Preschool Origins of Cross-national Differences in Mathematical Competence: The Role of Number-naming Systems

Kevin F. Miller, Catherine M. Smith, Jianjun Zhu, and Houcan Zhang

1Psychology Department and 2Beckman Institute for Advanced Science and Technology, University of Illinois at Urbana-Champaign; 3Psychological Corporation; and 4Beijing Normal University

Abstract—Differences in mathematical competence between U.S. and Chinese children first emerge during the preschool years, favor Chinese children, and are limited to specific aspects of mathematical competence. The base-10 structure of number names is less obvious in English than in Chinese; differences between these languages are reflected in children’s difficulties learning to count. Language differences do not affect other aspects of early mathematics, including counting small sets and solving simple numerical problems. Because later mathematics increasingly involves manipulation of symbols, this early deficit in apprehending the base-10 structure of number names may provide a basis for previously reported differences in mathematical competence favoring Chinese schoolchildren.

Because mathematics is fundamental to scientific discourse, cross-national differences in mathematical development constitute an issue of considerable importance. Dramatic differences in mathematical achievement between U.S. and Asian schoolchildren have been documented (Husen, 1967; Stevenson, Lee, & Stigler, 1986; Travers et al., 1987). These differences in achievement have been attributed to differences in basic abilities (Lynn & Dziobon, 1980), in cultural values and emphases (Stevenson et al., 1986), and in the content and contexts of instruction (Stevenson & Stigler, 1992; Stigler, Lee, Lucker, & Stevenson, 1982). Looking more closely at when such differences emerge in development and which mathematical abilities they involve may lead to a more refined understanding of the sources of the mathematical shortcomings American students exhibit. Cross-language data will also contribute to understanding how cultural and general developmental factors interact in developing mathematical competence. The research reported here demonstrates that (a) differences in mathematical competence appear well before school entry, by age 4 years, and (b) these early differences reflect variations in number-naming systems that make accessing some mathematical relations more difficult in English than in Chinese.

Early counting is an ideal domain for studying effects of language on cognitive development, because it is at the same time a universal cognitive accomplishment and one that utilizes specific cultural systems (i.e., for representing number). Although the base-10 Arabic numerals are used throughout the world, names for numbers in different languages reflect older, often more complex systems (Hurford, 1975, 1987; Menninger, 1969). The specific pattern of similarities and differences between Chinese and English suggests specific points in acquisition at which differences in structure might be reflected in different patterns of acquisition. For example, the base-10 Arabic numerals are used throughout the world, names for numbers in different languages reflect older, often more complex systems (Hurford, 1975, 1987; Menninger, 1969). The specific pattern of similarities and differences between Chinese and English suggests specific points in acquisition at which differences in structure might be reflected in different patterns of acquisition. Four portions of the number-naming sequence are particularly relevant. First, counting to 10 in either Chinese or English requires mastering an unordered set of names (i.e., one cannot predict that nine follows eight or that jiu follows ba). Second, after 10, the languages diverge. English names for 11 and 12 bear only a historical relation to one and two, and names for numbers in the teens are formed by a different rule than for higher numbers, with the unit value named before the decade value. Chinese number names above 10 follow a consistent base-10 rule (e.g., a literal translation of the Chinese name for 11 is "ten one"). Third, in the range from 20 to 99, both systems converge on roughly isomorphic rules: A decade unit (e.g., six) is followed by –ty or ten and then a unit value, if any, in the range from 1 to 9. The only morphological difference between Chinese and English names for numbers from 20 to 99 is that Chinese uses unit values for decade names (instead of modifying them as in English twenty- or thir-) and uses the unmodified name for 10 to designate decades (instead of the English –ty). Finally, above 100, both Chinese and English form hundred names by using unit values from 1 to 9 plus a term for the unit (hundred bāi). With one exception, names for the last two digits of numbers above 100 (e.g., the 12 of 112) are not affected by being incorporated into a larger number. The single exception is that Chinese number names from 100 to 109 (and 200 to 209, etc.) interpose a term (ling) to represent the absent 10s value. In general, however, both languages converge after 20 on a regular base-10 system for forming number names.

