Cognitive Psychology 88 (2016) 162–186

Contents lists available at ScienceDirect

Cognitive Psychology

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

Numerical morphology supports early number word learning: Evidence from a comparison of young Mandarin and English learners

Mathieu Le Corre [a,*], Peggy Li [b], Becky H. Huang [c], Gisela Jia [d], Susan Carey [b]

[a] Centro de Investigación Transdisciplinar en Psicología, Universidad Autónoma del Estado de Morelos, Mexico
[b] Harvard University, USA
[c] University of Texas at San Antonio, USA
[d] Lehman College, USA

A R T I C L E   I N F O

Article history:
Accepted 16 June 2016
Available online 16 July 2016

Keywords:
Number words
Cardinality
Singular/plural
Mandarin
English
Language acquisition

A B S T R A C T

Previous studies showed that children learning a language with an obligatory singular/plural distinction (Russian and English) learn the meaning of the number word for one earlier than children learning Japanese, a language without obligatory number morphology (Barner, Libenson, Cheung, & Takasaki, 2009; Sarnecka, Kamenskaya, Yamana, Ogura, & Yudovina, 2007). This can be explained by differences in number morphology, but it can also be explained by many other differences between the languages and the environments of the children who were compared. The present study tests the hypothesis that the morphological singular/plural distinction supports the early acquisition of the meaning of the number word for one by comparing young English learners to age and SES matched young Mandarin Chinese learners. Mandarin does not have obligatory number morphology but is more similar to English than Japanese in many crucial respects. Corpus analyses show that, compared to English learners, Mandarin learners hear number words more frequently, are more likely to hear number words followed by a noun, and are more likely to hear number words in contexts where they denote a cardinal value. Two tasks show that, despite these advantages, Mandarin learners learn the meaning of the number word for one three to six months later than do English learners. These results provide the strongest evidence to date that prior

* Corresponding author at: Universidad Autónoma del Estado de Morelos, Centro de Investigación Transdisciplinar en Psicología, Pico de Orizaba 1, Colonia Los Volcanes, Cuernavaca, Morelos 62350, Mexico.
E-mail address: mathieu@uaem.mx (M. Le Corre).

http://dx.doi.org/10.1016/j.cogpsych.2016.06.003
0010-0285/

knowledge of the numerical meaning of the distinction between singular and plural supports the acquisition of the meaning of the number word for one.

1. Introduction

Word learning is a hard problem (e.g., Quine, 1960). One might think that number word learning would be an exception. Unlike most words, number words are part of a structure, namely verbal counting, which, when understood, directly reveals their meaning (Gelman & Gallistel, 1978). This means the problem of number word learning might reduce to learning to count, which English-learning middle class children do shortly after their second birthday. However, a large body of evidence shows that it is not so; number word meanings do not come for free upon learning to count. Rather, children learn the meanings of the number words for the first four numbers (''one" through ''four" in English) in a drawn out process that takes over a year, and acquire the meanings of these four number words before they figure out the numerical significance of counting (Fuson, 1988; Le Corre, Van de Walle, Brannon, & Carey, 2006; Sarnecka & Lee, 2009; Wynn, 1990, 1992). Thus, as children do not deduce the meaning of the first three or four number words from their understanding of counting, the meanings of ''one" through ''four" must be achieved simply by hearing the words used to refer to cardinal values of sets.

Many studies have shown that syntax and/or morphology contribute to acquiring the meanings of words such as nouns, verbs and adjectives (e.g., Gleitman, 1990). Likewise, it may be that syntax and morphology provide information that constrains the acquisition of number words. Indeed, Bloom and Wynn (1997) proposed that English-learning children infer that each number word denotes a unique, exact numerosity from the fact that it is the only meaning that is consistent with the syntax and semantics of the different types of phrases where number words occur (see also Barner, Libenson, Cheung, & Takasaki, 2009; Syrett, Musolino, & Gelman, 2012).

Even more simply, number word learning may be supported by numerical morphology. In many languages, number is morphologically marked on various parts of speech, most commonly on nouns and verbs (Corbett, 2000). To see how numerical morphology could help children learn number word meanings, consider the English singular/plural distinction. First, in many (though not all) contexts, singular nouns are used to refer to a single individual and plural nouns are used to refer to more than one (see Spector, 2007 for example). Thus, whether English noun are marked with a plural could, in principle, convey numerical information, provided that one can identify the contexts where this is so. Moreover, since, for some tenses, some verbs take on different forms depending on the number of the noun that acts as their subject, they too can potentially convey numerical information. Second, there is a regular contingency between number words and singular/plural morphology – namely, when ''one" modifies a noun, the noun must be in singular form, whereas when a noun is modified by a number word that denotes a number greater than one, it must be in plural form. Now, suppose that, at least in some contexts, before they begin to learn number words, children interpret singular nouns as referring to a single individual and plural nouns as referring to more than one. They might thus be able to use the regular contingency between number words and nominal and verbal numerical morphology to learn that the semantic distinction between ''one" and other number words is a numerical distinction, and/or to learn that ''one" denotes the cardinality of collections of one element.

Accumulating evidence suggests that this ''morphological bootstrapping" hypothesis is plausible. English learners learn the meaning of ''one" sometime between 24 and 36 months (Le Corre et al., 2006; Sarnecka & Lee, 2009; Wynn, 1990, 1992). Various studies have shown that, a little prior to that – namely, between 18 and 30 months – English learners know that, in some contexts, the presence or absence of a plural marker on a noun and/or the presence or absence of a pluralized verb that agrees with a noun indicates whether the noun refers to one or more than one individuals (Davies, Xu

Rattanasone, & Demuth, 2015; Jolly & Plunkett, 2008; Kouider, Halberda, Wood, & Carey, 2006; Lukyanenko & Fisher, 2016; Wood, Kouider, & Carey, 2009; Zapf & Smith, 2007). Importantly, the simple presence or absence of the plural marker is sufficient for children to infer whether a noun refers to one or more than one individual. Indeed, children as young as 18-months use the presence or absence of a plural marker to infer whether one or more than one individuals are being referred even when the plural is marked (or unmarked) on novel nouns (Zapf & Smith, 2007; see also Davies et al., 2015). Thus, at least in principle, English learners could use the contingency between number words (“one” vs. “two, three...”) and singular/plural morphology to help them learn the meaning of “one.”[1]

Cross-linguistic comparisons provide evidence that suggests that children indeed use the numerical information conveyed by numerical morphology to learn number word meanings. Unlike English, Najdi Arabic and some dialects of Slovenian mark a tripartite distinction between singular, dual and plural on various parts of speech. Almoammer et al. (2013) obtained evidence that Slovenian and Arabic children know the meaning of the dual marker in their language in time to help them learn the meaning of the number word for two. Crucially, they also found that Slovenian and Arabic children learn the meaning of the number word for two earlier than do English learners, but are not faster at learning number words that denote numbers greater than two. This strongly suggests that the availability of a dual marker facilitates the acquisition of the meaning of the number word for two.

Other cross-linguistic comparisons have born on the morphological bootstrapping hypothesis. Some languages do not have any obligatory numerical morphology (e.g., Corbett, 2000). Japanese is an example. Although Japanese has some morphological means for marking plurality (e.g. reduplication or -*tachi*, a collective suffix), such means are often restricted to certain types of nouns and rarely used (Sarnecka et al., 2007). The reference of any given noun is therefore typically numerically indeterminate. For example, the very same form can be used to refer to a single chair or to a plurality thereof. Thus, if the morphological bootstrapping hypothesis is right, children who learn a language with singular/plural morphology should learn the meaning of the number word for one earlier than children learning Japanese. Sarnecka et al. (2007) tested this prediction by comparing number word knowledge in three-year-olds learning a language with singular/plural morphology – namely, English or Russian – to number word knowledge in Japanese learners of the same age. The prediction of morphological bootstrapping was confirmed; i.e., whereas virtually all of the English and Russian learners had learned the meaning of the number word for one, only 54% of the Japanese learners had done so. Barner, Libenson, et al. (2009) replicated this result with a different English-Japanese sample.

However, other differences between the languages and between the contexts of the learners could explain the delay. First, Japanese is a classifier language. As such, Japanese number words must be followed by a classifier, a morpheme that classify nouns. There are many different classifiers because different nouns require different classifiers. The simple fact that Japanese learners have to learn a classifier system but English learners do not could explain why learning the meaning of number words is more difficult in Japanese.

Second, Japanese has multiple forms for each number word. Due to heavy linguistic borrowing from the Chinese in ancient times, modern Japanese has two phonologically distinct count lists. One is of Chinese origin, the other is native to Japanese. For numbers one through five, the list of Chinese origin is “ichi”, “ni”, “san”, “shi”, and “go,” whereas the native Japanese list is “hitotsu”, “futasu”, “mittsu”, “yottsu”, and “itsutsu.” Both lists are learned in parallel during the preschool years (Sarnecka et al., 2007). In contrast, English has only one count list. Moreover, in Japanese, classifiers alter the phonological form of the number word to which they attach. This is true both for the number

[1] The semantics of the singular/plural does not reduce to a distinction between reference to one individual and reference to more than one. Formal semanticists have proposed far more complex theories to provide a semantics that accounts for all uses of singular and plural nouns. For several reasons, we do not present these accounts here. As far as we can tell, semanticists are still debating each other about what is the right uniform account of the semantics of singular and plural nouns (e.g., compare Chierchia, 1998; Krifka, 2004). We do not review this complex debate, because it hangs on the semantics of nouns that cannot be modified by a number word – e.g., mass nouns (e.g., “I sold my furniture”), generic nouns (e.g., “Beavers build dams,” or “The beaver builds dams”), nouns combined with negation (“There were no soldiers left standing”), and nouns combined with “any” (e.g., “Are any soldiers still standing?”). All that is required for the morphological bootstrapping proposal to work is that, in most of the contexts where nouns can be modified by a number word, children of number word learning age take singular nouns to refer to one individual and plural nouns to refer to more than one. As mentioned above, several studies suggest that this is true.

words of Japanese and of Chinese origin. For example, "ichi" (or "one" from the Chinese-derived count list) can alternatively be pronounced as "ippiki", "ichimai", "ikko", or "issatsu" depending on the classifier it combines with. English number word forms, in contrast, are virtually invariable. Therefore, it could be that Japanese children learn the meanings of number words later than English learners because the form of the number words they hear is more variable.

Third, Barner, Libenson, et al. (2009) point out that the word order relationship between number words and the nouns they modify is more variable in Japanese than in English. In English, number words that modify nouns occur pre-nominally only; e.g., "The two boys went to bed" is grammatical but "The boys two went to bed" is not. In contrast, Japanese number words can move from pre-nominal to post-nominal positions – this is known as "numeral floating" (Kobuchi-Philip, 2007). Barner, Libenson et al. reported that number words are floated to a post-nominal position in Japanese child-directed speech 57% of the time. Moreover, Barner, Libenson et al. note that Japanese is an argument-dropping language – i.e., it allows speakers to drop both the subjects and the objects of sentences, even if they have not been overtly mentioned in previous sentences (Zushi, 2003). This allows Japanese speakers to use number words without an overt noun. In a corpus analysis, Barner, Libenson, et al. (2009) found that Japanese speakers do this frequently – the Japanese forms for one and two were used without a noun over 80% of the time. However, Barner, Libenson et al. did not actually establish whether nouns are dropped more often in Japanese than in English (e.g., in "I'll have one," or "Take two stickers and give three to your brother," the nouns that specify the units of counting are dropped), because they did not estimate the rate of argument dropping in English.

Barner, Libenson et al. argue that the fact that the ordering of number words relative to nouns is less predictable in Japanese than in English, and that Japanese number words are frequently used without a noun could make number word learning harder in Japanese than in English in several ways. Perhaps the greatest effect of this variability is that it makes it harder to use nouns to determine the units of counting in Japanese than in English. Number words cannot be interpreted unless some unit of counting is provided. To be sure, when nouns are dropped, the units can be inferred from context. But it may be easier to identify the units when they are provided by an overt noun than when they must be inferred from context.[2]

Fourth, based on analyses of transcripts of conversations between children and caregivers in the CHILDES database (MacWhinney, 2000), Sarnecka et al. and Barner, Libenson et al. both found that Japanese children hear number words less frequently than American children. This could explain why American children learn the meaning of the number word for one earlier than Japanese children. Finally, neither of the studies that reported a delay in Japanese number word learning carefully matched their samples on the socioeconomic status (SES) of the families of the children. SES is known to affect the acquisition of numerical knowledge in general, and of number word learning in particular (Fluck & Henderson, 1996; Jordan, Huttenlocher, & Levine, 1992). Thus, an inadvertent difference in the SES of the Japanese and American children in these studies could have contributed to the difference in the rate of number word learning.

