Two for one? Transfer of conceptual content in bilingual number word learning

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Abstract

Bilingual speakers are confronted with a unique challenge when learning language as they must learn to express the same concept in two separate languages. Here, we examine whether learning number words in one language (i.e., L1) facilitates the acquisition of analogous number words in a second language (i.e., L2) or whether extensive experience and familiarity with numbers within the second language is required to learn words in L2. To do so, we tested 68 bilinguals speakers between the ages of 2 and 4 years and show that conceptual knowledge of numbers in L1 reliably predicted children's conceptual knowledge of numbers in L2, suggesting that knowledge transferred from one language to the other. The effect, however, was limited to two developmental transitions: one-knower to two-knower and subset knower to CP-knower. Familiarity with L2 numbers as well as age were also significant predictors of children's conceptual understanding of numbers.

Keywords: bilingualism; conceptual transfer; word learning; number words.

Introduction

When children learn language, they are confronted with the problem of discovering how words encode conceptual content and thus encode their experience of the world. Although children eventually overcome this challenge and learn to associate specific words with specific concepts, this process is slow and often involves making difficult inductive inferences regarding the meanings of words (Quine, 1960). In these cases where slow, inductive inferences are required it is often unclear whether children's difficulty lies with forming the concept to be referenced (see Carey, 2009) merely mapping the correct linguistic symbol to the correct concept. This distinction between conceptual and linguistic development is difficult to disentangle because linguistic experience is almost always correlated with other factors that influence conceptual development including biological maturation and non-linguistic experience. Although there are some striking examples where language can be isolated from these other developmental factors, for example international adoptees as well as late learners of sign language, these cases may have limited generalizability due to severe linguistic delay or a sharp disruption of first language learning.

In contrast, bilingual children sometimes have limited knowledge of their second language (i.e., L2) while still having an intact first language experience (i.e., L1). This separation of conceptual development and L2 linguistic development can provide a unique test case for exploring how linguistic competence and conceptual development are related, while avoiding the challenges introduced by late-learners of sign language and international adoptees.

More specifically, bilingual speakers allows us to test whether conceptual learning accomplished first in one linguistic medium might facilitate the acquisition of corresponding content in a second language by eliminating several steps in the second language acquisition, thus resulting in a faster second language acquisition rate relative to the first language acquisition. In cases where children must acquire concepts before mapping language to those concepts, L2 acquisition of those words should be faster than L1 acquisition because these concepts can transfer from L1 to L2. In contrast, when children merely require increased exposure to the language in order to map a word to a pre-existing concept, no L2 facilitation would be expected because this process is necessarily language-specific.

In the present study we explored this idea by investigating the acquisition of number words (e.g., *one*, *two*, *three*) – a central test case in the study of conceptual change (see Carey, 2009). To do so, we tested children learning two languages and asked whether learning number word meanings in one language (i.e., L1) facilitates the acquisition of analogous number words in a second language (i.e., L2).

Early in acquisition, children as young as two years learn to recite a partial count list in a serial order (e.g., *one*, *two*, *three*, *four*, *five*, *etc.*), pointing at objects as they do so (see Gelman & Gallistel, 1978; Frye, Braisby, Lowe, Maroudas, & Nicholls, 1989; Fuson, 1988). Despite this seemingly procedural understanding of the relationship between counting and cardinality, children at this stage in development typically have little to no understanding of how counting represents number (i.e., how the last number of the count list represents the exact cardinality of the set) nor have they acquired the meanings of any of the number words (i.e., that numbers refer to specific quantities of a set). Soon, however, children begin to acquire an exact meaning for the number *one*, reliably giving one object when asked for one and more than one when asked for a contrasting number. After six to nine months as a 'one-knower,' children learn the meaning of *two*, becoming a 'two-knower' and, following this sequential pattern, learn the meanings of *three* and *four* (Wynn, 1990, 1992). During these early stages of number word learning, these children who are classified as one-, two-, three-, and four-knowers have meanings for only a subset of their number words (i.e., *one*, *two*, *three*, and *four*) and are thus collectively referred to as 'subset knowers.' Eventually, twelve to eighteen months after children first acquire the concept of *one*, they discover the cardinal principle that governs counting and recognize that the counting procedure can be used to label the cardinality of sets, at which point they are considered Cardinal Principle knowers or 'CP-knowers' (for evidence and discussion regarding these stages, see Le Corre & Carey, 2007; Lee & Sarnecka, 2011; Piantadosi, Goodman, & Tenenbaum, 2012; Sarnecka & Carey, 2008; Wynn, 1990, 1992; for discussion of what these children actually know, see Davidson, Eng, & Barner, 2012).