A previous comparison of early mathematical development in the United States and China reported some differences favoring Chinese children exist in the year prior to school entry (Miller & Stigler, 1987), suggesting that American children enter school with a mathematical disadvantage. If the source of this disadvantage is the complexity of English number names, stronger predictions can be made: First, differences in counting ability between U.S. and Chinese children should emerge only after children begin to learn the teens, where differences in the number-naming sequence first appear. Second, differences in counting ability should focus on areas in which the languages differ; specifically, American children should have greater trouble learning teens names and the base-10 structure of number names than do Chinese children. Third, cross-
language differences in counting competence should generally be limited to the symbolic system of number names, and not involve other aspects of counting, such as understanding the mathematical basis of counting or using counting in problem solving (Gelman, 1991; Gelman & Gallistel, 1978). To test these predictions, data on a series of counting tasks were collected from preschoolers in the United States and China.

METHOD

Subjects

Subjects were recruited from preschools and through advertising in university communities in Champaign-Urbana, Illinois, and Beijing, China. Chinese subjects (total = 99) were twenty-nine 3-year-olds (3.2 to 3.95 years; mean age = 3.6 years), thirty-five 4-year-olds (4.0 to 4.9 years; mean age = 4.5 years), and thirty-five 5-year-olds (5.0 to 5.97 years; mean age = 5.5 years). U.S. subjects (total = 98) were thirty 3-year-olds (3.0 to 3.9 years; mean age = 3.5 years), thirty-two 4-year-olds (4.0 to 4.8 years; mean age = 4.5 years), and thirty-six 5-year-olds (5.0 to 5.98 years; mean age = 5.5 years).

Procedure

Children took part in a series of counting-related tasks.

In the abstract counting task, children were asked to count as high as possible and, if necessary, were prompted (“like 1, 2, 3, . . . ?”). Whenever they stopped, they were encouraged to continue with two prompts. First, they were asked, “What comes after N?” (where N = “Is that N candies?”). When children appeared to be done, they were routine queried in a neutral tone (“Is that all?—”) and, if necessary, were prompted (“like 1, 2, 3, . . . ”). This task was performed on these transcripts without regard to child’s language. To assess reliability of secondary coding, independent coders recoded one boy and one girl for each language at each age, with 97% agreement between codings.

RESULTS

Abstract Counting

Median levels of abstract counting are presented in Figure 1. An Age (3: 3, 4, and 5 years) x Language (2: English vs. Chinese) analysis of variance of counting level revealed significant effects of age (F[2, 191] = 68.28, p < .01) and language (F[1, 191] = 14.94, p < .01), and an Age x Language interaction (F[2, 191] = 3.35, p < .05). Bonferroni-adjusted language contrasts within age group showed significant differences favoring Chinese children at ages 4 and 5. These data show that significant differences in counting do not emerge until fairly late in the preschool period. The median levels of performance in Figure 1 suggest indirectly that these differences occur because English-speaking children require substantially longer than Chinese-speaking children to master names for numbers in the teens.

Analysis of both stopping points and errors indicates that U.S. children’s difficulty with teens accounts for language differences in abstract counting. Figure 2 presents the percentage of children by language (pooled over age) who reached each number. In order to assess whether specific portions of the number-naming sequence present special stumbling blocks for children learning the Chinese and English number-naming systems, these profiles of counting mortality were analyzed using survival analysis techniques (McCullagh & Nelder, 1991). Survival analyses revealed no significant language differences in percentage of counts terminating before 10. Significant language differences were found for the teens decade (shaded region of Fig. 2); 94% of American children and 92% of Chinese children could count to 10; 74% of Chinese children but only 48% of Americans could count to 20. From 20 to 99, there were no significant language differences in counting survival; both U.S. and Chinese samples showed a scalloped profile featuring mistakes at decade boundaries. Finally, after 100, Chinese subjects showed a large drop that was significantly greater than the drop for U.S. children. This larger drop corresponds to the greater complexity of Chinese compared with English number names from 100 to 109 (described earlier). The counting mortality profiles presented in Figure 2 map closely onto the linguistic analysis of the two number-naming systems.

