Do children preferentially mark unpredictable material? The case of optional plural marking

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Abstract

Speakers tend to assign more linguistic material to less predictable elements. This tendency is typically explained by a bias for an efficient trade-off between production effort and understandability and is claimed to shape linguistic structures across languages. Recent work suggests this trade-off enters the linguistic system through learning processes with learners deviating from their input by increasing marking for less predictable elements. However, no study to date has tested whether child learners also show such predictability-based marking, an important gap seeing that children are the primary learners in real-life language acquisition. A recent study showed that adults increase predictability-based marking of an optional-plural marker, in line with communicative efficiency. Here, we ask if children show a similar pattern. Results show that children, unlike adults, do not show an efficient trade-off in their productions. We discuss implications for the role of different language learners on language change.

Keywords: optional morphology; artificial language learning; language acquisition; language evolution

Introduction

Across languages, more frequent form-function associations tend to be coded with less linguistic material (such forms are often defined as "less marked", e.g., Bybee, 2007; Haspelmath, 2008). For instance, the present tense is more frequently talked about than the past tense. Accordingly, the latter tends to be expressed by longer forms than the former across languages (Greenberg, 1966; Haspelmath, 2008). It has been suggested that this tendency is driven by speakers' bias for communicative efficiency[1]: Producing less linguistic material for more predictable messages is one way of creating an optimal tradeoff between minimizing production effort on the one hand and maximizing understandability on the other (Givón, 1991; Haspelmath, 2008, 2014; Zipf, 1949). Indeed, many psycholinguistic studies show wide-spread effects of predictability on language production, from the syllable level to the sentence level (Aylett & Turk, 2004; Gibson, Bergen, & Piantadosi, 2013; Jaeger, 2013; Jaeger & Buz, 2017; Kurumada & Jaeger, 2015; Levy & Jaeger, 2007). For example, speakers tend to omit optional case marking when the meaning it encodes is more predictable given the context (Kurumada & Jaeger, 2015).

An intriguing and open question is how the bias for communicative efficiency impacts language structure. One influential suggestion is that this bias operates during language acquisition, such that learners change their input in ways that increase its communicative efficiency, leading to increased marking of less predictable material. This approach has recently gained support from artificial language learning (ALL) studies (Fedzechkina & Jaeger, 2020; Fedzechkina, Jaeger, & Newport, 2012; Fedzechkina, Newport, & Jaeger, 2016; Kurumada & Grimm, 2019). In these studies learners are presented with a novel artificial language that contains variable input. In their own productions, participants restructure the language they learned to become more communicatively efficient. For example, Fedzechkina et al. (2012) taught participants a language with variable word order and optional (arbitrary) case marking on objects (that could be either animate or inanimate). In their productions participants provided more marking for the less expected alignment of animacy and grammatical function (animate objects).

Importantly, previous studies have not tested this trade-off for *child* learners to see if they also tend to increase communicative efficiency by marking less predictable elements with more linguistic material. Looking at child learners is important for several reasons. First, seeing that children are the primary and most prototypical learners of language, claims about learning biases - and their impact on language structure - should also be tested on young learners (Culbertson & Newport, 2015; Raviv & Arnon, 2018). Looking at children can tell us whether the pervasive effect of predictability in adult language use is already found in young learners, or whether the trade-off between effort and understandability is acquired as a consequence of substantial linguistic experience. A second motivation comes from the study of language change: if communicative efficiency impacts language structure through learning biases (e.g., Fedzechkina & Jaeger, 2020), we need to know these biases are found across different types of learners. In particular,

[1] There are other possible explanations for the source of predictability effects in language use, such as production ease (e.g., Arnold, Kahn, & Pancani, 2012) and routinization (Bybee, 2006). The current study is not designed to differentiate between them, but only to test predictions stemming from the communicative efficiency hypothesis.

children and adults have been claimed to differ in their learning biases, with consequences for their role in language emergence and change (Lupyan & Dale, 2010; Raviv & Arnon, 2018). While some learning biases seem to operate similarly in both children and adults (e.g., Culbertson & Newport, 2015), this is not always the case. For example, children demonstrate a stronger bias towards regularization than adults (Hudson Kam & Newport, 2005, 2009; Samara, Smith, Brown, & Wonnacott, 2017), a finding taken to reflect children's greater role in regularizing grammatical patterns. This tendency for regularization could compete with, or replace, pressures for communicative efficiency.