By the time children acquire the concept of cardinality, they have experienced at least three important qualitative shifts in their conceptual understanding of numbers that differentiates non-knowers from one-knowers, one-knowers from two-knowers, and subset knowers from CP-knowers (for review, see Carey, 2009). First, in order to learn the meaning of *one*, children must have already acquired their first linguistic representations of an exact cardinality. During this stage, children begin to recognize that number words represent specific numerosities, for example that *one* represents precisely one item rather than an undefined quantity or an amount defined by contrasting a number, such as not *one*. Second, when children acquire the meaning of *two* in languages that mark the singular-plural distinction, they experience a fundamental shift in their understanding of quantity that differentiates one-knowers from two-knowers. Unlike the concept of *one*, which corresponds with the singular marker 'a,' the specific concept of *two* is not marked by morphology in English, French, and Spanish (the languages targeted in this study) as the plural morphology can refer to sets of any size *two* or greater. This suggest that once children acquire the concept of two, they may undergo a conceptual leap as they must acquire this new concept of duality. Third, when children become CP-knowers, they learn of the unique relationship between counting and cardinality, specifically that the counting procedure assigns number words to sets. That is, children understand that the last number recited in the count list refers to the specific cardinality of the set.

The idea that each stage involves significant conceptual change predicts that, once such changes have occurred in one language (i.e., the PNL), subsequent learning of words that encode identical concepts in a second language (i.e., the SNL) should be substantially easier, at least to the degree that acquisition in the PNL is delayed by the process of constructing the relevant content. For those children who understand the unique relationship between counting and cardinality, learning may also be facilitated by recognizing that the two count lists server similar functions in the respective languages, thus allowing the formation of an analogical mapping between the two (for a discussion of analogical mapping, see Gentner, 1983; 2003; Gentner & Markman 1997).

Although the construction of conceptual content predicts that children's understanding of numbers may transfer from one language to another, it is equally possible that acquiring concepts in one language is independent of acquiring identical concepts in a second language. For example, children may learn the meaning of *one* as a function of the frequency of associations between the word 'one' and sets of one, a process that is irrespective of children's acquisition of 'uno' in Spanish or 'un' in French. That is, knowledge may be acquired as a result of exposure to the number word and, therefore, may be represented and stored in the language in which the concept was originally acquired and fail to automatically transfer to a second language.

Previous studies of mathematical competence in bilinguals find little evidence of transfer across languages. For example, bilingual speakers exhibit a strong preference for one language over another when performing arithmetic, sometimes preferring the language of original instruction despite being a dominant speaker of another language (Dehaene, 1997; Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Spelke & Tsivkin, 2001). When asked to perform simple mathematical computations in their second language, bilinguals not only perform calculations more slowly but also do so with lower accuracy (Kolers, 1968; Marsh & Maki, 1976; McClain & Huang, 1982). However, these studies tell us little about how earlier processes of bilingual learning and representational transfer take place. This is because these studies focus on mathematical operations, which may depend on a different, broader, set of representational resources, including memorized procedures and facts that may be uniquely dependent on linguistic encoding (for discussion, see Dehaene, 1997). Thus, although relevant to understanding the bilingual representation of number, these studies do not directly address whether early transfer of numerical concepts is possible in bilingual learners, and thus whether the foundations of arithmetic learning can be shared across languages. Here, within the context of number word acquisition, we explored this issue by testing children who were second language learners and assessing their ability to successfully denote the cardinalities of number words in each language.

