Grammatical morphology as a source of early number word meanings

Alhanouf Almoammer[a,b,1], Jessica Sullivan[c,1], Chris Donlan[a], Franc Marušič[d], Rok Žaucer[d], Timothy O'Donnell[e], and David Barner[c,f,2]

[a]Division of Psychology and Language Sciences, University College London, London WC1N 1PF, United Kingdom; [b]Department of Health Rehabilitation Sciences, King Saud University, Riyadh, Saudi Arabia 11451; [c]Department of Psychology and [f]Department of Linguistics, University of California at San Diego; La Jolla, CA 92116; [d]Research Center for Humanities (Language and Cognitive Science), University of Nova Gorica, SI-5000 Nova Gorica, Slovenia; and [e]Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139

Edited by Susan E. Carey, Harvard University, Cambridge, MA, and approved September 30, 2013 (received for review July 19, 2013)

How does cross-linguistic variation in linguistic structure affect children's acquisition of early number word meanings? We tested this question by investigating number word learning in two unrelated languages that feature a tripartite singular-dual-plural distinction: Slovenian and Saudi Arabic. We found that learning dual morphology affects children's acquisition of the number word *two* in both languages, relative to English. Children who knew the meaning of *two* were surprisingly frequent in the dual languages, relative to English. Furthermore, Slovenian children were faster to learn *two* than children learning English, despite being less-competent counters. Finally, in both Slovenian and Saudi Arabic, comprehension of the dual was correlated with knowledge of *two* and higher number words.

counting | grammatical number

How does the structure of language affect children's acquisition of early number word meanings? Humans have a unique ability to express an unbounded set of exact numerical concepts, like "eighty-two" (1), which emerges only after children have begun using language (2). Cross-cultural studies find that number knowledge is typically related to learning a verbal count list, and that groups who lack large number words also lack the ability to represent large numerosities precisely (3–5). Together, such observations suggest that, across most human cultures, natural language plays a central role in the acquisition and use of number words, the basic building blocks of early mathematical development. However, beyond the fact that number word learning typically begins with acquiring a count list, surprisingly little is known about how the particular language a child speaks affects their ability to acquire number word meanings. In this article we investigated this question by testing how cross-linguistic differences in grammatical structure affect the early stages of number word development. In particular, we tested number word learning in two languages, Slovenian and Saudi Arabic, which provide rich morphological cues to the very first number words children acquire in development.

By some accounts, linguistic structure is important to the acquisition of number words chiefly because it provides a system of labels for expressing preexisting numerical concepts (6). By other accounts, language plays a stronger role by providing a system for combining content from diverse perceptual and conceptual systems, thus allowing humans to construct new concepts, such as the positive integers, which would otherwise not be possible (7). Each of these past accounts has focused on how language supports number word learning by allowing humans to express or combine concepts. Others, however, have argued that beyond merely expressing and combining content, language may also support number word learning by providing specific cues to meaning via its morphological and syntactic structures, in ways that vary from one language to another (8–12). Specifically, children might attend to how number words are used with linguistic structures that encode grammatical number, thereby learning that these words denote quantity, and even which specific quantities they denote. On this account, children exposed to languages with rich morphological cues to number might be faster to learn early number word meanings relative to children who learn languages with less number marking.

Several studies indicate that the grammatical structures of language encode conceptual content that is relevant to number word learning, and that children can leverage this content when learning the meanings of their first number words. First, in many languages number words are used in syntactic contexts that are also occupied by set-relational quantifiers, like *many*, *several*, and *all*. By noticing this relationship, children might infer—via "syntactic bootstrapping"—that number words, like quantifiers, encode information about sets and quantity (9–12). Consistent with this, children's ability to comprehend quantifiers is a significant predictor of number word comprehension in acquisition (10, 11). Second, some languages, like English, make a grammatical distinction between singular and plural, which could facilitate number word learning. Whereas the word *one* is typically used with singular agreement (*one cup*), all larger number words are used with the plural (*three cups*). Thus, children who know the singular-plural distinction might use this knowledge to speed their acquisition of the word *one* (e.g., by inferring that *one cat* refers to a single cat), thereby using existing linguistic concepts to interpret early number

Significance

Languages vary in how they grammatically mark number (e.g., in nouns, verbs, and so forth). We test the effects of this variability on learning number words—for example, *one*, *two*, *three*—by investigating children learning Slovenian and Saudi Arabic, which have singular-plural marking, but also dual marking (for sets of two). We find that learning the dual is associated with faster learning of the meaning of *two* than in any previously studied language, even when accompanied by less experience with counting. We conclude that although exposure to counting is important to learning number word meanings, hearing number words used outside of these routines—in the quantificational structures of language—may also be highly important in early acquisition.

Author contributions: A.A., J.S., C.D., F.M., R.Ž., T.O., and D.B. designed research; A.A., J.S., C.D., F.M., R.Ž., and D.B. performed research; A.A., J.S., C.D., F.M., R.Ž., T.O., and D.B. analyzed data; A.A., J.S., F.M., R.Ž., T.O., and D.B. wrote the paper; A.A. designed experiments and collected data for Saudi Arabic; J.S. designed studies and collected data for Slovenian and English and conducted statistical analyses; C.D. designed studies and oversaw data collection for Saudi Arabic; F.M. and R.Ž. designed studies and oversaw data collection for Slovenian; T.O. designed studies for Slovenian and conducted data analyses for all studies; and D.B. designed studies for Slovenian and English and oversaw data collection in English.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Freely available online through the PNAS open access option.

