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Acquiring the Last Plural: Morphophonological Effects on the Comprehension of /-əz/

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Abstract

English-speaking children use plural morphology from around the age of two, yet often omit the syllabic plural allomorph /-əz/ until age five (e.g., *bus(es)*). It is not clear if this protracted acquisition is due to articulatory difficulties, low input frequency, or fricative-final words (e.g., *bus, nose)* being treated as already plural, raising questions about when and how the representation of the syllabic plural develops in perception. Novel-word intermodal preferential looking studies have shown productive comprehension of the plural allomorph /-s/ (e.g., *cats*) at 24 months (Davies, Xu Rattanasone & Demuth, 2017). Using the same procedure, this study investigated when toddlers can comprehend the syllabic plural, and treat words ending in /s, z/ as singular (e.g., *bus vs. bus+es*). The results show that 30-month-olds (n=20) could not identify the number condition of either the singular or plural, but 36-month-olds (n=20) could identify both, showing productive knowledge of the syllabic allomorph and its singular counterpart with novel words. This suggests children's omission of the syllabic plural in production may be due to later acquired mental representations requiring a sophisticated understanding of English morphophonology.

(181 words)

Introduction

Many of the current models of language development suggest that children acquire grammatical morphemes through reanalysis and/or reorganisation of their existing lexical representations. Some accounts propose that children initially learn inflected words as whole lexical units, and then reanalyse these words later, (over)generalizing abstract morphological rules (e.g., Marcus et al., 1992). Other accounts see morphology emerging as a by-product of organisational properties of children's expanding lexicons, with input frequency (e.g., Tomasello, 2000) and phonological structure (e.g., Bybee, 2001) playing substantial roles. Yet, any account of children's acquisition of allomorphy must consider morphophonological effects. Examples of such morphophonological processes can be readily seen in cases of plural allomorphs, including the late acquired syllabic plural /-əz/, as in the word *buses*. It remains unclear as to *when* children acquire representations of the syllabic plural /-əz/, and *why* it appears to acquired later than its segmental counterparts, /-s/ and /-z/.

Studies of English-speaking children's acquisition of plural allomorphy paint a picture of a productive system emerging gradually. Children begin to reliably produce plural words in spontaneous speech from around 24 months (Brown, 1973; de Villiers & de Villiers, 1973; Lahey, Liebergott, Chesnick, Menyuk, & Adams, 1992; Mervis & Johnson, 1991). However, these studies suggest that children's early productions belie an incomplete understanding, or *misunderstanding*, of plural morphology. *Wug* tasks have shown that 4-year-olds, and even some 7-year-olds, have trouble producing plural forms of newly learnt words (/wʌg/ → /wʌgz/), especially for the low frequency syllabic plural allomorph /-əz/ (e.g., /nɪz/ → /nɪzəz/) (Berko, 1958; Graves & Koziol, 1971). In a more recent adaptation of the task, Zapf & Smith (2007) found that some 2-year-olds were able to inflect some novel nouns with the plural morpheme, as well as decompose some novel plurals into singulars. However, the few children who were able to do so required weeks of training. Interestingly, even though the Zapf

& Smith (2007) task was not designed to systematically explore the effect of allomorphy on children's production, the only novel word item (out of 14) testing children's use of the syllabic plural /-əz/ (i.e., *niz*), appeared to be one of the most difficult.

Perception tasks employing the Intermodal Preferential Looking paradigm (IPL) (Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987) have similarly shown that children's understanding of plural morphology is not as complete as their spontaneous productions may suggest. Kouider, Halberda, Wood, & Carey (2006) found that 3-year-olds, but not 2-year-olds, were able to identify the number condition on novel singular and plural words, such as *blicket* and *nools*. However, in an IPL study employing more systematic phonological control, Davies, Xu Rattanasone, & Demuth (2017) found that 24-month-olds could only comprehend novel plural nouns inflected with the *voiceless* allomorph /-s/, as in *tep**s*** /tɛp**s**/, but not the *voiced* allomorph /-z/, as in *kib**s*** /kɪb**z**/[1]. Although /-z/ is much more frequent as a plural allomorph, these toddlers seemed to comprehend the less frequent plural allomorph /-s/, possibly due to its longer duration/greater perceptual salience.

Thus, on the path towards acquiring adult-like representations of plural morphology, children need to learn these three different surface forms, or allomorphs, of the English plural, and the phonological contexts in which they each appear. The two segmental allomorphs are the voiceless plural /-s/, occurring on words ending with a voiceless segment (e.g., *cat* /kæt/ → *cats* /kæts/), and the voiced plural /-z/, occurring on words ending with vowel or a voiced segment (e.g., *bee* /bi:/ → *bees* /bi:z/; *dog* /dɔg/ → *dogs* /dɔgz/). The third allomorph, the syllabic plural /-əz/, is realized on words ending in a sibilant (*bus* /bɐs/ → *buses* /bɐsəz/; *peach* /pi:ʧ/ → *peaches* /pi:ʧəz/), adding another (unstressed, reduced) syllable to the word. It is

[1] The International Phonetic Alphabet (IPA) transcriptions employed here are those used for standard Australian-English (Harrington, Cox, & Evans, 1997).

through an understanding of plural morphophonology that learners must come to realize that the plural of *eye* /ɑe/ is not *ice* /ɑes/, but *eyes* /ɑez/, that the plural of *pea* /p^{h}i:/ is not *peace* /p^{h}i:s/, but *peas* /p^{h}i:z/, and that the plural of *bus* /bɐs/ is not /bɐss/, but needs an epenthetic vowel, becoming /bɐsəz/.

There is also growing evidence that English-speaking children build representations of plural morphology allomorph-by-allomorph, with the voiceless /-s/ emerging first at 24 months before the voiced equivalent /-z/ (Davies et al., 2017; Kouider et al., 2006). Data from Zapf & Smith's (2007) *wug* study with 2-year-olds also suggested an earlier emergence of plural /-s/. Articulatory studies using ultrasound measurements have further shown that 27-month-olds have slightly different productions of the word-final /ks/ clusters depending on the morphological context (e.g., morphologically simple (singular) *box* /bɑks/ vs. the morphologically complex (plural) *rocks* /ɹɑks/), suggesting an early awareness of plural /-s/ (Song, Demuth, Shattuck-Hufnagel, & Ménard, 2013).

However, children continue to variably omit plural /-əz/ in everyday speech years after systematic production of plural words ending in /-s/ and /-z/ (Brown, 1973). The syllabic plural is the latest acquired in *wug* tasks (Berko, 1958), and by both typically developing 5-year-olds and those with specific language impairment (SLI) when performing both elicited production and grammaticality judgement tasks (Tomas, Demuth, & Petocz, 2017; Tomas, Demuth, Smith-Lock, & Petocz, 2015). A closer examination of Kouider et al. (2006) also suggests that 36-month-olds struggle to comprehend novel words inflected with the syllabic plural /-əz/ (though this study was not designed to explicitly look at allomorphic variation). This is curious, as one might think that the addition of another syllable would be especially perceptually salient, even as a reduced syllable.

One potential explanation for the later acquisition of the syllabic plural might be its relative low frequency (only ~ 5% of all plurals in child-directed speech, by both type and token) (cf. Davies et al., 2017). Perhaps young children are unable to create robust representations of this allomorph simply because they do not have sufficient examples in the input they hear. Alternatively, perhaps young children simply lack the articulatory skills to reliably produce the syllabic plural. The fricatives /s/ and /z/ are relatively difficult for children to produce, especially in coda position at the ends of words and when part of a cluster, e.g., in *ca**ts*** (Chirlian & Sharpley, 1982; Smit, 1993). The production of plural /-əz/ may be especially challenging as it necessitates the articulation of a *sibilant-schwa-fricative* sequence. For example, Mealings, Cox, & Demuth (2013) showed that 3-year-olds are more likely to omit the syllabic plural in an elicited imitation task, or produce it in reduced form (e.g. *buses* /bɐsəz/ ➞ /bɐs/ ~ /bɐsə/ ~ /bɐsz/), compared to disyllabic words with a segmental plural, like *babies* (/bæɪbiːz/). Children are also more likely to omit word-final coda consonants from disyllabic words and from unstressed syllables than from stressed monosyllables (Kirk & Demuth, 2006), suggesting multiple challenges for producing the syllabic plural.

