *bréché* (/bréʃé/) and its morphological variant *brèche* (/brɛʃ/) behave like the French verb forms /repete/-/repɛt/ mentioned above. The /ʃ/ consonant is a syllabic coda in *brèche*, but resyllabified as the onset of the second syllable when the suffix /e/ is present (in *bréché*). There is also a phonemic change at the stem for the two morphological variants (i.e. br/e/ché-

br/ɛ/che). In addition, a different pseudo-verb *bréchit* (/breʃi/) was created, which has no morphological relationship with *bréché* and *brèche.* The two verbs *bréchit* and *bréché* form a minimal pair, and are phonological neighbors.

Training phase			
Label	**Sentence**	**IPA**	**English translation**
-	Il a *bréché*	/breʃe/	It did *bréché* (past tense)
-	Il a pas *bréché*	/breʃe/	It did not *béché* (past tense)
Test phase			
Label	**Sentence**	**IPA**	**English translation**
Baseline	Regarde, il a *bréché*	/breʃe/	Look, it did *bréché* (past tense)
Morphological variant	Regarde, il *brèche*	/brɛʃ/	Look, it *brèche* (present tense)
Morphologically unrelated, phonological neighbor	Regarde, il *bréchit*	/breʃi/	Look, it *bréchit* (present tense, a different verb)
Baseline	Regarde, il a *bréché*	/breʃe/	Look, it did *bréché* (past tense)

Table 1. Auditory stimuli.

A monolingual Quebec-French female speaker recorded the stimuli in an acoustic booth, using the infant-directed speech style. The recording was then transferred digital-to-digital to the computer, and prepared for the experiment.

The training phase consisted of two trial types: the *bréché* type, and the *pas bréché* type. In the *bréché* trials, infants heard three tokens of the sentence *Il a bréché* (It did *bréché*), while watching an animation of three fish each going over a bubble. In the *pas bréché* trials infants heard three tokens of the sentence *Il a pas bréché* (It did not *bréché*), while watching the same three fish each going under a bubble, i.e. a distinct action. The verb-event pairing was counterbalanced across infants, such that a different group of infants were presented with *Il a bréché* paired with the three fish going under a bubble in one trial, and *Il a pas bréché* paired with the fish going over a bubble in another trial. The two trial types, each 10.5 secs, were presented twice in alternation. The *bréché* trial type always occurred first during the training phase for all infants. The animation for each training trial was presented at the center of the monitor.

The test phase consisted of four trials. In the test trial the visual stimuli were two identical fish performing simultaneously the two actions of the training phase presented side by side on the monitor. The first and last trials constituted baseline trials, during which infants heard *Regarde, il a bréché, il a bréché* (Look, it did *bréché*, it did *bréché*), i.e., the same speech as that of the training phase. If children learned to map *bréché* to the trained event, they should look

more at that event during these baseline trials. The use of two baseline trials, one at the beginning and one at the end of the test phase, allowed us to more clearly determine if infants indeed learned *bréché* during the training phase. The other two trials in the middle of the test phase presented the verb forms *brèche* and *bréchit* respectively. In the *brèche* test trial (i.e., a morphological legal variant of *bréché*), infants heard *Regarde, il brèche, il brèche* (Look, it *brèche*, it *brèche*), while watching the two events. If infants had the knowledge of the *bréché-brèche* alternation, then upon hearing *brèche*, they should look more at the event that was mapped to *bréché*. In the *bréchit* test trial (i.e., morphologically unrelated to *bréché*, but a phonological neighbor of *bréché*), the infants heard *Regarde, il bréchit, il bréchit* (Look, it *bréchit*, it *bréchit*). If the infants had the knowledge of morphological alternations and used the rule to guide their mapping of meaning, they should not look more at the action that they mapped to *bréché* upon hearing *bréchit*. Instead, they should look more at the other event. The sides of the actions were counterbalanced across trials, and the order of the *brèche* and *bréchit* trials was counterbalanced across infants.