Some of the limitations of the English-Japanese comparison are addressed by Sarnecka et al.'s inclusion of Russian-learning children. To repeat, like English, Russian has obligatory singular/plural morphology, and, like English learners, Russian learners learn the meaning of the number word for one earlier than Japanese learners. However, Sarnecka et al. reported that, unlike the form of English number words, the form of Russian number word is not less, but *more* variable than the form of Japanese number words. Moreover, like Japanese, Russian allows speakers to use number words both before and after the noun they modify (Madariaga, 2007; Pereltsveig, 2007). Finally, Sarnecka et al. found that Russian children hear number words *less* frequently than Japanese children. Thus, the Russian-Japanese comparison arguably provides stronger evidence that singular/plural morphology facilitates the acquisition of the meaning of the number word for one.

[2] Note that in classifier languages such as Japanese and Mandarin, it is possible to infer the unit of counting in the absence of nouns from knowing the meaning of the classifiers. However, Japanese- and Mandarin-learning children probably cannot infer units of counting from classifiers at the age when they are learning their first number words. Indeed, studies suggest that Japanese- and Mandarin-learning children begin to learn meanings for number words before they begin to learn that classifiers denote units of counting (Barner, Libenson, et al., 2009; Li, Huang, & Hsiao, 2010).

However, Sarnecka et al.'s Russian-Japanese comparison has some limitations too. First, Russian and Japanese number word forms vary for different reasons. The former vary because they are marked for case and gender (Bailyn, 2014), whereas the latter vary because they adapt their phonological form to the classifier that follows them, and because Japanese has two count lists. As Sarnecka et al. acknowledge, it is hard to tell whether these different types of variability have the same effect on number word learning. Second, the transcripts used by Sarnecka et al. to compare the frequency of number words in English, Russian, and Japanese child-directed speech were not matched for context or for the socio-economic status of the caregivers. Given that caregivers' number word usage has been shown to correlate with their SES (Gunderson & Levine, 2011) and that some situations can yield greater number word use than others, it remains an open question whether Russian and English learners learn the meaning of the number word for one earlier than Japanese learners because they hear number words more frequently.

1.1. The present study

Like the earlier studies contrasting English-Russian-Japanese, the present study seeks to determine whether singular/plural morphology supports the acquisition of the meaning of the number word for one by asking whether it is learned earlier in a language with obligatory singular/plural morphology than in a language without it. But the present study goes beyond the previous ones by testing whether there remains evidence in favor of this hypothesis, even when the alternative explanations mentioned above are ruled out.

We chose a cross-linguistic contrast that allows us to rule out the effects of the variability of number word forms and of the variability of the relative order of nouns and number words. That is, we compared number word learning in English to number word learning in Mandarin. Like Japanese, Mandarin is a classifier language which almost never marks the singular/plural distinction. Mandarin has a morpheme (*-men*), which, like the Japanese (*-tachi*), indicates reference to a collectivity when it is marked on animate nouns and pronouns. However, it is infrequently used relative to the English plural and children learn its meaning many months after English learning children learn the numerical meaning of singular/plural morphology (Li, Ogura, Barner, Yang, & Carey, 2009). Crucially, unlike Japanese and like English, Mandarin has only one count list, its number words always have the same form,[3] and they do not float – they occur pre-nominally only (Kobuchi-Philip, 2007). Therefore, if Japanese children's delay, relative to English learners, results from any of these differences, we would not expect Mandarin learners to be similarly delayed.

In Study 1, we test whether Mandarin learners learn the meaning of the number word for one later than English learners with a large sample of two- to- four-year-olds (133 for each language), matched closely in age. Unlike previous studies, for a little over half of our total sample, we included a rough measure of the socio-economic status of the children's parents. Also, unlike the previous experiments exploring the Japanese-English contrast, we establish whether the delay in children learning a classifier language with no nominal or verbal singular/plural distinction, relative to learning English, is found *only* in the acquisition of the numerical meaning for the meaning for one, as predicted by the morphological bootstrapping hypothesis.

In Study 2, we analyze CHILDES transcripts of conversations between monolingual Mandarin and English learners and their parents to address the remainder of the alternatives considered above. Specifically, we estimate whether the following are more frequent in English than in Mandarin: overall number words uses, uses to refer to a cardinality (as opposed to other uses such as "number three bus") and uses with an overt noun. We also test an alternative explanation that has not been considered before, namely whether number word learning is easier in English than in Mandarin because English-speaking caregivers tend to use number words with nouns that denote individuals that are

[3] The only variability in Mandarin number word forms involves the Mandarin number word for two, which differs in form when used in the count list and when used as number word with a classifier in noun phrases ("èr" vs. "liǎng" respectively.) This difference is irrelevant to our purposes, since our question concerns the acquisition of the number word for one, not two. Furthermore, it does not constitute an exception to the generalization that number words retain the same form when bound to different classifiers in Mandarin.

not likely to be conceived as units of counting by young children (e.g., collections like "team"; see Shipley & Shepperson, 1990) less frequently than Mandarin-speaking caregivers. Importantly, unlike the CHILDES analyses reported in Sarnecka et al. (2007) and Barner, Libenson, et al. (2009), the English and Mandarin transcripts that were used for our analyses were matched for the context of the interaction of the dyads, and for the socioeconomic status of the caregivers.

2. Study 1: Comparison of English and Mandarin learners

2.1. Methods

2.1.1. Participants

Study 1 was conducted in two phases. Participants in Phase 1 were 63 American children from the New York City and Greater Boston metropolitan areas and 64 Chinese children from Shanghai and Beijing, China, and from Taipei, Taiwan. Children were aged between 30 and 44 months, with mean ages of 37.1 and 38.2 months, respectively.[4] Participants in Phase 2 were 70 American children from Los Angeles and 69 Chinese children from Taipei, aged between 24 and 44 months, with mean ages 34 and 34.1 months, respectively. All parents of the Phase 2 participants were invited to complete a questionnaire about their level of education, about their child's linguistic input, and about their child's gross linguistic and cognitive development. Data from this questionnaire showed that one Mandarin-speaking child and one English-speaking child had been diagnosed with a language delay. These children were not included in our sample.

The ages of the children in the two language groups were carefully equated. In Phase 1, the number of children in each three-month interval of the age range (30–32, 33–35, 36–38, 39–41, and 42–44) varied between 11 and 14 and was always the same for both language groups, with the exception of 33–35-month-olds where there were 12 American and 13 Chinese children. In Phase 2, there were ten children in each three-month interval of the age range (24–26, 27–29, 30–32, 33–35, 36–38, 39–41, and 42–44) for each language group, with the exception of 24–26-month olds where there were 10 American and 9 Chinese children.

All of the following were true in both phases. Roughly half of the children were boys. American children were monolingual in English and Chinese children in Mandarin, or used English or Mandarin as their dominant language. American children were tested either at a university child development laboratory or at local day care centers or nursery schools. The majority of the American children were from middle-class backgrounds, and most were non-Hispanic Caucasian children and a small number were Asian American, African American, and Hispanic American children. Chinese children were all ethnically Chinese and were living in China or Taiwan. They were either tested in their home or in daycares/preschools that were affiliated with universities or that served primarily middle-class communities. Teachers at all Chinese daycares interacted exclusively in Mandarin with their children; teachers at all American daycares interacted exclusively in English with their children.

2.1.2. Stimuli and procedure

Translation of Phase 1 and Phase 2 tasks and materials from English to Mandarin. The written materials (recruitment letters, parent consent forms, SES questionnaires) and the task protocols used in Phase 1 and 2 were translated to Mandarin Chinese by two of the authors (P.L., and G.X for Phase 1 and B.H. and P.L. for Phase 2). All translators were native speakers of Mandarin, and fluent English speakers. The materials were checked for accuracy and comparability by native speakers of the target languages and by another bilingual speaker.

2.1.2.1. Phase 1. Count list elicitation. To ensure that all participants knew the *form* of each of the number words used in the assessments of number word understanding, all children were asked to count a

[4] Data collected for 50 of the Phase 1 American children were previously reported in Le Corre et al. (2006) and in Le Corre and Carey (2007). All data from the Chinese children, all Phase 2 data, and data from 13 Phase 1 American participants are reported for the first time.

row of ten identical toys.[5] When children were reluctant to count, they were encouraged to do so by the experimenter. For example, when children who were asked to count a row did not start counting on their own, the experimenter pointed to the leftmost toy in the row, said the number word for one and then pointed to the next toy.

Give-N (GN). This task assessed the highest number word whose meaning each child knew. Children were asked to create sets of one to six small toys out of a pile of twelve to fifteen. In the Mandarin version of the task, all of the toys used as stimuli were denoted by Mandarin nouns that combined with the classifier that children were most likely to understand, namely the generic classifier "ge." In a staircase procedure, the first number requested was one and the highest was six. Whenever children gave a number correctly, the experimenter asked for the next higher number, stopping when she reached a number that children could not give correctly at least twice out of a maximum of three trials.

On trials where two or more toys were requested, children were always asked to check whether they had given the correct number of toys by counting the set they had given, unless they had already counted the toys as they gave them to the experimenter. If children counted and the last number of their count did not match the number of toys requested, the experimenter then asked children to fix their answer by saying: "But I wanted N strawberries – can you fix it so that there are N?" Thus, trials could end in three ways: (1) Trials where children counted out the correct number of objects (allowing for one counting error) following the experimenter's first request ended when children were done giving toys; (2) Trials where children gave the correct number of objects without counting ended when they counted the objects to check their answer, and (3) Trials where children gave an incorrect number of objects ended after they responded to the experimenter's request to fix their answer.

2.1.2.2. Phase 2. Count list elicitation. As in Phase 1, we checked whether children knew the forms of the number words for one through ten. Children were asked to count out loud until they reached "ten". If they stopped counting before they reached ten, the experimenter asked "What comes after N" (where N was the last number word the child had said). If the child did not continue counting with the first prompt, the experimenter then repeated the last three number words produced by the child, ending her count with a rising, expecting tone (e.g., in English, "five, six, seven...?"). If the child still did not continue counting, his or her count list was deemed to end at the last number word he or she had said.

Give-N (GN). The protocol for Give-N in Phase 2 was the same as in Phase 1, with one exception: the experimenter first named the toys in the pile – e.g., "Here are some strawberries" – and then never used the noun when requesting numbers – e.g., "Can you give me one/two?" Thus, the English-speaking American children in the Phase 2 version could not use the singular/plural distinction as an additional cue to distinguish requests for one toy from requests for more than one. Rather, they had to rely exclusively on their knowledge of individual number word meanings.

Point-to-N. Phase 2 included a second assessment of children's knowledge of number word meanings. It involved presenting children with two 22 × 28 cm cardboard cards each showing a set of objects, and asking them to point to one of the two sets.

Two warm-up trials involved a single object on each card, the objects differing in size or in color. Children were asked to indicate which picture depicted a small (or large) orange and which picture depicted a red (or blue) shoe. To be included in the analyses of the Point-to-N task, children had to succeed on at least one of the two warm-up trials. Only one child (a 34-month-old American) failed to meet this criterion.

On test trials, children saw two sets of objects, one displayed on each card. Children were asked to identify which of the two sets had a given cardinal value. Both in Mandarin and in English, the noun denoting the objects was always dropped and the generic classifier "ge" was used (e.g. Experimenter: "Can you point to the side with two?"; 你指給我看哪邊有兩個? nǐ zhǐ gěi wǒ kàn nǎ biān yǒu liǎng ge?).

