

# Counting on quantifiers: Specific links between linguistic quantifiers and number acquisition

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## Abstract

Knowledge of linguistic quantifiers (like *all*, *many* or *some*) correlates with number acquisition. However, it is unclear whether quantifier comprehension is exclusively related to exact number skills or whether the relationship also extends to approximate number skills. To find out, we tested German-speaking children on a quantifier comprehension task, two counting tasks ('How-many task', 'Give-*n* task') and a non-symbolic number comparison task ('ANS task'). We further assessed differences between two types of quantifiers: 'Exact' quantifiers like *both* (denoting 2) vs. 'non-exact' quantifiers like *some* (denoting various set-sizes). Overall, quantifier comprehension was found to correlate with counting skills, even when age was controlled for. A more detailed analysis revealed the correlation was restricted to exact quantifiers which also share more properties with cardinal numbers. In contrast, no age-independent correlation between quantifier comprehension and approximate number skills was obtained. Our results therefore suggest specific links between exact quantifiers and exact number skills.

**Keywords:** language acquisition, numerical cognition, quantifiers, counting

## Introduction

Numbers are omnipresent in our daily lives. We need them for reading the clock, counting sheep or paying for our groceries. However, despite the ubiquitous presence of numbers, it takes children quite some time to acquire numerical skills. Two distinct processes have to be distinguished here: Whereas the approximate number system (ANS) involved in estimating or comparing quantities is present from very early on in human development (e.g. Xu & Spelke, 2000), the exact number system (involved in counting or arithmetic) takes more time to develop. There is evidence that exact number skills are also linked to language (e.g. Frank et al., 2012; Pica et al., 2004, Spelke & Tsivkin, 2001, see however Gelman & Butterworth, 2005). For instance, speakers of languages without number words also seem to lack representations of exact numbers (e.g., Frank et al., 2012; Pica et al., 2004). Exact calculation tasks also activate language related areas of the brain (Dehaene, Molko, Cohen, & Wilson, 2004; Dehaene, Piazza, Pinel, & Cohen, 2003). Moreover,

children with Specific Language Impairment (SLI) – who demonstrate poor linguistic skills in the absence of intellectual or neurological impairment – have difficulties in exact number tasks, confirming links between linguistic and numerical abilities (e.g. Donlan, Cowan, Newton, & Lloyd, 2007; Nys, Content, & Leybaert, 2012)

More specific language-number links have been proposed between the comprehension of natural language quantifiers (like *many*, *all*, or *some*) and number acquisition (e.g. Bloom & Wynn, 1997; Carey, 2004). These proposals draw on the observation that quantifiers and numbers share a range of semantic, pragmatic, and syntactic properties. For instance, both quantifiers and numerals refer to quantities and form a scale from 'weaker' to 'stronger' elements (i.e., *all*, *many*, *some*; *three*, *two*, *one*, cf. Horn, 1972 in Papafragou, Gleitman, & Gelman, 2006), with stronger elements containing weaker ones (e.g. *all* includes *many* or *some*, *three* includes *two* or *one*). Moreover, numbers and quantifiers often require upper bounded interpretation. That is, a lower number or quantifier excludes a higher number or stronger quantifier (I ate *some/three* of the cookies implies that I did not eat *all/four* of the cookies). Both types of expressions also occur in specific syntactic frames, e.g. in the partitive construction (*three/some of the cookies*). Based on these commonalities, it has been proposed that knowledge of linguistic quantifiers can bootstrap number acquisition (e.g. Carey, 2004). In support of this proposal, 2- to 5-year-olds' ability to understand quantifiers was found to correlate with their comprehension of numbers (e.g. Barner, Chow, & Yang, 2009a; Barner, Libenson, Cheung, & Takasaki, 2009b).