2.2. Procedure

Participants were tested individually in the Split-Screen Preferential Looking Paradigm. In the sound-attenuated test booth the child sat on his/her parent's lap. The parent listened to masking music from noise cancellation headphones. At about two meters in front of the child, a 42-inch LCD monitor presented the visual stimuli and two loudspeakers adjacent to the monitor delivered sound. A Panasonic HD camcorder videotaped the child's face. The camcorder was connected to a monitor in an adjacent room allowing a researcher to observe the child's eye responses. The testing software HABIT (Cohen, Atkinson & Chaput, 2000) presented the stimuli in the test room. Each trial was initiated by the child, i.e., the researcher waited for the child to look toward the monitor before launching a trial. Once a trial started, it continued for the entire trial length. Between trials, an attention getter (an animation of a star accompanied by a whistle sound) was presented to attract the infant's attention.

The videotaped sessions were transferred with 33 ms accuracy on a Macintosh computer and converted into QuickTime video file format. With the SuperCoder software (Hollich, 2005), each child's looking behavior was coded offline frame by frame. The coder, who was blind to the audio and video of the trials, coded the child's eye gazes and their directions, i.e. left, right or away.

3. Results

For each test trial, we calculated the time that the child spent looking at one event (e.g. the event trained with *bréché*) and the time spent on the other event. Then, we calculated the proportion of looking time (LT) to the event that had been trained with the pseudo-verb form *bréché*, i.e. the looking time to the event *bréché* out of the sum of the looking times for the two events. For each test trial,

we analysed the looking behaviour during a 5-sec window, starting 300 milliseconds after the pseudo-verb onset (i.e., starting from 7.3 sec).

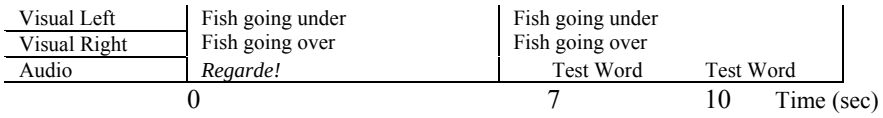

Fig. 1. Time line of an example test trial. The fish take 5.75 secs to complete their action one time. When the action is completed, the fish disappear for 0.5 secs. Then, the fish repeat their actions for a second time.

3.1. Baseline test trials

Before analyzing the verb variants presented during the test trials, it was crucial to determine whether the children learned to map *bréché* to the trained event. Therefore, we analyzed the baseline test trials (i.e., which presented the trained verb *bréché*). The proportion of LT to the event that had been trained with *bréché* was averaged across the two baseline trials. Infants were assessed individually based on a pre-established criterion. If an infant looked between 45% and 55% of the time at either of the two events upon hearing *bréché*, he or she was categorised as a "non-learner". That is, near equal looking times to the two events would suggest that the infant was uncertain about which event the word *bréché* was referring to. Seven fell into this "non-learner" category.

Interestingly, the 26 remaining infants were not all successful, in the sense that they were not all looking more at the trained event upon hearing *bréché* during the baseline test trials. Nine of them learned the verb-event pairing in the same way that they were trained. That is, upon hearing *bréché* during the baseline test trials, they looked more (above the pre-established criterion) at the trained event. We will refer to these infants as the "successful learners".

The remaining 17 infants showed the opposite learning pattern. They were not "non-learners" because they did not produce comparable (45%-55%) looking to both events. They definitively and consistently looked more at one of the two events during the baseline test trials, suggesting that they mapped the *bréché* to that event. Unlike the successful learners, these infants looked more at the opposite event, which was trained with *pas bréché* ("not bréché"). One possible explanation of this result is that the two events belong to the same global semantic class. Therefore, it may be difficult for the infants to remember which of the two events was presented with *bréché* during training. Note also that verb learning is in general harder than noun learning, and our training was quite short. Nevertheless, these infants did learn that *bréché* referred to one of the two events. We thus considered them as "alternate learners".

Subsequent to the above analyses, we assessed infants' interpretations of other pseudo-verb forms by analyzing successful and alternate learners separately, using their baseline performance as the reference points. This approach enabled us to make precise and meaningful predictions.