In the present study, we tested two populations of bilingual 2- to 4-year-olds: French-English speakers and Spanish-English speakers. Children participated in two tasks in each language. First, they completed a Give-a-Number task, which assessed their comprehension of number words, and second they completed a counting task, which assessed their familiarity with the count list in each language thus acting as a proxy for their relative exposure to numbers. Both of these measures allowed us to ask whether, when controlling for counting ability and, thus, familiarity with numbers, knowledge of number words in the L2 was predicted by knowledge of number words in the L1. More specifically, we asked whether there was evidence of conceptual transfer in subset knowers, CP-knowers, or both. Thus, we tested whether transfer is mediated by earlier acquisition of exact cardinal meanings, like *one*, *two*, *three*, and *four*, and whether it can be mediated by learning how the counting procedure works when children become CP-knowers.

Method

Participants

Sixty-eight bilingual learners of either English and French or English and Spanish from the San Diego metropolitan area participated. In the French-English (FE) sample, 23 children (13 male) between the ages of 2;11 and 5;0 (*M* = 3;9, *SD* = 0;6) participated. These children were primarily recruited from a French language preschool where instruction is conducted exclusively in French. In the Spanish-English (SE) sample, 45 children (22 male) between the ages of 2;2 and 5;0 (*M* = 4;2, *SD* = 0;9) participated after being recruited from either a Spanish immersion preschool or a departmental database. Participants were from predominately Non-Hispanic Caucasian or from Hispanic middle-class families and were contacted either through letters distributed by teachers at local preschools or by phone using a departmental recruitment database. An additional 15 children participated but were excluded for completing the tasks in a language other than the one being tested, for example, speaking in Spanish when the tasks were conducted in English (N = 2), for being trilingual speakers (N = 2) and for failure to complete the counting task in at least one language (N = 11).

As reported by the caregivers, 5 of the FE children were primarily French speakers, 14 of the SE children were primarily Spanish speakers, and 43 of the FE (N = 14) and SE (N = 29) children were primarily English speakers. Two additional children were listed as having both Spanish and English as their primary language. For the remaining four children, no primarily language was reported.

Procedures

Testing sessions lasted approximately 20 minutes and consisted of two tasks: a Give-a-Number task followed directly by a counting task. Both tasks were administered once in English and once in either French or Spanish, such that each child completed both tasks in one language before completing identical tasks in his or her second language. The order in which the languages were tested was randomized across children. As an additional measure of a child's fluency in both languages, we initially asked caregivers to complete the Language Development Survey in English and either French or Spanish (Rescorla, 1989). However, because many parents were unable to complete the survey in both languages (e.g., parents were monolingual), we discontinued its use and do not report the data here.

Give-a-Number Task This task was adapted from Wynn (1992) using the non-titration method developed by Sarnecka and Carey (2008) and was used to assess children's comprehension of number words in each language. The experimenter began by presenting the child with a red paper plate and ten plastic fish and inviting the child to play a game with her toys. For each trial, the experimenter asked the child to place a quantity of the fish inside the red circle, omitting singular and plural markings by asking, for example, "Can you put *N* in the red circle? Put *N* in the red circle 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?" and encouraged the child to count in the language tested. If the child recognized an error, the experimenter allowed the child to change his or her response. Following the completion of each trial, the objects were returned to their original positions and the next trial was administered until all were completed.

