# Why is Number Word Learning Hard? Evidence from Bilingual Learners

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**Abstract**

We investigated the developmental trajectory of number word learning in bilingual preschoolers to examine the relative contributions of two factors: (1) the construction of numerical concepts, and (2) the mapping of language-specific words onto these concepts. We found that children learn the meanings of small numbers independently in each language, indicating that the delay in the acquisition of small numbers is mainly due to language-specific processes of mapping words to concepts. In contrast, the logic and procedures of counting are learned simultaneously in both languages, indicating that these stages require the construction of numerical concepts that are not stored in a language-specific format.

**Keywords:** number word learning; bilingual speakers; conceptual change

## Introduction

Across a variety of languages and cultural groups, including Canada, the US, Japan, Russia, Bolivia, Slovenia, Taiwan, and Saudi Arabia, children learn number word meanings in distinct, protracted, stages (Almoammer, Sullivan, Donlan, Maruscic, Zaucer, O'Donnell, & Barner, 2013; Barner, Libenson, Cheung, & Takasaki, 2009; Li, Le Corre, Shui, Jia, & Carey, 2003; Piantadosi, Jara-Ettinger, & Gibson, 2014; Sarnecka, Kamenskava, Yamana, Ogura, & Yudovina, 2007; Wynn, 1990). In the first stage, children learn to recite a partial count list (e.g., one, two, three, four, five, etc.), often pointing at objects as they count. Yet, these children actually have little understanding of how number words represent quantity, and as a result are often classified as "non-knowers." Sometime later, they acquire an exact meaning for one, at which point they are called "1-knowers". Months later, they learn an exact meaning for two to become "2-knowers." They then learn three ("3-knowers") and sometimes four ("4-knowers"). Up until this point, children are generally referred to as "subset-knowers" since they only know the meanings for a subset of their number words. However, at the next stage children appear to recognize that the counting procedure can be used to enumerate sets, and that the last word in a count routine labels the cardinality of the entire set (for discussion of knower levels, see Wynn, 1990; Lee & Sarnecka, 2011; Le Corre & Carey, 2007; Piantadosi, Tenenbaum, & Goodman, 2012; Sarnecka & Carey, 2008; Davidson, Eng, & Barner, 2012). At this stage, children are generally referred to as cardinal principle knowers ("CP-knowers").

Even after becoming CP-knowers, children still appear unsure of how the counting procedure represents number. According to some accounts (Sarnecka & Carey, 2008; Wynn, 1990), children become CP-knowers – and understand how counting represents number – by noticing an isomorphism between the structure of the count list and the cardinalities that they represent. In particular, on such accounts, children learn the successor principle – that every natural number $n$ has a successor, defined as $n+1$. However, recent evidence suggests that many so-called CP-knowers do not have knowledge of this principle, and that instead they initially use a blind procedure for counting and giving correct amounts, with little insight into how this procedure works (Davidson, et al., 2012). When told that a box contains 4 objects and asked how many there are when one more is added, many CP-knowers are at chance.

Although it remains controversial when children fully understand how counting represents number, the basic developmental trajectory is robust (Lee & Sarnecka, 2011; Piantadosi, et al., 2012). However, despite this consensus on the developmental facts, it remains unknown what causes transitions between the stages of number word learning.

What we do know is that several sources indicate that the length of the delays between stages is highly malleable (e.g., Dowker, 2008; Klibanoff, Levine, Huttenlocher, Vasilyeva & Hedges, 2006). First, children who receive greater exposure to number words pass through knower level stages more quickly (Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010; Gunderson & Levine, 2011). Second, children's rate of number word learning appears to be affected by the structure of their language. Some languages, like English and Russian, have obligatory singular-plural marking, which might help children to identify that one refers to singleton sets, whereas two and larger numbers refer to sets of more than one (Carey, 2004, 2009). Consistent with this, children learning English and Russian become 1-knowers faster than children learning Japanese and Mandarin Chinese, which do not have obligatory singular and plural marking (Barner, et al., 2009; Li et al., 2003; Sarnecka et al., 2007). Languages like Slovenian and Saudi Arabic not only have singular-plural marking, but also have dual marking, which refers to sets of precisely two (Corbett, 2000). Remarkably, children learning these languages are faster to learn *one* and *two* (but interestingly not *three*) than children from any other previously studied group, even though they appear to receive less training than children from other countries (Almoammer et al., 2013).