Here, we explore this by asking whether children increase the marking of less predictable elements (Henceforth: Predictability-based marking). We do this using a child-friendly ALL paradigm where children learn a miniature language that includes unpredictable variation. If children are impacted by communicative efficiency, like adults, they should increase the marking of less predictable meanings relative to their input. We focus on optional plural marking systems as a test case.

Optional Plural Marking

In some languages the grammatical encoding of plural marking is not obligatory. For example, in Baka (an Ubangian language), the noun form 'gba' can be translated into English as "village" or "villages" (Haspelmath, 2013). Baka has a plural form corresponding to "villages" – 'gba-o' – which speakers can use to refer to plurality, but do not have to. This phenomenon, called Optional Plural Marking (OPM), is quite common cross-linguistically (Haspelmath, 2013), yet not well understood. The communicative efficiency hypothesis provides an intriguing explanation for such systems: the occurrence of plural marking may reflect the predictability of the plural meaning (Grimm, 2012). Specifically, entities that are talked about more often in the plural meaning than in the singular, will be less likely to be marked with the plural form (Kurumada & Grimm, 2019). For example, large animals are more likely to be conceptualized as individuals, whereas insects are more likely to be conceptualized as collectives, leading to more marking of plural animals compared to insects (Grimm, 2018).

This suggestion gains support from languages that have mixed plural marking systems (Grimm, 2018; Haspelmath & Karjus, 2017). In these languages, some nouns are obligatorily marked in the plural (as in English, *days* vs. *day*), while other nouns show the reverse pattern, such that the singular form is marked while the plural is not. Welsh, for example, exhibits such a mixed-system: the plural form of the word 'tad' "father" is created by adding a suffix-'tadau' "fathers". However, for other nouns, such as 'pys' "peas", the bare form corresponds to the *plural* meaning, while an additional suffix, 'en', is needed to mark their *singular* meaning. Interestingly, this mixed-marking system can be explained on the basis of the predictability of the plural meaning: Nouns which, across languages, are marked in the singular form rather than the plural form, appear more often in their plural meaning (compared to the singular meaning), across languages (Haspelmath & Karjus, 2017).

A recent study went beyond these correlational findings to ask whether learners whose language does not have OPM, will condition plural marking on the predictability of the plural meaning (Kurumada & Grimm, 2019). In this study, English speaking participants were exposed to a miniature artificial language that included two types of creatures: animals, that appeared mostly in the singular meaning (i.e., presented as singletons 75% of the time, and as multiples 25% of the time) and insects, that appeared mostly in the plural meaning (i.e., were presented as multiples 75% of the time, and as singletons 25% of the time). This language had an optional plural marker that occurred 66% of the time with plural nouns, regardless of character type. After exposure, participants completed a test phase where they described visual scenes containing singletons and plurals in the miniature language. If learners' use of the plural marker reflects its input frequency, they should use it more with insects than animals (because the plural marker appeared numerically more with the insects). Alternatively, if learners' use is driven by predictability, as predicted by the communicative efficiency hypothesis, then they should use it more for animals than insects, since this is the more surprising configuration (animals were less likely to appear in the plural). Supporting the communicative efficiency hypothesis, learners used more plural marking for animals than for insects. Here, extending this logic and paradigm, we ask whether children, like adults, will condition production of an optional plural marker based on the predictability of the meaning it encodes.