Knowledge of the meaning of the number words for one, two, and three was tested on three trials for each number word. On one trial, the target set contained the number of objects denoted by the number word, and the distractor set contained one more object (e.g., for "one", target = 1,

[5] Due to a technical error, the counting data for 28 of the Chinese children who were asked to count a row of objects were lost.

distractor = 2). On the other two trials, the distractor set contained two more objects than the target set (e.g., for "one," target = 1, distractor = 3).[6] The correct answer was on the left side of the card on about half of the trials. Three different kinds of items were chosen, one for each of the numerical targets tested (one = cake, two = ball, three = balloon). These items were selected because the Mandarin noun denoting them is associated with the generic classifier "ge." Trials were presented to all children in the same randomized order. All experimental sessions were videotaped.

Demographics questionnaire. A questionnaire was distributed to the parents of all the children who participated in Phase 2. It asked them to report the highest level of education they had completed. It also asked them to report (1) their child's primary language; (2) whether their child was exposed to languages other than the primary one; (3) whether their child produced two-word sentences; and (4) whether their child had been diagnosed with any developmental-behavioral condition (e.g., developmental delays, mental retardation, autism).

2.2. Results

2.2.1. Knowledge of number word meanings (from Give-N; Phases 1 and 2 combined)

Following Wynn (1990, 1992; see also Barner, Chow, et al., 2009; Le Corre et al., 2006, Lee & Sarnecka, 2011; Sarnecka et al., 2007), we first established the number word "knower level" of each child. To be considered to know the meaning of a number word "N", children had to:

(1) Give N objects on at least two out of a maximum of three trials when asked for "N" objects.
(2) Give N objects no more than half as often when asked for a different number.
(3) Satisfy conditions 1 and 2 for all numbers less than N.[7]

Children were deemed to have learned the cardinal principle – i.e., that the last number word of a correct count denotes the number of objects in the counted set – if they met the above criteria for all number words up to the number word for six. It has been shown that two- to four-year-olds show essentially the same knowledge of number word meanings when their knowledge is assessed with other tasks that make different processing demands (Le Corre et al., 2006; Wynn, 1992). Therefore, the criteria used here are a valid measure of knowledge of number word meanings.

Both Mandarin-learning children and English-learning children fell into the same number word knower levels. Some had not learned the meaning of any number word, some had learned the meaning of the number word for one only (a.k.a. "one-knowers"), for one and two only ("two-knowers"), for one, two and three only ("three-knowers"), for one, two, three, and four only ("four-knowers"), and some had learned the cardinal principle ("CP-knowers"). All children who met the criteria for the number word for five also met them for the number word for six. Thus, despite the fact that Mandarin and English are very different languages, learners of both languages learn number word meanings in the same sequence. Indeed, this is so for all languages yet studied (Almoammer et al., 2013; Barner, Libenson, et al., 2009; Piantadosi, Jara-Ettinger, & Gibson, 2014; Sarnecka et al., 2007; Villarroel, Miñón, & Nuño, 2011).

2.2.2. Testing whether Mandarin learners learn the meaning of the number word for one later than English learners

The logic of this analysis follows from three facts. First, much evidence suggests that children learn the meaning of the number words for one to four in increasing order, and then learn the cardinal principle; no child learns the meaning of a number word that denotes $n + 1$ before they learn the meaning of the number word that denotes n (e.g., Wynn, 1992), and no child learns the cardinal principle before they learn the meanings of the words for one to four. The fact that Mandarin-learners

[6] The task also included trials with targets = 4, 5, and 6. However, only a subset of the children were tested on these trials (English-learning, $N = 30$; Mandarin-learning, $N = 28$). Therefore, these trials are not included in the analyses.

[7] Six of the 133 Chinese children met criteria 1 and 2 for number words beyond their knower-level. Two failed on the word for one but succeeded on the one for two, one succeeded on the number word for one and on the one for three, one succeeded on the number words for one, two and four, and two succeeded on the number words for one, two, and five.

were categorized in the same knower-levels as the English-learners suggests that they too learn number word meanings in this sequence. Second, the children in the Mandarin group were of the same age as the children in English group; specifically, for every child in each three-month subdivision of the full age range of the Mandarin group there was a child in the same three-month subdivision in the English group. Third, the age ranges of both language groups extended early enough to include children who still had not begun to learn number words (i.e., non-knowers). Therefore, if the prediction of the morphological bootstrapping hypothesis is correct – i.e., if Mandarin learners learn the meaning of the number word for one later than English learners – the proportion of non-knowers should be greater in the Mandarin-learning group than in the English-learning group. Consequently, the proportion of children who are at least at the one-knower stage should be smaller in the Mandarin-group.

Both predictions of the morphological bootstrapping hypothesis are confirmed by the data. That is, the proportion of children who had not learned the meaning of any number word ("non-knowers") was significantly *greater* amongst Mandarin learners than amongst English learners (29% vs. 11%, respectively), $\chi^2(1) = 12.6$, $p < .001$ (see Fig. 1). Consequently, the proportion of children who had at least reached the one-knower stage was significantly *smaller* amongst Mandarin learners than amongst English learners, (71% vs. 89%), $\chi^2(1) = 12.6$, $p < .001$. We also found that significantly fewer Mandarin learners had at least reached the two-knower stage (47% vs. 71%), $\chi^2(1) = 14.9$, $p < .001$, the three-knower stage (26% vs. 46%), $\chi^2(1) = 11.9$, $p < .001$, and the four-knower stage, (13% vs. 23%), $\chi^2(1) = 4.4$, $p < .05$. Finally, we found that the proportion of children who had reached the CP-knower stage was marginally smaller amongst Mandarin learners (8% vs. 17%), $\chi^2(1) = 3.5$, $p = .06$.

Estimating the extent of the delay. To estimate the extent of Chinese children's delay, we plotted the percentage of children who had at least reached the one-knower stage, the two-knower stage, the three-knower stage, and the CP-knower stage in each of our six age groups: 24–29 months; 30–32 months; 33–35 months, 36–38 months; 39–41 months; and 42–44 months (see Fig. 2). Then, for each stage, we determined the youngest age group where 55–65% of the children had reached it. The dotted line in Fig. 2 indicates the midpoint between 55% and 65% – i.e., 60%. As can be seen from Fig. 2, there was no age group at which at least 55% of the children had reached the CP-knower stage in either of the language groups. Therefore, we set a criterion of 25–35% to compare the ages at which children in each language group become CP-knowers. The dotted line on the graph for CP-knowers indicates the midpoint between 25% and 35% – i.e., 30%. The age groups at which Mandarin and English learners reach the 55–65% mark for each number word (and the 25–35% mark for the cardinal principle) are reported in Table 1. If the 55–65% mark fell between two age groups, then we reported the age where a language group reached this mark as being between the mid-point of one age group and the mid-point of the next one.

Fig. 2 and Table 1 suggest that, on average, Mandarin learners learn the meaning of the number word for one some six months later than English learners, and that they also learn the meaning of the number word for two some six months later. The Mandarin delays in the acquisition of the meaning of the number word for three, and of the cardinal principle are somewhat shorter, namely between three and six months, and three months respectively.

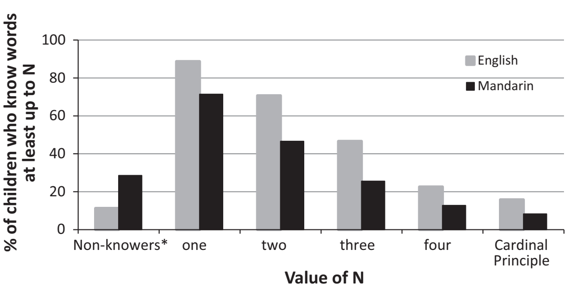

Fig. 1. Percentages of English and Mandarin two- to four year-old learners who knew the meaning of the number words for numbers at least up to one, two, three, four and the cardinal principle as per Give-N. *: The proportion of non-knowers includes non-knowers *only*.

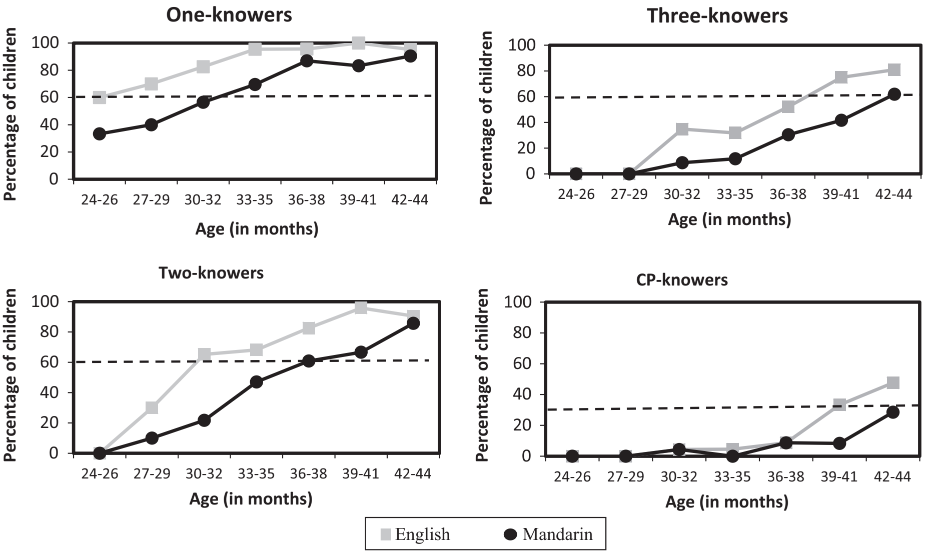

Fig. 2. Percentage of children in each language group who had at least reached the one-knower stage (top left), the two-knower stage (bottom left), the three-knower stage (top right) or who had learned the cardinal principle (bottom right) as a function of age (in months) as per Give-N.

Table 1
Age group (in months) where 55–65% of Mandarin and English learners have at least reached the one-knower stage, the two-knower stage, or the three-knower stage and age group where 25–35% had learned the cardinal principle.

Stage	Age group when criterion is met (in months)	
	Mandarin	English
One-knower	30–32	24–26
Two-knower	36–38	30–32
Three-knower	42–44	Between 36–38 and 39–41
Cardinal principle	42–44	39–41

Was the delay specific to the acquisition of the meaning of the number word for one? If the only difference between Mandarin and English number word learning is that the latter is supported by singular/plural morphology, then the Mandarin number word learning delay should be specific to the acquisition of the meaning of the number word for one. The results just described indicate that Mandarin learners reach *each* stage of the number word learning sequence later than English learners. However, this need not mean that every number word is harder to learn in Mandarin than in English. Rather, it may be that the Mandarin number word learning sequence *starts* later than the English one, but that, once they have started learning number word meanings, Mandarin learners move from one stage to the next at the same rate as English learners. It is this latter pattern that we see in Fig. 2 and Table 1. Mandarin and English learners both make the transition from knowing the meaning of the number word for one to knowing the meaning of the number words for one and two in about six months. The transition from the two-knower stage to the three-knower stage also takes about six months in both languages. However, Table 1 suggests that Mandarin learners go through the entire sequence – from knowing the meaning of the number word for one to knowing the cardinal principle – a little faster than English learners; i.e., the former take about 12 months whereas the latter take about 15. That the Mandarin delay is specific to learning the meaning of the number word for one is also suggested by the fact that the word learning curves in Fig. 2 have very similar slopes for Mandarin and English learners.

In sum, we find that, while Mandarin learners learn the meaning of the number word for one later than English learners, they then proceed through the rest of the sequence as fast as and perhaps even faster than English learners, exactly as predicted by the hypothesis that the only difference between English and Mandarin number word learning is that the former benefits from the numerical information conveyed by singular/plural morphology.

2.2.3. Testing alternative explanations of the delay

Did Chinese and American children count equally high? Chinese children may learn the meanings of number words later than American children because they encode the *forms* (as opposed to the meanings) of the words later, or because they engage in counting activities less often.