While quantifier knowledge appears to bootstrap abilities that can be classified as exact number skills (i.e., the verbal counting list), growing evidence suggests a close connection between exact and approximate number abilities (e.g. Halberda, Mazzocco, & Feigenson, 2008; Libertus, Feigenson, & Halberda, 2011; Mussolin, Nys, Leybaert, & Content, 2012; Wagner & Johnson, 2011). This link seems already present in children (e.g. Libertus et al., 2011; Wagner & Johnson, 2011). For instance, three- to five-year-olds' arithmetic ability was significantly correlated with performance in an ANS acuity task, even prior to formal school instruction (e.g. Libertus et al., 2011). In addition to tight links between exact and approximate number skills, the latter also seem directly involved in adults' quantifier comprehension (e.g. Olm et al., 2014; Shikhare et al., 2015;

Troiani, Peelle, Clark, & Grossman, 2009). The evaluation of quantifiers (like *most*, *many*, *few*) appears to recruit ANS processes such as estimation and comparison of quantities (e.g. Shikhare et al., 2015). Comprehension of quantifiers is also shown to involve brain areas which subserve approximate number comparisons (i.e., the intraparietal sulcus (IPS); McMillan et al., 2005; Olm et al., 2014).

These findings raise the question whether quantifier knowledge is exclusively related to children's exact number skills (i.e., cardinal number comprehension) or whether the relationship extends to approximate number skills as well. To find out, we tested German-speaking children on a quantifier comprehension task, two counting tasks ('How-many task', 'Give-*n* task') and a non-symbolic number comparison task (assessing ANS acuity). If quantifier comprehension is specifically linked to exact number skills, quantifier score and exact number skills should correlate but there should be no correlation between quantifier knowledge and ANS acuity. Alternatively, if quantifier comprehension is related to number skills more broadly, a correlation between quantifier knowledge and approximate number skills is expected.

In a second step, we seek to examine the relationship between quantifiers and exact number skills more closely. While quantifiers and numbers share a range of properties, they also differ in important ways. Unlike numbers that typically describe exact quantities (e.g. *three*, not any other number), quantifiers like *some* or *many* can refer to various set-sizes depending on the context. Accordingly, children seem to follow different strategies for evaluating numerals and quantifiers (e.g. Hurewitz, Papafragou, Gleitman, & Gelman, 2006; Papafragou & Musolino, 2003). For instance, 3-year-olds reject the claim that an alligator has *two* cookies when in fact he has *four*, whereas the same children accept that the alligator has *some* of the cookies when in fact he has *all* of them (Hurewitz et al., 2006). It thus appears children assign exact and mutually exclusive interpretations to numbers but not to quantifiers.

However, not all quantifiers work the same way. Whereas vague or 'non-exact' quantifiers like *some* or *many* can map to a range of quantities (e.g. *many* = 5-7 items, out of 8 items), other quantifiers are more number-like and require an exact interpretation (e.g. *all* = exactly 8 items, out of 8 items). Moreover, unlike non-exact quantifiers that rely heavily on the context for interpretation (5-7 may be *many* items if the total amount is 8, but only *a few* if the total amount is 20), exact quantifiers like *none* or *both* are context-independent (i.e., they always denote 0 or 2, respectively). Exact quantifiers thus seem to bear more similarities with numerals compared to non-exact quantifiers (like *some* or *many*). This observation raises the question whether the two types of quantifiers affect the acquisition of number skills differently. To find out, we divided the examined quantifiers into two groups: Exact quantifiers that refer to one specific quantity and non-exact quantifiers that can refer to a range of quantities. If numerals are more closely related to exact quantifiers, number

acquisition may benefit from exact quantifiers and a significant correlation between number skills and exact quantifiers is expected. At the same time, we expect a weaker or no correlation between number skills and non-exact quantifiers.

## Methods

### Participants

German-speaking children participated in the study ( $n = 19$ , 10 female, 9 male; mean age: 56 months, range: 40-73 months). Children were recruited from local childcare centers and compensated for their participation by a little gift.

### Stimuli and Procedure

Each child was tested individually on four tasks: (1) the Give-quantifier task, (2) the Give-*n* task, (3) the How-many task, (4) the approximate number task (ANS task). The tasks were presented on two different sessions and were part of a larger testing battery. To avoid spill-over effects due to task similarities, the experimental tasks were presented in a fixed order: In the first session, the How-many task and the Give-quantifier task were administered. In the second session, the ANS task and the Give-*n* task followed. In order to establish evaluation criteria for children's quantifier comprehension, we additionally tested adult speakers of German on the Give-quantifier task ( $n = 20$ ).