These facts suggest that the transitions between knower level stages can be accelerated by the frequent and informative use of number words. However, they leave open why frequent and informative input matters, and thus why learning is so hard. Here we consider two, mutually compatible, possibilities. First, it is possible that the protracted transitions between the stages of number word learning are affected by gradual processes of conceptual change: 1-knowers may take months to become 2-knowers because they do not yet have a concept of "exactly two" and must construct this as part of learning the word (Carey, 2004, 2009; Sarnecka & Carey, 2008; Spelke & Tsivkin, 2001). Consequently, hearing the word two used frequently and in supportive grammatical contexts may be important because it helps children construct the concept "two". Similarly, becoming a CP-knower may involve a conceptual change that is speeded by frequent exposure to number words and the counting routine. Alternatively, the primary reason for the delays may not be conceptual, but due to the problem of identifying how words in a particular language map onto numerical concepts (whether these concepts are innate, constructed but easy to acquire, or difficult to acquire but constructed sometime before the onset of number word learning). Consider, for example, a scenario in which the concepts "one", "two", and "three" are innately specified in the child's representational repertoire. In this case, the observed delays between knower level stages might be explained by the difficulty of identifying which words correspond to which set sizes. In the case of counting, a similar gradual, language-specific learning process might take place: learning the cardinal principle in English, for example, might not require conceptual change per se, but might instead involve a mapping of words onto innate concepts of cardinality (Leslie, Gelman, & Gallistel, 2008). This model, like the constructivist alternative, also predicts that frequency of input should affect rate of learning.

These two possibilities are by no means mutually exclusive, but they do make predictions that can distinguish the relative role each factor plays in learning. In particular, they make different predictions for bilingual learners. Specifically, if the primary cause of delays between stages of number word learning is conceptual, then when children acquire knowledge in one language (e.g., English), this knowledge may readily transfer to their secondary language of instruction (e.g., Spanish) with little additional language-specific learning required. However, if the primary challenge is the language specific problem of mapping words onto concepts, bilingual children may exhibit relatively independent learning trajectories in each of their two languages with little evidence of transfer. The best predictor of their number word knowledge, in this case, may be how much input they receive in a particular language, rather than what they know in another language.

To explore these questions, we tested three groups of bilingual children in the U.S. who spoke either English and French or English and Spanish. Each child was tested with Wynn's (1990) Give-a-Number task in order to establish their knower level in each language, and each child was asked to count as high as they could. In addition, we tested when bilingual children acquire the successor principle in each language, and whether it transfers between languages in a subset of the CP-knowers with a third task, called the Successor Task (see Sarnecka & Carey, 2008).

# Methods

## Participants

One hundred and forty-seven bilingual speakers of either English and French ($n$ = 20; $M$ = 3;8; range = 2;11-5;0) or English and Spanish ($n$ = 127; $M$ = 4;6; range = 2;2-5;6) from the San Diego area participated. Eighty-five children were from predominately low socioeconomic (SES) Hispanic families at a local preschool that caters to English learners. The remaining 62 children were from primarily non-Hispanic Caucasian, upper-middle class families.

Caregivers were asked to report their child's primary language on the consent forms that were sent home by the preschools. As reported on the returned consent forms, 83 children were primarily Spanish speakers, 3 were primarily French speakers, and 44 were primarily English speakers. 4 children were equally proficient in English and Spanish and 1 child was equally proficient in English and French. Twelve parents did not respond. To avoid decreasing our recruitment rate, parents were not asked any further questions about their child's language abilities. Although parent report is often predictive of children's overall verbal fluency, it is not necessarily a reliable indicator of children's familiarity with numbers, since children may be instructed in a language other than their primary language. Therefore, we also directly measured children's familiarity with numbers by assessing counting ability in each language. This was then used to determine each child's "Primary Number Language" (NL1) and "Secondary Number Language" (NL2).

## Procedures

Children completed four tasks, once in each language, in the following order: (1) Language Proficiency; (2) Give-a-Number; (3) Highest Count; and (4) Successor Task. The Successor Task was added to the procedures midway through data collection. Thus, only CP-knowers from the Low SES Spanish-English Group completed this task.

**Give-A-Number Task** This task, which was adapted from Wynn (1990), assessed children's knowledge of number words. On each trial, the experimenter presented the child with a plate and ten plastic fish and asked the child to place a quantity on the plate, avoiding singular and plural marking by asking, "Can you put n on the plate? Put n on the plate and tell me when you're all done." Once the child responded, the experimenter then asked, "Is that n? Can you count and make sure?" If the child recognized an error, the experimenter allowed the child to fix it. Two versions of Give-a-Number were used. Children who participated in an earlier version of the study completed up to twenty-one quasi-randomized trials, consisting of three trials for each of the seven numbers tested (i.e., 1, 2, 3, 4, 5, 8, and 10; see Lee & Sarnecka, 2011 for discussion). Children who participated later were given a staircased version of the Give-a-Number task (as in Wynn, 1990, Experiment 3).