Participants completed up to twenty-one trials, consisting of three trials for each of the seven numbers tested (i.e., 1, 2, 3, 4, 5, 8, and 10). The order was quasi-randomized such that each number was tested once before any number was repeated, thus resulting in three sets of seven numbers. 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*, did so in response to a request for *N* on at least two-thirds of all trials. If children responded correctly on two out of the three trials for each number tested, then they were classified as CP-knowers.

Counting Task After administering the Give-a-Number task, the experimenter asked the child, "Can you count as high as you can?" If the child failed to respond or indicated that he or she did not know how to count, the experimenter provided the first number of the count list (e.g., *one*) with rising intonation in an attempt to clarify the instructions and encourage the child to continue counting. In the event that the child failed to respond after the prompt, the experimenter reassured the child and ended the task.

After the task, the experimenter recorded the highest number recited, noting any errors such as omission (e.g., "…13, 14, 16") and cyclical repetition (e.g., "…8, 9, 10, 1, 2"). The child's highest number was defined as the largest number counted to before error. For example, fourteen was the highest number recorded for a child who omitted fifteen, whereas ten was the highest number recorded for a child who cyclically repeated the first ten numbers. In cases where children failed to accurately count at the onset of the task yet recited a string of numbers (e.g., "6, 7, 8…"), the highest number was recorded as zero. In contrast, children who refused to count were excluded from the analysis.

For each child, the language with the highest number recorded (e.g., fourteen) was coded as his or her Primary Number Language (i.e., PNL), while the language with the lowest number recorded (e.g., diez) was coded as the child's Secondary Number Language (i.e., SNL). For example, a child who counted to fourteen in English and diez in Spanish was coded as having English as her PNL and Spanish as her SNL. In cases where the highest number recited was matched in both languages (e.g., ten and diez), PNL was defined as the child's primary language as reported by the parent (N = 1) or, when the parent indicated no preference for either language, was instead coded as

English (N = 1). The highest number children counted to without error ranged from 1 to 100 in PNL and from 0 to 39 in SNL. Except in the one case noted earlier, parental report was not used to determine a child's primary language for numbers. This is because children frequently encounter number words in formal classroom settings where instruction is often conducted in a language that is not spoken by the parent.

Results

Figures 1 and 2 reveal the mean performance on the counting task in each language at each knower level separated by FE speakers and SE speakers. As expected, children's familiarity with the count list as reflected in the highest number recited increased as their comprehension of number words progressed. Preliminary analyses revealed no significant difference in performance between FE and SE children. As a result, all analyses are collapsed across languages.

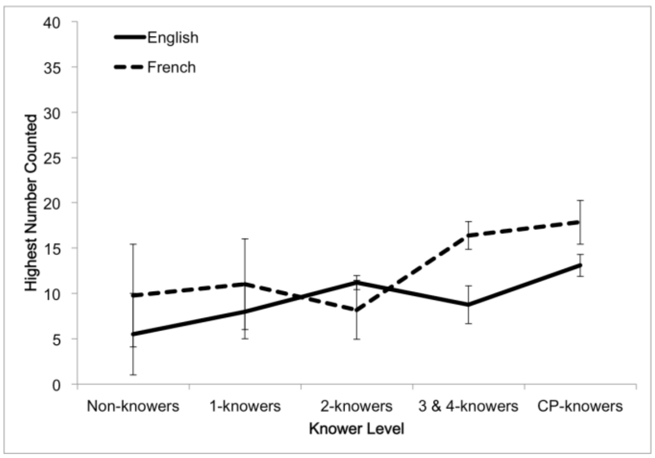

Figure 1: The mean performance on the counting task by knower level for French-English speakers.

