Number-Concept Acquisition and General Vocabulary Development

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Abstract

How is number-concept acquisition related to overall language development? Many current theories of number development assign language a central role in the child’s acquisition of natural-number concepts. Such theories imply that children with greater language knowledge should also have greater number knowledge. However, the only empirical study to date (Ansari et al., 2003) found no such relationship. The present study set out to replicate and extend those findings by measuring number-word knowledge and vocabulary in 59 children, ages 30 to 60 months. In contrast to earlier results, the present study found a strong correlation between number-word knowledge and two vocabulary measures, independent of age. This finding supports the idea of a close link between language development and natural-number-concept acquisition.
It takes a long time to acquire the concept *five*. There is a large literature documenting the extended learning process that children must go through in order to represent the exact cardinal meanings of number words such as “five,” “six,” “seven,” and so forth (e.g., Carey, 2009; Sarnecka & Carey, 2008; Condry & Spelke, 2008; Le Corre, Van de Walle, Brannon & Carey, 2006; Sarnecka & Lee, 2009; Slusser & Sarnecka, 2007, 2009; Wynn, 1990, 1992).

The process starts shortly after the child’s second birthday. One of earliest things children learn is to recite the beginning of the number-word list (*one, two, three, four five*, etc.; Fuson, 1988). At this point, the list is largely empty of meaning; the words are placeholders. The challenge for the child is to fill in those placeholders with the right meanings. The child learns the exact, cardinal meanings of “one,” “two,” “three” (and sometimes “four”) one at time, and in order (Sarnecka & Lee, 2009; Wynn, 1990, 1992). For convenience, we will follow the convention of calling children “*one*-knowers” when they know the meaning only of “one,” “two”-knowers when they know the meaning of “one” and “two,” and so on. Sometime after a child has learned the meanings of “one,” “two,” “three,” and possibly “four,” she makes a major inductive leap: she understands that the last word spoken in counting indicates the cardinality of the whole set, called the *cardinality principle* (R. Gelman & Gallistel, 1978). A child who has achieved this is called a *cardinal-principle-knower*, or CP-knower for short.

One might reasonably expect, *a priori*, this process of learning number-words should be closely related to other word-learning processes. However, the one study to test that assertion empirically found it lacking; Ansari, Donlan, Thomas, Ewing, Peen, and Karmiloff-Smith (2003) found no statistically significant relationship between expressive
vocabulary and a proxy for number-word knowledge, when partialled for age. From this, they concluded that “typical development of exact number representation appears to be scaffolded, at least initially, by the development of non-verbal competencies” (p. 61) and further that “it is only over developmental time that non-verbal representation of number becomes integrated with verbal numerical competence to lead to a language-dependent representation of exact number” (p. 61).

The logic of their argument runs like this: if language skills are an important tool in the process of number-concept creation, then children with better language skills should be better number-concept constructors, and thus should have mastered more number concepts (on average). Finding otherwise is evidence that children are, at best, drawing only on skills that they all have by the time they learn the counting list (roughly 24 months). At that point, it starts to make more sense to look for a way for the child to accomplish the task without drawing on language; we don’t mean to denigrate the young child’s amazing ability to learn language, but an average 24 month-old’s language skills are probably not yet up to the task of driving number-concept creation.

These conclusions stand in contrast to theories put forward by much of the rest of the field; there are many prevalent theories asserting that (a) the learning of smaller parts of various number concepts is scaffolded heavily by developments in language skill and (b) representations of exact number are entirely language-dependent. We now turn to a short review of that part of the literature.

*The Role of General Language Skills*

During the process of number-word learning, the child must figure out many different aspects of number-word meaning. For example, the child must discover that
number words have something to do with quantification (Bloom & Wynn, 1997; R. Gelman & Gallistel, 1978); that each number word picks out a particular quantity (Bullock & R. Gelman, 1977; Sarnecka & S. Gelman, 2004); that number words are used discontinuous quantitification only (Slusser & Sarnecka, 2007, 2009); and that number words coming later in the list denote larger collections (Le Corre & Carey, 2007; Sarnecka & Carey, 2008). Carey and others have argued that as children discover these aspects of number-word meaning, they are in fact constructing natural-number concepts (Carey, 2009; see also Block, 1986; Quine, 1960).