Another possible explanation for its later acquisition is that children simply regard words ending in /s/ or /z/ to be plural already. In her original *wug* study, Berko (1958) hypothesised that children have problems with the syllabic plural /-əz/ not because of any properties of the allomorph itself, but rather because of the phonological structure of the singular words onto which it attaches. She found that 91% of 4- to 7-year-olds were able to appropriately inflect novel words with the segmental plural allomorph /-z/ (e.g., wug /wʌg/ → wugs /wʌgz/), whereas only 36% were able to appropriately inflect novel words with the syllabic plural /-əz/ (e.g., nizz /nɪz/ → nizzes /nɪzəz/). Production difficulty was unlikely the cause of this discrepancy since 91% of these children were able to successfully produce the familiar word *glasses.* Berko (1958) thus suggested that children's inability to inflect novel words with the syllabic plural /-əz/ was due to the fact that the singular novel words in this task already ended in /s/ or /z/, and were therefore already interpreted as being plural. That is, young children may be paying attention to the *phonological* structure of words in order to determine number (cf. Köpcke, 1998). Note, however, that the nouns *rose* and *rows* share the same phonological structure /ɹəʉz/, yet one is singular (*rose*), and the other plural (*row+s*). Learners therefore need some additional knowledge above phonological structure alone to know when a word ending in /z/ is plural, and when it is not.

In English, the segmental plural allomorph assimilates in voicing to the preceding segment. Since vowels are voiced, they must appear with the voice plural allomorph /-z/, as in *bees* /bi:z/. Thus, a word with the shape CVs, as in *bus* /bɐs/, can only be singular. Furthermore, English monosyllabic words cannot end in a short (lax, monomoraic) vowel. This is due to a language-specific word-minimality constraint, requiring that open class lexical items in English contain at least a certain amount of phonological content (cf. Demuth, Culbertson, & Alter, 2006). Thus, a CV word in English must contain a long vowel or diphthong, as in *bee* /bi:/; a CV word ending in a short/lax vowel such as */bɪ/ or */bɐ/ would be phonotactically ill-formed. Thus, a word such as *fizz* /fɪz/ must be singular, as must the novel word *nizz* /nɪz/.

Although it is not clear when children have learned about the importance of voicing assimilation for the plural, children do seem to be aware of the word-minimality constraint in production by at least 27 months (cf. Miles, Yuen, Cox, & Demuth, 2016). Thus, if children interpret novel CVs and CVz words with short vowels as singular, this would suggest that they are aware of the English word minimality constraint, and can use this distributional information to help inform their morphological segmentation processes. If, however, children are simply paying attention to the final consonant of a word, and interpreting fricative-final words as plural, these novel CVs and CVz words could be interpreted as plural. However, given that previous IPL studies have shown no sensitivity to the singular before the age of 3 (e.g., Davies et al., 2017; Kouider et al., 2006), it is possible that children might treat these novel words as neither singular nor plural.

The present study therefore employed a novel-word IPL paradigm similar to that used in Kouider et al. (2006) and Davies et al. (2017) to probe 30- and 36-month-olds' representations of the plural (Experiments 1 and 2, respectively). Novel words were used because they allow us to assess children's *productive* knowledge of plural morphology without interference from their lexical knowledge. That is, while children may have memorised a word such as *buses* /bɐsəz/ as meaning *more than one bus*, the only way to comprehend that a novel word such as *nizzes* /nɪzəz/ is plural, is by recognizing its morphological structure: /nɪz/+/əz/. Kouider et al. (2006) suggest that, by 36 months, children are sensitive to all three allomorphs. We therefore aimed to capture any developmental trends across this early period of plural acquisition by asking two questions: 1) when does comprehension of the syllabic plural emerge, and 2) when do learners understand that words with a short vowel ending in /s/ or /z/ (e.g. *bus*) must be singular. It was hoped that answers to these questions would shed light on *when* the syllabic plural becomes well established as a productive morpheme in children's mental lexicon, thereby helping inform *why* this plural allomorph is acquired later than its segmental counterparts in production.

Method

Experiment 1

Participants

The participants were twenty Australian English-speaking 30-month-olds (9 girls, 11 boys). None had any reported hearing, speech or cognitive impairments. All were recruited from a university database to which parents had voluntarily signed up. Children's ages ranged from 129 to 137 weeks, with a mean age of 133 weeks (2;6.3 years). Two additional girls and one boy were excluded for failing to return sufficient trials due to fussiness and/or inattention. One additional girl was excluded from the analysis for returning difference scores greater than three standard deviations from the mean (see results).

Auditory Stimuli

Participants listened to three different types of words: *familiar practice words*, *familiar filler words*, and *novel test words*. The practice trials included four familiar singular words (*dog*, *cat*, *bird*, *cow*). The filler trials included three familiar singular/plural words (*bus(es)*, *house(s)*, *horse(s)*). The purpose of the filler trials, using real words, was simply to maintain children's attention during the task. Target words for the *test* trials were composed of 12 novel, monosyllabic, fricative-final novel word stems. The purpose of using novel test words was that children could only determine whether these were singular or plural through their understanding of morphological structure, i.e., they could not use any lexical knowledge to perform the task. Half of the novel test word stems were /s/-final and half were /z/-final. Each word stem was recorded as both a CVC singular word (with no inflection) and as a CVCəz word (with the syllabic plural morpheme /əz/; see Table 1). Because CVz words containing long vowels and diphthongs can be either singular (e.g., *cheese* /ʧi:z/) or plural (e.g., *bees* /bi:z/), only the short vowels /æ/, /e/, /ɪ/ and /ɔ/ were used, ensuring that these were phonotactically unambiguously singular.

Table 1 *Singular and plural target test items.*

Singular		**Plural**	
bess	/bes/	besses	/besəz/
dass	/dæs/	dasses	/dæsəz/
dozz	/dɔz/	dozzes	/dɔzəz/
giss	/gɪs/	gisses	/gɪsəz/
gozz	/gɔz/	gozzes	/gɔzəz/
kazz	/kæz/	kazzes	/kæzəz/
koss	/kɔs/	kosses	/kɔsəz/
nass	/næs/	nasses	/næsəz/
nizz	/nɪz/	nizzes	/nɪzəz/
pezz	/pez/	pezzes	/pezəz/
poss	/pɔs/	posses	/pɔsəz/
tizz	/tɪz/	tizzes	/tɪzəz/

All stimuli were produced by a female native speaker of Australian English using child-directed speech, and were recorded in a sound-attenuated room. Each stimulus item was recorded with the carrier phrase "*Look at the X*" as a complete utterance (e.g., "*Look at the koss*"). During the experiment, each child heard three singular novel words ending with /s/, three ending with /z/, and six inflected syllabic plural words ending in /-əz/. Audio was digitally recorded using Cool Edit Pro 2.0, and sampled at 48 kHz. Stimuli with singular novel words were 1445 ms in duration, and plural stimuli were on average 1591 ms in duration. The /-əz/ morpheme was 517 ms in duration.

Visual Stimuli

Visual stimuli for the practice and filler trials contained drawings of familiar animals/objects. Practice and filler pictures were displayed in realistic colours for the given animal/object (e.g., a brown horse, a yellow bus). Visual stimuli for the novel test trials contained 16 novel cartoon animals. The animals were depicted with happy faces and closed eyes, designed to not resemble any real or fictional animals (see Figure 1). Each visual stimulus depicted either one animal (for singular pictures) or five identical smaller animals (for plural pictures) against an off-white background. Each complete picture measured 23.3 cm by 27.7 cm. Singular and plural animal depictions were size matched to 179.3 cm^2, or 27.8% of the surface area of each picture. Two versions of each picture were created, one in solid red and the other solid blue. Colour variation across trials was designed to make the experiment more interesting for the children. During the experiment, only pictures of the same colour were displayed side-by-side within a trial.