Children were defined as an n-knower (e.g., three-knower) if they correctly provided n (e.g., 3 fish) on at least two out of the three trials that n was requested and, of those times that the child provided n, two-thirds of the times the child did so it was in response to a request for n. If n was five or higher, the child was classified as a CP-knower.

**Highest Count Task** After the Give-a-Number task, the experimenter asked, "Can you count as high as you can?" The child's Highest Count was defined as the largest number counted to before an error. For each child, "Primary Number Language" (i.e., NL1) was defined as the language in which she counted highest. The other language was labeled her "Secondary Number Language" (i.e., NL2). In cases where the Highest Count matched in both languages, the NL1 was defined according to parent report (n = 6).

**Successor Task** This task was modeled after Sarnecka and Carey (2008) and was designed to assess children's understanding of the successor principle, operationalized here as the knowledge that adding one object to a set (i.e., n) results in an increase of exactly one unit on the count list (i.e., $n + 1$). Children identified as CP-knowers were shown with an empty opaque box and a container filled with identical plastic toys (e.g. apples). To begin each trial, the experimenter directed the child's attention to the box by exclaiming, "Look, there's nothing in the box!" and permitted the child to look inside to confirm it was empty. The experimenter then held up the container of objects, stating that she had n items, poured the objects inside the box, and closed the lid (e.g., "I have fourteen apples. I'm putting fourteen apples in the box"). The experimenter then asked a memory-check question, e.g., "How many apples are in the box?" Once the child correctly answered the memory-check question, the child watched as the experimenter added one identical object to the box. The experimenter then asked whether there were $n + 1$ or $n + 2$ objects, e.g., "Are there fifteen apples or sixteen apples in the box?" Children were tested on two small numbers (5 and 8), three medium numbers (12, 14, and 16), and three large numbers (21, 23, and 27) in a counterbalanced order.

# Results

## Highest Count

Highest count identified children's NL1 and NL2. In the high SES French-English group ($n$ = 20), the average Highest Count in French was 13.9 ($SD$ = 7.0) and in English was 10.7 ($SD$ = 4.0). Sixteen of these children counted higher in French, and 4 counted higher in English. In the high SES Spanish-English group ($n$ = 42), the average Highest Count in Spanish was 12.3 ($SD$ = 9.6) and in English was 20.9 ($SD$ = 20). Eight children counted higher in Spanish, and 32 counted higher in English. Two children counted equally high in Spanish and English, and NL1 was classified by parent report ($n$ = 1, English; $n$ = 1, Spanish). In the low SES Spanish-English group ($n$ = 85), the average Highest Count in Spanish was 17.7 ($SD$ = 11.0) and in English was 10.4 ($SD$ = 4.1). Sixty-eight children counted higher in Spanish, and 13 in English. Four additional children counted equally high in Spanish and English, and we classified their NL1 by parent report ($n$ = 4, Spanish).

## Give-A-Number Task

Across the three groups of bilingual children, there were a total of 33 non-knowers, 29 1-knowers, 34 2-knowers, 24 3-knowers, 18 4-knowers, and 156 CP-knowers (where each child contributed two knower level classifications, since each spoke two languages).

**Predictors of NL2 Knower Level** Our main question was whether children's number knowledge in their NL1 facilitated analogous learning in their NL2 via transfer. Our first analysis tested this idea in its simplest form. We asked whether children's NL2 knower level increased as a function of their NL1 knower level. To examine this, we compared two ordinal logistic models with Age, NL1 and NL2 Highest Count as predictors of NL2 knower level. Model 2 also included NL1 knower level as a predictor.

To compare these models, we computed their relative fits to the data using three sets of criteria. Model 1, which excluded NL1 knower level, had an overall misclassification rate of 0.33, a RMSE (root mean squared error) of 0.55 and an AICc (Akaike Information Criterion value) of 287. Adding NL1 knower level (as shown in Model 2) reduced the misclassification rate to 0.27, lowered the RMSE to 0.49 and lowered the AICc to 245, suggesting that Model 2 was a better fit than Model 1. For Model 2, the effect likelihood ratio tests found that NL1 knower level, $\chi^2(5) = 53.6$, $p <$ 0.001, NL2 Highest Count, $\chi^2(1) = 7.72$, $p = 0.006$ and Age, $\chi^2(1) = 4.35$, p = 0.037, were significant predictors of NL2 knower level, whereas NL1 Highest Count, $\chi^2(1) = 0.208$, p = 0.65, and Group, $\chi^2(2) = 1.74$, $p = 0.42$, were not.