As such, many theories related to number-word learning involve language as an important part of the process. In fact, for Carey, language plays a central role from the very beginning. “The long-term memory models that support the meanings of singular, dual, and triple markers, as well as the child’s first numerals … must be created in the course of language learning.” (Carey, 2009, p. 324). According to this account, the conceptual content that underlies singular/dual/trial/plural marking is what children use to define one, two and three (see also Barner, Libenson, Cheung, & Takasaki, 2009; Le Corre & Carey, 2007; Li, et al., in press; Sarnecka, Kamenskaya, Yamana, Ogura & Yudovina, 2007).

Barner, Chow and Yang (2009) similarly found that a child’s understanding of quantifiers and determiners (words like a, some, all) is correlated with that child’s number-word knowledge, independent of age. They suggest that “[q]uantifiers may play a facilitating role by highlighting the semantic function of numerals … [L]earning quantifiers may make the general hypothesis space of sets and individuals more salient as a hypothesis space for integer acquisition” (p. 217).
Other authors have suggested that the syntactic and semantic contexts of number-word use could help children figure out their meanings. Bloom and Wynn (1997) identified four such cues. (1) Number words can only be used with count nouns, not mass nouns (e.g., we say three blocks, but not *three sands); (2) Number words cannot appear with modifiers (e.g., we say very many cats, but not *very five cats); (3) Number words precede adjectives within the noun phrase (e.g., we say five brown dogs, not *brown five dogs, at least in English); (4) Number words can appear in the partitive construction (e.g., we say five of the boys, but not *brown of the boys). Even theories emphasizing the role of innate capacities often suppose that the child uses subtle, language-based cues to assign the correct meaning to the number words (e.g., Dehaene, 1997; R. Gelman & Gallistel, 2004).

The implication of any of these theories is that, all else being equal, children who know more language should know more numbers. Taking vocabulary as a marker of general language development, if children with very limited language skills show no deficits with learning number words, then that should cast a great deal of doubt on the idea that language is so vital to the process and that children lever such subtle language cues. Though the hypothesized correlation won’t prove any of those theories, it is a necessary condition for many of them to be true. It is therefore surprising that the one previous study to look for such a correlation didn’t find it (Ansari et al., 2003).

The Present Study

The present study further examined the relation between number knowledge and general vocabulary knowledge in normally-developing children. While our study and Ansari et al.’s have a great many similarities, we have on offer one methodological
improvement that may help clarify things. Both studies used the Give-N task, where children are asked to give various numbers of items to a prop, to look at knowledge of number words. However, they collected a fixed set of trials and analyzed them by percent correct. We used a titrating method that hones in on the edge of a child’s knowledge and analyzed the data directly by the child’s knower-level. This method should allow us to sort out some lucky guesses and some performance errors, reducing noise in the data.

Experiment 1 used a test of expressive vocabulary and a standard Give-N task; Experiment 2 replicated the results of Experiment 1 and included a measure of receptive vocabulary as well. Experiment 3 is a simulation study to help explore if our methodological changes might explain why we obtained different results.

Experiment 1
Method
Participants
Participants included 26 children, aged 2 years, 6 months to 4 years, 9 months (mean age 3;7). All children were monolingual English-speakers, as determined by parental report. All participants were recruited from private child-care centers in and around Irvine, a suburban community in southern California. Families received a prize (e.g., a small stuffed animal) when they signed up to participate in the study; no prizes were given at the time of testing.

No questions were asked about socio-economic status, race, or ethnicity, but participants were presumably representative of the community from which they were recruited. In this community, 95% of residents have at least a high-school education;
most residents identify themselves either as white/Caucasian (61%) or as Asian/Pacific Islander (29%); and median incomes are in the middle to upper-middle class range.

**Procedure**

Children were given two tasks, a Give-N task and a vocabulary task, in counterbalanced order. Children completed both tasks in the same session; the total time to complete both tasks was less than twenty minutes.