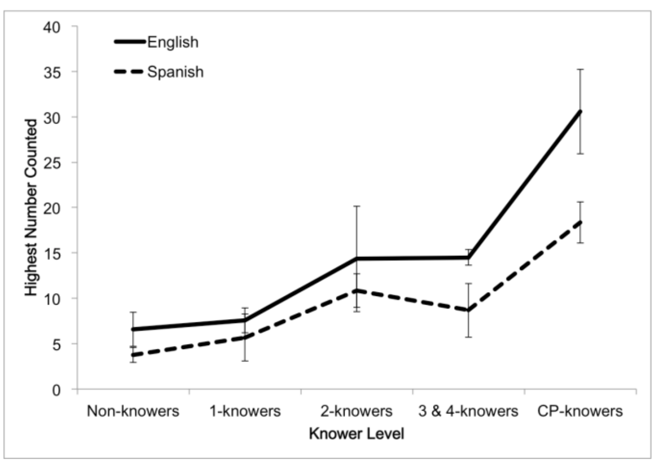

Figure 2: The mean performance on the counting task by knower level for Spanish-English speakers.

To examine the relationship between children's comprehension of numbers, children's familiarity and exposure to number words, and children's general maturation, we conducted Spearman's correlations between knower level, highest count, and age. Not surprising, SNL knower level was significantly correlated with PNL knower level, $\rho = 0.81$, $p < 0.01$, SNL counting, $\rho = 0.72$, $p < 0.01$, and age, $\rho = 0.67$ =, $p < 0.01$, indicating that children's understanding of numbers deepened as a function of their familiarity with the count list and their general cognitive development.

To isolate the individual effects of familiarity with the count list on the one hand and comprehension of numbers on the other hand, we conducted a logistic regression to predict children's knower level in SNL using SNL counting, PNL knower level, and age as predictors. The full model, when compared against a constant only model, significantly predicted SNL knower level, indicating that the predictors as a set reliably differentiated children's knower level in SNL, $r^2(U) = 0.45$, $\chi^2(6) = 85.8$, $p < 0.01$, with a misclassification rate of 0.27. A likelihood ratio test further revealed a main effect of PNL knower level, $\chi^2(4) = 24.07$, $p < 0.01$, suggesting that children's comprehension of numbers in PNL significantly predicted children's comprehension of numbers in SNL, perhaps through conceptual transfer (see Figure 3). However, the effect was restricted to two developmental transitions, as reflected in the parameter estimates: a transition from a 1-knower to a 2-knower, $\beta = 2.91$, $\beta(SE) = 1.13$; $\chi^2(1) = 5.20$, $p = 0.02$, and a transition from a subset knower to a CP-knower, $\beta = 2.41$, $\beta(SE) = 0.91$; $\chi^2(1) = 3.51$, $p = 0.06$. There were also effects of SNL counting, $\chi^2(1) = 12.05$, $p < 0.001$ and age, $\chi^2(1) = 3.90$, $p = 0.05$.

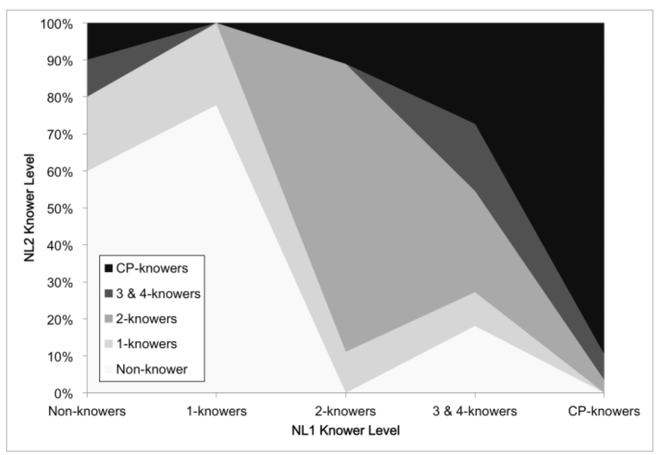

Figure 3: The percentage of children at each SNL knower level by PNL knower level.

Discussion

We asked how transfer of number concepts from a first language and familiarity with numbers in a second language may facilitate the acquisition of number words in the second language. We found that familiarity with number words facilitated the acquisition of number concepts and that when children acquired the meaning of number words in their primary language that knowledge transferred to their secondary language during two stages of conceptual development. Transfer was seen when children became two-knowers and when they became CP-knowers.

