How does multilingualism interact with early number concepts?

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Abstract

This study explores the impact of multilingualism on early number concepts in preschool children. We compared the performance of mono- and multilingual preschoolers on four tasks that test early number concepts. The tasks were counting, Give-N, magnitude judgements, and number identification. The sample included 59 Australian children aged 3.5 to 5.5 years, with 25 multilingual children exposed to at least one language in addition to English. Our results indicated that age was a significant predictor across all tasks, and mono- versus multilingual experience alone did not have a substantial effect on these tasks. However, there was a significant age-by-language experience interaction in the counting task, where older multilingual children counted significantly higher than the older monolinguals. These findings lend new insights into the nuanced role that multilingualism plays in the development of number concepts.

Keywords: Give-N; number concept; preschooler; multilingualism

Introduction

Globally, multilingualism is increasingly recognised as the norm rather than the exception. Estimates suggest that over half of the world's children grow up in environments where more than one language is spoken. This linguistic diversity has profound implications for cognitive and educational development, yet research in developmental psychology often focuses on monolingual children, leaving a gap in our understanding about whether multilingualism creates a different pathway to key developmental concepts.

Here we focus on the acquisition of number concepts like cardinality, magnitude judgements, verbal counting, and numeral identification. We use four well-established tests to examine how early number concepts in multi- and monolingual Australian preschoolers compare to the ones reported in the current literature.

Development of early number concepts

One of the earliest steps in learning to count typically starts around two years of age. Toddlers start to produce counting lists. Their counting consists of memorised sequences without an understanding of numerical meaning (Carey, 2009; Wynn, 1990, 1992). The ability resembles singing a song in an unfamiliar language. For children growing up with more than one language, they typically learn to count in more than one language. The counting sequences are well aligned across languages because they each have a specific order, and the high alignment could foster comparisons and faster learning (Gentner & Hoyos, 2017).

Understanding the meaning of the counting words "one, two, three, and eventually four" is a slow process. In the United States, many two-year-olds understand the exact meaning of *one* (e.g., you can have *one* cookie) and these children are called one-knowers. Approximately 6-9 months later, they learn the exact meaning of *two*, and these children are called two-knowers. Several months later, they become three-knowers, and sometimes there is a four-knower period. Together, these children are called subset-knowers because they only know a subset of the number word meanings (Le Corre & Carey, 2007; Sarnecka & Lee, 2009). Next, the slow, gradual learning process shifts to rapid inductive inference. After fixing the meaning of the first few words, children appear to have an insight. For example, when children are asked to produce eight items, they use the counting sequence to enumerate the set (Davidson et al., 2012). This analogy has been documented in children across many different languages (Barner, Libenson, et al., 2009; Piantadosi et al., 2014; Sarnecka et al., 2007). When children acquire this insight, they become cardinal-principle knowers in that they can use the counting routine to determine the exact number of items in any set up to the limit of their count list.

The Give-a-Number (Give-N) task has become the standard for assessing children's cardinal knowledge level

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(Barner, Chow, et al., 2009; Le Corre & Carey, 2007; Schaeffer et al., 1974; Sella et al., 2017; Wynn, 1990, 1992). In this task, children are typically presented with a large set of items and are asked to give a specific number of them to the experimenter.

Our study is novel because we look at the influence of growing up with two or more languages on the development of number concepts like the ones described above. More specifically, we investigate the transition from subset knower to cardinal-principle knower. We predict that if the relational insight of becoming a cardinal-principle knower relies on analogy, then exposure to multiple languages could foster comparison across languages and facilitate the analogical insight into a cardinal-principle knower.

Another aspect of early number knowledge is the child's non-symbolic, approximate number sense (ANS) (Libertus & Brannon, 2009; Starr et al., 2013). This innate ability enables children to estimate and compare quantities without relying on formal number symbols. Even infants can differentiate between sets of varying sizes, such as identifying that a group of sixteen objects is larger than a group of eight (Brannon, 2002; Suanda et al., 2008). In preschool, children's ANS accuracy correlates with their understanding of cardinality, numeral identification, and symbolic magnitude judgements (e.g., Geary & vanMarle, 2016; vanMarle et al., 2014). Our prediction is that the number of ambient languages would not influence ANS since it emerges early and maintains consistency through early childhood.