The current study

In the current study, we use an artificial language to ask whether child learners, like adults, achieve a trade-off between effort and understandability, by introducing predictability-based marking. The experiment was modeled after Kurumada and Grimm (2019), with adaptations to children. Children learned novel nonce nouns for referents from two classes: animals and insects. We manipulated how often referents appeared as singletons or multiples (i.e., in a group) according to their class. As in the original design, animals mostly appeared as singletons (75% of the time)

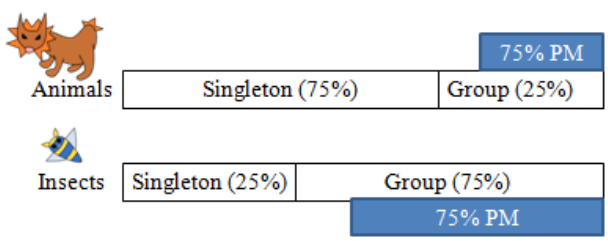

Figure 1: Proportions of plurality and plural marker (PM) in the input.

Table 1: regression model for all children's productions

	Estimate	Std. Error	z -value	p-value
(Intercept)	-3.9834497	0.6763089	-5.890	**<0.0001 *****
Character type (insect)	0.2228726	0.1310394	1.701	0.089 .
Plurality (singleton)	-2.2956497	0.1608716	-14.270	**<0.0001 *****
Trial	-0.0008169	0.0107102	-0.076	0.939
Age	0.5387599	1.0046834	0.536	0.592
Character type (insect) * plurality (singular)	-0.1743242	0.1311803	-1.329	0.184

while insects mostly appeared in groups (75% of the time). When appearing in groups, nouns were marked with a post-nominal nonce plural marker ("-pak") 75% of the time regardless of their animal/insect class membership. Following exposure, we examined production of the singletons and multiples in the novel language

We can contrast three different predictions: If children show predictability-based marking, they should mark plurality more for animals, whose appearance in the plural is less predictable, than for insects. Adults in Kurumada and Grimm (2019) exhibited this tendency even though, numerically speaking, the plural marker appeared more frequently with insects in training (because they appeared more in groups, see Figure 1). If, in contrast, children's learning is characterized by a strong bias towards systematization (Hudson Kam & Newport, 2005, 2009), they should use the marker categorically for all the plural referents, regardless of character type. The same prediction could be made if children are more influenced by their native language (where the plural form is the same for insects and animals). Finally, if children faithfully reproduce the form frequency of the optional marker (Diessel, 2007), they will mark insects more than animals, since the plural marker appears (numerically) more frequently with insects[2]. The study was done on Hebrew-speaking children, and not on English-speaking ones like the adults tested in Kurumada and Grimm (2019). However, Hebrew has an obligatory plural suffix, similar to English, suggesting that speakers of the two languages will not differ in their existing expectation about plural marking.

[2] Hudson Kam & Newport (2005,2009) found that children tend to eliminate free variation in their input, and instead use one form or the other consistently. They call this behavior regularization. In the current task, different types of regularization can be made based on the input (i.e., marking all plurals as opposed to marking all plural insects), making it tricky to apply Hudson Kam & Newport's sense of regularization here. To better capture the different production possibilities in this paradigm, we adopt "systematization", a term used by Hudson Kam & Newport to define children who use optional markers deterministically. This tendency is differentiated from the tendency to regularize the marker only for insects - "reproduction of form frequency". We return to this distinction in the discussion.

Method

Participants

53 Hebrew-speaking children participated in the experiment (age range: 7;0-9;0y, mean age: 7;11y, 29 boys and 24 girls). This age range was chosen because children at this age are capable of performing an adult-like ALL task, but often differ from adults in their patterns of learning (Raviv & Arnon, 2018; Tal & Arnon, 2019). All children were visitors at the Bloomfield Science Museum in Jerusalem. They were recruited for this study as part of their visit to the Israeli Living Lab in exchange for a small reward. Parental consent was obtained for all children. All children were native Hebrew speakers, and none of them had known language or learning disabilities.

Materials

Children learned eight nonce nouns for referents from two classes: big animals and small insects (four in each class, the visual stimuli were taken from Kurumada & Grimm, 2019). The lexicon was composed of 8 semi-artificial Hebrew nouns (Hebrew nouns with nonce suffixes). A nonce plural marking ("pak") followed 75% of the plural referents, regardless of the referent type (animals vs. insects).