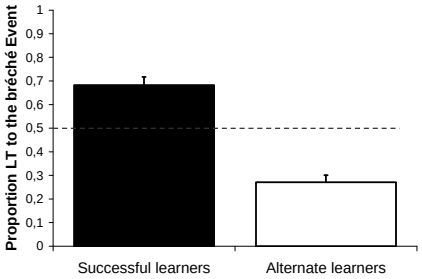

Fig. 2. Baseline test trials: proportion of LT to the event that had been trained with the pseudo-verb form *bréché*.

3.2. Key test trials

For each type of learners (i.e., successful and alternate), we conducted two kind of statistical analyses of the test trials: comparisons of the proportion of LT of each trial with the chance level, and comparisons of the proportions of LT between the trials. Chance level was defined as a proportion of LT of 0.5 to each of the two events, i.e. equal proportions of LT for the two events. We predicted that if infants can appropriately map meaning to morphological variants, then upon hearing the verb variant *brèche,* they should look above chance at the event that they mapped to *bréché*. Also, upon hearing the unrelated *bréchit*, they should look more at the opposite event, i.e., the one that they did not map to *bréché*, or equally at both events.

3.2.1 Successful learners

For each test trial, one-sample t-test compared the proportion of LT to the *bréché* event (the action that was trained with *bréché*) with the chance level (i.e., 0.5). While hearing *bréché* (i.e., the baseline trial), the successful learners yielded a proportion of LT significantly above the chance level, M=0.68; SE=0.03, $t(8)$=5.375, p= .01. This was expected, as we had selected the infants who looked 55% or more at the *bréché* event for the baseline. Our primary interest concerned the two key trials. In one key trial, the proportion of LT to this same *bréché* event while infants heard the morphologically unrelated *bréchit* was below chance level (M=0.28; SE=0.09),, $t(8)$=-2.211, p= .058. This indicates that *bréchit* was mapped to the *pas bréché* event, distinct from these infants' *bréché* interpretation. However, the proportion of LT to the *bréché* event while infants heard the morphological variant *brèche* was not different from chance, M=0.63; SE=0.11, $t(8)$=1.208; p= .262.

We also performed a repeated measure ANOVA to compare the proportions of LT of the three test trials, and showed a significant difference, $F(1,8)$=6.415, p= .009. Further analyses between trials were conducted. The proportion of LTs to the *bréché* event during the *bréchit* trial (morphologically unrelated verb)

versus during the baseline *bréché* trial were significantly different, *F(1,8)*=10.689, *p*= .011. The *bréchit* test trial also differed significantly from the *bréche* trial, as shown in Fig. 3, *F(1,8)*=7.173, *p*= .028. These looking patterns suggest that *bréchit*, a pseudo-verb that is morphologically distinct from *bréché* and *brèche*, was indeed interpreted distinctly from the two verbs. The proportions of LTs between the *bréché* and *brèche* trials were not significantly different (the first 2 columns of Fig. 3). This result is consistent with the hypothesis that infants have some understanding of morphological relatedness between *bréché* and *brèche.*

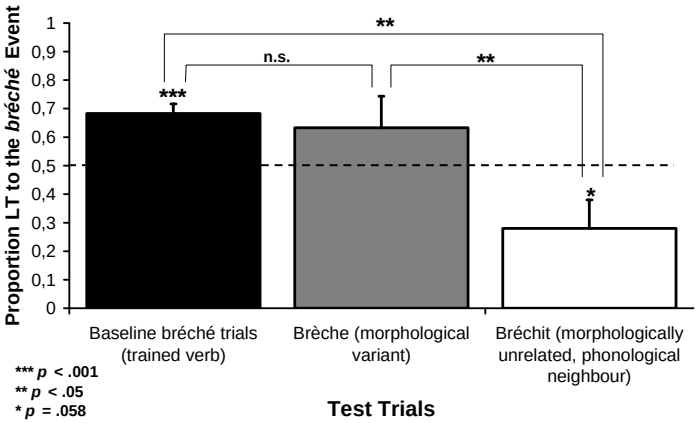

Fig. 3. Successful learners' proportion of LT to the event trained with the pseudo-verb form *bréché* during test trials.