Error data confirm that U.S. children have particular trouble learning teens names and inducing the base-10 structure of number names. When first count
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Fig. 2. Percentage of children reaching each number in the abstract counting task. The difficulty U.S. children have in mastering the teens structure is shown by their rapid drop-off in performance during this range (shaded region).

The difficulty U.S. children have in mastering the teens structure is shown by their rapid drop-off in performance during this range. For example, they may count, "Twenty-eight, twenty-nine, twenty-ten, twenty-eleven, twenty-twelve." Overall, this type of mistake was produced by 14 children, 2 Chinese subjects (both 3-year-olds) and 12 Americans (three 3-year-olds, seven 4-year-olds, and two 5-year-olds). Reflecting the simpler nature of decade names in Chinese, Chinese children were somewhat more likely than U.S. children to mistakenly count by 10s, most commonly, this took the form of counting, "... shi-bā, shi-jì, èr-shí, sān-shí, sì-shí" (literally, "10-8, 10-9, 2-10, 3-10, 4-10"). This mistake was made by 12 Chinese children but by only 5 U.S. children.

The most common error in both countries was to skip a number name, with 61% of U.S. children and 39% of Chinese children skipping at least one number name. English-speaking children were much more likely than Chinese speakers to omit one or more teen number names (41% of U.S. subjects vs. 10% of Chinese subjects), providing yet another indication that learning teens names is more difficult in the English than in the Chinese system.

Object Counting and Problem Solving

Despite large language effects on abstract counting, no language differences were found in children's ability to solve simple mathematical problems or to count arrays of 10 or fewer objects. Both tasks are difficult for young children, but neither revealed language differences.

The most common errors were presented in Table 1. These errors were categorized into three types:

- Principle errors (violating the rule that there should be one and only one number name spoken each time an object is counted),
- Attention errors (skipping or recounting objects),
- Sequence errors (any violations of the conventional number-naming sequence).

For U.S. children, n = thirty 3-year-olds, thirty-two 4-year-olds, and thirty-six 5-year-olds. For Chinese children, n = twenty-nine 3-year-olds, thirty-five 4-year-olds, and thirty-five 5-year-olds. Small sets contained 3 to 6 items, middle sets contained 7 to 10 items, and large sets contained 14 to 17 items.

Table 1. Object-counting errors by country and age

<table>
<thead>
<tr>
<th>Counting pattern</th>
<th>3-year-olds</th>
<th>4-year-olds</th>
<th>5-year-olds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small set</td>
<td>Middle set</td>
<td>Large set</td>
</tr>
<tr>
<td>Correct</td>
<td>73.3</td>
<td>33.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Principle error</td>
<td>6.7</td>
<td>23.3</td>
<td>36.7</td>
</tr>
<tr>
<td>Attention error</td>
<td>20.0</td>
<td>56.7</td>
<td>90.0</td>
</tr>
<tr>
<td>Sequence error</td>
<td>0.0</td>
<td>10.0</td>
<td>53.3</td>
</tr>
</tbody>
</table>

Chinese children

| Correct          | 82.8      | 37.9       | 3.4       | 97.1      | 71.4       | 25.7      | 94.3      | 85.7       | 60.0      |
| Principle error  | 3.4       | 20.7       | 37.9      | 0.0       | 5.7        | 8.6       | 0.0       | 0.0        | 2.9       |
| Attention error  | 6.9       | 44.8       | 96.6      | 2.9       | 22.9       | 74.3      | 5.7       | 14.3       | 40.0      |
| Sequence error   | 6.9       | 17.2       | 37.9      | 0.0       | 0.0        | 8.6       | 0.0       | 0.0        | 0.0       |