Procedure

Participants were told they were going to meet aliens who "say things differently from us" and would learn to speak like these aliens. Children sat with headphones in front of a computer next to a research assistant. They saw drawings and heard recorded descriptions of these drawings in the alien-language (spoken by a female Hebrew speaker). The experiment had three stages. First, a noun exposure phase, in which children saw each character as a singleton, heard its name in the alien language, and had to repeat each name outloud (8 trials, one per noun). This was followed by a word learning game (32 trials) where participants saw four drawings, heard one label and had to match the label to the correct drawing. Feedback was provided after each trial. In this phase, individual creatures (animals) and collective creatures (insects) were presented as singletons and multiples at different rates. Individuals occurred 75% of the time as a singleton (i.e., as one animal), and 25% as

Table 2: regression model for children's productions – only children who produced the marker

	Estimate	Std. Error	z -value	p-value
(Intercept)	-1.229905	0.392411	-3.134	**0.00172 ****
Character type (insect)	0.224474	0.130193	1.724	0.08468 .
Plurality (singleton)	-2.250666	0.157502	-14.290	**<0.0001 *****
Trial	-0.001224	0.010721	-0.114	0.90913
Age	-0.088477	0.623975	-0.142	0.88274
Character type (insect) * plurality (singular)	-0.174894	0.130349	-1.342	0.17968

multiples (i.e., as a group). Collectives had the inverse distribution (25% singleton, 75% multiples). Both individual (animal) nouns and collective (insect) nouns were followed by the plural marker ("pak") 75% of the time when occurring as multiples (see Figure 1 for an illustration of the input). The last part of the experiment was a production phase (32 trials), in which children saw drawings of the refrents as multiples and as singletons and had to describe them in the alien-language. Each character appeared once as a singleton and 3 times as multiples, regardless of the character type (animals and insects were equally likely to appear as multiples during test). Children's productions were coded for the use vs. non-use of the plural marker by a research assistant blind to the hypotheses. The task took between 10 to 15 minutes to complete.

Results

Children successfully learned the lexicon, as indicated by their performance in the word learning game (M=96%, SD=0.06%). One child failed to achieve mean accuracy of 75% and was therefore excluded from further analyses. The results did not change when this child was included.

We used a mixed-effect logistic regression model to examine the effect of character type and plurality on the production of the plural marker (using the glmer function in R software, Bates, Maechler, Bolker, & Walker, 2015, and the maximum random effect structure justified by the data that converged, Barr, Levy, Scheepers, & Tily, 2013). The dependent variable was whether the plural marker was produced on each trial (as a binary variable). The model included fixed effects for character type (animal vs. insect, effect coded), plurality of the character (singleton vs. multiples, effect coded), their interaction, age and trial number as centered continuous factors, and random intercepts for participants (see Table 1 for full model). Overall children produced the marker more for multiples than singletons, indicating that they correctly understood the marker signals plurality (42% vs. 0.5%, β=-2.3±0.16, p<.0001). Unlike adults (Kurumada & Grimm, 2019), however, children did not mark animals more. Instead, they seem to have marked the insects more than the animals (45% vs. 39%), a difference that was marginally significant (β=0.22±0.13, p=.09).

Note that the proportion of overall marking is much *lower* than the input, unlike for adults (Kurumada & Grimm, 2019). This is due to the fact that a large number of children never used the marker in their productions (N=19). Crucially, we cannot tell whether these children noticed the marker, let alone understood its meaning. Therefore, following previous studies with optional marking (Fedzechkina et al., 2012), we excluded those children from further analysis. Importantly, this exclusion did not change the effects (we used the same model as before), but made the marking more similar to the input (see Table 2 for full model).