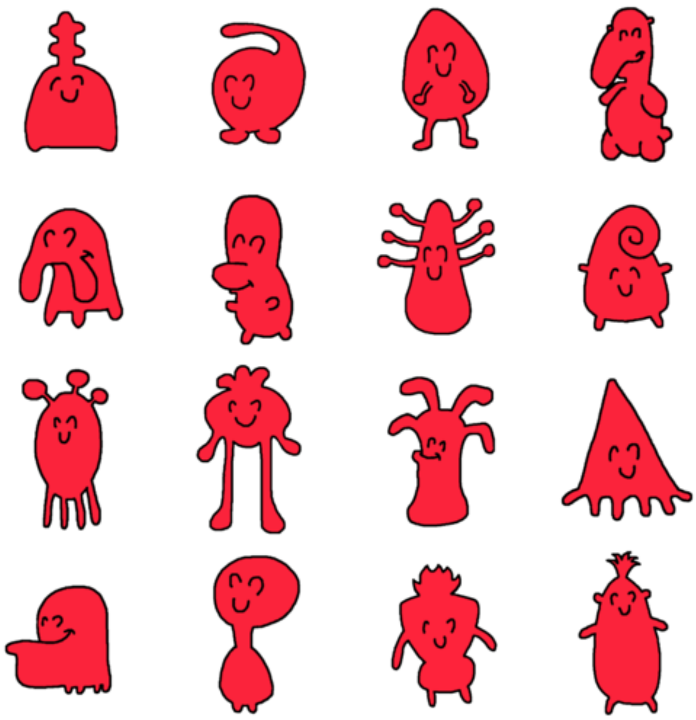

Figure 1. Novel animals used as visual stimuli

To ensure children's continued attention during the task, each target picture (both novel and familiar) also had a "dancing" animation at the end of the trial (see below). The animated pictures also danced during a character parade at the beginning and the middle of each experiment.

Apparatus

A Tobii x120 Eye Tracker (Tobii Technology, Danderyd, Sweden) was used to record participant looking behaviour. The eye tracker was positioned approximately 60 cm in front of the child and tilted at a 30° angle. The eye tracker recorded gaze data from both eyes at a sample rate of 120Hz. Visual stimuli were presented on a widescreen 27" LG Flatron W2753VC monitor, positioned 15 cm behind the eye tracker.

Auditory stimuli were played through two Edifer USB M1250 computer speakers positioned either side of the monitor. Experimental media were presented through Tobii Studio (3.2.3) as .AVI files, encoded in MPEG-4 at 24 frames-per-second, and displayed at 1080 x 1920 pixels at 81.6 pixels-per-inch. Audio was 128-bit MPEG Audio at 48 kHz played at a normal speech level (≈ 65 dBA).

Procedure

Parent and child were invited into a small test room to watch a short video. Parents wore opaque glasses to prevent their gaze from being recorded, and to ensure they were blind to the task. They were told they could encourage their children to "*watch the movie*", or "*look at the screen*" if the child got distracted or fussy, but instructed to not repeat any of the audio stimuli, or use number-indicative pronouns such as "that" or "those". Each child was seated facing forward, on the parent's lap, approximately 75 cm in front of the monitor and 60 cm from the eye tracker.

Each participant watched 18 trials in total, including three practice trials, three familiar filler trials and twelve novel test trials. Each experiment began with the practice trials containing pictures of familiar animals/objects. These displayed two singular animals, side-by-side (e.g., *cat* vs. *bird*) where the target was always singular. Across the four experimental versions, practice trials were always presented in the same order with the same target picture (underlined): *dog* vs. *cow, cat* vs. *bird* and *bird* vs. *cow*, pseudo randomized with respect to side of the screen.

The filler trials were interspersed throughout the experiment to maintain the child's attention and to ensure they were doing the task. In the filler trials, a picture of one familiar animal/object (e.g., *bear*) was displayed alongside a picture of five familiar animals/objects (e.g. *horses*); the target was either singular or plural. Filler trials had no set order across different experimental versions, however the target pictures *bus(es)*, *rose(s)* or *horse(s)* were always yoked to the distractor pictures *house(s)*, *tree(s)* and *bear(s)*, respectively. The inclusion of these familiar filler trials ensured that participants attended to the task throughout.

The novel test trials also displayed both a singular and plural picture side-by-side, one depicting a solitary novel animal (singular picture) and one depicting five identical instantiations of another novel animal (plural picture). The auditory stimulus was either singular or plural and corresponded to the number condition of the target picture. While the practice and filler trials provided an indication of whether children understood and were paying attention to the task, only the novel test trials examined children's productive knowledge of singular vs. plural morphology.

Each practice, filler and test trial was composed of five phases: (1) the pre-naming phase, (2) the gaze-centring phase, (3) the naming phase, (4) the post-naming phase, and (5) the animation phase (see Figure 2).

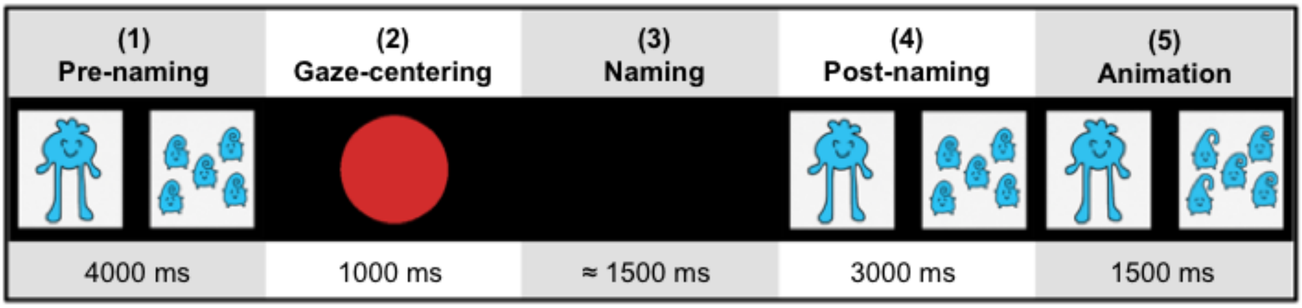

Figure 2. Phases in an example novel test trial.

During the **pre-naming phase**, participants were shown two pictures side-by-side on the screen. After 1250 ms, one picture blinked on the screen followed by the other picture (a blink was created by having the pictures disappear briefly for 250 ms, then reappear). This sequential blinking encouraged children to look at both pictures. Across the experiment, the order of blinking was counterbalanced across left versus right sides, singular versus plural picture, and target versus distractor. After blinking, both pictures then remained on the screen for another 2000 ms.

Following this was the **gaze-centring phase**, where a looming red ball was presented in the middle of the screen which grew and shrank against a black background for 1000 ms to maintain the children's attention. Next was the **naming phase**, where a recorded voice encouraged the children to "*look at the X*". This phase ended 300 ms after the offset of the audio.

The pictures then reappeared at the beginning of the **post-naming phase**, and remained for 3000 ms. This was the critical phase during which looking times were measured. This was followed by the **animation phase,** where the target picture became animated and danced to music for 1500 ms.

During the session, children also watched two character parades, one at the beginning of the experiment, and one in the middle of the experiment (after the eighth trial). This was to ensure that all children had been exposed to the test items before beginning the experiment and ensured that these active toddlers remained engaged during the session. At the beginning of the experiment, each animal/object from the first half of the experiment was displayed on the screen dancing to music. Each animated picture was presented alone for 3000 ms, in the same colour, number condition and side of the screen in which it appeared in the test trials. In the middle of the experiment the second parade, with the animals/objects used in the second half of the experiment, was presented.