Early number concepts and multilingualism

Recent research highlights both the advantages and challenges associated with number concepts in multilingual children. On the one hand, acquiring multiple languages enhances executive functions, such as working memory and cognitive flexibility, which are foundational for early mathematical skills (Chu et al., 2016; Daubert & Ramani, 2019). On the other hand, multilingual children may face challenges, such as reduced exposure to numerical vocabulary in each language, potentially delaying their acquisition of the cardinality principle (Mou et al., 2023; Whitehead et al., 2024). Wagner et al. (2015), one of the few papers that have looked at bilingual children and number concepts, found that children learn the meanings of small number words (e.g., "one," "two," "three") independently in each language. Interestingly, children tend to acquire the ability to count larger sets (five or more) simultaneously across both languages, suggesting that early counting challenges arise from conceptual mapping rather than linguistic differences. Furthermore, bilingual children's understanding of successors develops incrementally, with some transfer between languages, indicating that the logic of positive integers is not stored in a language-specific format. Sarnecka et al. (2023) expanded on this by demonstrating that early symbolic number concepts, such as transitive counting (e.g., counting individual objects) and intransitive counting (e.g., counting by reciting the number song), Give-N task, and numeral identification, follow a clear progression. Proficiency in foundational abilities like counting is necessary for success in more advanced tasks, such as number line estimation. Notably, the study found that bilingualism does not impact these abilities positively or negatively. Furthermore, bilingual children performed as well or better in their preschool language (English) compared to their home language (Spanish). One limitation of these studies is that most of the data collected were from the United States and most of the studies have Spanish as the second language.

The Experiment

To better understand the interplay between multilingualism and number acquisition, it is necessary to look at more diverse linguistic samples. Here, we test a sample of Australian English children, who were divided into monolingual or multilingual from a diverse range of languages (see Table 1). We posed two key questions: (1) Do early number concepts differ between monolingual and multilingual preschoolers? (2) Do multilingual children exhibit different knower levels compared to monolingual children of the same age?

Method

Participants

Fifty-nine children aged 3 years 5 months to 5 years 6 months (M_{age} = 53.59 months, SD = 7.09) participated in the study. Of these, 25 were multilingual (M_{age} = 52.04 months, SD = 7.20; 15 females, 10 males), with at least 80% exposure to one or more languages other than English in the family environment, see Table 1 for an overview of the language diversity. Ninety-one percent of the parents indicated that the child was learning the two (or three) languages from birth. The remaining 34 children were monolingual (M_{age} = 54.68 months, SD = 6.90; 17 females, 17 males), with at least 80% or more exposure to English only. Language exposure was assessed using the LEAP-Q (Marian et al., 2007). All children acquired English as one of their languages. Parents indicated that all children were highly proficient in understanding English (age-appropriately). Most mothers (monolingual group: 82%; multilingual group: 88%) had completed a technical degree or higher. Parents provided informed consent before the experiment. All procedures were approved by the Western Sydney University Ethics Committee. Parents were given $30 as compensation for their participation, and their child was given a graduation certificate and a gift.

Materials and Procedure

Counting

Children were asked to count as high as possible, with a maximum of 120. The highest score corresponded to the highest number the child counted without errors.

Give-N

Children were asked to place a specified number of ducks on a plate. Children were prompted on each trial to "count and make sure it's [*N*]." With this prompt, children were given the opportunity to recognise and correct any mistakes. Their final responses were documented and used to inform the subsequent trial. The numbers 1-10 were presented in a fixed but random order. A titration method was used: if the child placed the correct number, the next higher number was asked; if incorrect, the next lower number was requested. The highest level was determined if the child correctly placed the requested number of ducks on the plate in two out of three trials. "No" responses were coded as incorrect.

Magnitude Judgement

Children completed 24 trials using the Panamath program on the discrete quantity discrimination task (http://panamath.org/). The parameters were modelled on Geary et al. (2019). Each trial displayed arrays of 5 to 21 dots for 2,533ms, with ratios of blue to yellow dots randomly varying between 1.29 and 3.38. The accuracy in identifying the side with more dots was the outcome measure (Geary et al., 2019).

Numeral Identification

Children were shown 20 cards (numbers 1-20) face down and randomised on a table. The child picked one card at a time, turned it over, and told the experimenter what number was printed on the card while handing the card to the experimenter. This process was repeated until all the cards were gone. The score was the number of correctly named numerals.

Table 1: Language diversity and number of children per language

Language 1	Language 2	Language 3	Nº of children
Bangla	English		1
Cantonese	English		1
Cantonese	English	Spanish	1
Cantonese	Korean	English	1
English	Tagalog		2
English	Cantonese		2
English	Korean		1
English	Turkish	German	1
English	Gujarati		1
English	Hindi		1
English	Arabic		1
English	Vietnamese		1
Greek	English		1
Gujarati	English		1
Hindi	English		2
Korean	English		1
Nepali	English		1
Punjabi	English		1
Swiss German	English		1
Tagalog	English		1
Urdu	English		1
Vietnamese	English		1
English			34

Results

Do early number concepts differ between monolingual and multilingual preschoolers?