When we looked at the remaining children (N=33), there was no difference in the amount of plural marking between their input and output for both insects (71%, Wilcoxon Signed-Rank test over by-participant proportions: V= 246.5, p =.74) and animals (61%, V=196.5, p=.13). In other words, children probability matched their input, using the plural marker as often as they heard it for each of the types. There was still a marginally significant effect of character type,

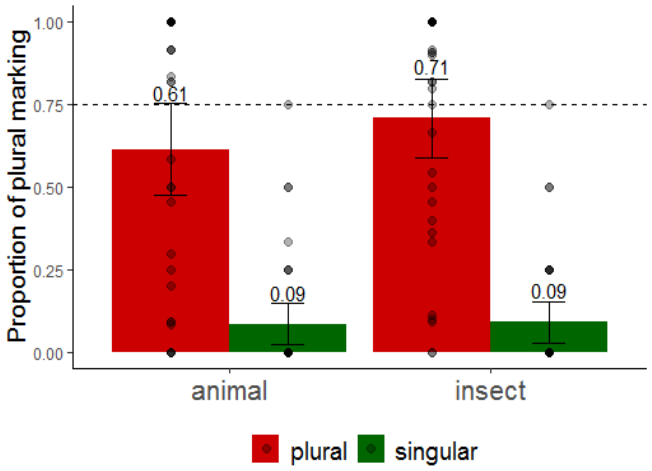

Figure 2: Proportion of plural marking by character type and plurality. Dashed line represents the plural marking in the input (for entities that appeared in the plural, singletons were never marked). Error bars indicate confidence intervals; individual points indicate by-participant means.

such that children used the marker more with insects than with animals (β=0.22±0.13, p=.08, see Figure 2). Taken together, these results suggest that, unlike adults, children did *not* condition the use of the plural marker on the predictability of the plural meaning. Instead, they seem to have used the marker more with insects than animals, reflecting the form frequency in their input. This preference was not significant and should be interpreted with caution.

To further investigate children's productions, we looked at the individual production patterns of the participants. Following Kurumada and Grimm (2019), we classified participants into different types in the following manner: participants who marked animals more than insects (no matter how much so) were classified as "predictability-based markers"; participants who showed the opposite pattern (marking insects more than animals) were classified as "form-frequency markers", and participants who always used the marker for all plural referents, regardless of character type, were classified as "systematizers". This classification is presented in Figure 3. Strikingly, there are twice as many "form-frequency markers" in our sample as "predictability-based markers" children (16 vs. 8). In addition, 9 children were "systematizers": these children used the plural marker for all plural referents. In other words, only a minority of the children behaved in accordance with the predictability-based marking hypothesis. Furthermore, as can be seen in Figure 3, the "predictability-based markers" showed only a moderate preference to mark animals more than insects, whereas the "form-frequency markers" showed a bigger preference for the opposite trend.

Interestingly, these patterns are strikingly different from the individual patterns found in the Kurumada and Grimm (2019) adult study. Out of 41 adult participants that used the plural marker in their productions (the adult study had overall 42 participants, but one participant never used the plural marker), the biggest group of participants (20) showed predictability-based marking. 17 participants were "systematizers", whereas only 4 participants were "form-frequency markers". A chi-square goodness of fit test was calculated to compare the proportion of the different production patterns between the two studies. The difference was significant (χ2(df=2)=56.41, p<.001): while adults' use of the plural marker was predominantly based on the predictability of the plural meaning, most children marked plural referents based on the frequent patterns in their input.

Discussion

Various studies suggest that communicative efficiency biases can drive changes in language through learning (Fedzechkina & Jaeger, 2020; Fedzechkina et al., 2012, 2016; Kurumada & Grimm, 2019). However, all of these studies have only examined adult learners. Given that children are the primary language learners in naturalistic settings, any claim about language learning biases should (also) be tested on them. Our study set out to ask whether children, like adults, increase marking of less predictable