One possible mechanism explaining the effect of transfer at the level of CP-knowers is a process of analogical reasoning that results in the mapping of analogous concepts across languages. As CP-knowers, children not only learn the meanings of numbers greater than *four* but also recognize the unique relationship between counting and cardinality. More specifically, CP-knowers learn that counting can be used to label the cardinality of sets and eventually that each successive number is one greater than the preceding one (i.e., N+1). Importantly, however, by recognizing that number words belong to a class that forms a structured list, children may infer that the lists in each of their languages operate according to the same principles. As a result, children who are CP-knowers may transfer their knowledge of counting from one list to the other through this process of analogical reasoning.

Another possible mechanism is that number word learning, in general, is a process of conceptual change in which new concepts, such as *one*, *two*, and *three*, are constructed. According to Carey (2009), prior to learning small number words, children cannot represent exact cardinalities via language (see also Le Corre & Carey, 2007; Sarnecka & Gelman, 2004; Wynn, 1990, 1992). Although infants can keep track of small numbers of individual objects (Feigenson & Carey, 2005), and can represent the approximate cardinality of large sets (e.g., Xu & Spelke, 2003), they may not be able to represent the precise numerosity of sets as a property distinct from the individuals themselves. On this view, number word learning is hard, in part, because it involves creating new conceptual resources. Consequently, once these resources have been built, learning the same meanings in a second language should be substantially easier – i.e., there should be "conceptual transfer." In this case, language transfer might also be observed in bilingual speakers during each of the subset stages of number word acquisition.

In contrast, we failed to find evidence of any transfer from the primary to the secondary number language when children become 1-knowers and 3-knowers. This supports an alternative view that children learn the meanings of these number words (*three* and *one*) as a function of their exposure to the number words in their secondary number language, indicating that they must employ a language-specific mapping between words and meanings. That is, children may consistently hear the word "uno" in association with sets of one and, as a result, form direct mappings between the specific word, "uno," and the quantity, one. Without knowledge of the count list structure that CP-knowers are privy to, bilingual subset knowers are unable to draw comparisons between these numbers. Consequently in these two cases, children gained little advantage in their SNL number knowledge by graduating to the next level of n-knower in PNL.

While transfer failed to occur at most subset knower levels, there was evidence that the transition from being a one-knower to a two-knower did transfer across languages despite these children's lack of knowledge of the count list structure. This particular transition may mark a significant, conceptual milestone in number word learning that can be transferred across languages. Whereas English, French, and Spanish use singular-plural morphology to mark the exact quantity of *one* (e.g., "a"), none of these languages use morphology to mark the exact cardinality of *two* (e.g. a dual marker like that used in Slovenian, Corbett, 2000). For this reason, there may be a conceptual barrier that children have to pass before they are able to map number words *two* or greater onto their corresponding quantities. Once this barrier is passed in one language, children are able to learn the words *two* and *three* in both languages, given that they have sufficient familiarity with number words in both languages. After passing this barrier, the transition from two-knower to three-knower is not transferred across languages, unlike the previous transition from one-knower to two-knower.

The singular-plural morphology in English, French and Spanish also explains why no transfer was seen when children become 1-knowers. The singular-plural morphology may facilitate a concept of the exact cardinality of one before children begin the number acquisition process (Barner, Libenson, Cheung, & Takasaki, 2009).

In conclusion, we found that learning number words in one language facilitates the acquisition of the analogous number words in a second language at particular points in the number word acquisition process that are characterized by conceptual milestones. Although we suggest that relatively simple concepts, like counting, transfer across languages, it remains uncertain to what extent this occurs. Future studies should explore the generalizations and limitations of conceptual transfer by testing more advanced numerical abilities like estimation.

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