The results thus far indicate that NL1 knower level is an important predictor of NL2 knower level. However, different processes may drive children's learning of small (1-4) and large (5+) number words. Consistent with this, parameter estimates from Model 2 showed that transfer only occurred at the CP-knower level (and perhaps 4-knower).

To explore this, we conducted an ordinal logistic regression which excluded children who were CP-knowers in both languages, $R^2 = 0.196$, $\chi^2(9) = 37.7$, p < .001. This analysis found no significant effect of transfer (despite finding other significant effects), suggesting that transfer at the CP-knower stage drove the effects that were described above. Specifically, effect likelihood ratio tests found that NL2 Highest Count, $\chi^2(1) = 5.61$, $p = 0.018$, and Age, $\chi^2(1) = 3.93$, $p = 0.047$, were significant predictors of NL2 knower-level; however, NL1 knower level, $\chi^2(4) = 7.40$, $p =$ 0.12, NL1 Highest Count, $\chi^2(1) = 0.231$, $p = 0.63$, and Group, $\chi^2(2) = 0.959$, $p = 0.62$, were not. In contrast, an analysis that examined only transfer of CP-knower status found a relationship between NL1 and NL2 knower level. An ordinal logistic regression that coded children in each language as either a CP-knower or subset-knower found that NL1 CP-knower status, $\chi^2(1) = 33.4$, $p < 0.0001$, NL2 Highest Count, $\chi^2(1) = 8.58$, $p = 0.003$, and Age, $\chi^2(1) = 5.51$, $p = 0.019$, but not Group, $\chi^2(1) = 5.08$, $p = 0.08$, predicted NL2 CP-knower status. Thus, we again found evidence of cross-linguistic transfer at the CP-knower stage.

## Successor Task

Although our analyses thus far indicate that transfer occurs at the CP-knower stage, these analyses do not address what exactly transfers (e.g., knowledge of a procedure or knowledge of the logic of counting). To investigate this, we asked whether all CP-knowers understood the successor principle – i.e., that every natural number, n, has a successor defined as n + 1. Evidence that some CP-knowers do not have this knowledge would suggest that effects of CP-knower transfer reported above do not reflect transfer of this conceptual understanding.

For each child, a trial was included in the analyses if the child's Highest Count measure in the corresponding language was greater than the target number of the trial. For example, data from the "12" trial was only included if a child could count to at least 13 in the tested language. This ensures that the task measured children's conceptual understanding of the successor principle, rather than their knowledge of the count list. Children who had fewer than two valid trials in either language ($n = 5$) were excluded from analyses, resulting in 41 children ($M$ = 4;11, $SD = 4.6$ months), who were included. On average, children contributed 5.4 trials ($SD = 2.0$ trials) for their NL1 and 2.6 trials ($SD = 1.1$ trials) for their NL2.

Overall, performance on the Successor Task was greater than chance (i.e., 0.50) in both NL1, $M = 0.68$, $SD = 0.23$; $t(40) = 5.00$, $p < 0.001$, and NL2, $M = 0.61$, $SD = 0.33$; $t(40) = 2.17$, $p = 0.036$, and there was no significant difference between NL1 and NL2, $t(40) = 1.56$, $p = 0.13$. Nevertheless, there were large individual differences between children. Specifically, 30% of children were at or below chance in their NL1 and 49% were at or below chance in their NL2.

**Transfer of Successor Principle from NL1 to NL2** Even if CP-knowers do not initially understand the successor principle, it remains possible that this knowledge transfers later in development. We therefore asked whether knowledge of the successor principle transferred across languages or if it is learned separately in each language.

For this analysis, we will only compare performance on the small numbers (i.e. 5 and 8) because the majority of our participants could not count high enough to contribute valid data on the next highest number (i.e. 12). A standard least squares regression, $F(4,36) = 3.3$, $p = 0.02$, $R^2 = 0.27$, revealed that knowledge of the successor principle in NL2 small numbers was significantly predicted by NL1 successor principle knowledge of small numbers, $F(1,36) = 10.4$, $p = 0.003$, but not by NL2 Highest Count, $F(1,36) = 0.66$, $p = 0.42$, NL1 Highest Count, $F(1,36) = 0.69$, $p = 0.41$, or Age, $F(1,36) = 0.05$, $p = 0.83$. These results are consistent with the idea that knowledge of the successor principle in a child's first language transfers to their second language, at least for some numbers.