We examined whether number concepts differed between monolingual and multilingual children using linear regression models (Counting, Magnitude Judgement, and Number Identification) with age, language group (mono- or multilingual), sex, maternal education, and their interaction as predictors for the different tasks.

Counting Task

On average, monolingual children counted to 29 (SD = 34), while the multilingual children counted to 36 (SD = 42) out of the maximum of 120. The model accounted for around 47% of the variance (R^2 = 0.4688, adjusted R^2 = 0.419, $F(5,53) = 9.35$, $p < .001$). Age was a strong positive predictor ($\beta = 3.63$, $p < .001$), and the interaction between age and language group was significant ($\beta = -1.22$, $p = .032$), indicating a differential effect of age on counting performance between monolingual and multilingual children, see Figure 1. Language group alone showed a marginal effect ($\beta = 57.54$, $p = .060$). Sex and maternal education were not significant predictors ($p > .24$ for both).

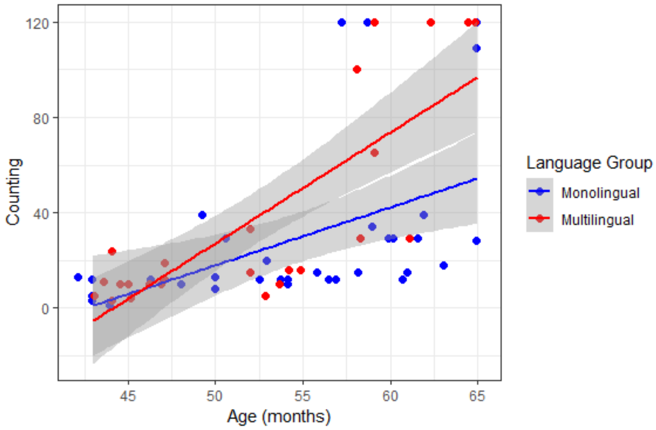

Figure 1: Comparison of performance by monolingual and multilingual children on Counting Task. The dots represent the highest count of each participant (blue monolingual, red multilingual children). The grey shaded area represents the 95% confidence level interval.

Magnitude Judgement

On average, monolingual children achieve around 79% (SD = 16.60) and multilingual children 75% (SD = 23.08) accuracy in the magnitude judgement task. The model explained around 48% of the variance ($R^2 = 0.478$, adjusted $R^2 = 0.428$, $F(5,53) = 9.69$, $p < .001$). Age significantly predicted ANS performance ($\beta = 1.82$, $p < .001$). Neither language group, sex, maternal education, nor the interaction between age and language group were significant predictors ($p > .10$ for all), see Figure 2.

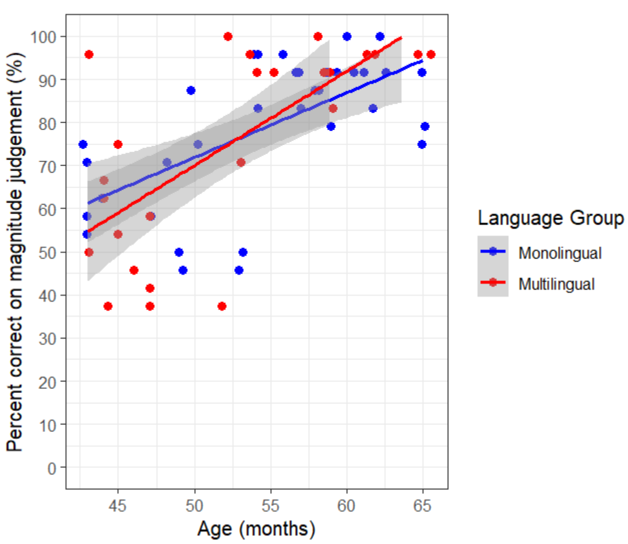

Figure 2: Comparison of performance by monolingual and multilingual children on Magnitude Judgement. The dots represent the highest percentage of correct responses for each participant (blue monolingual, red multilingual children). The grey shaded area represents the 95% confidence level interval.