These results suggest that the morphologically unrelated form *bréchit* was treated as having a different meaning than *bréché*. It is less clear whether the infants mapped the variant *brèche* to the same meaning as *bréché*. The comparison to chance level failed to show that *brèche* was assigned to the same event as *bréché*. But the between-trial comparison showed that *bréché* and *brèche* were not significantly different in looking time, both in opposite looking direction of *bréchit*. We interpret these results as suggesting that infants at this age have an emerging knowledge of the morphophonemic alternations of this type of verbs.

The finding that infants assigned distinct meanings to *bréchit–bréché*, but not to *brèche–bréché*, is significant. Note that the verb *bréchit* is a much closer phonological neighbour to *bréché* than *brèche* to *bréché*. It is interesting that infants did not clearly assign distinct meaning to the more distinct form *brèche*. These results suggest an emerging morphological knowledge in infants.

3.2.2. Alternate learners

As in the case of the successful learners, for each test trial, a one-sample t-test was used to compare the proportion of LT to the *bréché* event (the action that was trained with the verb *bréché*) with the chance level (i.e., 0.5). During the baseline test trial (i.e., while hearing *bréché*), the alternate learners' proportion of LT was significantly below the chance level, M=0.27; SE=0.03, $t(16)$= -7.266, $p < .01$. This was not surprising since the alternate learners were those who reached the criterion of below 0.45 in their proportion LT to the trained event. That is, they mapped the verb *bréché* to one of the two events (the *pas bréché* event) consistently. Hence, these infants were learners, unlike the non-learners (who showed chance level looking pattern, i.e., confusion).

Following the baseline analysis, the key test trials were assessed. For the *bréchit* trial (morphologically unrelated), the proportion of LT to the *bréché* event (i.e., the action trained with *bréché*) was not significantly different from chance, M=0.62; SE=0.07, $t(16)$=1.677; p=.113. The proportion of LT during the *brèche* (morphological variant) trial was also non-significant from chance, M=0.43; SE=0.07, $t(16)$= -1.007; p= .329.

In the second analysis, we conducted a repeated measure ANOVA. There was a significant difference when the three trials were compared together, $F(1,16)$=10.040, $p < .001$. Subsequently, between-trial comparisons were conducted. Upon hearing the morphologically unrelated verb *bréchit*, the proportion of LT to the *bréché* event (the one trained with *bréché*) was significantly different from the proportion of LT of the baseline test trial (the *bréché* verb), $F(1,16)$=20.939, $p < .001$. The *bréchit* trial was also significantly different from the *brèche* trial, $F(1,16)$=4.656, p= .046. Unlike in the case of the successful learners, the proportions of LTs of the *bréché* and *brèche* trials in alternate learners were also significantly different, $F(1,16)$=5.333, p= .035. In sum, each paired comparison for the test verbs was significantly different, as shown in Fig.4.

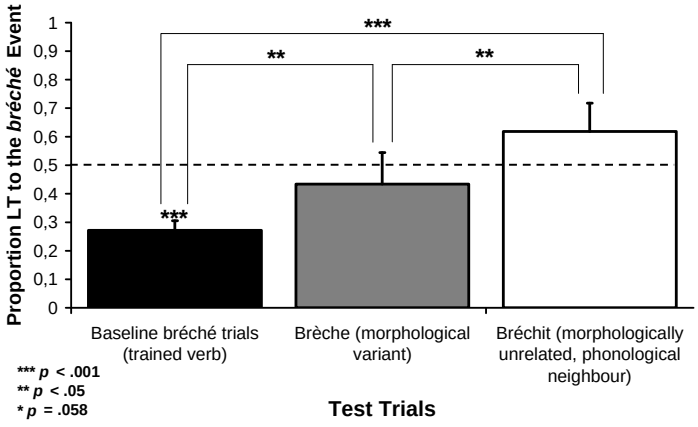

Fig. 4. Alternate learners' proportion of LT to the event trained with the pseudo-verb form *bréché* during test trials