[1]A.A. and J.S. contributed equally to this work.

[2]To whom correspondence should be addressed. E-mail: barner@ucsd.edu.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1313652110/-/DCSupplemental.

words (8). In support of this hypothesis, children learning English are significantly faster to learn the meaning of the word *one* than are children learning languages that lack obligatory singular and plural marking, such as Japanese and Chinese (11, 12).

These previous studies are consistent with the thesis that the morphology and syntax of language encode content that is relevant to acquiring early number words, and that differences in exposure to these structures affect the rate of number word learning both within and across languages. However, the evidence for this conclusion is controversial. Within-language correlations between the acquisition of quantifiers and number words may exist not because of a specific causal relation between the two, but because children who are rapid language learners are more advanced learners across the board. Similarly, cross-linguistic differences in the rate of number word learning, although correlated with differences in grammatical structure, may also be because of other linguistic or cultural differences that are not measured in these studies (e.g., variability in children's exposure to number words). Although languages like Japanese and English differ with respect to singular-plural marking, they also differ in many other ways that might cause differences in number word learning that are not specific to the word *one* (11). More generally, although these studies provide compelling correlational data, they do not yet support the strong claim that learning the meanings of early number words (e.g., *one, two*, and *three*) is facilitated by grammatical marking of number.

In the present study, we tested this idea by studying the acquisition of two languages that feature distinctive number morphosyntax: Slovenian, a Slavic language, and Saudi Arabic, a Semitic language. Although many languages, like English, make only a distinction between singular and plural forms, Slovenian and Saudi Arabic make a finer distinction between singular, dual, and plural (13). Thus, these languages grammatically mark reference to sets of two, regardless of whether numerals are explicitly used. In Slovenian, a noun like *button* can occur in the singular (*gumb*), the dual (*gumba*), or the plural (*gumbi*). In addition, agreement occurs on adjectives, like *red*, and on verb phrases (example 1, below). Perhaps most interesting, in Slovenian the small number words—*one*, *two*, *three*, and *four*—behave like adjectives and agree with the noun in number. Thus, the word *two* (*dva*) receives dual agreement, whereas *four* (*štirje*) receives the plural. In colloquial Saudi Arabic, which we also investigated here, dual marking appears on the noun (example 2), although not on adjectives or verbs (except in media, schools, or written texts, where Standard Arabic is used and dual agreement occurs throughout the sentence). Thus, a singular car, for example, is *sayara*, dual is *sayarten*, and plural is *sayarat* (for details of each morphological paradigm, see *Supporting Information*).

Example 1, Slovenian:

Dva	*rdeča*	*gumba*	*ležita*	*na mizi.*
$\text{two}_{\text{M.DUAL}}$	$\text{red}_{\text{M.DUAL}}$	$\text{button}_{\text{M.DUAL}}$	lie_{DUAL}	on table

"Two red buttons are lying on the table."

Example 2, Saudi Arabic:

Mudarrisen	*(ethnen)*	*twal*	*waqfeen*	*'ala altareeq.*
$\text{teacher}_{\text{DUAL}}$	two	$\text{tall}_{\text{PLURAL}}$	$\text{stand}_{\text{PLURAL}}$	on road

"Two tall teachers are standing on the road."

We exploited the presence of dual marking in these languages to test whether learning dual morphology specifically affects the acquisition of the meaning of *two*, and thus whether cross-linguistic variation in number morphology causes differences in number word learning. Critically, unlike previous studies, our study was not restricted to testing the relative speed with which children acquire the system of number words as a whole (which might be because of any number of factors). Instead, we specifically probed the role of the dual in learning the meaning of *two*. We tested this relationship in two ways. First, we tested the relative frequency of children who knew the meaning of the word *two* in Saudi Arabic, Slovenian, and English 2-, 3-, and 4-y-olds (which we also compared with previous reports of Russian, Japanese, and Chinese). If learning a singular-dual-plural distinction facilitates learning the meanings of *one* and *two*, but does not help children learn higher numbers like *three* and *four*, then children who know the meaning of *two* should be especially frequent in dual languages. Second, we tested whether children's comprehension of *two* was specifically related to acquiring the dual, by probing dual knowledge in three tasks. Finally, as in previous cross-linguistic work, we asked whether children learning a dual language are faster overall to learn the meaning of *two*, compared with children learning English, when controlling for age and exposure to number words.

Experiments

The studies reported here were conducted by two separate groups. Authors J.S., F.M., R.Ž., T.O., and D.B. did the Slovenian and English studies without knowledge of the concurrent Saudi study, run by A.A. and C.D. Because of this, the tasks and age groups differed, as we describe below. For English and Slovenian we tested 2-, 3-, and 4-y-olds (English mean = 3;6 y; Slovenian mean = 3;2 y), and for Saudi we tested 3- and 4-y-olds (mean = 3;9 y).

The English and Slovenian children were given two tests of number word knowledge. The Give-a-Number (Give-N) task (14) identified the number words that children comprehended. Children who knew no number word meanings were called nonknowers. Those who knew the meaning of *one*, but not higher words, were called *one*-knowers. Children who knew the meanings of *one* and *two* were called *two*-knowers. We also identified *three*- and *four*-knowers, and finally cardinal principle (CP)-knowers, who we defined as children who could use counting to determine the cardinality of any number in their count list (in this study numbers up to 10; see *Materials and Methods* for details). The Highest Count task tested how high each child could recite numbers in a counting routine, and was used as a proxy for pedagogical exposure to number words and counting. The Saudi Arabic speakers also completed the Give-N task, but not the Highest Count task. The one difference in method for the Saudi Give-N task was that numbers up to 5 (instead of 10) were tested, and CP-knowers were defined as children who comprehended words up to *five*.