To explore these alternatives, we identified the highest number word each child counted to correctly in any of the tasks he or she participated in, including the counting elicitation task. Counts were counted as correct if they included no more than one sequence error (i.e., saying one number word out of order). For example, a child whose longest count was "one, two, three, four, six" would be said to be able to count to up to "six" because she only made one sequence error in counting to that number. The results of this analysis are reported in Fig. 3. We find no evidence that English learners count higher than Mandarin learners (and vice-versa). At every three-month age group, the mean highest number word counted to for English learners was not significantly different (with α corrected to 0.007 for multiple comparisons) from the mean highest number word counted to for Mandarin learners (all t's < 2.1, all p's > .06). More generally, on average, Mandarin (mean count list length = 10.1; range 3–20) and English (mean count list length = 9.8; range 5–18) learners counted equally high.[8] Moreover, aside from a few rare exceptions, all children in our sample could recite their languages count list at least up to six, the highest number probed in Give-N (94% of Mandarin and 98% of English learners, $p = 0.1$). Therefore, evidence that Chinese children start learning number word meanings later than American children cannot be attributed to their having weaker counting skills or to their knowing fewer of the forms of the number words that were used in our tasks.

Did the Chinese children learn the meaning of the number word for one later than the American children because their parents were less educated? In Phase 2, the parents of 52 of the American children (74.3%), and of 51 of the Chinese children (73.9%) completed the questionnaire. All parents reported that their child was part of a two-parent family where at least one parent had obtained at least a college degree. Thus, the educational levels of the parents of the Phase 2 children were highly comparable. The delay in learning the meaning of the number word for one also held for the Phase 2 sample alone (proportion of children who had at least reached the one-knower stage: Mandarin-learners = 68% (46/69); English-learners = 86% (60/70), $\chi^2(1) = 5.95$, $p < .05$).[9] This suggests that differences in the level of education of children's parents are not sufficient to explain the Mandarin-learners' delay in learning the meaning of the word for one.[10]

[8] All participants were given an opportunity to count up to 10 at least once, but most of them were *not* given an opportunity to count beyond 10. For example, when phase 2 children were asked to count out loud, they were stopped when they reached the word for 10. Therefore, the children who were given an opportunity to count higher than 10 and did count higher than 10 were coded as counting up to 10 to make sure that differences in counting tasks across children did not skew the results. Twelve American children (mean age = 37 months; mean highest count = 12.3) and thirteen Chinese children (mean age = 38.25 months; mean highest count = 17) counted beyond 10. The fact that the mean highest count for children who counted beyond 10 was higher for Chinese than for American children suggests that, had we let all children count as high as they could, Chinese children would have shown greater counting skill than American children. This is consistent with what has been reported elsewhere (Miller, Smith, Zhu, & Zhang, 1995). Crucially, it further strengthens the point that it is not the case that Mandarin learners learned the number word for one later than English learners because they had weaker counting skills.

[9] There were also fewer Mandarin learners who had reached the two-knower stage (39% vs. 59%, $\chi^2(1) = 4.5$, $p < .05$) and the three-knower stage (26% vs. 39%, $\chi^2(1) = 1.9$, $p = .16$), but the latter difference was not statistically significant, possibly due to lack of power.

[10] We repeated the same analysis but only including the Phase 2 children whose parents completed a questionnaire. We obtained the same pattern of results – i.e., fewer Mandarin learners had at least reached the one-knower stage (63% vs. 86%), the two-knower stage (45% vs. 60%), and the three-knower stage or more (29% vs. 44%). Crucially, we still found that the difference in the proportions of children who had at least reached the one-knower stage was significant, $\chi^2(1) = 6.51$, $p < .05$. The other two differences were not significant (both p's > .18), possibly due to a lack of power.

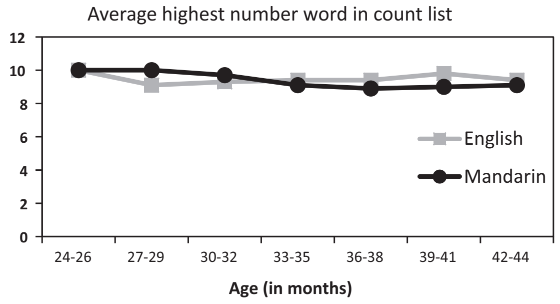

Fig. 3. Average highest number word counted to (max = 10, but see footnote 8) by English and Mandarin learners as a function of age.

Did the Chinese children learn the meaning of the number word for one later than the American children because non-target languages made up a larger proportion of their input? All Chinese parents who completed the Phase 2 questionnaire reported that Mandarin was their child's primary language. Likewise, all American parents who completed the questionnaire reported that English was their child's primary language. Moreover, the teachers at all Chinese daycares interacted exclusively in Mandarin with their children, and the teachers at all American daycares interacted exclusively in English with their children.

However, of those who completed the questionnaire, more Chinese parents (31/51 or 61%) than American parents (25/52 or 48%) reported that their child was exposed to another dialect of their first language or to another language altogether at the time of the study.[11] To explore whether exposure to another language slows down the acquisition of number word meanings, we created a subset of the Phase 2 data that formed two language groups that contained similar proportions of children who essentially never exposed to a non-target language. We included only those children whose parents reported that they were exposed to another language no more than a few days per week, and those children who were not exposed to any other language. Within this subset of the data, the proportion of Mandarin learners who had some exposure to another language (33% or 11/33) was somewhat lower than the corresponding proportion of English learners (41% or 16/39). The two subgroups were also matched for age (English learners: mean age = 34.2; months; range 25–43; Mandarin learners: mean age = 35.4 months; range 25–43).

This subset of the data closely matched the data from the full set of Give-N data reported above. Sixty-seven percent (22/33) of the Mandarin learners in the subset of the data had at least reached the one-knower stage, whereas 85% (33/39) of the English learners had done so. This difference was not statistically significant, $\chi^2(1) = 2.27$, $p = .13$., but the proportions are virtually identical to the whole sample (whole sample: Mandarin = 71%; English = 89%, an 18% difference in both cases). This suggests that the difference observed in the subset of the data was not significant because of a lack of power. We conclude that Mandarin learners did not start learning number words later than English learners because they were exposed to other languages more frequently.

Was English learners' performance on Give-N inflated by their knowledge of the numerical distinction between singular and plural morphology? The experimenter's requests in the English version of Phase 1's Give-N included nouns marked for number. Therefore, English learners could have correctly differentiated requests for one toy from requests for greater numbers of toys without having to know the meaning of any number word. Instead, they could have succeeded by drawing solely on

[11] The languages or dialects that the Chinese children were exposed to included Taiwanese, Hakka (both Chinese languages), and English. Those that the American children were exposed to included Spanish, Cantonese, French, Japanese, Korean, Hungarian, Vietnamese and Hindi. More specifically, of the Chinese children, 20 (39.2%) were exposed to a language other than Mandarin for one to four hours every day, 7 (13.7%) for one to three days a week, and 4 for a few times a month (7.8%). As for the American children, 10 (19.2%) were exposed to a language other than English for one to two hours a day, 12 (23%) for one to two days a week, and 2 (3.8%) for a few times a month.

knowledge of the meaning of numerical morphology. If so, more English learners would have distinguished requests for one toy from requests for more than one toy in Phase 1 (where the requests included nouns marked for singular/plural) than in Phase 2 version (where the requests did not include nouns, and therefore did not include singular/plural marking). Matching the participants of the two phases for age (including only children who were 30 months of age or older because Phase 1 did not include any include any children under 30 months), the proportion of children who distinguished requests for one from requests for greater numbers was equal (94%) in both conditions. Confirming Sarnecka et al.'s (2006) conclusion, this suggests that English learners succeeded on requests for one toy because they had learned the meaning of the number word "one," not because they were merely responding on the basis of their knowledge of the numerical meaning of the singular-plural distinction.

Was the Chinese delay caused by factors that are specific to the Give-N task? Evidence that English learners performed better than the Mandarin learners on tasks other than the Give-N task would confirm that the difference between the two groups was genuinely due to their knowledge of number word meanings, rather than to task-specific factors. To test this, we asked whether the children's performance on Wynn's (1992) Point-to-N task (included in Phase 2 only) converged with their performance on the Give-N task. Convergence across the tasks requires children's knower-level to be the same on Give-N and on Point-to-N – that is, children who know "n" as per Give-N should correctly identify the referent of "n" on Point-to-N but fail to identify the referents of number words that refer to numbers greater than n. The two tasks converged perfectly (see Fig. 4). In both language groups, children correctly identified a target number only if it was within their Give-N knower-level. Non-knowers did not identify any target correctly; i.e., they did not perform significantly above chance on any target (p's $\geqslant .17$).[12] One-knowers correctly identified one (both t's > 3, both p's < .005), and they did not perform above chance on 2 and 3: two-knowers correctly identified one and two (all t's > 2.5, all p's < .02), and they did not perform above chance on 3. Finally, the three- and four-knowers correctly identified one, two, and three (all t's > 3.5, all p's < .01).[13] These data extend Wynn's (1990, 1992) finding that number-word knowledge as indicated by Give-N predicts number word understanding on tasks that make very different processing demands (see also Le Corre & Carey, 2007) to Mandarin-learners.

To test the prediction that the Mandarin delay should also be observed on Point-to-N, we obtained the average number of correct answers on the Point-to-N task for each of the seven age groups that were used in our analyses of Give-N. Then, for each language group, we determined the youngest age group where (1) children were more accurate than predicted by chance; and (2) all older groups also were significantly more accurate than predicted by chance. Comparisons to chance were carried out with one-tailed, one sample t-tests, with $\alpha = 0.05$.[14]

Table 2 shows that the results of the Point-to-N task paint the same picture as the results of the Give-N task. They provide evidence that Mandarin learners reach each step in the number word learning sequence three (for the one- and three-knower stages) to six months (for the two-knower stage) later than English learners. Moreover, they also confirm that, although Mandarin learners started learning number words later than their English learners, both groups went through the sequence at the same rate: both took about twelve months to go from the one-knower stage to the three-knower stage.

2.3. Discussion

Study 1 yielded four important results. First, the sequence of number word acquisition in Mandarin is the same as that observed in all languages studied thus far – i.e., Mandarin-learners first learn the meaning of the number words for one, two, three and sometimes four one at a time, in that order, and

[12] Since we were only interested in testing whether children performed significantly *above* chance, we only carried out t-tests for targets where the mean number of correct answers was greater than 1.5/3. Thus, we only report p-values for these targets.

[13] In both language groups, three- and four-knowers were combined because the four-knowers were too few (less than 5) to be treated as a single group.

[14] We did not correct alpha level for multiple comparisons because we required that all age groups above the youngest one where children performed significantly above chance also be above chance.

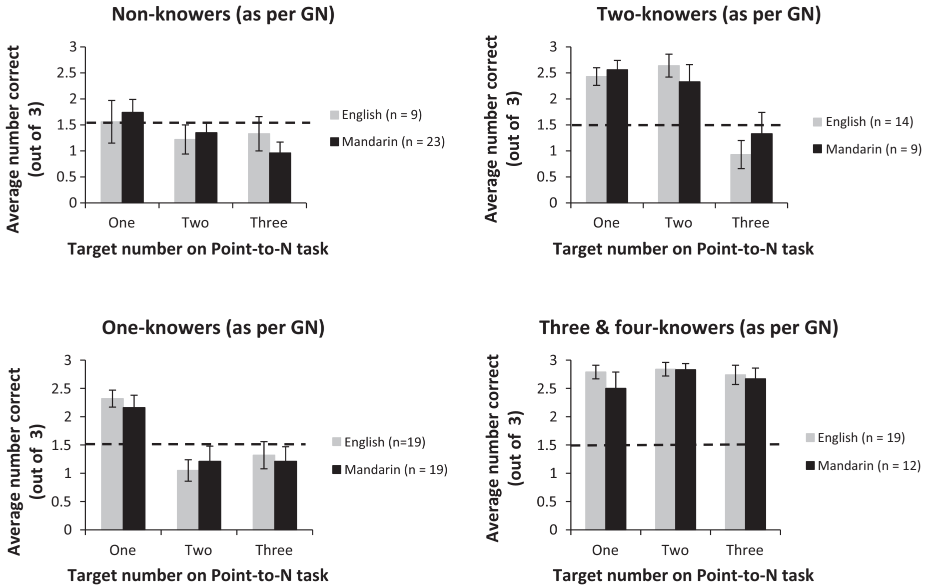

Fig. 4. Performance on Point-to-N task as a function of knowledge of number word meanings according to Give-N. Error bars represent the standard error of the mean. The dashed line indicates the level of performance expected by chance (1.5/3).