Design

Four pseudo-randomized versions of the experiment were constructed to ensure there were no stimulus presentation order effects. Visual stimuli were counterbalanced for (a) whether they were presented as a plural or singular picture, and (b) whether they were presented as a target or distractor. Across the four different versions, no two novel animals (regardless of number condition) were displayed next to each other more than once. No novel target word (regardless of number inflection) was ever presented with any novel animal more than once. Each pseudo-randomized version of the experiment is presented in the appendix.

Data Analysis

Data analysis was conducted on the novel test trials only. Raw looking data were converted into fixations using the IVT fixation filter in Tobii Studio (3.2.3). Using the default IVT fixation filter settings, fixation points were averaged across both eyes over a three-sample window, with missing data points interpolated for up to 60 ms. Areas of interest (AOIs) were defined for the target and distractor picture in each trial.

Individual trials were excluded if the child failed to return fixations on both the target and the distractor during the pre-naming phase, or if they failed to return any samples during the post-naming phase. Trials were also excluded if the child did not return any samples anywhere on the screen while the auditory stimulus was played, taken as an indication of not paying attention to the stimulus. Participants were excluded from the analysis if they failed to return at least 50% of the singular and 50% of the plural trials (n = 2; see Participants section above). The final dataset included 98 novel singular test trials (M = 4.9 trials per participant) and 101 novel plural test trials (M = 5.05 trials per participant).

Two dependent measures were used in this analysis: *proportion looks to target* and *difference score*. Proportion looks to target was calculated by dividing the total time spent fixating on the target picture by the sum fixation time of both the target and distractor pictures, excluding any time not spent looking at either picture. The difference score was calculated by subtracting the proportion looks to target during the **pre-** from the **post-naming phase**, and multiplying by one hundred to make a percentage. The difference score indicates the amount of change in children's looking towards the target picture after hearing the auditory stimulus. The difference score therefore provides a within-subjects control/baseline for target picture preference throughout the trial.

Two types of analyses were then conducted. The first examined changes in proportion of looks to target (**difference score**). If children could identify the number condition of words, this was indicated by a positive difference score (i.e., greater than chance). The second analysis examined changes in proportion of looks to target across time. This time course analysis was conducted over the 3000 ms post-naming phase, and provides more fine-grained information on real-time looking behaviour across each trial. Together the two measures provide evidence for children's ability to identify the number condition of words and how this was processed over time. However, note that while children's difference scores during practice and familiar filler trials were analysed as a measure of their attention to the task, these items were not examined by looking at proportion of looks to target across time.

Results

To evaluate 30-month-olds' ability to perform the task, analyses were first carried out on the difference scores from the familiar practice and filler trials using the statistical analysis program R (R Core Team, 2016). Because these trials presented children with familiar pictures and stimuli (singular vs. singular for practice trials; singular vs. plural for familiar filler trials) it was expected that they would return significantly positive scores compared to chance (positive shifts to target during post- naming phase). With alpha set at 0.05, planned *t*-tests compared difference scores to chance (zero). As expected, the difference scores were significantly above chance for both practice trials (*M* = 22.8 (t(19) = 3.56, $p < .01$)) and the familiar filler trials (*M* = 22.70 (t(19) = 6.78, $p < .01$)), suggesting that 30-month-olds could perform the task.

To check for possible biases in looking behaviour, children's proportion of looks to either singular or plural pictures during the pre-naming phase was measured against chance, but no significant differences were found: (t(19) = 1.14, $p = .27$). To check that their performance did not increase over the session, i.e. due to training effects from the animation at the end of trials, Pearson product-moment correlation coefficients were calculated for children's difference scores by trial number and no correlation was found (r = -.03, $p = .62$).

Difference scores for the novel trials were then calculated. Alpha was set to 0.05. To control for multiple comparisons (2), p-values were adjusted using the Bonferroni method, using the base R *p.adjust* function. The 30-month-olds returned positive mean difference scores for both the singular (*M* = 4.4) and plural (*M* = 1.7) conditions. However, these difference scores were not significantly above chance for either the *singular* (t(19) = 2.00, $p = .12$) or *plural* conditions (t(19) = 0.43, $p = .67$) (see Figure 3). There was also no difference between s- and z-final singulars (t(19) = 0.32, $p = .75$). Figure 4 shows each participant's proportion looks to target for pre- and post-naming phases during the singular and plural trials. Figure 5 shows children's performance on each stimulus word. Though note that participants only heard each novel word in either its singular or plural form (e.g., either *nizz* or *nizzes*; not both), meaning that each boxplot in Figure 5 represents only half of the participants, at most.

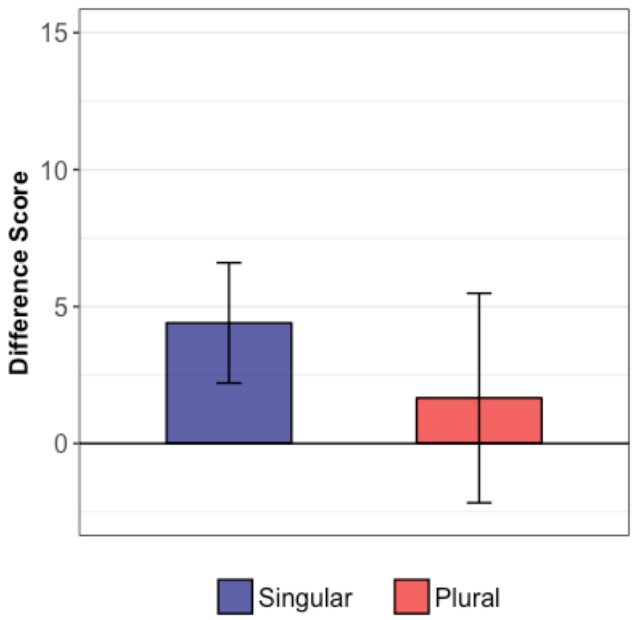

Figure 3. 30-month-olds' difference scores for singular and plural trials. Difference scores were calculated by subtracting the proportion looks to target during the pre-naming phase from the post-naming phase, and multiplying by one hundred to make a percentage. Error bars ± 1 S.E.

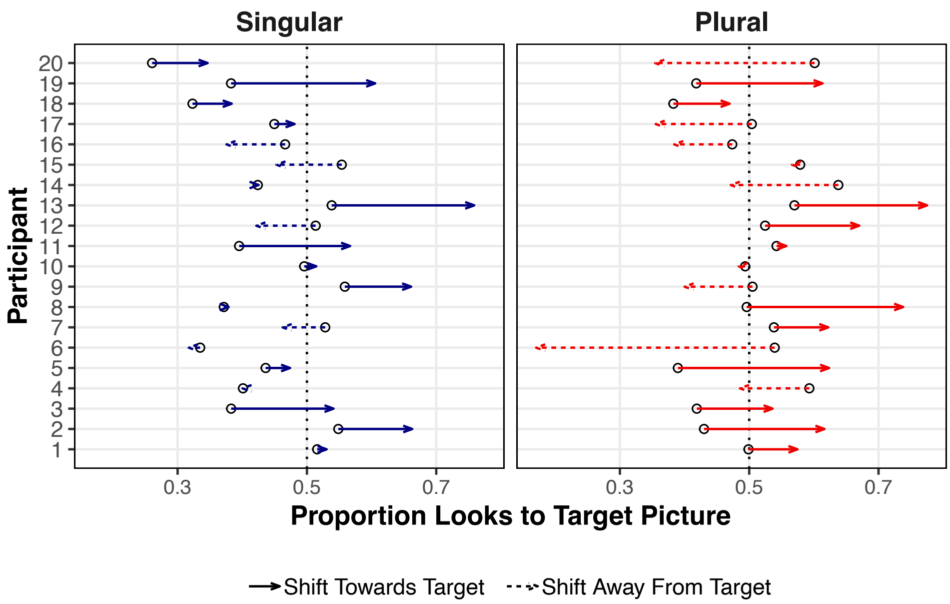

Figure 4. 30-month-olds' change in proportion of looks to target during post-naming phase. Dot points represent each participant's proportion looks to target during the pre-naming phase. The arrows point towards each participant's proportion looks to target during the post-naming phase.