Children also received tests of dual comprehension to determine its relationship to number word comprehension. The Slovenian children did two morphology tasks. In the Give-Morphology (Give-M) task (10, 11) the experimenter asked children to give sets of objects using nouns with either singular, dual, or plural morphology. In the What's-on-this-Card task (WOC) (15) the experimenter asked the children to describe sets on cards. Half the children were prompted to label sets using number words and nouns and half were not prompted to use number words, although they were free to do so. The number prompts allowed us to probe whether children could use appropriate number agreement when using number words. Saudi children were tested with a forced-choice method, in which three arrays were presented on a card (1, 2, and 5), and children pointed at an array in response to requests that included either singular, dual, or plural nouns.

Results

Give-N Task. If number morphology facilitates the acquisition of number word meanings, then learning the singular-dual-plural distinction may help children acquire the meanings of numbers up to *two*. To test this idea, we compared Slovenian, Saudi, and English children on the Give-N task, using a series of logistic regressions. For English and Slovenian, analyses used language, age, and counting ability as predictors of number-knower level. For Saudi Arabic, no counting data were available and this factor was excluded from our models. In addition, as already noted, there were no 2-y-olds in the Saudi dataset. These differences made it impossible to test whether Saudi children were faster to acquire *two*, relative to English, and also whether effects of language were driven by explicit training with the count routine

PSYCHOLOGICAL AND COGNITIVE SCIENCES

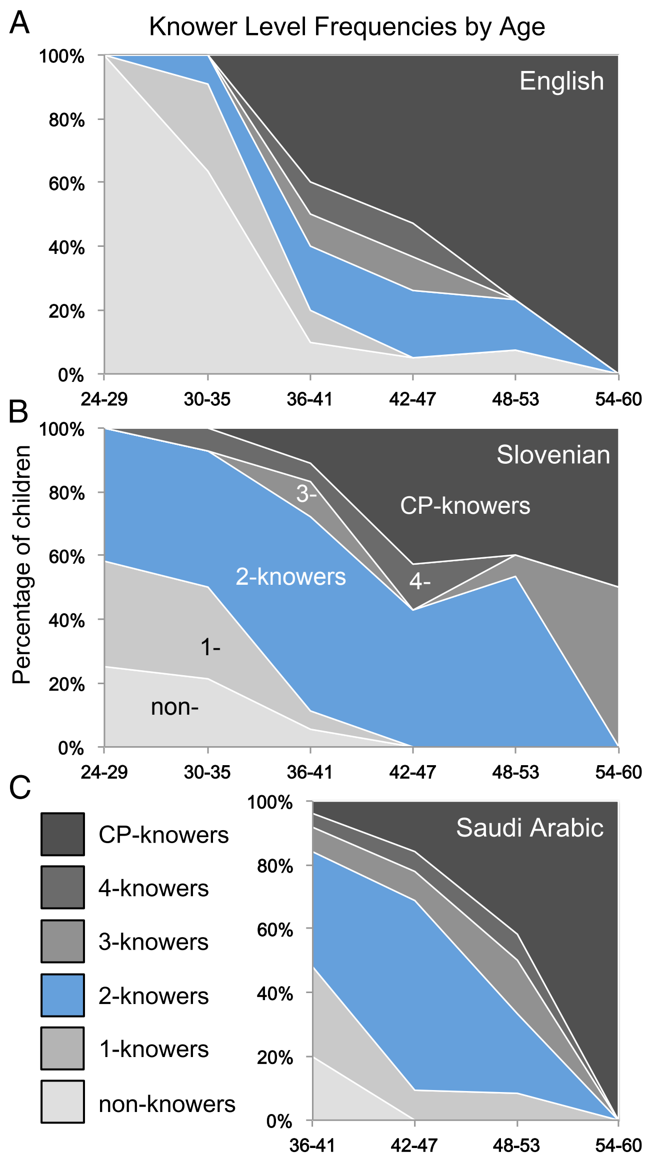

Fig. 1. Frequency of non-, *one-*, *two-*, *three-*, *four-*, and CP-knowers in (*A*) English, (*B*) Slovenian, and (*C*) Saudi Arabic in children aged 24–60 mo.

vs. dual morphology. Still, it was possible to ask whether *two*-knowers were overall more frequent in Saudi Arabic.

In the first analysis (Fig. 1), which predicted children's status as *two*-knowers, a comparison of English and Slovenian children found significant effects of language ($\beta = 1.349$, $P = 0.004$), counting ability ($B = -0.11$, $P = 0.019$), and a marginally significant effect of age ($B = 0.056$, $P = 0.073$). Here and elsewhere in the report, likelihood-ratio tests revealed the same pattern of results. The language effect reflected a much higher frequency of *two*-knowers in Slovenian (49%) compared with English (11%). Surprisingly, this was true for each age group: 2-y-olds (42% vs. 4%); 3-y-olds (58% vs. 20%); and 4-y-olds (44% vs. 8%). A parallel analysis comparing English and Saudi Arabic children also found a significant effect of language ($B = 1.24$, $P = 0.006$), and a marginally significant effect of age ($B = -0.07$, $P = 0.052$). Again, there was a dramatically higher frequency of *two*-knowers in Saudi Arabic (41%) compared with English (11%), which was again true for each age group separately: 3-y-olds (49% vs. 20%) and 4-y-olds (23% vs. 8%). In this comparison, the same pattern of results was found whether English 2-y-olds were included in the analysis or whether instead they were excluded, such that only 3- and 4-y-olds were compared (as in the analysis presented here). Finally, there was no difference in the frequency of *two*-knowers between Saudi Arabic and Slovenian ($B = -0.45$, $P = 0.243$), and no effect of age ($B = -0.06$, $P = 0.098$).