Table 2
Youngest age (in months) of knowledge of meaning of number words for one, two and three respectively on the Point-to-N task.

Number word	Youngest age (in months)	
	Mandarin	English
For one	31	28
For two	37	31
For three	43	40

then learn the cardinal principle. Whatever differences between Mandarin and English account for the Mandarin-learners' delay in learning the meaning of the number word for one do not change the sequence of acquisition of number word meanings.

Second, Mandarin-learning children learn the meaning of the number word for one some three to six months later than English-learning children. This finding converges with previous evidence from comparisons of number word learning in English to Japanese (Barner, Libenson, et al., 2009; Sarnecka et al., 2007). Importantly, two of the factors that might have accounted for the delay in Japanese children, namely, the presence of numeral floating and the greater variability in number word forms, are not present in Mandarin. It thus follows that these alternative factors cannot explain the present result, and that they are probably not sufficient to explain the Japanese delay either.

Third, we found that although Mandarin learners learn the meaning of the number word for one later than English learners, they proceed through the rest of the sequence at the same rate as English learners. In other words, the Mandarin number word learning delay is specific to the number word for one. These results are as predicted by the morphological bootstrapping hypothesis.

Fourth, Phase 2 of Study 1 goes beyond previous work in showing that the evidence that children learning a language with obligatory singular/plural marking learn the meaning of the number word for one earlier than children learning a language with little numerical morphology is not due to details of the task used to assess number word knowledge, and is not due to differences in the SES of the children's parents.

The findings of Study 1 provide evidence for the morphological bootstrapping hypothesis. However, other interpretations of later learning of the meaning of the word for one by Mandarin learners remain open. It may be that English learners hear number words more frequently. Moreover, like Japanese and unlike English, Mandarin is an argument-dropping language – i.e., speakers can drop the subject and/or the object of a sentence even if they were not mentioned in previous discourse. Thus, as Barner, Libenson, et al. (2009) suggested for Japanese, it may be that number words are harder to learn in Mandarin than in English because Mandarin learners are more likely to hear number words without the noun they modify, and thus may have a harder time identifying what is being counted.

Two previous studies suggest that these factors probably do not explain the Mandarin delay observed here. Chang and Sandhofer (2009) and Chang, Sandhofer, Adelchanow, and Rottman (2011) reported that number words (occurring with or without an overt noun) are *more* frequent in Mandarin than in English child-directed speech. Nonetheless, these studies have some limitations. Chang and Sandhofer (2009) analyzed transcripts of conversations between bilingual Mandarin-English parents and their child reading the same picture book to their child once in Mandarin and once in English. The parents were native Mandarin speakers. Thus, they might have used more number words in Mandarin because they were more fluent in that language Chang et al. (2011) analyzed everyday conversations between monolingual English-speaking children and adults and between monolingual Mandarin-speaking children and adults, but did not match the contexts of the conversations they analyzed. Study 2 improves upon the studies by Chang and colleagues by analyzing the frequency of number words (with and without nouns) in caregiver-child conversations that are matched for both caregivers' fluency and for context. Our analysis also explicitly matches caregivers' socioeconomic status.

3. Study 2: CHILDES analyses

3.1. Methods

3.1.1. Participants

We analyzed the utterances produced by the parents in the conversations of the 52 parent-child dyads of the CHILDES New England corpus (Ninio, Snow, Pan, & Rollins, 1994) and in the conversations of the 46 parent-child dyads of the Zhou corpus (MacWhinney, 2000; Zhou & Zhang, 2008). The ages of the children in the dyads ranged from 14 to 32 months, covering the period that extends from the very beginning of language learning to the age when children begin to learn the meanings of number words. The Zhou study followed the design of the New England study, with the exception that the Zhou corpus was cross-sectional and the New England corpus was longitudinal, with children sampled three times, at 14 months, 20 months, and again between 27 and 32 months. To match the New England corpus, the Zhou corpus included a sample of 14 month-olds ($n = 11$), a sample of 20 month-olds ($n = 16$), and a sample of 26 ($n = 11$) and 32 month-olds ($n = 11$). The parents in both corpora were from lower-middle to upper-middle class backgrounds, and all dyads were instructed to engage in free play with similar sets of toys. All interactions lasted approximately twenty minutes.[15]

3.2. Results

English-speaking parents provided 1.7 times more utterances per transcript. Due to the fact that the New England study was longitudinal with multiple recorded sessions per child, that it included more dyads, and more talkative parents, there were many more parental utterances in the New England corpus (45,335 vs. 8534). The average MLU of child-directed speech for English and Mandarin corpora, respectively 3.8 and 4.1, were comparable as confirmed by an ANCOVA comparing Mandarin and English parental MLU, with age of children in months as covariate ($F(1,184) = 1.64$, $p = .20$).

[15] Chang et al.'s (2011) study drew upon some entries of the Zhou corpus, so there was overlap between our choice of Chinese transcripts and theirs. However, there was no overlap between our American transcripts and theirs.

3.2.1. Overall frequency of number words in parental input

Most of the parents (86% of the American parents; 90% of the Chinese parents) used number words for one through nine to refer to the number of things in a set at least once during the course of these 20 min conversations. Following Barner, Libenson, et al. (2009), we calculated frequency as the number of occurrences of each target word per 1000 utterances of parents over all transcripts for each child-parent dyad. Then, we averaged this number over all dyads in each language; i.e., over 52 dyads for English, and over 46 for Mandarin. Fig. 5 presents the average frequency for each word form in parental speech in the two languages.

Replicating Chang et al., Mandarin-speaking parents used number words significantly more often than English-speaking parents—roughly three times more for the number word for one (Mandarin: 70 uses per 1000 utterances; English: 25 uses per 1000 utterances, $t(185) = 10.694$, $p < .001$) and five times more often for the number word for two through nine (24 vs 5 uses per 1000 utterances, respectively, $t(1,185) = 52.6$, $p < .001$).[16] Averaging over all nine number words, we found that this difference held in each of our three age groups (14-months: 81 vs. 21 per 1000 utterances; $t(61) = 9.06$, $p < .001$; 20 months: 65 vs. 29 per 1000 utterances, $t(62) = 3.44$, $p < .001$; 27–32 months[17]: 114 vs. 44 per 1000 utterances, $t(57) = 8.45$, $p < .001$).

3.2.2. Uses in cardinal contexts

Because some uses of number words are more helpful than others for identifying their meanings, the remaining analyses concern how Mandarin- and English-speaking parents use number words in conversation with their young children. We first tested whether Mandarin parents use number words to denote a cardinal number (henceforth, ‘‘cardinal uses”) less frequently than English parents. Clear examples of cardinal uses were number words followed by an overt noun such as ‘‘three ducks” in English and ‘‘三個小碗” (sān gè xiǎo wǎn /three CL_{indiv} small bowls, ‘three small bowls’) in Mandarin. Many uses of number words without an overt noun were also counted as cardinal uses. Examples from our transcripts include the English ‘‘you have four” in reference to four crayons and the Mandarin ‘‘有四個” (yǒu sì gè/exist four $CL_{individual}$; ‘there are four’) in reference to four toy blocks.[18] Examples of non-cardinal uses are reference to an Arabic digit (‘‘this is an eight,” while pointing to the number ‘‘8”) and reference to dates (‘‘八月一號,” eight-month-one-number, ‘August first.’).

Also counted as non-cardinal were the Mandarin uses of the number word forms that denote cardinalities to denote ordinals by combining them with the prefix ‘‘$di_{ordinal}$” (e.g., 第二天, $di_{ordinal}$-two-day, ‘second day’). Finally, number words are also used in counting routines or rhythm chants (e.g., ‘‘one, two, three, four”; ‘‘one-two-one-two”). In cases such as ‘‘one, two, three, four ducks”, ‘‘four ducks” was counted as a cardinal use of a number word (because the last word of a count denotes the cardinality of the counted set), whereas ‘‘one,” ‘‘two” and ‘‘three” were not.

All utterances containing one or more number words were singled out from the transcripts, and a single Mandarin-English bilingual coder examined each number word one by one and judged whether it could have been used to refer to a cardinal value. Virtually all number words in the transcripts were used in cardinal contexts (Mandarin: 95%; English: 97%). Cardinal uses of the number word for one were almost two times more frequent in Mandarin (41.97/1000 utterances) than in English (24.01/1000 utterances) child-directed speech, $t(185) = 5.20$, $p < .01$ (see Table 3). The difference is

[16] Frequencies were also tabulated by number of uses per transcript, accounting for the possibility that English-speaking children, with more talkative parents, were exposed to more language than Mandarin-speaking children in the same duration. Although the overall magnitude of the difference between the two languages was sometimes smaller in the analyses by transcript, the results of these analyses converged with the results of the analyses of frequency per thousand utterances.

[17] The Mandarin mean for this age group was obtained by combining the group of 26 month-olds with the group of 32 month-olds.

[18] On some analyses, some uses of ‘‘one” without an overt noun in English are taken to be pronouns rather than nominal ellipsis (e.g., ‘‘I'll take the orange one,” in the context of a choice between an orange and a yellow candy, Jackendoff, 1997). However, Llombart-Huesca (2002) convincingly argues that even in these uses, ‘‘one” is a number word in a nominal ellipsis. Specifically, she shows that ‘‘one” anaphora is best analyzed as ‘‘one” being inserted into the empty head of a number phrase, when NP ellipsis prevents the head from being licensed. Therefore, we took all uses of ‘‘one” without an overt noun to be instances of a number word in nominal ellipsis. The use of ‘‘one” as a generic pronoun (e.g., ‘‘One must not lie.”) is the only use that is not a number word. Such uses did not appear in our transcripts.

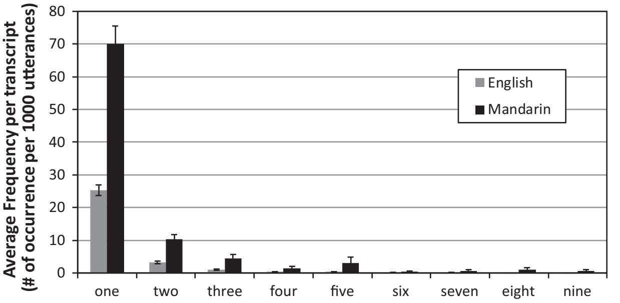

Fig. 5. Frequency of word forms for numbers between one and nine in English and Mandarin child-directed speech.

even more pronounced for the words for two through nine; cardinal uses are approximately four times more frequent in Mandarin (13.89/1000 utterances) than in English (3.56/1000 utterances), $t(185) = 6.7$, $p < .001$ (see Table 3).

Although the proportion of all uses that were non-cardinal was negligible in both languages, non-cardinal uses were more frequent overall in Mandarin than in English (number word for one: 2.43/1000 utterances vs. 0.72/1000 utterances, respectively, $t(185) = 2.88$, $p < .01$; words for two to nine: 8.66/1000 utterances vs. 1.49/1000 utterances, respectively, $t(185) = 4.82$, $p < .001$). Moreover, the bulk of the non-cardinal uses occurred in what is arguably the context that is least likely to interfere with learning the cardinal meaning of number words, namely counting routines or chants (Mandarin: 70%; English: 79%). Therefore, it seems unlikely that differences in the amount of noise created by non-cardinal uses can explain why Mandarin learners learn the meaning of the number word for one later than English learners.

However, as we searched the transcripts for non-cardinal uses of the Mandarin number word for one, we found that it is used in non-cardinal compounds: verb reduplication and various compound words. The verb reduplication (V-yi-V) construction means "to perform a little of the action denoted by the verb" (e.g., kàn yī kàn; look-one-look – have a look). The compound words include adverbials (e.g., "yíxìa" and "yīhŭir" – awhile; "yīdĭanr" – a little; "yīqĭ", "yídào", "yigòng" – (al)together), a modal ("yídìng" – must), and an adjectival ("yíyàng" – same, of one kind). Possible English compounds are the quantifiers "no one," "someone," "anyone" and "everyone."