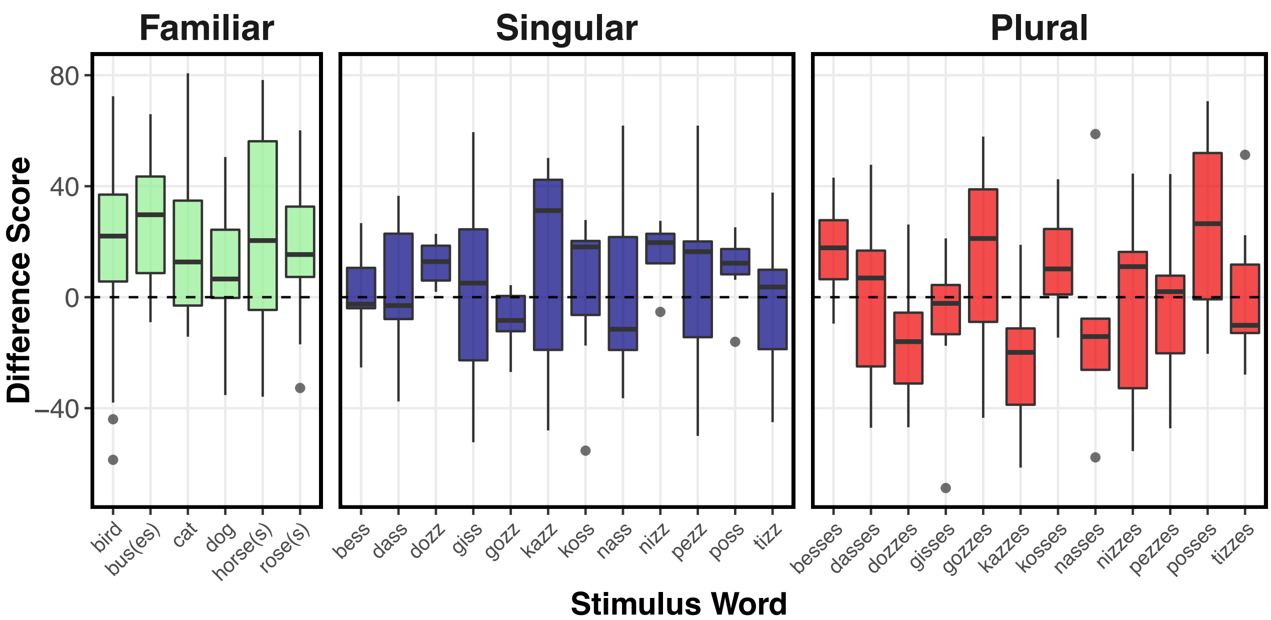

Figure 5. 30-month-olds' Difference Scores by item for familiar, novel singular and novel plural words. Difference scores were calculated by subtracting the proportion looks to target during the pre-naming phase from the post-naming phase, and multiplying by one hundred to make a percentage.

Cluster based permutation analyses were then carried out on children's proportion of looks to target during the post-naming phase to provide more detailed information on changes in children's looking behaviour over time. The analysis was conducted using the open-source program FieldTrip (Oostenveld, Fries, Maris, & Schoffelen, 2011) in MatLab (R2014b, 8.4.0.150421). This analysis is often used to analyse different responses to grammatical vs. ungrammatical real-time EEG data during sentence processing, and is not affected by any time-window biases: it preserves the granularity of time series and preserves alpha, allowing for multiple comparisons. With a sample rate of 120 Hz, at each time point of 8.3 ms, a one-tailed *t*-test compared proportion of looks to target to chance (zero). With alpha set at 0.05, adjacent significant time points were grouped together into a cluster. Proportion looks to target were transformed via an arcsin square function to better fit *t*-test assumptions (see Dautriche, Swingley, & Christophe, 2015). For each test across number condition, 1000 randomized simulations were conducted. No significant time window was found for the *singular* trials. However, a significant cluster was found for the *plural* trials in the time window 2350 – 3000 ms (p = .02). Within this window, the proportion of looks to target plural items was significantly above chance (see Figure 6).

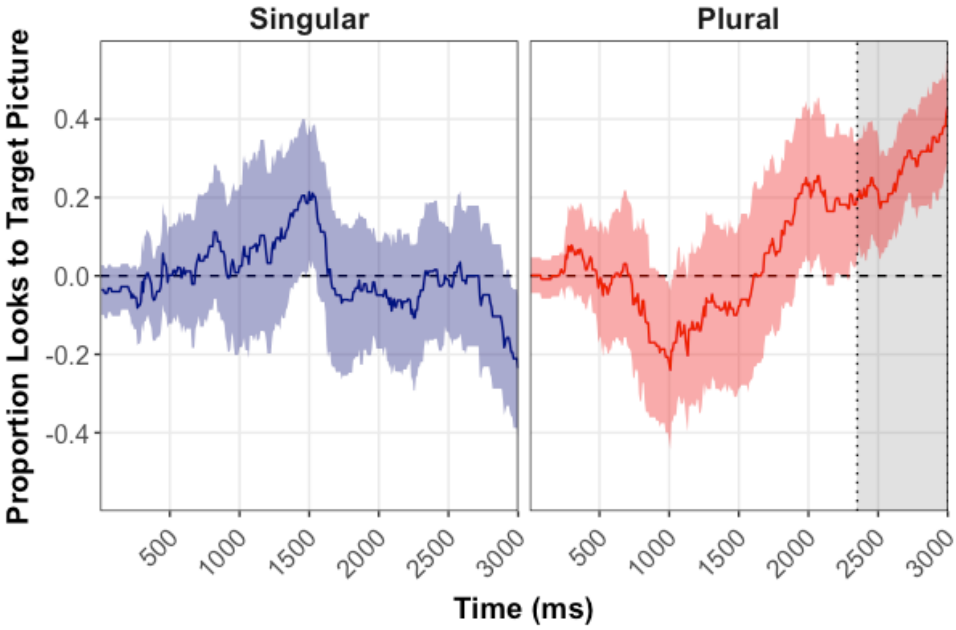

Figure 6. 30-month-olds' proportion of looks to target during post-naming phase. Colored area ± 95% C.I. Shaded area *p = .02

Discussion

The difference scores returned by the 30-month-old participants did not demonstrate any comprehension of novel fricative-final singular words nor any comprehension of novel words inflected with the syllabic plural /-əz/. However, the time course analysis did hint at some differences in looking behaviour across the singular and plural trials. During the singular trials, there was no shift in looks towards either the singular (target) or plural (distractor) picture. However, during the plural trials, children did begin to fixate on the plural (target) picture roughly 2350 ms into the post-naming phase, and continued to do so till the end of the 3000 ms trial window. At the very least, the time course analysis shows that 30-month-olds do not employ a fricative-final heuristic to identify a novel word a plural, as suggested by Berko (1958). Yet when taken together, the difference scores and time course analysis suggest that children at this age do not readily comprehend novel fricative-final singulars, and that their comprehension of the syllabic plural /-əz/ is questionable at best. Experiment 2 therefore investigated the comprehension of these items by 36-month-olds to determine if they might have developed an understanding that fricative-final words with a short vowel must be singular, and that /-əz/ is an allomorph of the plural.

Experiment 2

Participants

Participants were twenty monolingual Australian English-speaking 36-month-olds (7 girls, 13 boys). No child had any reported hearing, speech or cognitive impairment. Participants were recruited from a university database to which parents had voluntarily signed up. Children's ages ranged from 154 to 163 weeks, with a mean age of 158 weeks (3;0.2 years). An additional three boys were excluded for failing to return a sufficient number of trials (minimum 50% singular and plural trials) due to fussiness and/or inattention. A further boy and girl were excluded for returning difference scores greater than three standard deviations from the mean. The final dataset included 102 singular novel test trials (M = 5.1 trials per participant) and 105 plural novel test trials (M = 5.25 trials per participant). The experimental stimuli, design, procedure and analysis was identical to that in Experiment 1.