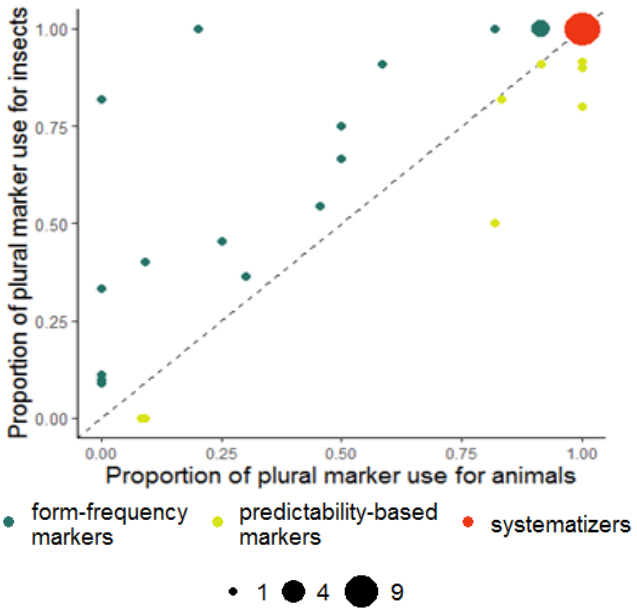

Figure 3: Plural marker use by different participants. Points below the diagonal dotted line indicate predictability-based markers (a tendency to use the marker more often when plural meaning is less predictable). Points above the diagonal indicate form-frequency markers (a tendency to use the marker more often for referents it appeared with more often in the input).

forms, as expected by communicative efficiency biases. To do so, we examined learning of an OPM system using an ALL paradigm, where animals and insects were similarly marked for plurality (75% of the time), but differed in how often they appeared in the plural (insects appearing more than animals as multiples rather than singletons). This design allowed us to distinguish the impact of form frequency (higher frequency of the plural marker with insects) and predictability of meaning (animals less likely to appear as multiples).

Unlike adults, children did *not* show predictability-based marking: Even though animals were less likely to appear as plurals than insects in their input, children did not increase marking of plural animals. Instead - though this preference was not statistically significant, they seem to have used the plural marker more with insects, a pattern compatible with the form frequency in their input (where insects appeared more frequently with the plural marker compared to animals). This pattern was also seen in participants' individual production patterns: the largest group of children (48%) marked insects more than animals, reflecting its higher token frequency. A smaller group of children (27%) generalized the plural marker to all plural nouns, a preference we discuss in detail below. Finally, a third group (24%) showed a moderate preference to mark the animals more than the insects, in accordance with the communicative efficiency hypothesis. Taken together, children's productions diverge from the adult findings

(Kurumada & Grimm, 2019). While adults seem to condition marking by predictability of *meaning*, children, if anything, seem to condition marking on predictability of *form* (Diessel, 2007). These findings join others pointing to different learning biases in children and adults (Hudson Kam & Newport, 2005, 2009; Samara et al., 2017).

Interestingly, both in the adult study and in the current study, a large number of participants were "systematizers", i.e., used the plural marker for all plural nouns. This tendency could be interpreted in two different ways. First, this can reflect a bias for regularization, such that participants regularize a probabilistic plural marker to all plural referents, regardless of character type. Previous studies have found that regularization is stronger for children than adults (Hudson Kam & Newport, 2005, 2009; Newport, 2019): More children were "systematizers" than adults. Under this interpretation, our findings are at odds with the previous literature: only 27% of the child participants in our study were systematizers compared to 41% of the adult participants in Kurumada & Grimm. In this paradigm, adults seem to systematize more than children. It is important to note, however, that the input language in the current study was more complicated than the one used in previous regularization studies (Hudson Kam & Newport, 2005, 2009) as it involved two noun classes that differed in the frequency of the marker. Alternatively, the systematization found in both studies could reflect transfer from participants' native language: in both Hebrew (the native language of the child participants) and English (the native language of the adult participants) the plural marker is used with all plural referents. The larger proportion of adult "systematizers" could reflect a stronger L1 transfer effect or more meta-linguistic knowledge (Ullman 2001). The current study can not differentiate between these two possible interpretations.