### The Give-quantifier task

The Give-quantifier task was adapted from Barner and colleagues (2009a, b). Stimuli consisted of a white plastic bowl and three sets of small plastic fruits (i.e., 8 bananas, 8 oranges, and 8 strawberries). Sets were presented in separate piles organized by kind. To make sure children could distinguish the different kinds, the experimenter first asked questions like "What is this called?", "Do you know what this is?" or "Can you tell me what these are?". Once the child demonstrated knowledge of each fruit, the experimenter explained the task to the child. On each trial, the experimenter pointed to the empty bowl and asked the child to put a quantity of a particular kind of fruit into it (e.g. "Kannst du *alle* von den Bananen in die Schüssel legen?" "Can you put *all* of the bananas into the bowl?"). Comprehension of the following 7 German quantifiers was assessed: *alle* (all), *eine* (a), *keine* (none), *die beiden* (both), *die meisten* (most), *viele* (many), and *einige* (some). All quantifiers were used in the partitive construction (e.g. *many of the Xs*). For the quantifier *both*, children were presented with one token of each fruit type (i.e., 1 banana, 1 orange, 1 strawberry) and asked: "Can you find both of these that you like best and put them into the bowl?". After each trial, all fruits were returned to their original piles. Quantifiers were presented in three different orders between participants, with pairings of quantifiers and fruit kinds quasi-randomized. Children were tested three times with each quantifier, resulting in 21 trials in total. Adults were

tested in the same set-up but only one time with each quantifier (7 trials).

### The Give-*n* task

The Give-*n* task was adapted from Wynn (1990; 1992) to test numeral comprehension (i.e., to determine the child's number-knower level). Children were first introduced to a glove puppet called "Tillman the Dog". The experimenter told the children that the dog was hungry and asked whether they were willing to feed him. Stimuli consisted of a white plastic bowl and eight plastic lemons. The child was then asked to put a specific number of lemons into the bowl. Requests were of the form: "Can you give the dog *n* lemons?" Following Wynn (1992), a titration method was used: Children were first asked for one item and then for three items. Further requests always depended on the children's earlier responses. When children responded correctly to a request for *N* (e.g. 3), they were subsequently asked for *N*+1 (e.g. 4). However, when children responded incorrectly to a request for *N*, they were subsequently tested on *N*-1 (e.g. 2). The highest number requested was "6". Children were called *N*-knowers (e.g., two-knowers) if they correctly gave *N* lemons two out of three times but failed to give the correct number two of three times for *N*+1. Children who had at least twice as many successes as failures for trials of five and six were classified as cardinal principle-knowers (CP-knowers), indicating they had learned that the last word in a counting sequence reveals the cardinality of the whole set (see e.g. Wynn, 1992).

### The How-many task

This task was adapted from Ansari and colleagues (2003). Participants were introduced to a glove puppet called "Emil the Duck". The experimenter told the children the puppet had forgotten how to count and asked them to count stickers for him. Children were then shown pieces of cardboard covered with various numbers of stickers. Stickers depicted different kinds of animals (e.g. a squirrel), fruit (e.g. a strawberry), or plants (e.g. a fir tree). Children were presented with displays of 2-10 stickers, offered in a pseudo-randomized fashion. On each trial, the child was asked to count (aloud) the stickers for the puppet, for a total of 9 trials. After counting each set, children were asked "How many stickers were there?". The experimenter coded whether or not the child had counted the sets of stickers correctly, without skipping or double counting. Proportion of correct counting responses was calculated for each child.

### The ANS task

To measure the precision of the children's approximate number system (ANS), a non-symbolic number comparison task was administered by using Panamath (Halberda et al., 2008; <http://panamath.org/>). Children were presented with cartoon characters Big Bird and Grover on a 15.6 inch PC laptop screen. In case children were unfamiliar with the characters, a familiarization phase was added during the pretest. Children were told Big Bird (who was presented on the left side of the screen) had a box of yellow balls and