The non-numerical structures are very frequent in the Mandarin child-directed speech in the transcripts – an average of 25.66 tokens per 1000 utterances – but are almost never used in English child-directed speech – 0.72 tokens per 1000 utterances (see Table 3). Could this explain why Mandarin learners learn the meaning of the number word for one later than English learners? While we cannot answer this question definitively, we think that it does not. The main reason is that the non-cardinal compounds and the number words have very different meanings and occur in very different sets of syntactic frames and are thereby likely treated as different words. A few studies suggest that children do not take word forms that belong to different syntactic categories as tokens of the same word or morpheme (e.g., Dautriche, Fibla, & Christophe, 2015; Dautriche, Swingley, & Christophe, 2015; Hall, Lee, & Bélanger, 2001; Katz, Baker, & Macnamara, 1974). In particular, recent studies teaching toddlers novel meanings for known words (e.g., "an eat" to refer to an animal rather than an action of eating), found that children have no difficulties learning homophones when either the meaning or the syntactic category differ (Dautriche, Fibla, et al., 2015; Dautriche, Swingley, et al., 2015). Therefore, the uses of "yi" in non-cardinal compounds are unlikely to interfere with the acquisition of the meaning of the number word "yi." We address this issue in greater detail in the general discussion.

3.2.3. Nominal ellipsis

Barner, Libenson, et al. (2009) suggested that the meaning of a number word might be easier to infer when it occurs with an overt noun. We tested whether English learners hear number words with an overt noun more frequently than Mandarin learners. As can be seen from Table 3, Mandarin

Table 3
Frequency (per thousand utterances) of cardinal and non-cardinal uses of number words and of non-cardinal compounds.

Types of uses	Number words			
	For one Frequency per 1000 utterances		For two through nine Frequency per 1000 utterances	
	Mandarin	English	Mandarin	English
Cardinal with overt noun	21.37	3.48	10.3	2.56
Cardinal with ellipsis	20.60	20.53	3.59	1.00
Total cardinal	41.97	24.01	13.89	3.56
Count routine/count chants	1.71	0.57	4.23	1.08
Ordinals	0.09	0.00	0.05	0.00
Arabic numerals	0.63	0.15	2.77	0.41
Names	0.00	0.00	1.61	0.10
Total non-cardinal	2.43	0.72	8.66	1.59
Non-cardinal compounds	25.66	0.57	–	–

children hear the number word for one, as well as the number words for two through nine, with overt nouns far more often than do English learners (Mandarin "yi": 21.37 occurrences/1000 utterances; English "one": 3.48/1000, $t(185) = 11.18$, $p < .001$; words for two through nine, Mandarin: 10.30/1000; English: 2.56/1000, $t(185) = 5.71$, $p < .001$).

We also asked whether uses of number words *without* an overt noun are more frequent in Mandarin than in English. For number words "yi"/"one" heard in cardinal contexts, nominal ellipsis is not more common in Mandarin than in English (20.6 occurrences/1000 utterances vs. 20.5/1000, $t(185) = .02$, n.s.). For number words for two through nine, nominal ellipsis is statistically more common in Mandarin than in English (3.6/1000 utterances vs. 1.0/1000, $t(185) = 3.54$, $p < .01$), but such ellipsis is relatively infrequent.

Finally, when one considers the relative proportions, cardinal uses with an overt noun actually make up a greater proportion of the cardinal uses in the Mandarin input than in the English input. Over half of Chinese parents' cardinal uses of "yi" occurred in full noun phrases with an overt noun (50.9%), whereas such uses comprised only 14.5% of American parents' cardinal uses of "one." Number words for two through nine mostly occurred with overt nouns, both in Mandarin input (74%) and English input (72%). Thus, there is no evidence that the Mandarin delay is the result of more nominal ellipsis in Mandarin parental input.[19]

3.2.4. Units of counting

To learn the cardinality denoted by number words from their use in the utterances of other speakers, children must be able to determine what counts as a unit of enumeration (hereafter, "unit.") Preschool children readily conceive of individuals that are discrete objects or discrete temporal intervals as units (e.g., dogs, jumps, claps; Brooks, Pogue, & Barner, 2011; Cheung, Barner, & Li, 2010; Giralt & Bloom, 2000; Shipley & Shepperson, 1990; Wagner & Carey, 2003). However, they find it difficult to conceive of collections (e.g., families or armies) and kinds (e.g., kinds of animals; Bloom & Kelemen,

[19] An anonymous reviewer suggested that frequent ellipsis might actually help rather than hinder number word learning because children may find it easier to learn the meaning of number words when the units of counting are established prior to their occurrence. This probably does not explain why English learners learn the meaning of the number word for one earlier than Mandarin learners. Indeed, we find that, although cardinal uses without an overt noun make up a greater proportion of all cardinal uses of the number word for one in English, English learners do not hear them significantly more frequently than Mandarin learners (see Table 3) As for number words for numbers greater than one, while they are rarely used without an overt noun in both languages, such uses are actually significantly *less* frequent in English than in Mandarin. Yet, we find that English and Mandarin learners learn the meaning of these number words at the same rate. Furthermore, Barner, Libenson, et al. (2009) report that uses without an overt noun make up 81% of the uses of the number word for one in Japanese child-directed speech. Thus, Japanese caregivers use the number word for one without a noun *more* frequently than Mandarin caregivers (who do so on 49.1% of all number word uses) and as frequently as English speaking caregivers (who do so on 85.5% of all number word uses). Yet, contrary to what should have been the case if nominal ellipsis helped number word learning, Barner, Libenson et al. find that, like Mandarin learners, Japanese learners learn the meaning of the number word for one later than English learners.

Table 4
Frequency (per thousand utterances) of use of number words with easy and with difficult units of counting.

Type of unit of counting	Number words			
	For one Frequency per 1000 utterances		For two through nine Frequency per 1000 utterances	
	Mandarin	English	Mandarin	English
Easy	19.44	3.29	7.59	2.19
Difficult	1.93	0.19	2.64	0.37

1995; Huntley-Fenner, 1995) as units. That is, when they are asked to count collections or kinds, three- and four-year-olds tend to count the discrete objects that are elements of the collections or kinds, rather than the collections or kinds themselves (Huntley-Fenner, 1995). Preschoolers also struggle to identify the units of counting denoted by attributives (e.g., "three-bedroom cottages"; Foushee, Falkou, & Li, 2015), and by units of measurement (e.g., "two cups of sand" or "two liters of milk"; Gal'perin & Georgiev, 1969; Li, Barner, & Huang, 2008; Li et al., 2010; Wang, Li, & Carey, 2013).

In order to assess whether Chinese and American parents differ in their choices of units of enumeration, every noun in a number word-noun pair was classified as denoting an easy or a difficult unit of counting. By "easy" unit of counting, we mean discrete objects or temporal intervals, and by "difficult" unit of counting, we mean collections, kinds, attributives, and units of measurement. No nouns were unclassifiable. Table 4 shows the frequency of number words combined with nouns of each type. Mandarin-learners hear number words with overt nouns that designate easy units of counting three to eight times more frequently than American English learners (for one: $t(185) = 10.21$, $p < .001$; for two through nine: $t(185) = 5.62$, $p < .001$). Furthermore, Mandarin and English child-directed input contain similar proportions of number words that modify nouns that designate easy units of counting, especially in case of the number word for one (91.0% vs. 94.5% of number word for one and 74.2% vs. 85.3% of the number words for two through nine). Differences in the frequency or proportion of number words used with easy units of counting cannot explain why Mandarin learners learn the meaning of the number word for one later than English learners.

3.3. Discussion

By extending the delay Japanese learners have to Mandarin learners in acquiring the meaning of number words, Study 1 ruled out many alternatives to morphological bootstrapping as explanations for the Japanese delay. Study 2 examined further alternative explanations, deriving from possible systematic differences in parental input that could account for the Mandarin delay. The overall lesson from Study 2 is that differences in the way Chinese and American parents use number words in speech to their children cannot explain why Mandarin learners learn the meaning of the number word for one later than English learners. Chinese parents use number words more frequently overall when talking to their children, and use them equally or more frequently to denote cardinal values, with overt nouns that denote what we called easy units of counting. Therefore, none of these features of number word input can explain the Mandarin delay. If anything, they predict a result opposite to what we found in Study 1 – i.e., that Mandarin children should learn number words faster than English learners.

4. General discussion

The present study yielded two theoretically important results. First, despite marked linguistic differences between Mandarin and English, we found that Mandarin and English learners learn number word meanings in the same stages. They start by memorizing part of their language's count list. Then, they learn the meaning of the number word for one, two, and three (sometimes four) one at a time in that order. Finally, they acquire the cardinal principle – they learn that the last number word of a correct count denotes the number of objects in the counted set. Thus the presence or absence of singular/plural marking on nouns and on verbs does not affect the sequence of acquisition of number word meanings and of the cardinal principle. Given evidence of the same sequence in multiple languages, namely, English (e.g., Wynn, 1990, 1992), Arabic and Slovenian (Almoammer et al., 2013), Japanese and Russian (Barner, Libenson, et al., 2009; Sarnecka et al. 2007), Tsimane' (Piantadosi et al., 2014), and Basque and Spanish (Villarroel et al., 2011), this suggests that the hypothesis space that constrains number word learning is cross-linguistically universal.

Second, we found that Mandarin learners learned the meaning of the number word for one some three to six months later than English learners. Importantly, our data suggest that the delay was specific to the acquisition of the meaning of the number word for one. That is, although Mandarin learners learned the meaning of the number word for one later than English learners, they proceeded through the number word learning sequence at the same rate as the English learners – i.e., on average, all children took about a year to go from learning the meaning of the number word for one to learning the cardinal principle.

The present evidence that Mandarin learners learn the meaning of the number word for one later than English learners converges with previous evidence that children learning Japanese – another language that does not have obligatory singular/plural morphology – also learn the meaning of the number word for one later than English and Russian learners (Sarnecka et al., 2007). However, Miller et al. (1995) obtained evidence which seems to conflict with ours. They found that young Mandarin learners knew the cardinal meaning of as many number words as English learners of the same age. Closer inspection of Miller et al.'s data shows that this is not a genuine conflict. Their youngest participants were 38 months old – a full fourteen months older than the youngest participants in our study. Moreover, compared to ours, the number of participants Miller et al.'s youngest group (38–48 month-olds) was very small – summing across Chinese and American participants, Miller et al.'s youngest group only included 29 participants. When we take these differences into account, we see that our results actually converge with Miller et al.'s. For example, extrapolation from our Fig. 2 suggests that average number word knowledge in the age range of Miller et al.'s youngest group is probably very similar in Mandarin and English learners, or at least too similar for a difference to be detected with a sample as small as Miller et al.'s.

The convergence with the English/Japanese contrast strengthens the case in favor of the hypothesis that singular/plural morphology supports the acquisition of the meaning of the number word for one. In particular, it shows that the acquisition of the meaning of the number word for one is delayed even when many of the alternative factors that have been proposed to explain the Japanese delay are absent, including the fact that Japanese has more than one count list, the fact that the form of each number word is highly variable because it changes depending on the classifier following it, and the fact that the relative order of nouns and number words is less predictable than in English because number words can float to post-nominal positions. None of these differences can account for the delay observed here because Mandarin does not differ from English in any of these ways.

Another alternative explanation (i.e., other than lack of informative singular/plural morphology in Japanese) of Japanese children's delay relative to English-learners is that number word usage is less frequent in Japanese parental input than in English parental input (Barner, Libenson, et al., 2009; Sarnecka et al., 2007). Our analyses of number word usage in child-directed speech converge with those of Chang and colleagues (Chang & Sandhofer, 2009; Chang et al., 2011) in suggesting that this alternative does not apply to the Mandarin-English comparison. Rather, unlike what has been reported for Japanese children, Mandarin learners hear number words as or even more frequently than American English learners. This is true whether we look at all uses of number word forms, or whether we specifically look at cardinal uses of number words, at uses with an overt noun, or at uses with nouns that denote what we called "easy" units of counting (i.e., discrete objects and discrete temporal intervals). Moreover, cardinal uses, uses with an overt noun, and uses of with easy units of counting make up similar proportions of total number usage in both Mandarin and English. Thus, none of these features of number word input can explain the Mandarin delay.