Numeral Identification Task

The mean number of correctly identified numbers was 11.41 (SD = 6.82) in the monolingual children group and 12.52 (SD 7.01) in the multilingual children group. The model explained around 48% of the variance ($R^2 = 0.479$, adjusted $R^2 = 0.429$, $F(5,53) = 9.73$, $p < .001$). Age significantly predicted numeral identification ($\beta = 0.67$, $p < .001$). Neither language group, sex, maternal education, nor the interaction between age and language group were significant predictors ($p > .10$ for all), see Figure 3.

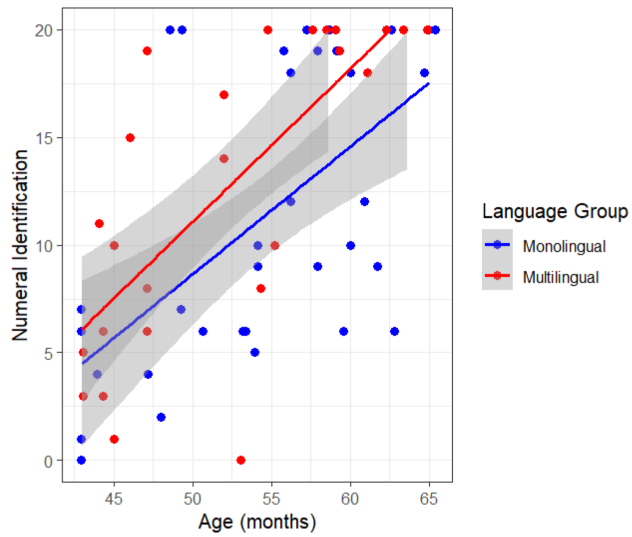

Figure 3: Comparison of performance by monolingual and multilingual children on Numeral Identification. The dots represent the highest count for each participant. The grey shaded area represents the 95% confidence level interval.

Do multilingual children exhibit different knower levels compared to monolingual children?

To answer this question, we performed an ordinal regression model of the Give-N performance with age and language group (monolingual vs multilingual). Table 2 shows the knower levels of the two language groups.

Table 2: Number of children per knower-level of monolingual and multilingual children

Task	Monolingual	Multilingual
Pre-number knower	1 (3%)	0 (0%)
1-knower	0 (0%)	0 (0%)
2-knower	1 (3%)	2 (8.0%)
3-knower	1 (3%)	0 (0%)
4-knower	2 (6%)	3 (12%)
5-knower	3 (9%)	2 (8%)
CP-knower	26 (76%)	17 (68%)

The mean age of monolingual CP-knowers was 56.23 months (SD = 5.71), and that of multilingual was 55.10 months (SD = 6.51), see Figure 4.

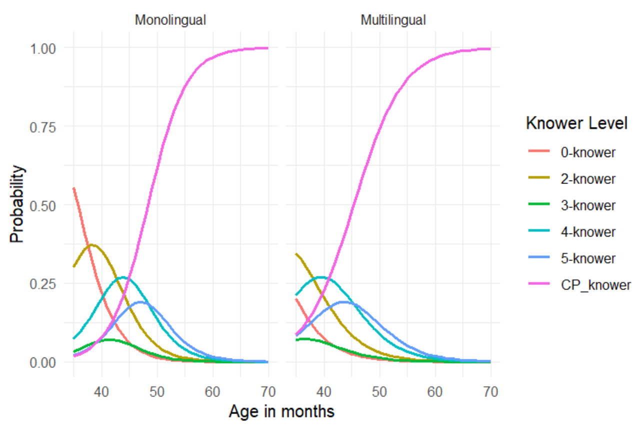

Figure 4: Comparison of performance by monolingual and multilingual children on Give-N.

Age had a highly significant effect on the Give-N performance, $\chi^2(1) = 42.228$, p < .001, indicating that older children were more likely to score higher in the Give-N task. However, language group ($\chi^2(1) = 3.169$, $p = .075$) and the interaction between language group and age was not significant ($\chi^2(1) = 0.054$, $p = .816$).

Discussion

The present study investigated the relationship between multilingualism and early number concepts among Australian preschool children. Across all tasks, age was a consistent and significant predictor of performance in that older children performed better. These findings align with the well-established findings from the United States (Barner, Chow, et al., 2009; Wynn, 1990).

There was a significant age-by-language interaction in the counting task, showing that multilingual children could count significantly higher than monolingual children in the older part of the age range. One possible interpretation is that multilingual children find it easier to learn the count sequences because they are exposed to two exemplars, and the alignment across exemplars could facilitate learning the relations (Gentner & Hoyos, 2017). A remaining question is: at what age do the monolingual children catch up to the multilingual children on the highest count?