*Give-N Task* (Schaeffer, Eggleston & Scott, 1974; Wynn, 1990, 1992). The purpose of this task was to determine what number-word meanings each child knew (i.e., to determine the child’s number-knower-level.) The experimenter began the game by bringing out a stuffed animal (e.g., a lion), a plate, and a bowl of 15 small identical rubber toys (e.g., toy bananas, approx. 3 cm long). The experimenter said to the child, “In this game, you’re going to give something to the lion, like this [experimenter pantomimes putting an item on the plate and sliding it over to the lion]. I’m going to tell you what to give him.” Instructions were of the form, “Can you give the lion TWO bananas?”

All children were first asked for one item, then three items. Further requests depended on the child’s earlier responses. When a child responded correctly to a request for N, the next request was for a higher number. When they responded incorrectly to a request for N, the next request was for a lower number. The requests continued until the child had at least two successes at a given N (unless the child had no successes, in which case they were classified as a pre-number-knower) and at least two failures at N+1 (unless the child had no failures, in which case they were classified as a cardinal-principle-knower). The highest number requested was "six". Children received
generalized positive feedback after each trial (e.g., “Thank you!”). Every child completed between six and nineteen trials, with a mean of ten trials per child.

A child was credited with knowing the meaning of a given number word if they had at least twice as many successes as failures for that number word. Failures included either giving the wrong number of items for a particular word $N$, or giving $N$ items when some other number was requested. Each child's knower-level corresponds to the highest number they reliably generated. (For example, children who succeeded at “one” and “two,” but failed at “three” were called “two”-knowers.) Children who had at least twice as many successes as failures for trials of "five" and "six" were called cardinal-principle-knowers\(^1\). These sorting criteria are consistent with those used in other studies (e.g., Condry & Spelke, 2008; Le Corre & Carey, 2007; Le Corre, Van de Walle, Brannon & Carey, 2006; Sarnecka & Lee, 2009; Wynn, 1990, 1992).

**Vocabulary test.** Children also completed the Woodcock-Johnson Picture Vocabulary Test from the Woodcock-Johnson II-R (Woodcock & Johnson, 1985). In this task, the experimenter showed the child pictures of various objects (e.g., banana, bicycle, horse) and asked the child to name them. The pictures gradually became more difficult (e.g. dog $\rightarrow$ helicopter $\rightarrow$ thermostat). Testing ended when the child produced six wrong answers in a row. The child’s score was the number of objects they named correctly.

**Results and Discussion**

The design included three variables: age, knower-level (from the Give-N task), and expressive vocabulary (from the Woodcock-Johnson task). Vocabulary scores were

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\(^1\) Children who are not yet cardinal-principle-knowers are believed to use subitizing, a special cognitive mechanism that lets people rapidly enumerate a small number of items, to solve the Give-N task (e.g., Le Corre & Carey, 2007). Because subitizing only works up to 3 or 4 items, children who reliably succeed at “five” and “six” must do so by counting and correctly applying the cardinal principle.
kept in raw form. They ranged from 14 to 33 (mean = 22.69; standard deviation = 4.4). Give-N task results yielded three pre-number-knowers, four “one”-knowers, four “two”-knowers, two “three”-knowers, two “four”-knowers, and eleven CP-knowers. Knower-levels were coded as zero through five, spaced evenly. (For that reason, the following correlations are smaller than similar measures of effect-size that allow the distance between groups to vary, such as those from an ANOVA.)

All three simple correlations were significant: number-word knowledge and vocabulary, \( r(24) = .746, p < .01 \); number-word knowledge and age, \( r(24) = .567, p < .01 \); age and vocabulary, \( r(24) = .484, p = .012 \). However, number-word knowledge was also related to expressive vocabulary when partialled for age, \( r(23) = .652, p < .01 \), meaning that the children with larger vocabularies tended to know more cardinal number-word meanings, independent of their age. In contrast, the relationship between number-word knowledge and age, when partialled for vocabulary, was only marginally significant, \( r(23) = .353, p = .083 \).