Results

Analyses were first performed on the difference scores from the practice trials and familiar filler trials using statistical analysis software R (R Core Team, 2016). With alpha set at 0.05, planned *t*-tests compared difference scores to chance (zero). As expected, children were significantly above chance for practice trials (M = 22.8 (t(19) = 4.39, p < .01) and for familiar filler trials (M = 22.70 (t(19) = 6.01, p < .01). Children's proportion looks to either singular or plural pictures during the pre-naming phase was not significantly different to chance (t(19) = 1.13, p = .27), showing no looking preference biases. To check for any learning effects, Pearson product-moment correlation coefficients were calculated for children's difference scores by trial number, with no signicant correlation found (df = 205, r = .10, p = .16).

Difference scores for the novel trials were then calculated. Alpha was set to 0.05. To control for multiple comparisons (2), p-values were adjusted using the Bonferroni method, using the base R *p.adjust* function. The 36-month-olds returned positive mean difference scores for both the singular (M = 6.0) and plural (M = 8.1) conditions, which were both significantly above chance (singular: t(19) = 2.51; p = .04; plural: t(19) = 3.08, p < .02) (Figure 7). There was no difference in looking measures between s- and z-final singulars (t(19) = -0.75, p = .46). Figure 8 shows each 36-month-old participant's proportion looks to target for pre- and post-naming phases during both singular and plural trials. Figure 9 shows children's performance across each stimulus item.

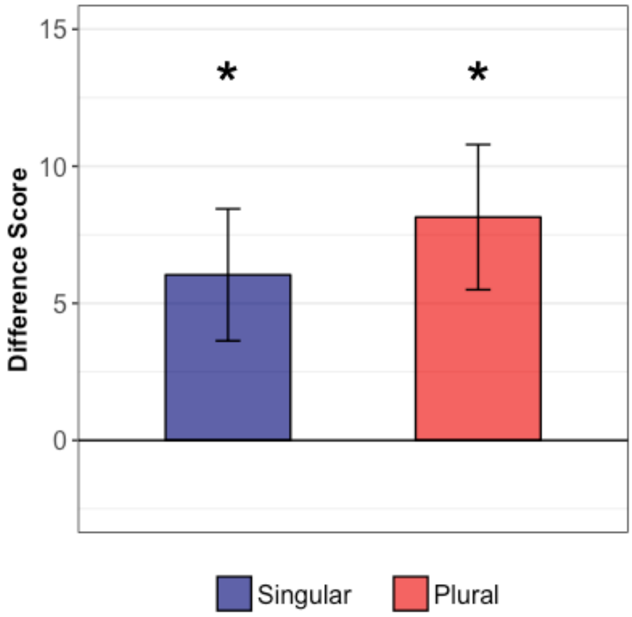

Figure 7. 36-month-olds' difference scores for singular and plural trials. Difference scores were calculated by subtracting the proportion looks to target during the pre-naming phase from the post-naming phase, and multiplying by one hundred to make a percentage. Error bars ± 1 S.E. *$p < .04$

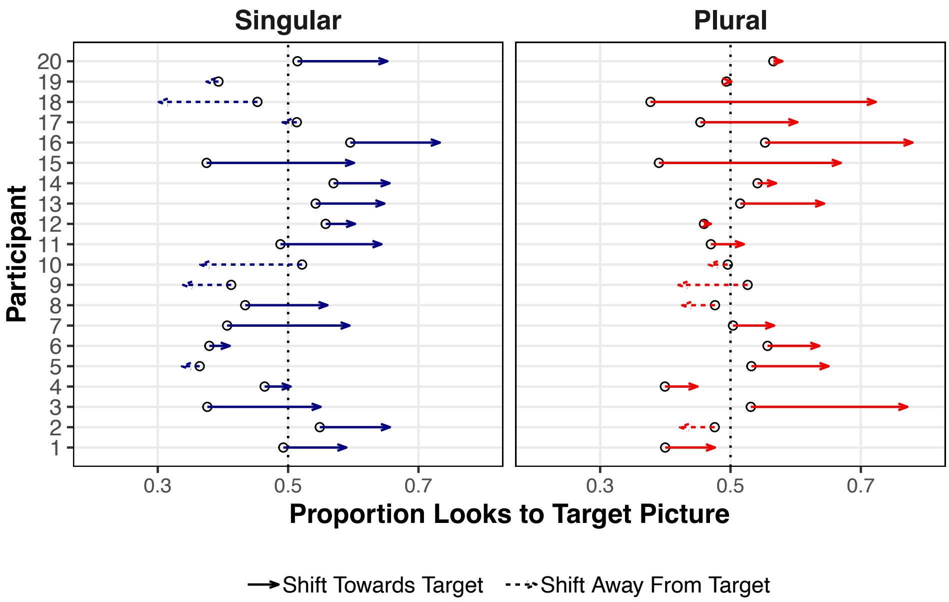

Figure 8. 36-month-olds' change in proportion of looks to target during post-naming phase. Dot points represent each participant's proportion looks to target during the pre-naming phase. The arrows point towards each participant's proportion looks to target during the post-naming phase.

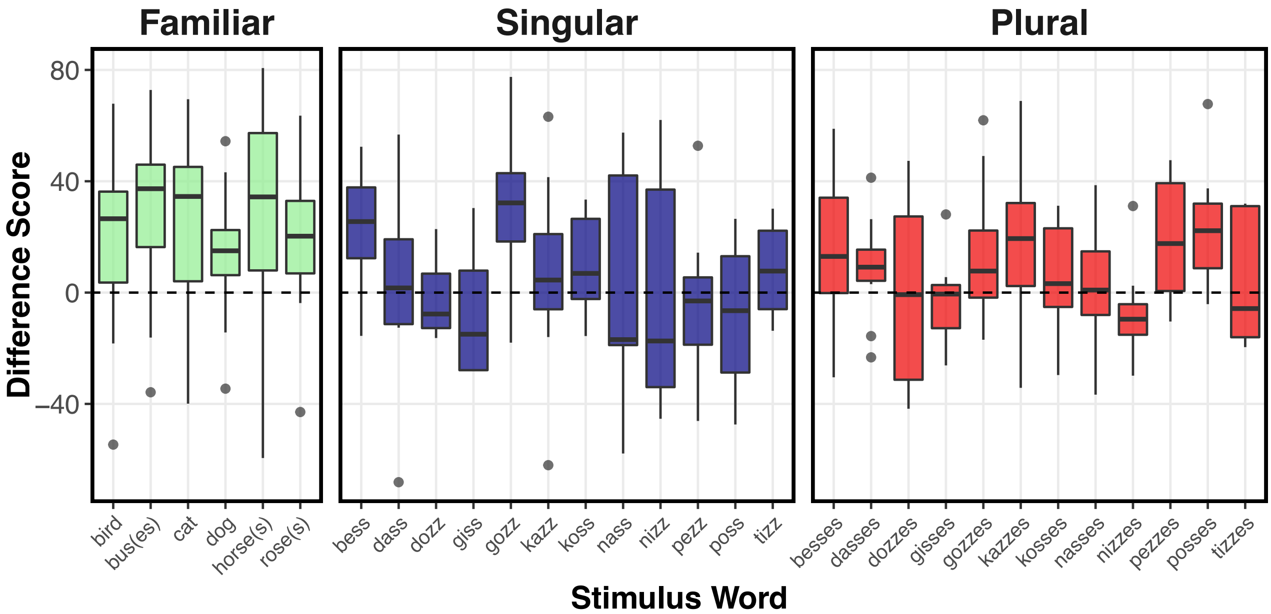

Figure 9. 36-month-olds' difference scores by item for familiar, novel singular and novel plural words. Difference scores were calculated by subtracting the proportion looks to target during the pre-naming phase from the post-naming phase, and multiplying by one hundred to make a percentage.