To further examine the effect of transfer of the successor principle knowledge, we asked if knowing the successor of a particular number in NL1 (e.g., *cinco*) predicted successor knowledge of the same number in NL2 (e.g., *five*). To test this, we examined what predicted children's performance on the "5" and "8" trials independently. First, to predict children's NL1 performance on the "5" trial, we implemented an ordinal logistic regression, $R^2 = 0.09$, $\chi^2(3) = 0.2$, $p = 0.2$, using NL1 performance on "5", NL1 performance on "8", and NL2 performance on "8". Results showed that NL1 performance on "5", $\chi^2(1) = 4.6$, $p = 0.03$, was the only significant predictor. Neither NL1 performance on "8", $\chi^2(1) = 0.18$, $p = 0.67$, nor NL2 performance on "8", $\chi^2(1) = 0.007$, $p = 0.93$, were significant. Likewise, we conducted another ordinal logistic regression, $R^2 = 0.18$, $\chi^2(3) = 10.1$, $p = 0.02$, on NL2 performance on "8" and found that NL1 performance on "8", $\chi^2(1) = 6.1$, p = 0.01, was the only significant predictor, but NL1 performance on "5", $\chi^2(1) = 2.8$, $p = 0.10$, and NL2 performance on "5", $\chi^2(1) = 0.18$, $p = 0.67$, were not.

# Discussion

We investigated number word learning bilingual children to examine the causes of the long delays between stages. Specifically, we tested whether these delays are best explained by processes of gradual conceptual change or by language-specific processes of mapping words onto concepts. Our findings suggest that in the 1-knower, 2-knower, and 3-knower stages of number word learning, knowledge is acquired independently in each language. In contrast, children's classification as Cardinal Principle knowers in their NL2 was strongly predicted by being a CP-knower in their NL1 (in addition to NL2 counting ability, but not NL1 counting ability). This result suggests that the scope of inference at this stage is not restricted to a particular language but may instead involve a moment of insight that applies to counting in general, independent of any particular language. Finally, we replicated previous findings that not all CP-knowers understand the successor principle, and thus that learning this principle does not likely drive children's ability to use the counting procedure to label and generate sets. Instead, children likely learn about the successor principle gradually in both languages after they become competent users of the counting procedure, with some evidence of transfer.

These results allow us to draw several important conclusions regarding the nature of number word learning, not only as it occurs in bilinguals, but also as it occurs in monolingual learners. First, our results support the intuition described in previous studies (i.e., Le Corre & Carey, 2007; Sarnecka & Lee, 2009; Wynn, 1990) that number word learning involves multiple, discontinuous stages of learning, such that small and large number words are acquired via different mechanisms. In our study, the rate at which children learned labels for “one,” “two,” and “three” was best explained by their exposure to these words in a particular language and not by whether they had previously learned corresponding words in another language. This result strongly suggests that the delays between subset knower stages are not caused by difficulties in constructing new concepts, but instead are due to problems in identifying which concepts correspond to which words. The situation is different, however, when it comes to how children learn to count. Although learning the counting procedure requires substantial linguistic experience with number words, once knowledge of this procedure is acquired it becomes available to children in a format that transcends natural language.

Second, given these basic conclusions, our data also speak to debates regarding the origin of numerical concepts. Although our findings cannot decide whether concepts like “one”, “two”, and “three” are innate, they do have important implications regarding this question. In recent years, the protracted, stage-like process of acquiring small number words like one, two, and three has been interpreted by some researchers as evidence for a constructivist theory of number word learning – on the assumption that delays between stages must be driven by the problem of constructing new concepts (see Le Corre & Carey, 2007, for one example). According to this reasoning, if such concepts were innate, we would expect children to quickly map words onto meanings once they are made available in their language input. However, the results of the current study bring this logic into question: number word learning requires not only the availability of relevant concepts but also the ability to identify how these concepts are expressed by a particular language. Our data suggest that this second problem is not trivial. Even on nativist views where the concepts “one”, “two”, and “three” are given innately, children may nevertheless struggle to identify how they are encoded by words in their language.