For Slovenian, two factors explain why *two*-knowers were so frequent relative to English. First, in the analysis just presented, the likelihood of being a *two*-knower was negatively correlated with counting ability, suggesting that poor counters got stuck as *two*-knowers and better counters progressed to higher-knower levels. As shown in Fig. 2, there were very important differences in counting ability between groups. Slovenian children were substantially poorer counters than English children, especially at older ages. For example, at 54 mo Slovenian children counted as high as English children who were a year younger. In a model predicting highest count, we found an effect of language ($B = -9.06$, $P < 0.0001$), an effect of age ($B = 0.75$, $P < 0.0001$), and interaction between language and age ($B = -0.86$, $P < 0.001$). This relatively poor counting ability likely reflects a smaller emphasis on explicitly training children to count in Slovenia, relative to in the United States, and thus less exposure to number words overall. Such a difference in exposure might explain why, despite being faster to acquire *two* (as we show below), Slovenian children are not faster to learn the meanings of higher number words.

The second reason that *two*-knowers were more frequent in Slovenian was that Slovenian children were faster to become *two*-knowers than English children, despite the fact that they had much weaker knowledge of counting. The percentage of children who knew the meaning of at least *two* was higher in Slovenian (S) than in English (E) for 24- to 30-mo-olds (S = 41%; E = 0%), and 30- to 36-mo-olds (S = 50%; E = 9%), but less so in 36- to 42-mo-olds (S = 88%; E = 80%), and older children. An analysis that predicted being at least a *two*-knower found significant effects of language ($B = 2.64$, $P < 0.001$), age ($B = 0.249$, $P < 0.0001$), and counting ability ($B = 0.197$, $P = 0.034$). In addition, language remained a significant predictor of knowing at least *two* when excluding children over 35 mo of age ($B = 3.64$, $P < 0.013$), showing that the effect was not driven by greater numbers of *two*-knowers at older ages. Finally, an analysis that predicted being at least a *three*-knower revealed no effect of language ($B = 0.176$, $P = 0.753$), despite showing significant effects of age ($B = 0.113$, $P = 0.003$) and counting ability ($B = 0.208$, $P < 0.001$), suggesting that speaking Slovenian was specifically associated with learning *two* more quickly, but not *three*. Instead, age and counting ability were the best predictors of knowing higher-number words.

To further probe the generality of these effects, we next compared our findings with data from Russian, Japanese, and Mandarin Chinese. First, we considered data from Russian, originally collected by Sarnecka et al. (12). Russian is interesting because it is a Slavic language like Slovenian, and thus has very similar number morphology. Critically, although Russian has a singular-plural distinction and like Slovenian has different declension patterns

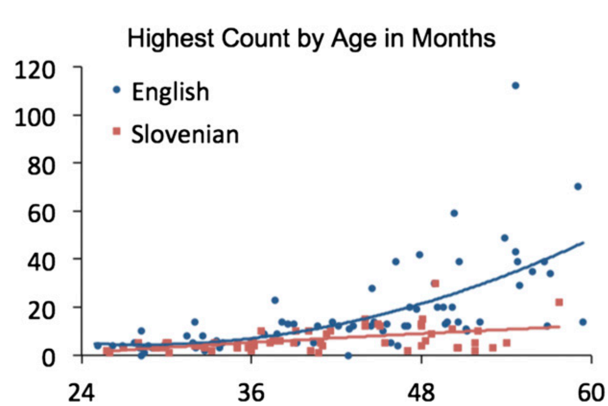

Fig. 2. Highest number counted by English and Slovenian children, for children aged 24–60 mo.

for different numerals, it does not have a dual form (13). Thus, Russian is a near-perfect control case for evaluating the Slovenian data. We compared Slovenian and Russian in a model that included age as a factor, but not highest count, because no comparable open-ended measure of counting was available for Russian (*Supporting Information*). We found that Slovenian children (49%) were significantly more likely to be *two*-knowers than Russian children (25%; $B = -1.00$, SE = 0.43, $P = 0.019$). We next compared Russian to Saudi Arabic (41% *two*-knowers). Here, although ages were sampled very differently across language groups in a way that likely exaggerated the proportion *two*-knowers in Russian (see *Supporting Information* for details), we found a marginally significant difference between the groups ($B = -0.94$, SE = 0.50, $P = 0.059$). Finally, we compared the dual languages to our own previously published Japanese data (9% *two*-knowers; total $n = 104$) and to new Mandarin Chinese data (11% *two*-knowers; total $n = 79$), where ages were comparable to Slovenian, and found that *two*-knowers were much less frequent in these languages, relative to the dual languages (Slovenian vs. Japanese: $B = -2.28$, SE = 0.43, $P < 0.0001$; Slovenian vs. Mandarin: $B = -1.97$, SE = 0.43, $P < 0.0001$; Saudi vs. Japanese: $B = -2.17$, SE = 0.45, $P < 0.0001$; and Saudi vs. Mandarin: $B = -2.09$, SE = 0.49, $P < 0.0001$). These analyses thus confirm that the frequency of *two*-knowers in Slovenian and Saudi Arabic is highly unusual, and not found in any previously studied language.