Cluster based permutation analyses were then carried out on children's proportion looks to target during the post-naming phase. This analysis was conducted using the open-source program FieldTrip (Oostenveld et al., 2011) in MatLab (R2014b, 8.4.0.150421). A significant cluster was found for the *singular* novel trials in the time window between 917 – 1350 ms (p = .02), and a significant cluster was found for the *plural* novel trials in the time window between 2125 – 3000 ms (p < .01). This shows that, while 36-month-olds systematically looked more to both the singular and plural targets during the post-naming phase, they were much faster to do so for the singular targets (see Figure 10).

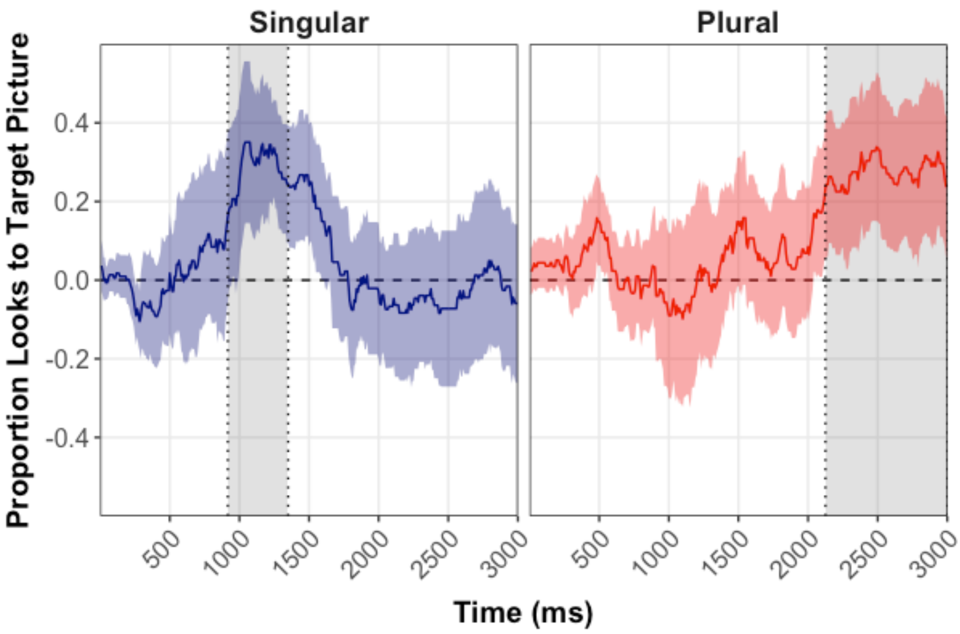

Figure 10. 36-month-olds' proportion of looks to target during post-naming phase. Colored area ± 95% C.I. Shaded area *$p \leq .02$

Discussion

The results of Experiment 2 thus show that, by the age of 36 months, these children have developed robust representations for plural morphology; they not only demonstrate representations for the later acquired syllabic plural, but also treat words that phontactically must be singular as singular, even though these ended in /s/ and /z/.

General Discussion

The goal of the present study was to determine when young English-speaking children develop productive morphological representations for the syllabic plural, learning to identify morphologically simple vs. complex (singular vs. plural) novel words ending in a fricative (e.g., *bus, buses*).

At 30 months, children could not identify the number condition for either the fricative-final novel singular word (e.g., *nizz*) or the plural word (e.g., *nizzez*). This suggests that

30-month-olds have not yet developed robust representations for the number condition for either fricative-final singular words or for the syllabic plural. However, note that they did not misidentify these novel singular forms as plural words, suggesting a developing sensitivity to the phonotactic and morphological structure of English words. The more-fine grained looking time course analysis also showed that 30-month-olds began to fixate on the target plural picture significantly more than chance after 2350 ms into the post-naming phase, continuing to do so until the end of the 3000 ms trial. This suggests that there may be an *emerging sensitivity to the syllabic plural*, but that the online processing of this information may be slow. It is possible that if the post-naming phase had been longer, a significantly positive difference score might have been found.

At 36 months, however, children did identify novel words ending in /s, z/ as singulars, and novel words ending in /əz/ as plurals. This provides strong evidence that 36-month-olds do not rely on a fricative-final plural strategy, but have successfully learned the morphological structure of words, correctly identifying words ending in /s, z/ (following a short vowel) as singular, and correctly identifying those ending in /-əz/ as plural.

The looking time course analysis for the 36-month-olds also revealed that they were faster to fixate on the target picture in the *singular* trials compared to the *plural* trials. After the reappearance of the pictures during the post-naming phase, children took roughly 900 ms to fixate on the target *singular* picture. In contrast, they took more than twice as long (2100 ms) to fixate on the target *plural* picture. This difference might reflect the extra time needed to process these morphologically more complex plural words.

Alternatively, the longer processing time found for these novel plural words could simply be a reflection of the greater time needed to parse more segmental material: Recall that the singular target words (CVs/z) were composed of one syllable and 3 segments, whereas the plural target words (CVCəz) were composed of two syllables and 5 segments. This suggests that future studies, using more segmentally/syllabically balanced CVCVC singular vs. plural items (e.g. *wagon* vs. *buses*), and/or disyllabic segmental vs. syllabic plurals (e.g., *buses* vs. *babies* (cf. Mealings et al., 2013)), would be helpful in determining if 36-month-olds really need more time to process morphologically complex words, or not. Note that the 36-month-olds in this study also fixated on the plural target pictures 250 ms earlier than the 30-month-olds, suggesting a developing sensitivity to these low frequency plural allomorphs. This study therefore provides a baseline for much further investigation about how young children's language processing skills develop over time, not only for the plural, but for other types of grammatical morphology and grammatical structures more generally.

Neither the 30-month-olds nor the 36-month-olds gave any indication of interpreting the singular novel words as plural, even though they ended in an /s/ or /z/. One might have expected that children would be more likely to interpret the /z/-final singulars as being plural since 24.9% of /z/-final words are plural by token, and 51.8% are plural by type in the input children hear. This contrasts with only 7.9% of /s/-final words being plural by token, and only 30.1% being plural by type (cf. Davies et al., 2017). However, no differences were found between children's performance on the /s/-final vs. /z/-final singulars. These results suggests that, at least by 36 months, children were not using a 'fricative-final' heuristic to identify plurals, as suggested by Berko (1958) and Köpcke (1998).

The fact that the 36-month-olds treated /s/- and /z/-final words as singular also shows that, by this age, they have developed robust representations for the both the phonotactics and morphophonology of English. Recall that the plural morpheme assimilates to the voicing of the previous segment. Thus, CVs words cannot be plural. Furthermore, monomorphemic words in English must contain at least two moras of phonological structure (i.e. either a long vowel (e.g., *bee*) or diphthong (e.g., *tie*), or a coda consonant (e.g., *dog*)). Since all the novel CVz target words used in this study contained a short vowel, these could not be well-formed words of English if the final fricative was treated as a morpheme. These findings are thus consistent with observation that children are sensitive to issues of vowel length and word formation by around the age of 2 (Miles et al., 2016; Song & Demuth, 2008). Here the data show that, by 36 months, children are also immediately parsing these forms as singular, even for novel words heard in running speech.