These results suggest the opposite conclusion from that reported by Ansari and colleagues (2003). However, the two studies differed in that ours measured expressive vocabulary, or production,\(^3\) whereas Ansari et al. measured receptive vocabulary, or comprehension (the British Picture Vocabulary Scale; Dunn et al., 1992). One possibility is that number-word knowledge is related to expressive but not receptive vocabulary. Experiment 2 examined this hypothesis using both types of vocabulary test.

Experiment 2  

\(^2\) For comparison, Ansari et al. (2003) report \( r = .049 \) for the correlation between Give-N percent correct and language development, partialled for age.

\(^3\) The Woodcock-Johnson II-R’s Picture Vocabulary Test does have six warm-up trials testing receptive vocabulary. All participants answered all of these trials correctly.
Method

Participants

Participants included 33 children, aged 2 years, 6 months to 5 years, 0 months (mean age 3;9). All children were monolingual English-speakers, as determined by parental report. Of these children, 23 were recruited from Irvine, California preschools, as described in Experiment 1. The remaining ten children were recruited by phone from the local community, and were tested in a university child development laboratory. Parents who brought their children in for testing received reimbursement for their travel expenses and a token gift for their child.

Procedure

Children completed the Give-N task and the Woodcock-Johnson Picture Vocabulary Test as described in Experiment 1. Additionally, a measure of receptive vocabulary (the Peabody Picture Vocabulary Test III; Dunn & Dunn, 1997) was added. In the Peabody Picture Vocabulary Test, the child sees a page with four line drawings and is asked to point to a specific one (e.g., the child might be asked to point to the “balloon,” from among four pictures: a hot-air balloon, a helicopter, a fighter jet and a glider). The test is broken into blocks of twelve items of increasing difficulty. Testing ends when a child produces eight incorrect answers in the same block. The child’s score is the overall number of correct answers. Each child completed one vocabulary test, then Give-N, then the other vocabulary test. Order of vocabulary tests was counterbalanced across subjects.

Results and Discussion

The design included four variables: age, knower-level (from the Give-N task), expressive vocabulary (from the Woodock-Johnson test), and receptive vocabulary (from
the Peabody Picture Vocabulary Test). Vocabulary scores were kept in raw form.

Expressive vocabulary scores ranged from 18 to 32 (mean = 22.82; standard deviation = 3.67). Receptive vocabulary scores ranged from 21 to 82 (mean = 53.06; standard deviation = 17.49). There were two pre-number-knowers, five “one”-knowers, seven “two”-knowers, four “three”-knowers, one “four”-knower, and fourteen CP-knowers.

As in Experiment 1, results showed that number-word knowledge was related to expressive vocabulary, independent of age, $r(30) = .582, p < .01$. The same relationship held for receptive vocabulary, $r(30) = .546, p < .01$. All three simple correlations were also significant ($p < .01$), as was the relationship between age and knower-level, independent of expressive vocabulary, $r(30) = .398, p = .024$. An analysis merging data from both experiments also showed that number-word knowledge is related to both expressive and receptive vocabulary, when age is controlled (see Figure 1 and Table 1).

For a more detailed picture of how these three variables contribute to number-knower-level, we used a form of hierarchical regression analysis (see Table 2). For Model 1, we entered age, then receptive and productive vocabulary, revealing that all steps added to the fit. For Model 2, we entered receptive and productive vocabulary, then age. In this case, age did not contribute significantly to the fit. Finally, we calculated the correlation between age and knower-level when controlling for the vocabulary scores. This correlation was not significant $r(29) = .184, p = .320$. These analyses provide strong evidence that knower-level is related to language skill, independent of the child’s age.

The results from Experiments 1 and 2 bring up the question of why we saw such different results from Ansari et al. (2003). One possible explanation is purely methodological: we analyzed correlations by knower-level, whereas the other study
analyzed correlations by percent correct in the Give-N task. Unfortunately, we used a
titrating method to collect our data and the other study used a fixed number of trials for
each number word; as such, analyzing our data by percent correct would not
meaningfully speak to whether or not this methodological differences can fully explain
the difference\(^4\). Experiment 3 is a simulation study that was run to check that analyzing
by knower-level is, in principle, a plausible explanation for why we found a correlation
that a previous study did not.