Morphology Tasks. Our hypothesis is that learning dual morphology facilitates acquiring the meaning of *two*. Thus, our next analyses tested whether comprehension of dual morphology was associated with learning the meaning of *two*. Such a correlation is not strictly required by the hypothesis that dual morphology facilitates number word learning. For example, dual learning might be complete before children receive significant exposure to number words, and yet might still facilitate number word learning. This scenario would result in no correlation. Still, the presence of a correlation would lend credence to the idea that the large differences in knower level distribution between languages are not coincidental, and instead are related to the variable of interest (i.e., dual knowledge).

We conducted three analyses for each test of dual comprehension. First, we compared dual comprehension in pre–*two*-knowers (children who are nonknowers or *one*-knowers) and children who knew the meaning of at least *two* (*two*-, *three*-, *four*-, and CP-knowers). Second, we compared pre–*two*-knowers to *two*-knowers. Finally, we compared *two*-knowers to post–*two*-knowers (*three*-, *four*-, and CP-knowers), where no particular relationship was expected (on the hypothesis that benefits of learning the dual are specific to *two*). All analyses were Wilcoxon/Kruskal–Wallis rank sums tests, although two-tailed *t* tests found similar results. For all morphology tasks we focus on results for dual trials, and report singular-plural data in the *Supporting Information*. It is important to note that performance on dual trials was often related to performance on the plural, in particular, because responses for the two were nonindependent. For example, consistently labeling sets of two with the dual would by necessity increase plural performance by precluding the possibility of using the plural to label sets of two. Thus, although we focus attention here to the dual, ultimately acquiring the dual must be considered one part of a broader mastery of the morphological paradigm.

Give-M. Children were asked to give quantities with sentences that featured singular, dual, or plural morphology. For the dual, only responses of "two" were considered correct. A set of analyses comparing dual knowledge across knower levels (Fig. 3) found a large and significant difference between children who knew at least *two* and those who did not ($P = 0.0004$), as well as a large difference between pre–*two*-knowers and *two*-knowers ($P = 0.002$), but no significant difference between *two*-knowers and post–*two*-knowers ($P = 0.371$). These data suggest that knowledge of morphology—and especially the dual and plural forms—is related to acquiring the meaning of the word *two*.

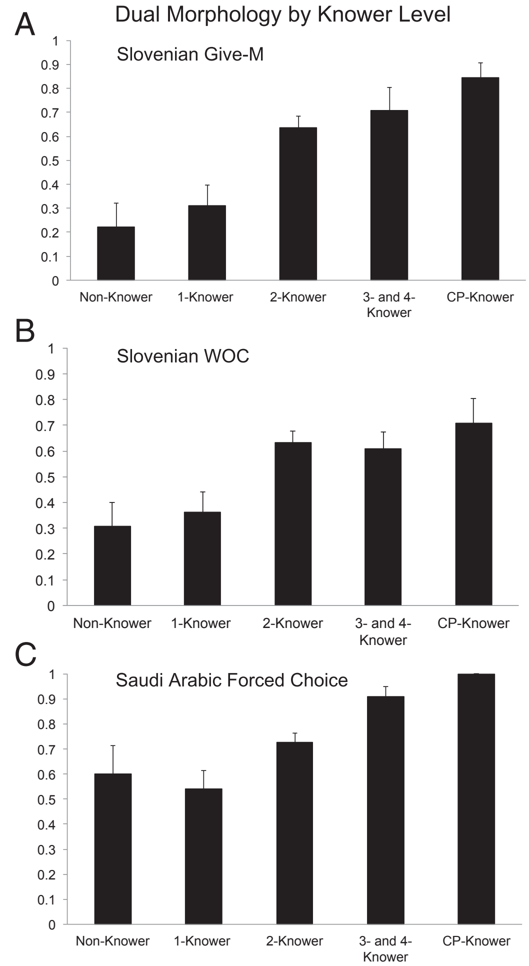

Fig. 3. Percent correct on dual for (*A*) Slovenian Give-M, (*B*) Slovenian WOC, and (*C*) Saudi Arabic forced-choice for non-, *one*-, *two*-, *three*-, *four*-, and CP-knowers. Error bars represent SEM.

What's-on-this-Card? For the WOC task, we conducted two main analyses to test the relationship between knower level and acquisition of morphology. First, for children who uttered the word *two*, we asked whether they used the appropriate dual agreement on the noun that labeled the set (independent of whether two things were actually on the card, and thus whether the response was correct in relation to the set). We found that when children used the word *two* to label sets [either because they were in the Number Prompt condition, or because they did so spontaneously (*Supporting Information*)], they almost always used dual marking on the noun that accompanied the numeral, regardless of knower level: nonknowers (89%), *one*-knowers (88%), *two*-knowers (84%), *three*- and *four*-knowers (100%), and CP-knowers (97%). This finding suggests that even before knowing the meaning of *two*, at least some children are able to use *two* with correct dual agreement on the noun, a prerequisite for using this agreement to guide number word learning.

Our second analysis (Fig. 3) tested the degree to which children at different knower levels used the dual for sets of two objects. When children were presented with a set of two, correct use of the dual differed significantly between those who knew the meaning of at least *two* and those who did not ($P = 0.008$). In addition, there was a difference between pre–*two*-knowers and *two*-knowers ($P = 0.017$), but not between *two*-knowers and post–*two*-knowers ($P = 0.592$). Thus, as in the Give-M tasks, we found that acquiring the meaning of *two* was significantly associated with increased comprehension of the dual.