One place where we predicted finding a language-experience difference but did not find one was for the Give-N task. One explanation for this could be due to a ceiling effect in our sample, with over 70% of the participants performing as cardinal-principle knowers. By testing more young children, we will gain clarity on this problem.

Previous studies have shown mixed results when exploring the impact of multilingualism on early number concepts. Some research suggests that bilingual or multilingual children might experience delays compared to their monolingual peers, especially in tasks that involve a high degree of verbal components (Bar & Shaul, 2021; Bonifacci et al., 2016; Garcia-Martin et al., 2024), while other studies suggest that children who speak more than one language outperform their monolingual peers, at least in some tasks (e.g., scaffolded number-line task, Sarnecka et al., 2023). In our sample, we can largely rule out the possibility that task effects were driven by language barriers related to English proficiency. Most parents reported high levels of English proficiency for their children, and 91% of the multilingual participants had been exposed to English from birth. This supports findings from recent systematic review showing no differences between high-proficient bilinguals and monolinguals in task performance (Gonzalez-Martin et al., 2024).In our study, age remained the dominant predictor of performance, with no significant differences between multilingual and monolingual children on cardinality, magnitude judgement, and numeral identification. Both groups performed similarly, suggesting that the basic number concepts assessed in these tasks, which include magnitude judgements and identifying written numerals, are likely driven by factors such as age rather than linguistic factors per se. This is in line with findings from Sarnecka et al. (2023), who found no significant impact of bilingualism on early number concepts.

While multilingual children did not exhibit uniformly superior performance, an age-by-language group interaction in the Counting task suggests that the influence of multilingualism may vary across developmental stages. This aligns with research indicating that bilingual children often develop certain cognitive abilities, such as working memory and cognitive flexibility, more robustly than their monolingual peers (Chu et al., 2016; Daubert & Ramani, 2019). These cognitive advantages may facilitate number concept learning indirectly by supporting attentional control and problem-solving. However, since this effect was not consistently observed across all tasks, we propose that a language-specific explanation might be more plausible.

Multilingual environments may also expose children to multiple exemplars, potentially fostering a comparison that highlights the alignment across two languages. The regularities of one could highlight the important relations. For example, East Asian languages feature regular oral counting systems that directly correspond to the written number system, contrasting with English's irregular counting system (e.g., "twelve" vs. "ten-two" in Mandarin). Historical studies have suggested that English speakers might face a disadvantage due to this irregularity (Edgeworth & Edgeworth, 1835). Empirical research further supports this: Miller et al. (1995) found that Chinese children exposed to a regular counting system advanced in counting higher numbers faster than their American peers. Similarly, Dowker et al. (2008) found that bilingual Welsh-English-learning children, whereby Welsh has a regular and English an irregular counting system, demonstrate advantages in reading and comparing two-digit numbers compared to monolinguals. Future studies could elaborate on these ideas by looking specifically at the age of transition in a longitudinal study within these linguistically diverse samples.

In our sample, 14 of 25 multilingual children were exposed to a regular counting system, suggesting that such exposure may aid their English counting skills. These findings imply that some multilingual children may have a slight advantage in counting tasks. However, larger sample sizes are needed to substantiate this conclusion. It would also be interesting to model future studies on the transitive/intransitive distinction that Sarnecka et al. (2023) introduced to test whether the linguistic advantage in transitive counting is also generalised to higher intransitive counting levels in these populations.

Limitation

A notable limitation of the present study is the underrepresentation of a younger age group (e.g., 3;0-3;5 years). Given that number concepts develop rapidly in early childhood, it is possible that the developmental trajectories of younger children may differ from those observed in the older cohort. This limitation highlights the need for further data collection from younger children to more accurately assess the impact of age on number concepts. Additional data from this group will be gathered and analysed prior to the conference, which will help to address this problem and provide a more comprehensive understanding of the developmental trajectory.

Conclusion

Our findings suggest that multilingual exposure does not significantly delay or impede the development of early number concepts. This aligns with previous research that indicates bilingual and multilingual children can develop these abilities at similar rates to their monolingual peers (Sarnecka et al., 2023). However, our results also point to the potential role of specific linguistic features, such as the regularity or irregularity of a language's counting system, in supporting counting. For instance, languages with a regular counting system, such as Mandarin, may facilitate a more straightforward understanding of counting compared to languages like English, which has irregularities in its number words (e.g., "eleven" vs. "ten-one"). This suggests that the structural properties of a language could play a significant role in shaping early number concepts, offering a more nuanced view of how multilingualism interacts with cognitive development. Further research is needed to explore these linguistic influences in greater detail, particularly within different multilingual contexts.

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