Our study is an important first step in investigating the effect of communicative efficiency on children. However, there are several limitations that need to be addressed. First, exposure was shorter in the current study than in the original one. It is possible that more exposure is needed to learn the different distribution of animals vs. insects. However, children were at ceiling in learning the nouns; they learned the meaning of the marker (using it for plural forms); and showed some distinction between the classes (as evidenced by their greater use of the marker with insects). An additional issue has to do with the visual stimuli, that was slightly different in the two studies: in the original study, adults heard sentences that included a novel verb, and saw short videos corresponding to the sentences they learned. In these videos, the characters either moved together (if they were collectives like insects) or separately (if they were individuals like animals). In the current study, we did not use a novel verb, and consequently used still images rather than movies. Interestingly, a third experiment reported in the original study indicates that movement facilitated the differential marking: adult participants were less likely to mark animals more when they moved together as a group (like the insects, Kurumada & Grimm, 2019). If moving together is what gives rise to preferentially marking animals, then the fact that the current experiment presented no movement could also underlie the present findings. We are currently working on follow-up studies to investigate whether any of these differences changes the pattern of results we found. Finally, although children in our study differed from adults, it would be instructive to look at younger children and compare their behavior with the current findings.

Importantly, the present findings should be complemented with studies on children's spontaneous production. Numerous studies show that adults assign more marking to less predictable meanings in natural language (e.g., Kurumada & Jaeger, 2015; Levy & Jaeger, 2007). These findings provide the basis for the postulated effect of communicative efficiency on language learning more generally. However, no study to date has reported similar patterns in child speech. We do not know if children show such trade-offs in language use, a finding that has implications for the generality of the effects. We are currently conducting several corpus-studies that ask whether children show predictability-based marking in spontaneous speech. From the perspective of language change, since languages do mark frequent forms with less linguistic material, finding that children don't would support the suggestions that children do not play a significant role in language change (Labov, 2007), or alternatively, that they play a *different* role than adults (Lupyan & Dale, 2010).

In sum, unlike adults, children did not seem to assign more linguistic material to less predictable meanings, suggesting their productions were not impacted by a communicative efficiency bias. The present study serves as an important first step for understanding whether child learners efficiently tradeoff between production and understandability, with consequences for their role in language change.

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References

Arnold, J. E., Kahn, J. M., & Pancani, G. C. (2012). Audience design affects acoustic reduction via production facilitation. *Psychonomic Bulletin & Review*, *19*(3), 505–512.

Aylett, M., & Turk, A. (2004). The Smooth Signal Hypothesis: A functional explanation for relationships between redundancy, prosodic prominence, and duration in spontaneous speech. *Language and Speech*, *47*(1), 31–56.

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67, 1–48.

Barr, D. J., Levy, R., Scheepers, C., & Tily, H. J. (2013). Random effects structure for confirmatory hypothesis testing : Keep it maximal. *Journal of Memory and Language*, *68*(3), 255–278.

Bybee, J. (2006). From Usage to Grammar: The Mind's Response to Repetition. *Language*, *82*(4), 711–733.

Bybee, J. (2007). *Frequency of use and the organization of language*. Oxford: Oxford University Press.

Culbertson, J., & Newport, E. L. (2015). Harmonic biases in child learners: In support of language universals. *Cognition*, *139*, 71–82.

Diessel, H. (2007). Frequency effects in language acquisition, language use, and diachronic change. *New Ideas in Psychology*, *25*(2), 108–127.

Fedzechkina, M., & Jaeger, T. F. (2020). Production efficiency can cause grammatical change: Learners deviate from the input to better balance efficiency against robust message transmission. *Cognition*, *196*.

Fedzechkina, M., Jaeger, T. F., & Newport, E. L. (2012). Language learners restructure their input to facilitate efficient communication. *Proceedings of the National Academy of Sciences*, *109*(44), 17897–17902.

Fedzechkina, M., Newport, E. L., & Jaeger, T. F. (2016). Balancing Effort and Information Transmission During Language Acquisition: Evidence From Word Order and Case Marking. *Cognitive Science*, (March), 1–31.

Frank, A. F., & Jaeger, T. F. (2008). Speaking Rationally: Uniform Information Density as an Optimal Strategy for Language Production. *The 30th Annual Meeting of the Cognitive Science Society (CogSci08)*, 939--944.

Gibson, E., Bergen, L., & Piantadosi, S. T. (2013). Rational integration of noisy evidence and prior semantic expectations in sentence interpretation. *Proceedings of the National Academy of Sciences*, *110*, 8051–8056.