Forced-Choice Morphology. This task, given to Saudi children, also tested how learning dual morphology was related to learning *two* (for singular-plural data, see *Supporting Information*). Children saw one card on each trial that depicted three arrays with one, two, or five objects (not always in the order). In a request that had singular, dual, or plural marking they were asked to point to a set.

On dual trials (Fig. 3) we found a significant difference between children who knew the meaning of at least *two* and those who did not ($P = 0.0003$). This result stemmed from a marginally significant difference between pre–*two*-knowers and *two*-knowers ($P = 0.078$), and a significant difference between *two*-knowers and post–*two*-knowers ($P = 0.0006$). Critically, by the time children became *two*-knowers, they pointed to the correct set in response to dual requests 71% of the time, which was significantly greater than chance ($P = 0.002$). Thus, as in Slovenian, we found that dual knowledge was associated with knower level, although results for Saudi Arabic were not as robust as those for Slovenian. This weaker effect may be because of the absence of 2-y-olds in this study. However, another reason may be that the forced-choice task differed from the Slovenian tasks in a way that is known to mask competence in studies of English singular-plural comprehension (16). Specifically, on dual trials both the dual card and the plural card contained at least two items. Thus, on these trials either choice is technically correct if children restrict attention to a subset of two items, because both a set of two and a set of five contain two items, consistent with the dual. A secondary analysis revealed that when children made errors on singular trials these errors were randomly distributed between the remaining two-item (54%) and five-item (46%) cards ($\chi^2 = 0.974$, $P = 0.324$). However, when children made errors on dual trials, they were made significantly more to five-item (63%) than to one-item (37%) cards ($\chi^2 = 5.003$, $P = 0.025$). This finding shows that these children had some nonsingular meaning for the dual—and possibly a dual meaning—but leaves open the possibility that they interpreted it as a plural. However, a subset of children almost certainly had a dual interpretation when they incorrectly chose sets of five: seven Saudi children pointed specifically to a subset of an array (i.e., to two items) on at least one dual trial. Although these ambiguous choices were not included in our analysis (and had no effect if included, regardless of how they were coded), it is likely that other children also intended subsets of arrays when pointing, leading us to underestimate comprehension of the dual on some trials. Critically, independent of this detail, we found that in Saudi Arabic, as in Slovenian, comprehension of the dual was robust by the time children became *two*-knowers, and was strongly associated with knowing the meaning of at least *two*.

Discussion

In a study of two dual languages, we found that grammatical morphology can affect the acquisition of early number word meanings, resulting in striking cross-linguistic differences in number word learning. In both Slovenian and Saudi Arabic—two unrelated languages in completely different cultural contexts—*two*-knowers were surprisingly frequent, relative to English. In addition, in the dual languages, comprehension of *two* was associated with knowledge of dual number marking. Additional analyses in Slovenian, for which we had 2-y-old children and a measure of counting ability, found a significantly earlier acquisition of *two*, relative to English, but no advantage for learning higher words. Whereas learning dual morphology appears to have speeded the acquisition of words up to *two*, counting ability and age were the best predictors of acquiring larger numbers. In fact, the likelihood of being a *two*-knower was negatively correlated with counting ability, suggesting that Slovenian children were fast to acquire *two*, but got stuck as *two*-knowers because of their relative lack of exposure to number words. Finally, differences were also found when comparing Slovenian and Saudi data to data from Russian, Japanese, and Mandarin Chinese. Thus, we find that the frequency of *two*-knowers in Slovenian and Saudi Arabic is very unusual, and unlike any language previously studied.

These results show that when concepts like "dual" are made explicit in the morpho-syntax of a language, the acquisition of corresponding number word meanings is facilitated. This conclusion is consistent with the broader thesis that hearing number words used in informative grammatical structures speeds the acquisition of their meanings (17–19). Consequently, our data lend support to the idea that previously reported differences between English and Japanese (8, 11, 12), for example, are indeed driven by cross-linguistic differences in grammatical number (e.g., the availability of singular-plural marking only in English). More generally, our data suggest that although frequent exposure to counting is likely important to learning number word meanings, hearing number words used outside of these routines—in the quantificational structures of language—may also be highly important in early acquisition. Future studies should investigate this possibility by testing how, within a given language, learning is affected by training that emphasizes the use of number words in informative grammatical structures.

Several questions are left open by this study. First, although a natural conclusion to draw from our data is that number morphology can affect the acquisition of number word meanings directly, it is also possible that a less-direct relationship exists between the forms. For example, it is possible that acquiring the dual speeds number word learning because it involves constructing a new concept, "twoness," the general availability of which speeds the independent acquisition of the word *two* (10). This result, like a more direct syntactic bootstrapping account, would also predict the correlated emergence of *two* and the dual. Second, although our data suggest that morphological forms like the dual encode concepts similar to meanings of number words like *two*, we have not addressed how such concepts might arise in the first place. It is possible that the acquisition of morphology and number words both depend on a single conceptual change (which in Slovenian and Saudi occurs when children acquire the dual), or that both depend on a shared set of innate semantic representations, which underlie other logical quantifiers and connectives in natural language (see ref. 18 for discussion).