Note. The numbers in the table show the percentage of children showing each counting pattern. Principle errors involve a violation of the principle that there should be one and only one number name spoken each time an object is counted. Attention errors involve skipping or recounting objects. Sequence errors are any violations of the conventional number-naming sequence. For U.S. children, n = thirty 3-year-olds, thirty-two 4-year-olds, and thirty-six 5-year-olds. For Chinese children, n = twenty-nine 3-year-olds, thirty-five 4-year-olds, and thirty-five 5-year-olds. Small sets contained 3 to 6 items, middle sets contained 7 to 10 items, and large sets contained 14 to 17 items.
Because both successful performance and errors are categorical variables, logistic regression analyses were conducted for each error category and for success on the object-counting and Panda tasks. Significant language differences were found, favoring Chinese children, only with the large sets (14–17 items); for success, $G^2(1, N = 197) = 5.39, p < .05$, and for sequence errors, $G^2(1, N = 197) = 21.29, p < .01$. This was the only set size for which the greater difficulty English-speakers have in learning teens names might affect object counting, and it did so. U.S. and Chinese children showed similar developmental patterns in preserving one-to-one correspondence between objects and names in counting and in their ability to keep track of counted items. Logistic regression analyses of problem-solving (Panda task) data found significant age effects, but no language differences for any set size (2, 4, 7, and 12 items).

Object-counting and problem-solving results extend the pattern shown on the abstract counting task. U.S. children do not demonstrate any disadvantage in the attentional and conceptual aspects of counting involved in successfully counting or producing small sets of objects. Compared with their Chinese peers, however, they have a substantially greater difficulty mastering the system of number names that their native language employs.

**DISCUSSION**

Although language differences were confined to tasks involving number-naming systems, later mathematical development largely involves learning relations and operations represented symbolically. The English number-naming system appears to present obstacles to children's understanding of the base-10 principle of number representation, and to acquiring arithmetical carrying and borrowing strategies (Fuson & Kwon, 1992; Miura, 1987; Miura, Kim, Chang, & Okamoto, 1988). Furthermore, research on the development of addition points to the importance of counting in children's early addition strategies (Hitch, Cundick, Haughey, Pugh, & Wright, 1987; Siegler, 1987), and the accuracy of children's counting strategies for particular problems shows up as a strong predictor of adult performance on those problems. Even with single-digit numbers, the sophistication of addition strategies of U.S. and Chinese children have been shown to differ significantly at the time of school entry (Geary, Fan, & Bow-Thomas, 1992).

Arabic numerals provide a consistent base-10 representation for numbers; use of these numerals may partly compensate for the complexity of English number names. American adults show a greater decrement in performing numerical manipulations with words instead of numerals than do Chinese adults with characters versus numerals (Miller, 1990; Miller & Zhu, 1991). Familiarizing American children with Arabic numerals at an earlier age than at present might help compensate for the complexity of English number names. That very complexity, however, constitutes a stumbling block to using Arabic numerals. Fuson, Frai villig, and Burghardt (1992) found that explicit instruction using multunit blocks was a necessary prerequisite to teaching American children the 10s-structured addition methods taught in East Asian countries.

Finding large cross-national differences in mathematical competence before school entry implies that the U.S. educational system does not bear all the responsibility for differences in older children. Nonetheless, shortcomings in U.S. education have been well documented (Stevenson & Stigler, 1992). Such shortcomings would exacerbate disadvantages English-speaking children show at school entry. The finding that U.S.-Chinese differences center on verbal systems for representing number does call into question claims that such differences reflect variations in general intelligence or innate mathematical competence. These results suggest further that efforts at improving early mathematical development in the United States should include efforts aimed at making the base-10 structure of number names more accessible to young children.

Acknowledgments—Research reported here was supported by National Science Foundation Grant BNS 85-22466. Preparation of this article was supported by Grants R01 MH50222 and K02 MH01190 from the National Institute of Mental Health. Renée Baillargéon, Kay Bock, Neal Cohen, Gary Dell, Cynthia Fisher, Gerald DeJong, Judy DeLoache, Melissa Jurist, Greg Murphy, Alice Penrose, Jenny Singleton, Jim Stigler, and David Uttal provided helpful comments on previous versions.

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(RECEIVED 2/15/94; ACCEPTED 6/22/94)

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