**Experiment 3**

*Method*

We used a model by Lee and Sarnecka (2010). This is a full generative model of
the Give-N task, for all six knower-levels. It allowed us to input a child’s knower-level
and a request for a number of items, and have it sample a response. These responses
closely mimic the actual responses of children. For example, a 2-knower is very likely to
give 2 when asked for “two”, but not quite every time; in contrast, she is unlikely to
generate 2 items when asked for “three”. What the model provides is exact percentages to
explicate how likely various responses are. With this in hand, we can generate simulated
responses, analyze them by (a) inferring back the knower-level as we did in Experiments
1 and 2 and (b) percent correct in Give-N.

After generating inferred knower-levels and Give-N percentages for 28 children,
we then generated ages and vocabulary scores for each child. These were drawn from a
bivariate normal distribution around the true knower-level. (This simulates the models
used in multiple regression analysis.) The variance-covariance matrix we used was found

\(^4\) For the extremely curious, we did run such an analysis on our data and found there to be no significant
correlation between knower-level and percent correct when controlled for age.
by averaging our observed matrix with an estimate of Ansari’s. Finally, we calculated partial correlations and checked to see if they were statistically significant. This simulation was run 10,000 times to generate a sampling distribution and to allow power analysis.

Results and Discussion

Analyzing by inferred knower-level was somewhat more powerful, detecting a significant correlation about 20% more often; testing by inferred knower-level tended to give larger sample partial correlations. Our observed correlation for receptive vocabulary was in the 20th percentile of sample correlations when analyzing by inferred knower-level. Ansari et al.’s observed correlation was in the 90th percentile when analyzing by percent correct. As such, both at least fall into 95% confidence intervals. This means that part of the difference in results can plausibly be explained by differences in analysis method and the rest can be plausibly explained by chance.

General Discussion

Together, the results of Experiments 1 and 2 provide evidence that number-word learning is tied to non-numerical vocabulary development. Both expressive and receptive vocabulary scores are correlated with number-word knowledge, even when partialled for age. In a hierarchical regression model, both vocabulary scores add significantly to the fit when entered after age. In contrast, age does not add significantly to the fit when added after vocabulary scores, and age is not correlated with knower-level when partialled for vocabulary. These findings strongly suggest that it is language development, not age per se, that predicts number-word knowledge.
These results differ from those reported by Ansari and colleagues (2003). Experiment 3 was a simulation study that confirmed the difference can be plausibly attributed to methodological differences. To be specific, Ansari et al. (2003) analyzed Give-N results as ‘percent correct’, collapsed across all set sizes. In the present study, Give-N was used to assign each child a knower-level, and knower-level was the variable used in the analysis. The knower-level framework provides a principled way to say that some correct answers are lucky guesses and some incorrect answers are performance errors. For example, imagine that a child is asked for “three” items on each of three trials. The child gives 6, 3, and 4 items, and then later gives 3 items when asked for “five”. By the logic of the knower-level framework, the child’s single correct answer (i.e., giving 3 for “three” on one trial) is not enough to demonstrate real knowledge of the meaning of “three.” The single correct answer is outweighed by three incorrect answers (i.e., giving 6 and 4 for “three,” and giving 3 for “five”). The knower-levels method of analysis thus ignores the anomalous trial, reducing noise in the data. A ‘percent correct’ scoring system lacks this strength. Experiment 3 confirmed that both study’s results can be plausibly taken from the same underlying relationship when these methodological differences are considered.

The present findings are consistent with theories that connect language development to number-concept development – or minimally, to number-word learning (e.g., Barner, Libenson et al., 2009; Barner, Chow & Yang, 2009; Carey 2009; Dehaene, 1997; R. Gelman & Gallistel, 2004; Mix, Sandhofer & Baroody, 2005; Sarnecka et al., 2007). But the question of causal direction remains to be answered. It seems implausible that number-word knowledge could drive overall vocabulary development. Excluding
that possibility, we are left with two plausible alternatives, either or both of which may be true: (a) language development could facilitate the learning of number-word meanings; (b) both number-word learning and overall vocabulary learning could be caused by some other factor.