4. Discussion and Conclusion

We examined French-learning toddlers' interpretation of verb meanings during word learning. Three pseudo-verb forms were used, *bréché*, *brèche*, and *bréchit*. According to the French grammar, the first two forms are morphological variants of the same verb, and thus have the same basic meaning. The third form *bréchit* belongs to a different verb. Phonologically, however, the first and the third are more similar in form (/breʃe/-/breʃi/) than the two morphologically related ones (*bréché* - *brèche*). We found that infants who learned the meaning of *bréché* in the way we taught them (called "successful learners") interpreted the morphologically unrelated *bréchit* as having a distinct meaning. In contrast, these infants did not seem to treat the morphologically related *bréché* and *brèche* as being semantically distinct, although *brèche* is much more different phonologically from *bréché* than *brèche* is. This suggests that infants showed an emerging knowledge of verb morphological alternations.

Another group of infants did not assign the verb *bréché* to the action that we taught them to map. They nevertheless assigned the verb consistently to another action, and were thus called "alternate learners". Using their interpretation of *bréché* as the baseline, we found less evidence of morphological knowledge in these learners. Although they showed significant difference between *bréchit* and *bréché* trials, they also showed significant difference between *brèche* and *bréché* trials. Crucially, these infants' looking times to both *brèche* and *bréchit* were not different from chance, suggesting that they were confused with the meaning of both forms. They did not interpret the morphologically related *bréche* and *bréché* as having the same meaning. Moreover, *bréchit* was not assigned a distinct meaning from *bréché*.

Therefore, the evidence was more robust in successful learners for the knowledge of verb morphological alternations. Nevertheless, both the successful and alternate learners show the same general direction of looking. Neither group interpreted the phonological neighbor *bréchit* as semantically closer to *bréché* (than *brèche* is to *bréché*). For both groups, the proportion of LT of the *bréchit* trial was in the opposite direction to that of the *bréché* trial, while the proportion of LT of the *brèche* trial was in the middle. This could be interpreted as evidence of the beginning of morphological learning. If phonological similarity were instead to drive the direction of responses, the proportion of LT during *bréché* and *brèche* trial could have gone in opposite directions, and the proportion of LT during *bréché* and *bréchit* trials in the same direction. Therefore, our results rule out the phonological similarity hypothesis. Given no phonological neighborhood effect for verb learning, infants should be expected to interpret both *bréchit* and *brèche* as equally different in meaning from *bréché* if they have absolutely no morphological knowledge. This is, however, not what we observed. Successful learners, for example, clearly interpreted *bréchit*, but not *brèche*, as having a distinct meaning from *bréché*. Therefore, we can conclude that infants between 20 and 24 months of age have the emerging

knowledge of morphological alternations, although this knowledge is still limited.

Based on previous preferential listening studies, it is known that before one year of age, infants begin to process phonological alternations (White, Peperkamp & Morgan, 2008), and morphological alternations (Shi & Marquis, 2009), prior to word learning. Infants begin to parse stems and suffixes at about 11 months of age (Mintz, 2004; Marquis & Shi, 2009; Shi & Marquis, 2009). We suggest that it is the parsing of the highly frequent and regular affixes from the stem and the processing of related regular morphophonemic rules that allow infants to link morphological variants and map them to the same core meaning.

The results of the present study indicate that close to two years of age, infants begin to correctly associate meaning to morphological variants that follow morphophonemic alternation rules. Infants' performance in our experiment was remarkable given that verb learning is known to be hard.

Acquiring a mental lexicon requires children to learn, on the one hand, to treat phonologically different word forms as contrastive in meaning, and on the other hand, to treat phonologically different forms that are morphologically related as non-contrastive in core meaning. Based on the existing word learning literature and the new findings of the present study, we can conclude that infants can learn both aspects early in language acquisition.

Acknowledgment

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