Gibson, E., Futrell, R., Piandadosi, S. T., Dautriche, I., Mahowald, K., Bergen, L., & Levy, R. (2019). How Efficiency Shapes Human Language. *Trends in Cognitive Sciences*, 1–19.

Givón, T. (1991). Markedness in Grammar : Distributional , Communicative and Cognitive Correlates of Syntactic Structure. *Studies in Language*, *15*(2), 335–370.

Greenberg, J. (1966). *Language universals: With special reference to feature hierarchies*. The Hague: Mouton.

Grimm, S. (2012). *Number and Individuation*. Stanford University.

Grimm, S. (2018). Grammatical number and the scale of individuation. *Language*, *94*(3), 527–574.

Haspelmath, M. (2008). Frequency vs. iconicity in explaining grammatical asymmetries. *Cognitive Linguistics*, (19), 1–33.

Haspelmath, M. (2013). Occurrence of Nominal Plurality. In M. Haspelmath, M. S. Dryer, D. Gil, & B. Comrie (Eds.), *The world atlas of language structures* (pp. 142–145). Oxford: Oxford University Press.

Haspelmath, M., & Karjus, A. (2017). Explaining asymmetries in number marking : Singulatives, pluratives and usage frequency. *Linguistics*, *55*(6), 1213–1235.

Hudson Kam, C. L., & Newport, E. (2005). Regularizing Unpredictable Variation: The Roles of Adult and Child Learners in Language Formation and Change. *Language Learning and Development*, *1*(2), 151–195.

Hudson Kam, C. L., & Newport, E. L. (2009). Getting it right by getting it wrong: When learners change languages. *Cognitive Psychology*, *59*(1), 30–66.

Jaeger, T. F. (2013). Production preferences cannot be understood without reference to communication. *Frontiers in Psychology*, *4*(April), 1–4.

Jaeger, T. F., & Buz, E. (2017). Signal Reduction and Linguistic Encoding. In E. Fernández & H. Cairns (Eds.), *The Handbook of Psycholinguistics* (pp. 38–81). Hoboken: John Wiley & Sons.

Kurumada, C., & Grimm, S. (2019). Predictability of meaning in grammatical encoding: Optional plural marking. *Cognition*, *191*.

Kurumada, C., & Jaeger, T. F. (2015). Communicative efficiency in language production: Optional case-marking in Japanese. *Journal of Memory and Language*, *83*, 152–178.

Labov, W. (2007). Transmission and Diffusion. *Language*, *83*(2), 344–387.

Levy, R., & Jaeger, T. F. (2007). Speakers optimize information density through syntactic reduction. In B. Schlökopf, J. Platt, & T. Hoffman (Eds.), *Advances in neural information processing systems (NIPS) 19* (pp. 849–856). Cambridge: MIT Press.

Lupyan, G., & Dale, R. (2010). Language Structure Is Partly Determined by Social Structure. *PLoS ONE*, *5*(1).

Newport, E. L. (2019). Children and Adults as Language Learners: Rules , Variation , and Maturational Change. *Topics in Cognitive Science*, 1–17

Raviv, L., & Arnon, I. (2018). Systematicity, but not compositionality: Examining the emergence of linguistic structure in children and adults using iterated learning. *Cognition*, *181*(August), 160–173.

Samara, A., Smith, K., Brown, H., & Wonnacott, E. (2017). Acquiring variation in an artificial language: Children and adults are sensitive to socially conditioned linguistic variation. *Cognitive Psychology*, *94*, 85–114.

Tal, S., & Arnon, I. (2019). Redundant morphological marking facilitates children's learning of a novel construction. In *Proceedings of the 41st Annual Conference of the Cognitive Science Society* (pp. 2912–2918).

Ullman, M. T. (2001). The neural basis of lexicon and grammar in first and second language: the declarative/procedural model. *Bilingualism: Language and Cognition*, 4(1), 105–122.

Zipf, G. K. (1949). *Human behavior and the principle of least effort: An introduction to human ecology*. Cambridge: Addison-Wesley Press.