The current evidence is not sufficient to prove option (a), but there are several reasons to consider it seriously. First, there are rich cues to the meaning of number words available in the language, and many of them are subtle, requiring somewhat advanced language skills to detect (e.g., Bloom & Wynn, 1997). Second, the child’s knowledge of other words, especially non-numeral quantifiers, could make the correct hypothesis space for number-word meanings more salient (Barner, Chow & Yang, 2009). Third, the acquisition of singular/dual/trial markers – or whatever grammatical-number marking exists in a particular language – may require the creation of long-term memory models, which could support the learning of the first few number words (Carey, 2004; 2009; Le Corre & Carey, 2007; Sarnecka et al., 2007).

The relation between number-concept development and language development also has important practical implications. A recent meta-analysis of six databases and over 34,000 students found that pre-kindergarten math skills, many of which depend on the child’s success in constructing natural-number concepts, are the single best predictor of later school achievement (Duncan et al., 2007). Early math knowledge not only predicts later math knowledge, but also later reading ability – better than early literacy, attention skills, socioemotional skills, family background measures, or IQ. In other words, the acquisition of pre-kindergarten math and number concepts is vitally important to the child’s later academic success.
However, research on early math education lags far behind research on early literacy. The development of educational interventions to support number learning is relatively new (e.g., Greenes, Ginsburg & Balfans, 2004; Griffin, Case & Siegler, 1994; Starkey & Klein, 2000). As these interventions continue to evolve, the link between number development and vocabulary may be an important piece of the puzzle. For example, it’s possible that successful interventions will emphasize the use of number words in full sentence contexts (e.g., “I can see three bears on the carpet, and two of the bears are brown”), in conjunction with counting contexts (e.g., “How many bears? One, two, three.”), to take advantage of all possible linguistic cues. Similarly, there may be good reason to teach preschool math to English-language learners in their first language, because their vocabulary in that language is likely to be far larger than in English. If nothing else, these findings imply that interventions proven to build young children’s vocabulary should be considered as a potential aid to number-concept development as well.
References


Table 1
Simple Correlations and Partial Correlations for Age – Pearson’s R and Spearman’s Rho

<table>
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<tr>
<th></th>
<th>Age</th>
<th>Knower-Level</th>
<th>Expressive Vocabulary</th>
<th>Receptive Vocabulary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>--</td>
<td>.628†</td>
<td>.559†</td>
<td>.729</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(.668†)</td>
<td>(.621†)</td>
<td>(.710)</td>
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<tr>
<td>Knower-Level</td>
<td>--</td>
<td>--</td>
<td>.754†</td>
<td>.748</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(.792†)</td>
<td>(.723)</td>
</tr>
<tr>
<td>Expressive</td>
<td>--</td>
<td>.624†</td>
<td>--</td>
<td>.744</td>
</tr>
<tr>
<td>Vocabulary</td>
<td></td>
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<td></td>
<td>(.773)</td>
</tr>
<tr>
<td>Receptive</td>
<td>--</td>
<td>.546</td>
<td>.594</td>
<td>--</td>
</tr>
<tr>
<td>Vocabulary</td>
<td></td>
<td>(.454)</td>
<td>(.570**)</td>
<td></td>
</tr>
</tbody>
</table>

Note. Simple correlations appear above the diagonal; partials for age appear under. Spearman’s Rho is in parentheses. All are significant at p < .01. †Merged data from both experiments. Separated analysis is in the main text.

Table 2
Hierarchical Regression Models

<table>
<thead>
<tr>
<th>Step</th>
<th>Predictor</th>
<th>R²</th>
<th>ΔR²</th>
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<td>.468**</td>
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<td>Receptive Vocabulary</td>
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<td>.133**</td>
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<td>3</td>
<td>Expressive Vocabulary</td>
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<td>Receptive Vocabulary</td>
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<td>.560**</td>
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<td>.095**</td>
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<td>Age</td>
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<td>.020</td>
</tr>
</tbody>
</table>

* p < .05, ** p < .01
Figures

*Figure 1.* Relationships among expressive vocabulary, receptive vocabulary, and knower-level variables. Concentric markers are used when data points overlap.