Finally, although our study addresses the role of grammatical number in early, foundational stages of number word learning, it leaves open the role of language at later stages of number word and mathematical development. Children across different cultures learn *one*, *two*, and *three* before they understand how counting works, just as they acquire singular, dual, and trial marking independent of a counting system (8, 13, 20). Critically, learning *one*, *two*, and *three* appears to be a necessary step to understanding counting and more advanced mathematical knowledge. However, children appear unable to learn words that encode sets of five or more—whether number words or grammatical morphology—in the absence of counting (14, 20). These facts suggest that grammatical cues to number are most important to learning the meanings of early number words, like *one*, *two*, and *three*, and that distinct processes govern later number word learning. For example, becoming a CP-knower, and learning how counting is used to enumerate sets larger than four, involves acquiring knowledge that lies beyond the scope of natural language morphology (see refs. 18–20 for discussion). Although grammatical structures may play an important role in getting number word learning off the ground, they are not sufficient for acquiring mathematical knowledge, which emerges later in development (21).

In sum, we found that grammatical morphology can facilitate the acquisition of early number word meanings, resulting in dramatic cross-linguistic differences. Although being trained to use a count list is an important part of number word learning, at the earliest stages children are also strongly affected by hearing number words used in naturalistic speech, particularly if their language features rich cues to number. These data suggest that acquiring number words—basic building blocks of later mathematical learning—is importantly affected by the structures with which they are used in speech, and thus by differences in the grammatical expression of number across individual children, and cross-linguistically.

Materials and Methods

Experiment 1. ***Participants.*** Slovenian children included 71 2-, 3-, and 4-y-olds (mean age = 3;3 y), tested in Ljubljana, Slovenia. All were native speakers of Central Slovenian. There were 28 2-y-olds, (2;1–2;11 y, mean = 2;6 y), 26 3-y-olds, (3;0–3;11, mean = 3;4 y), and 17 4-y-olds (4;0–4;9, mean = 4;2 y). Of these children, 68 successfully completed the Give-N task, and were included in analyses. English children included 79 2-, 3-, and 4-y-olds (mean = 3;6 y), tested in San Diego, CA. There were 26 2-y-olds, (2;1–2;9 y, mean = 2;5 y), 29 3-y-olds, (3;1–3;11 y, mean = 3;7 y), and 24 4-y-olds (4;0–4;11y, mean = 4;5 y). Children gave verbal assent, and caregivers gave signed consent. Recruitment and experimental procedures were approved by the UCSD Human Research Protection Program.

Slovenian children were tested in their school by a female experimenter who spoke Central Slovenian. Each child completed all four tasks (WOC, Give-N, Give-M, Highest Count) in order in one session. Two additional tests of pragmatic reasoning were administered on a separate day (*Supporting Information*). Testing took ~30 min. For computer tasks, audio was prerecorded by a native speaker of Central Slovenian. For all other tasks, the experimenter gave verbal instructions. English children were tested in their school or the laboratory by a female experimenter who spoke English. Sixty-two Slovenian children and 72 English children completed the Highest Count task and were included in all analyses. Children who did not complete the Highest Count task were included in all analyses that did not consider counting a factor.

Give-N. Children were given 10 objects and were asked to give *n* items (where *n* = 1–10), and to tell the experimenter when they were done. The experimenter requested *n* without a noun to avoid number agreement: "Can you put *n* in the red circle?" (see *Supporting Information* for translations). Once the child was done, the experimenter asked, "Is that *n*?" If the child gave an incorrect number, they were asked, "Can you count and make sure?" Children were asked for each *n* three times, in pseudorandom order. Children were classified as *n*-knowers for the largest number for which: (*i*) they provided *n* items two-thirds of the time when asked for *n*, and (*ii*) on two-thirds of the trials for which they gave *n*, they did so for the number *n* (21).

WOC. Warmup trials tested if children could name the four types of objects used during test: paintbrushes, buttons, balloons, and drums. The children were shown one card at a time and asked, "Can you tell me what's on this card?" If they didn't respond, the experimenter asked, "Can you say *X*?", where X was the singular form. Once the child had named the objects, the experiment began. The children were shown images of one, two, three, five, or eight items on each card. Each item type was presented on five trials, once for each set size. On each trial, the experimenter asked, "What's on this card?" There were two trial orders.

Half of children were assigned to a Number condition, half to a No-Number condition. In the Number condition, children were prompted to use number words: the experimenter gave feedback on the first trial, after the child saw one object: for example, "That's right, that's one drum." On later trials, if the child failed to use a number word, they were prompted with, "How many?" If they used a number word but no noun, they were prompted: for example, "Two what?" In the No-Number condition, there was no prompt, and most children did not use number words as a result. Regardless of condition, all trials on which children used numbers were used in analyses that tested use of morphology with numbers.

Give-M. Children were shown 10 buttons and asked to place a quantity into a box, using the singular (*gumb*), dual (*gumba*), or plural (*gumbe*), four times each. Children told the experimenter when they were done. Sixty-five children completed this task. Of these, all but nine completed all trials. These nine completed at least six trials (two for each ending) and were therefore included in analyses.

Highest count. Children were asked to count as high as they could. If they did not respond they were prompted by the experimenter, who said, "*one…*" (with rising intonation). The child's highest count was the largest number reached before making an error. In both the Slovenian and English samples seven children refused to count.