Further observations suggest that the delay in Mandarin children's learning of the meaning of the word for one, relative to American children, is not due to differences in factors that affect learning in general. First, the parents of the children recruited in Phase 2 of Study 1 all had the same level of education. Yet, we found that Mandarin learners learn the meaning of the number word for one later than English learners when we restricted our analyses to that phase only.

Second, because the delay is specific to the acquisition of the meaning of the number word for one, it is highly unlikely that Mandarin learners are delayed because they were slower at learning language in general, or because they had weaker processing skills. Further support for this claim comes from studies that have established that one- and two-year-old Mandarin learners have larger vocabularies than American English learners of the same age (e.g., Hao et al., 2015; Tardif, Gelman, & Xu, 1999; vocabulary norming results from Frank, Braginsky, Yurovsky, & Marchman, in press), and that middle-class Chinese three-year-olds have stronger executive function than middle-class American three-year-olds (Sabbagh, Xu, Carlson, Moses, & Lee, 2006). Thus, Chinese children seem to be overall *more* efficient learners than American children at the ages studied here. This strongly suggests that the Mandarin delay in learning the meaning of the number word for one is not a downstream consequence of a prior delay in aspects of language learning or cognitive development that takes place before children start learning number words.

In our view, there remain only four factors that could explain the Mandarin delay: (1) the fact that Mandarin number words are always followed by a classifier, (2) the high frequency of uses of the Mandarin word form for one (‘‘yi”) in what we referred to as non-cardinal compounds, (3) better distributional overlap between number words and quantifiers in English than in Mandarin, and (4) the lack of obligatory singular/plural morphology on nouns and verbs in Mandarin. We now consider each of these in turn. To foreshadow, we argue that the lack of singular/plural number morphology is the most likely explanation.

4.1. Classifiers

Relative to English, Mandarin phrases that contain number words are more complex at least in the simple sense of being composed of an additional overt element on the surface – i.e., a classifier. For example, the Mandarin equivalent of the English noun phrase ‘‘two big brown bears” is ‘‘兩隻大棕熊” (liǎng ZHĪ dà zōng xióng or ‘‘Two CLASSIFIER big brown bear”). Moreover, different nouns require different classifiers. Mandarin has more than a hundred different classifiers, 30 of which are commonly used in everyday speech (Chao, 1968). The pairing between nouns and classifiers is determined by conceptual and/or perceptual features of the referents of the nouns. The process of learning these pairings is a protracted one (Li et al., 2008; Wang et al., 2013). Thus, it could be that Mandarin number word learning is delayed with respect to English because it involves one more problem, namely learning classifiers.

Our data suggest that this is not the right explanation. In Mandarin, all number words must be followed by a classifier. Thus, one might think that, if the problem of learning classifiers delays number word learning at all, it should delay all Mandarin number word learning relative to English – i.e., the entire number word learning sequence should take longer in Mandarin than in English. But this is not what we found. Rather, we found that the delay is specific to learning the meaning of the number word for one. Therefore, we conclude that it is unlikely that the Mandarin learners were delayed relative to English learners because they had to learn classifiers.

4.2. Uses of ‘‘yi” in non-cardinal constructions

Our CHILDES analyses showed that the Mandarin number word for one (‘‘yi”) is also used in what we have called ‘‘non-numerical compounds,” namely, the V-yi-V verb reduplication construction and in compound words such as the adverbials ‘‘yíxìa” and ‘‘yīhǔir.” The English word form ‘‘one” is also used in what could be called be compounds, namely quantifiers such as ‘‘everyone” and ‘‘anyone.” But, proportionally speaking, the number word for one is used in non-numerical compounds some twenty times more frequently in Mandarin than in English.

In principle, this difference could explain the Mandarin delay. However, on closer inspection, it seems unlikely. The occurrences of ‘‘yi” in non-numerical compounds pose a problem for the acquisition of the meaning of the number word ‘‘yi” only if children take the non-numerical compounds and the number word to be tokens of a single word and try to find a meaning that fits all of its uses. This probably does not happen because the non-numerical compounds and the number word are used in very different syntactic frames and with different meanings. One of the non-numerical compounds is a verb, one is a modal, one is an adjectival, and the others are adverbials. Many studies have shown that, at least by 24 months of age, the meaning children assign to a word form depends on its syntactic category. For example, they take the word form "zav" to refer to a particular individual if they hear it being used as an NP ("This is Zav") but not if they hear it as a noun preceded by a determiner ("This is a zav"; Hall et al., 2001; Katz et al., 1974). This suggests that Mandarin children probably take the use of "yi" in non-numerical compounds and as a number word as tokens of *different words* (or morphemes) with *different meanings*. Moreover, recent studies teaching toddlers novel meanings for known words (e.g., "an eat" to refer to an animal rather than an action of eating), found that children have no difficulties learning homophones when either the meaning or the syntactic category differ (Dautriche, Fibla, et al., 2015; Dautriche, Swingley, et al., 2015). Therefore, the uses of "yi" in non-numerical compounds are unlikely to interfere with the acquisition of the meaning of the number word "yi."

4.3. Distributional overlap between number words and quantifiers

Following a hypothesis first put forth by Bloom and Wynn (1997; see also Wynn, 1992), Barner, Libenson, et al. (2009) proposed that "a frequent distributional overlap of quantifiers and [number words] might allow children to infer that [number words] denote the properties of sets, like quantifiers, thereby initiating their acquisition." (p. 434). On Barner, Libenson et al.'s definition of distributional overlap, a number word overlaps with a quantifier if it can be replaced by the quantifier without making the sentence ungrammatical. For example, in "I ate two apples", "two" overlaps with "some" and "many" but not with "each" or "all."

On this view, the more number words overlap with quantifiers, the easier it is to learn their meaning. There are theoretical problems with this proposal. First, number words and quantifiers do not have the same syntax. For example, number words can be used as modifiers ("I gave water to these three boys") but quantifiers cannot (*"I gave water to these some/each/all boy(s)"; Giusti, 1991). Therefore, from the point of view of syntax, analyzing number words as quantifiers might hinder learning instead of helping it. The same is true of semantics. To our knowledge, no formal analysis of the semantics of number words takes them to have the same semantics as all quantifiers, and indeed, quantifiers differ semantically in deep ways among themselves. On some analyses, number words have the same semantics as quantifiers such as "many" and "some" but do not have the same semantics as universal quantifiers such as "each" and "all," or as proportional quantifiers such as "most" (e.g., Keenan, 1996). On other analyses, number words are not quantifiers at all (e.g., Heim, 1988; Ionin & Matushansky, 2006). Therefore, at best, overlap between number words and quantifiers might help children learn their meaning but only if the overlap is restricted to some quantifiers. It is also possible that it does not help at all.

Second, suppose that we disregard the aforementioned problems and assume that number words are quantifiers. Then, overlap with quantifiers will help children discover that number words are quantifiers only if it is greater for quantifiers than for other lexical categories. For example, if number words overlap more with adjectives than with quantifiers, then overlap is not helpful, at least not on the view that number words are quantifiers. Barner, Libenson et al. did not analyze how much number words overlap with words from lexical categories other than quantifiers. Therefore, their analysis cannot tell us whether overlap actually supports number word learning in English to a greater extent than in Japanese.

Building on Barner et al.'s overlap analysis, we conducted more complete analyses for English and Mandarin. Using the CHILDES New England corpus for English child-directed speech and the Zhou corpus for Mandarin (see Study 2), we determined how frequently number words in input to children could be replaced with any of five frequent quantifiers (every/měi, some/xiē, all/suǒyǒu, several/jǐ, and many/duō), but could not be replaced with an adjective (big/dà). Since it is not clear that the linguistic assumptions of this analysis are valid, we do not report it here, but have placed it online (https://software.rc.fas.harvard.edu/lds/wp-content/uploads/2015/07/Le-Corre-et-al-supp-materials-July-2015.pdf). In short, we found no overlap advantage for English. We find the opposite: the number word for one overlaps with quantifiers but not adjectives a bit more in Mandarin than in English, and the number words for two to nine overlap with quantifiers but not adjectives about four times more often in Mandarin than in English. This analysis provides empirical evidence against the hypothesis that distributional overlap between number words and quantifiers can explain why Mandarin learners learn the meaning of the number word for one later than English learners, supplementing the theoretical problems summarized above.

4.4. The morphological bootstrapping hypothesis: a more parsimonious explanation

In addition to the fact that none of the many alternatives considered above provide satisfactory explanations of the Mandarin delay, we see another strong reason to favor the morphological hypothesis. The availability of numerical morphemes that express the same number as a number word has now been shown to correlate with facilitated acquisition of this number word in four pairs of languages: Mandarin-English, Arabic-English and Slovenian-English (Almoammer et al., 2013), Japanese-English (Barner, Libenson, et al., 2009; Sarnecka et al., 2007) and Japanese-Russian (Sarnecka et al., 2007). The languages and the contexts of language acquisition in each pair differ from each other in multiple ways. Thus, the delays observed in each particular case could possibly be due to factors other than differences in numerical morphology. However, differences in numerical morphology are likely to be the only factor that predicts the relative rates of number word learning in *all* the pairs. This strongly suggests that such differences are part of the explanation of the difference in rate of number word learning observed in each case.

To be sure, it may be that the factors other than numerical morphology add to the delay in each case. For example, Japanese learners' delay is greater than Mandarin learners'. Sarnecka et al. (2007) found that 100% of English 33–40-month-olds had at least reached the one-knower stage, whereas only 54% of Japanese learners had done so. The corresponding proportions in the present data were 98% for English learning 33–40-month olds and 84% for Mandarin learners of the same age. Similarly, Barner, Libenson et al. found that 74% of their English-learning 2-year-olds had learned the meaning of the number word for numbers equal to or greater than one, compared to 22% of their Japanese learning 2-year-olds. The corresponding proportions in the present data were 80% for English learning 2-year-olds and 55% for Mandarin-learning 2-year-olds. Thus, relative to English learners, Japanese learners are significantly more delayed in learning the meaning of the number word for one than Mandarin learners. This is not due to methodological differences between the studies because the proportions of English learners who had learned the meaning of the number word for one were remarkably similar across them. It is thus likely that, relative to English, there are more factors that hinder the acquisition of the meaning of the number word for one in Japanese than in Mandarin, namely the very factors that have been controlled for in the present study.

4.5. Conclusion

The morphology of many human languages encodes numerical information (Corbett, 2000). A few studies have provided evidence that the numerical information encoded in numerical morphology supports the acquisition of number word meanings (Almoammer et al., 2013; Barner, Libenson, et al., 2009; Sarnecka et al., 2007). The present study extends this body of evidence by providing the strongest evidence thus far that prior knowledge of the numerical meaning of the morphological distinction between singular and plural nouns (and perhaps other parts of speech such as verbs) helps children learn the meaning of the number word for one. It seems likely that this occurs because some number words and numerical morphology share common meanings. As suggested by Carey and her colleagues (Carey, 2004, 2009; Carey & Sarnecka, 2006), it thus may be that some of the conceptual roots of our representations of the natural numbers are found in the meanings expressed by linguistic distinctions as widespread and basic as the one between singular and plural.

Acknowledgments

Thanks are due to David Barner and Pierina Cheung for answering all our questions on their analyses of Japanese input, to Barbara Sarnecka, Moriko Moher, and Yoko Futagi for help with Japanese syntax, and to Sarah Turner for help with Russian syntax. Thanks also to Rende Shui, Marvin Li, and Wen-shong Li for help with data collection and/or analysis, and to Jody Tomchishen, and Samantha

Shortall for their grammaticality judgments. Finally, we thank the many parents, children, and day care personnel who generously contributed to this project. This research was supported by NIH Grant # RO1-HD038338 and NSF ROLE Grant # REC-0196471 to S.C. and by NSERC Discovery grant 371718-2009 and a PRODEP grant to M.L.C.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cogpsych.2016.06.003.