Because the singular is typically used for one referent (and no more), whereas the plural can be used to refer to any number of referents (including one in certain cases), some have argued that the singular is semantically more complex (Sauerland, Anderssen, & Yatsushiro, 2005). For example, the statement (1a) “you’re welcome to bring your child” strongly implies the existence of one child only, and is roughly equivalent to the statement (1b) “you’re welcome to bring your one child”. Contrastively, (2a) “you’re welcome to bring your children” does not imply two or more children, and is not equivalent to statement (2b) “you’re welcome to bring your two or more children”. Indeed, bringing just one child seems felicitous with statement (2a). This view sees the singular as having a more restricted meaning than the plural, making it the semantically marked form (Sauerland, Anderssen, & Yatsushiro, 2005) While there are indeed some shortcomings to this argument (including how to deal with number-generic referents), perhaps it helps to explain why previous studies showing early sensitivity to the plural have not shown a similar sensitivity to the singular. Using similar IPL studies, both Kouider et al. (2006) and Davies et al. (2017) showed that 24-month-olds were not yet sensitive to singular novel words, and Arias-Trejo, Cantrell, Smith and Canto (2014) showed that Mexican Spanish-speaking 24-month-olds also fail to comprehend singular novel words. Yet children in all these studies showed sensitivity to at least some forms of the plural. In English, nouns are typically inflected for plural number, yet this is a language-specific phenomenon that children must learn: Bantu languages, for example, morphologically mark both singular and plural words (Demuth & Weschler, 2012). It would therefore be interesting to explore these issues cross-linguistically, in morphologically richer languages, to better understand the different roles that morphophonology, allomorph frequency, and other factors may play in learning plural (and singular) morphology.

In sum, this study shows that children's comprehension and processing of English plural morphology develops gradually between the ages of 2 and 3. Children may have an emerging understanding of the syllabic plural /-əz/ at 30 months, but this becomes much more robust by the age of 3, when they have also learned that fricative-final words can (or must) be singular. We suggest that this gradual emergence of both singular and plural may go hand-in-hand, showing joint synergies between word segmentation and the learning of morphophonological structure (e.g., Johnson, Christophe, Dupoux, & Demuth, 2014). This process may be delayed in the case of the syllabic plural due to its very low frequency in the input children hear, complicated by the fact that the singular forms of these words already end in a fricative, sounding like they are already inflected (cf. Berko, 1958). These findings thus raise many learnability questions about the factors that contribute to early vs. later acquisition of morphological systems more generally, both across languages (e.g. Tomas, van de Vijver, Demuth, & Petocz, 2017) and populations (e.g. bilinguals, or those with hearing loss, where fricative sounds/morphemes are hard to perceive).

In conclusion, this study suggests that learners encode the *phonological* structure of words in order to determine *morphological* structure, and thus number. Although the syllabic plural is less frequent in the input children hear, its phonological properties, and that of its corresponding singulars, may obscure its underlying form, making the positing of lexical representations more challenging. Models of language acquisition must therefore take into account these types of synergies between phonological and morphological representations, and the role these play in the developing lexicon.

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Appendix

Trial counterbalance versions 1- 4

Version One

Trial	Trial type	Target side	Stimulus	Left Picture	Right Picture
1	Orientation	L	dog (sng)	Dog	Cow
2	Orientation	L	cat (sng)	Cat	Bird
3	Orientation	R	bird (sng)	Cow	Bird
4	Familiar	R	bus (plu)	House sng	Bus plu
5	Plural	L	tizz (plu)	E plu (red)	M sng (red)
6	Singular	R	dass (sng)	B plu (red)	J sng (red)
7	Singular	L	pezz (sng)	D sng (blue)	L plu (blue)
8	Plural	L	giss (plu)	A plu (red)	I sng (red)
9	Familiar	R	rose (sng)	Tree plu	Rose sng
10	Plural	R	bess (plu)	C sng (blue)	K plu (blue)
11	Singular	L	koss (sng)	H sng (blue)	P plu (blue)
12	Singular	R	nizz (sng)	F plu (red)	N sng (red)
13	Plural	R	dozz (plu)	G sng (blue)	O plu (blue)
14	Familiar	L	horse (sng)	Horse sng	Bear plu
15	Plural	L	nass (plu)	P plu (blue)	G sng (blue)
16	Singular	R	gozz (sng)	L plu (blue)	C sng (blue)
17	Plural	R	kazz (plu)	M sng (red)	F plu (red)
18	Singular	L	poss (sng)	I sng (red)	B plu (red)

Version Two

Trial	Trial type	Target side	Stimulus	Left Picture	Right Picture
1	Orientation	L	dog (sng)	Dog	Cow
2	Orientation	R	cat (sng)	Bird	Cat
3	Orientation	R	bird (sng)	Cow	Bird
4	Familiar	L	horse (plu)	Horse plu	Bear sng
5	Singular	R	nizz (sng)	A plu (blue)	B sng (blue)
6	Plural	R	kazz (plu)	K sng (red)	L plu (red)
7	Singular	L	dass (sng)	C sng (red)	D plu (red)
8	Plural	L	dozz (plu)	M plu (blue)	N sng (blue)
9	Familiar	R	bus (sng)	House plu	Bus sng
10	Plural	R	tizz (plu)	O sng (red)	P plu (red)
11	Singular	L	pezz (sng)	G sng (red)	H plu (red)
12	Plural	L	bess (plu)	I plu (blue)	J sng (blue)
13	Singular	R	poss (sng)	E plu (blue)	F sng (blue)
14	Familiar	L	rose (sng)	Rose sng	Tree plu
15	Plural	L	giss (plu)	D plu (red)	K sng (red)
16	Singular	R	gozz (sng)	H plu (red)	O sng (red)
17	Singular	L	koss (sng)	J sng (blue)	A plu (blue)
18	Plural	R	nass (plu)	N sng (blue)	E plu (blue)

Version Three

Trial	Trial type	Target side	Stimulus	Left Picture	Right Picture
1	Orientation	R	dog (sng)	Cow	Dog
2	Orientation	L	cat (sng)	Cat	Bird
3	Orientation	R	bird (sng)	Cow	Bird
4	Familiar	R	bus (plu)	House sng	Bus plu
5	Plural	L	koss (plu)	N plu (blue)	B sng (blue)
6	Singular	L	tizz (sng)	K sng (red)	G plu (red)
7	Singular	R	bess (sng)	M plu (blue)	A sng (blue)
8	Plural	R	dass (plu)	L sng (red)	H plu (red)
9	Familiar	L	rose (plu)	Rose plu	Tree sng
10	Singular	R	dozz (sng)	I plu (blue)	E sng (blue)
11	Singular	L	giss (sng)	O sng (red)	C plu (red)
12	Plural	L	pezz (plu)	J plu (blue)	F sng (blue)
13	Plural	R	nizz (plu)	P sng (red)	D plu (red)
14	Familiar	R	horse (sng)	Bear plu	Horse sng
15	Singular	L	nass (sng)	F sng (blue)	I plu (blue)
16	Plural	L	poss (plu)	G plu (red)	L sng (red)
17	Singular	R	kazz (sng)	C plu (red)	P sng (red)
18	Plural	R	gozz (plu)	B sng (blue)	M plu (blue)

Version Four

Trial	Trial type	Target side	Stimulus	Left Picture	Right Picture
1	Orientation	L	dog (sng)	Dog	Cow
2	Orientation	L	cat (sng)	Cat	Bird
3	Orientation	R	bird (sng)	Cow	Bird
4	Familiar	R	bus (sng)	House plu	Bus sng
5	Plural	L	dass (plu)	F plu (red)	A sng (red)
6	Singular	L	dozz (sng)	P sng (blue)	K plu (blue)
7	Plural	R	gozz (plu)	D sng (blue)	G plu (blue)
8	Singular	R	giss (sng)	J plu (red)	M sng (red)
9	Familiar	L	horse (plu)	Horse plu	Bear sng
10	Singular	L	bess (sng)	L sng (blue)	O plu (blue)
11	Plural	R	poss (plu)	H sng (blue)	C plu (blue)
12	Plural	L	pezz (plu)	B plu (red)	E sng (red)
13	Singular	R	kazz (sng)	N plu (red)	I sng (red)
14	Familiar	R	rose (plu)	Tree sng	Rose plu
15	Plural	L	koss (plu)	O plu (blue)	D sng (blue)
16	Singular	L	tizz (sng)	A sng (red)	N plu (red)
17	Singular	R	nass (sng)	K plu (blue)	H sng (blue)
18	Plural	R	nizz (plu)	E sng (red)	J plu (red)