Experiment 2. ***Participants.*** The Saudi sample included 84 3- and 4-y-olds (mean = 3;9 y), tested in Riyadh, Saudi Arabia. All children were native speakers of Saudi Arabic. There were 57 3-y-olds, (3;0–3;11 y, mean = 3;6 y), and 27 4-y-olds (4;1–4;6 y, mean = 4;4 y). All children provided verbal assent, and caregivers gave signed consent. Recruitment and experimental procedures were approved by the UCL Research Ethics Committee.

Children were tested in their school by a female native speaker in a session lasting 10–20 min. Each child completed the two tasks (Give-N; forced-choice morphology). Task order was randomized between subjects.

Give-N. Children were shown 25 small balls and asked to put *n* items in a bowl (where *n* = 1, 2, 3, 4, or 5), and to count aloud. In a warm-up trial, the experimenter placed six balls one at a time in the bowl, counting aloud. Instructions were given without a noun, "Can you give me *n*?" to avoid number-marking cues (see *Supporting Information* for translation). When a child gave an incorrect number, the experimenter said, "Can you make sure that this is *n*?" to allow one correction. Children were asked for each *n* three times, in one of two pseudorandom orders.

Forced-choice morphology. Children were presented one training card followed by 12 test cards. Each card depicted three arrays (one, two, or five objects) of the same type (cars, chairs, trees, or spoons). For each type of thing there were three tokens, which varied across trials. The location of the singular, dual, and plural sets on the cards also varied across trials. For familiarization, children saw a card with three sets of balls (one, two, or five), and the experimenter used the number-inflected noun (*ball*, *ball-dual*, *ball-plural*) while pointing to each set (for translations, see *Supporting Information*). Each number-inflected noun was then repeated, but this time the child was asked to point and was given feedback if needed. The experimenter then moved to the test trials. Children saw one card at a time and were asked, "Can you show me the picture of *car-dual*?"

ACKNOWLEDGMENTS. We thank Vesna Plesničar, Tina Razboršek, Pierina Cheung, and Katie Kimura for their roles in collecting data; Naja Ferjan for help translating materials; Mike Frank, Veronique Izard, Steve Piantadosi, and members of Ladlab for comments; and Barbara Sarnecka for sharing Russian data from a past report. This research was supported by a James S. McDonnell Scholar Award (to D.B.); funding from King Saud University (to A.A.); a National Science Foundation Graduate Research Fellowship Program award (to J.S.); and Slovenian Research Agency Research Program funds (to R.Ž. and F.M.).

1. Dehaene S (1997) *The Number Sense: How the Mind Creates Mathematics* (Oxford Univ Press, New York).
2. Feigenson L, Dehaene S, Spelke ES (2004) Core systems of number. *Trends Cogn Sci* 8(7):307–314.
3. Pica P, Lemer C, Izard V, Dehaene S (2004) Exact and approximate arithmetic in an Amazonian indigene group. *Science* 306(5695):499–503.
4. Gordon P (2004) Numerical cognition without words: Evidence from Amazonia. *Science* 306(5695):496–499.
5. Frank MC, Everett DL, Fedorenko E, Gibson E (2008) Number as a cognitive technology: Evidence from Pirahã language and cognition. *Cognition* 108(3):819–824.
6. Leslie AM, Gelman R, Gallistel CR (2008) The generative basis of natural number concepts. *Trends Cogn Sci* 12(6):213–218.
7. Spelke ES, Tsivkin S (2001) Language and number: A bilingual training study. *Cognition* 78(1):45–88.
8. Carey S (2009) *The Origin of Concepts* (Oxford Univ Press, New York).
9. Bloom P, Wynn K (1997) Linguistic cues in the acquisition of number words. *J Child Lang* 24(3):511–533.
10. Barner D, Chow K, Yang SJ (2009) Finding one's meaning: A test of the relation between quantifiers and integers in language development. *Cognit Psychol* 58(2):195–219.
11. Barner D, Libenson A, Cheung P, Takasaki M (2009) Cross-linguistic relations between quantifiers and numerals in language acquisition: Evidence from Japanese. *J Exp Child Psychol* 103(4):421–440.
12. Sarnecka BW, Kamenskaya VG, Yamana Y, Ogura T, Yudovina YB (2007) From grammatical number to exact numbers: early meanings of 'one', 'two', and 'three' in English, Russian, and Japanese. *Cognit Psychol* 55(2):136–168.
13. Corbett GG (2000) *Number* (Cambridge Univ Press, Cambridge, UK).
14. Wynn K (1992) Children's acquisition of number words and the counting system. *Cognit Psychol* 24(2):220–251.
15. Gelman R (1993) *Learning and Motivation*, ed Medin D (Academic, New York), Vol 30, pp 61–96.
16. Kouider S, Halberda J, Wood J, Carey S (2006) Acquisition of English number marking: The singular-plural distinction. *Lang Learn Dev* 2(1):1–25.
17. Syrett K, Musolino J, Gelman R (2012) How can syntax support number word acquisition? *Lang Learn Dev* 8(2):146–176.
18. Piantadosi ST (2012). Learning and the language of thought. PhD thesis, (Massachusetts Institute of Technology, Cambridge, MA).
19. Barner D (2012) Bootstrapping numeral meanings and the origin of exactness. *Lang Learn Dev* 8(2):177–185.
20. Le Corre M, Carey S (2007) One, two, three, four, nothing more: An investigation of the conceptual sources of the verbal counting principles. *Cognition* 105(2): 395–438.
21. Rips LJ, Bloomfield A, Asmuth J (2008) From numerical concepts to concepts of number. *Behav Brain Sci* 31(6):623–642, discussion 642–687.