References

Almoammer, A., Sullivan, J., Donlan, C., Marušič, F., Žaucer, R., O'Donnell, T., & Barner, D. (2013). Grammatical morphology as a source of early number word meanings. *Proceedings of the National Academy of Sciences, 110*, 18448–18453.
Bailyn, J. F. (2014). *The syntax of Russian*. Cambridge, U.K.: Cambridge University Press.
Barner, D., Chow, K., & Yang, S. (2009). Finding one's meaning: A test of the relation between quantifiers and integers in language development. *Cognitive Psychology, 58*, 195–219.
Barner, D., Libenson, A., Cheung, P., & Takasaki, M. (2009). Cross-linguistic relations between quantifiers and numerals in language acquisition: Evidence from Japanese. *Journal of Experimental Child Psychology, 103*, 421–440.
Bloom, P., & Kelemen, D. (1995). Syntactic cues in the acquisition of collective nouns. *Cognition, 56*, 1–30.
Bloom, P., & Wynn, K. (1997). Linguistic cues in the acquisition of number words. *Journal of Child Language, 24*, 511–533.
Brooks, N., Pogue, A., & Barner, D. (2011). Piecing together numerical language: Children's use of default units in early counting and quantification. *Developmental Science, 14*, 44–57.
Carey, S. (2004). Bootstrapping and the origin of concepts. *Daedalus, 3*, 59–68.
Carey, S. (2009). The making of abstract concepts: A case study of natural number. In D. Marischal (Ed.), *The making of abstract concepts*. Oxford University Press.
Carey, S., & Sarnecka, B. W. (2006). The development of human conceptual representations. In M. Johnson & Y. Munakata (Eds.), *Attention and performance: Vol XXI. Processes of change in brain and cognitive development* (pp. 473–496). Oxford, UK: Oxford University Press.
Chang, A., & Sandhofer, C. (2009). Language differences in bilingual parent number speech to preschool-aged children. In N. A. Taatgen & H. van Rijn (Eds.), *Proceedings of the thirty-first annual conference of the Cognitive Science Society* (pp. 887–892). Austin, TX: Cognitive Science Society.
Chang, A., Sandhofer, C. M., Adelchanow, L., & Rottman, B. (2011). Language, culture, and number: Differences in numerical language input in Mandarin Chinese and English. *Journal of Child Language, 38*, 341–355.
Chao, Y. R. (1968). *A grammar of spoken Chinese*. Berkeley & Los Angeles: University of California Press.
Cheung, P., Barner, D., & Li, P. (2010). Syntactic cues to individuation in Mandarin Chinese. *Journal of Cognitive Science, 10*, 135–147.
Chierchia, G. (1998). Reference to kinds across languages. *Natural Language Semantics, 6*(4), 339–405.
Corbett, G. G. (2000). *Number*. Cambridge: Cambridge University Press.
Dautriche, I., Swingley, D., & Christophe, A. (2015). Learning novel phonological neighbors: Syntactic category matters. *Cognition, 143*, 77–86.
Dautriche, I., Fibla, L., & Christophe, A. (2015). Learning homophones: Syntactic and semantic contexts matter. *Paper presented at the Fortieth Annual Boston University conference on language development, Boston, MA, USA*.
Davies, B., Xu Rattanasone, N., & Demuth, K. (2015). Revisiting 2;0-year-olds understanding of plural morphology. *Paper presented at the Fortieth Annual Boston University conference on language development, Boston, MA, USA*.
Fluck, M., & Henderson, L. (1996). Counting and cardinality in English nursery pupils. *British Journal of Educational Psychology, 66*, 501–517.
Foushee, R., Falkou, N., & Li, P. (2015). 'Two pounds cookies' or 'two pounds of cookies': Children's appreciation of quantity expressions. *Paper presented at the Fortieth Annual Boston University conference on language development, Boston, MA, USA*.
Frank, M. C., Braginsky, M., Yurovsky, D., & Marchman, V. A. (in press). Wordbank: An open repository for developmental vocabulary data. *Journal of Child Language* (in press).
Fuson, K. C. (1988). *Children's counting and concepts of number*. New York: Springer-Verlag.
Gal'perin, P. Y., & Georgiev, L. S. (1969). The formation of elementary mathematical notions. *Soviet Studies in the Psychology of Learning and Teaching Mathematics, 1*, 189–216.
Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number*. Cambridge, Mass: Harvard University Press.
Giralt, N., & Bloom, P. (2000). How special are objects? Children's reasoning about objects, parts, and wholes. *Psychological Science, 11*, 497–501.
Giusti, G. (1991). The categorial status of quantified nominals. *Linguistische Berichte: Forschung, Information, Diskussion. Opladen, 1991*, 438–454.
Gleitman, L. (1990). Structural sources of verb learning. *Language Acquisition, 1*(1), 1–63.
Gunderson, E. A., & Levine, S. C. (2011). Some types of parent number talk count more than others: Relations between parents' input and children's cardinal-number knowledge. *Developmental Science, 14*(5), 1021–1032.
Hall, D. G., Lee, S. C., & Bélanger, J. (2001). Young children's use of syntactic cues to learn proper names and count nouns. *Developmental Psychology, 37*(3), 298–307.
Hao, M., Liu, Y., Shu, H., Xing, A., Jiang, Y., & Li, P. (2015). Developmental changes in early child lexicon in Mandarin Chinese. *Journal of Child Language, 42*, 505–537.

Heim, I. (1988). *The semantics of definite and indefinite noun phrases*. New York: Garland Publishers.
Huntley-Fenner, G. (1995). *The representation of objects, non-solid substances, and collections in infancy and early childhood*. Unpublished MIT doctoral dissertation.
Ionin, T., & Matushansky, O. (2006). The composition of complex cardinals. *Journal of Semantics, 23*, 315–360.
Jackendoff, R. (1997). *X-Bar Syntax: A Study of Phrase Structure*. Cambridge, MA: MIT Press.
Jolly, H. R., & Plunkett, K. (2008). Inflectional bootstrapping in 2-year-olds. *Language and Speech, 51*, 45–59.
Jordan, N. C., Huttenlocher, J., & Levine, S. C. (1992). Differential calculation abilities in young children from middle- and low-income families. *Developmental Psychology, 28*(4), 644–653.
Katz, N., Baker, E., & Macnamara, J. (1974). What's in a name? A study of how children learn common and proper names. *Child Development, 45*(2), 469–473.
Keenan, E. L. (1996). The semantics of determiners. In S. Lappin (Ed.), *The handbook of contemporary semantic theory* (pp. 41–64). Oxford, UK: Blackwell.
Krifka, M. (2004). Bare NPs: Kind-referring, indefinites, both, or neither? In R. B. Young & Y. Zhou (Eds.), *Proceedings of semantics and linguistic theory (SALT) XIII*. Seattle: University of Washington.
Kobuchi-Philip, M. (2007). Floating numerals and floating quantifiers. *Lingua, 117*, 814–831.
Kouider, S., Halberda, J., Wood, J. N., & Carey, S. (2006). The acquisition of English number marking: The singular-plural distinction. *Language Learning and Development, 2*(1), 1–25.
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*, 395–438.
Le Corre, M., Van de Walle, G., Brannon, E. M., & Carey, S. (2006). Re-visiting the competence/performance debate in the acquisition of counting as a representation of the positive integers. *Cognitive Psychology, 52*(2), 130–169.
Lee, M. D., & Sarnecka, B. W. (2011). Number-knower levels in young children: Insights from a Bayesian model. *Cognition, 120*, 391–402.
Li, P., Barner, D., & Huang, B. (2008). Classifiers as count syntax: Individuation and measurement in the acquisition of Mandarin Chinese. *Language Learning and Development, 4*(4), 249–290.
Li, P., Huang, B., & Hsiao, Y.-L. (2010). Learning classifiers count: Mandarin-speaking children's acquisition of sortal and mensural classifiers. *Journal of East Asian Linguistics, 19*(3), 207–230.
Li, P., Ogura, T., Barner, D., Yang, S., & Carey, S. (2009). Does the conceptual distinction between singular and plural sets depend on language? *Developmental Psychology, 45*, 1644–1653.
Llombart-Huesca, A. (2002). Anaphoric one and NP-ellipsis. *Studia Linguistica, 56*(1), 59–89.
Lukyanenko, C., & Fisher, C. (2016). Where are the cookies? Two- and three-year-olds use number-marked verbs to anticipate upcoming nouns. *Cognition, 146*, 349–370.
MacWhinney, B. (2000). *The CHILDES project: Tools for analyzing talk* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.
Madariaga, N. (2007). Russian patterns of floating quantification: Non-agreeing quantifiers. In P. Kosta & L. Shürcks (Eds.), *Linguistic investigations into formal description of Slavic languages (postdam linguistic investigations)* (pp. 267–281). Frankfurt Am Main: Peter Lang.
Miller, K. F., Smith, C. M., Zhu, J., & Zhang, H. (1995). Preschool origins of cross-national differences in mathematical competence: The role of number-naming systems. *Psychological Science, 6*(1), 56–60.
Ninio, A., Snow, C. E., Pan, B. A., & Rollins, P. R. (1994). Classifying communicative acts in children's interactions. *Journal of Communication Disorders, 27*, 158–187.
Pereltsveig, A. (2007). The universality of DP: A view from Russian. *Studia Linguistica, 61*(1), 59–94.
Piantadosi, S. T., Jara-Ettinger, J., & Gibson, E. (2014). Children's learning of number words in an indigenous farming-foraging group. *Developmental Science, 17*(4), 553–563.
Quine, W. V. O. (1960). *Word and object*. Cambridge, MA: MIT Press.
Sabbagh, M. A., Xu, F., Carlson, S. M., Moses, L. J., & Lee, K. (2006). Executive functioning and theory of mind in preschool children from Beijing, China: Comparisons with U.S. preschoolers. *Psychological Science, 17*, 74–81.
Sarnecka, B., Kamenskaya, V. G., Yamana, Y., Ogura, T., & Yudovina, J. B. (2007). From grammatical number to exact numbers: Early meanings of 'one', 'two', and 'three' in English, Russian, and Japanese. *Cognitive Psychology, 55*, 136–168.
Sarnecka, B. W., & Lee, M. D. (2009). Levels of number knowledge in early childhood. *Journal of Experimental Child Psychology, 103*, 325–337.
Shipley, E., & Shepperson, B. (1990). Countable entities: Developmental changes. *Cognition, 34*, 109–136.
Spector, B. (2007). Aspects of the pragmatics of plural morphology: On higher-order implicatures. In U. Sauerland & P. Stateva (Eds.), *Presuppositions and implicatures in compositional semantics* (pp. 243–281).
Syrett, K., Musolino, J., & Gelman, R. (2012). How can syntax support number word acquisition? *Language Learning and Development, 8*(2), 146–176.
Tardif, T., Gelman, S. A., & Xu, F. (1999). Putting the 'noun bias' in context: A comparison of English and Mandarin. *Child Development, 70*(3), 620–635.
Villarroel, J. D., Miñón, M., & Nuño, T. (2011). The origin of counting: A study of the early meaning of 'one', 'two', and 'three', among Basque-and Spanish-speaking children. *Educational Studies in Mathematics, 76*(3), 345–361.
Wagner, L., & Carey, S. (2003). Individuation of objects and events: A developmental study. *Cognition, 90*, 163–191.
Wang, J., Li, P., & Carey, S. (2013). Exploring language and thought relation in learning how stuff counts. In S. Baiz, N. Goldman, & R. Hawkes (Eds.), *Proceedings of the 37th Boston University child development conference* (pp. 456–468).
Wood, J. N., Kouider, S., & Carey, S. (2009). Acquisition of singular-plural morphology. *Developmental Psychology, 45*(1), 202–206.
Wynn, K. (1990). Children's understanding of counting. *Cognition, 36*(2), 155–193.
Wynn, K. (1992). Children's acquisition of the number words and the counting system. *Cognitive Psychology, 24*(2), 220–251.
Zapf, J. A., & Smith, L. B. (2007). When do children generalize the plural to novel nouns? *First Language, 27*, 53–73.
Zhou, J., & Zhang, J. R. (2008). *Language studies of Chinese speaking children: Using CHILDES to do child language study in chinese context*. Beijing: Education Science Publication.
Zushi, M. (2003). Null arguments: The case of Japanese and Romance. *Lingua, 113*, 559–604.