A third important conclusion suggested by our study is that becoming a Cardinal Principle knower is much more complex than previously argued, possibly involving several distinct steps. Sarnecka and Carey (2008) argued that learning the successor principle allows children to become CP-knowers on the basis of data that showed that children classified as CP-knowers by Wynn’s Give-a-Number task were more likely than subset knowers to exhibit understanding of the successor principle. Although it may be true that CP-knowers are more likely than subset knowers to understand the successor principle, Davidson, Eng, and Barner (2012) note that CP-knowers are nevertheless highly heterogeneous in their knowledge, and that the least experienced counters among them often show no evidence of understanding the successor principle. These findings led them to conclude that learning the successor principle and generalizing it to all numbers cannot be what drives children to become CP-knowers. Instead, Davidson et al. argued that when children become CP-knowers, their initial knowledge is purely procedural in nature and may better be understood as “Counting Procedure” knowers, at least until they show evidence of understanding the logic of counting. Our results are consistent with this conclusion. Like Davidson et al. (2012), we found that children first learn the counting procedure before showing evidence of understanding the successor principle, even for very small numbers, and that even our most experienced counters were still far from having generalized the successor principle to all numbers in their count list.

However, our findings add an additional wrinkle to the story reported by Davidson et al. First, consistent with the idea that learning the successor principle involves a type of epiphany or conceptual change, we found that if children were able to infer successors in one language, they were generally able to do so in their second language, too. However, curiously, we found that this transfer was remarkably restricted to specific numbers like the labels for “five” and “eight”. Because this result was not predicted, and has not yet been replicated, it remains possible that the degree of specificity we report is an anomaly. Still, it is clear that despite showing some evidence of transfer across languages, children did not generalize knowledge of the successor principle within languages. Although we are unable to explain precisely why this might be, given our current dataset, the result is consistent with two broad alternatives. First, one possibility is that children’s failure to generalize to larger numbers may be due to their relatively less fluid knowledge of the count sequence for larger numbers. Although children are sufficiently familiar with the list to allow them to name the successors of large words (Davidson et al., 2012), the additional problem of doing this while simultaneously tracking changes to the cardinality of a set may prove especially taxing for larger, less familiar, number sequences. Against this hypothesis, however, children’s ability to apply the successor function for a particular number in their NL2 was not predicted by their counting ability in this language. Instead, surprisingly, it was strongly predicted by their ability to apply the successor function for the same number in their NL1. This result is difficult to explain on the hypothesis that children’s familiarity with the counting procedure mediates their expression of the successor principle.

Another possibility is that successor knowledge is item-based both within a language and across languages. On this hypothesis, the mechanism that allows children to transfer knowledge of a blind counting procedure from NL1 to NL2 – i.e., the procedure that makes them CP-knowers – may involve forming a type of structure mapping between the count lists of their two languages, such that knowledge about particular sequences within count lists is transferred. Children might know that *five* and *cinco* represent the same quantity, as do *six* and *seis*, such that when they learn that *five* plus *one* equals *six* they can readily infer that *cinco* and *uno* equal *seis*. If we take seriously the specificity of transfer we report, then such a hypothesis may be the most parsimonious explanation of children’s behavior.

While the focus of this study was to explain delays between knower levels, one additional result is also implicit in the data that we reported. Generally it is assumed that because children move through knower level stages one-by-one in sequence, this sequence must therefore be necessary and by some accounts, universal (Piantadosi, Jara-Ettinger, & Gibson, 2014). Our study suggests that this need not be true, and that stages in principle can be skipped. Although we do not have longitudinal data to directly address this question, we found that when children were identified as CP-knowers in one language, they were very likely to also be CP-knowers in their second language. Because this was not true for lower knower levels, it would appear that a child who is a 3-knower in one language but only a 1- or 2-knower in their other might become a CP-knower in both languages at once, thereby skipping several stages in their secondary number language. This is interesting because it suggests that, at least in principle, small number word meanings can be defined from the start by their role in the counting routine, rather than by associations between individual words and set sizes (as is presumably normally the case). This result does not necessarily mean that such a process occurs in monolingual children, but it does raise the possibility that stages could in principle be skipped given the appropriate training.

To summarize, in a large sample of bilingual children, we found evidence that language-specific learning likely explains delays between early knower levels. However, once a child learns the counting procedure in either language, they are able to transfer this knowledge to their other language. After learning this counting procedure, children next learn the successor principle, which also transfers across languages, but in a curious, incremental, fashion. Overall, these data suggest that in bilinguals and monolinguals alike number word learning is importantly discontinuous and depends on different learning processes at different moments in development.

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