Grover (who was presented on the right side of the screen) had a box of blue balls (see Figure 1). Balls were represented by arrays of spatially separated yellow and blue dots, each array surrounded by a frame. Children were asked to indicate who had more balls and press the corresponding button on a response box (i.e., a yellow button on the left for Big Bird, a blue button on the right for Grover). In case children did not manage to press the buttons themselves, they pointed to the respective character and the experimenter immediately pressed the corresponding button. Both stimulus arrays of blue and yellow balls were presented side by side and visible for 2500 milliseconds. Afterwards the balls disappeared and a blank screen remained until children gave a response. The number of dots in each array (yellow and blue) ranged from 4 to 15 (see also Libertus et al., 2011). Test trials were randomly drawn from one of four numerical ratio bins: 1:2, 2:3, 3:4, and 4:5. For each ratio, on half of the trials, the larger set of balls took up more total surface area (area correlated trials), and on the other half, the smaller number of items had more total surface area (area anti-correlated trials). Twelve trials were presented for each number ratio (half area correlated, half anti-correlated), resulting in a total of 48 test trials. Trials were presented in randomized order. Correct response side was counterbalanced across trials. The winning side (Big Bird or Grover), trial type (area correlated, area anti-correlated), ratio presented, and absolute number of items presented varied randomly across trials. To ensure children understood the task, a pretest with 8 practice trials (similar to the test trials) was administered.

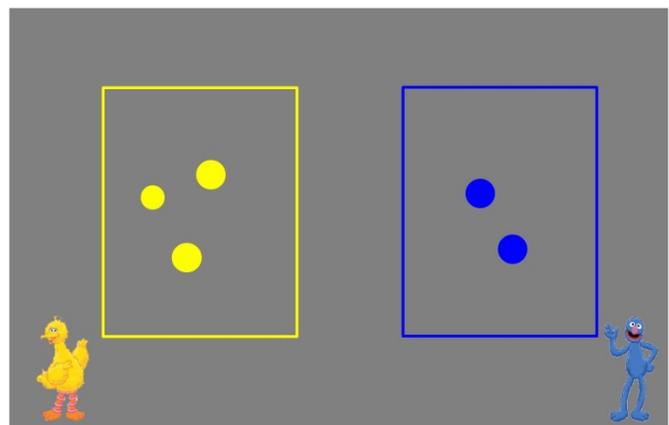


Figure 1: Example of a practice trial. Children were asked to judge who of the two characters had more balls by pressing the corresponding button on a response box.

## Results

**Quantifier comprehension in adults** Correct responses for each quantifier were defined on the basis of Barner and colleagues' evaluation criteria (2009a, b). Additionally, we assessed quantifier comprehension in adult speakers of German. Table 1 shows correct number of items (i.e., correct response) for each quantifier. When asked for the quantifiers *all*, *none*, *a*, *both*, 100% of the adult participants gave the following number of items: 8, 1, 0, 2. Responses

are thus in line with Barner and colleagues' results for speakers of English and Japanese. When asked for the quantifier *most*, 95% of the adults gave 5-7 items (in line with Barner et al., 2009 a). Only one participant gave 8 items. For the quantifier *many*, 90% of the adult participants gave 5-7 items. While Barner and colleagues (2009 b) allowed 5-8 items as a correct response range, only one German-speaking participant gave 8 items. Another participant gave 4 items. We therefore restricted the range of correct responses for *many* to 5-7 items. Moreover, unlike Barner and colleagues who considered 2-7 items as correct for the quantifier *some*, the German use of *einige* (some) appears to be more restricted. Especially when contrasted with *viele* (many), *some* seems to be upper-bounded and rather understood as *a few*. This intuition was shared by adult speakers of German. In response to the quantifier *some*, 95% of the adults gave 2-4 items. Only one adult gave 6 items. We therefore restricted the range of correct responses for *some* to 2-4 items.

Quantifier	Correct response	Quantifier type
<i>alle</i> (all)	8	Exact
<i>keine</i> (none)	0	Exact
<i>eine</i> (a)	1	Exact
<i>die beiden</i> (both)	2	Exact
<i>die meisten</i> (most)	5-7	Non-exact
<i>viele</i> (many)	5-7	Non-exact
<i>einige</i> (some)	2-4	Non-exact

Table 1: Quantifiers, correct response (correct number of items), and quantifier type (exact vs. non-exact).

**The relation between quantifier and numeral comprehension in children** We calculated an overall quantifier score ranging from 0 to 3 for each child. The score was defined as the average number of correct responses (out of 3 trials) a child made for each quantifier. Correctness was determined on the basis of the adults' performance (outlined above). To assess the relation between quantifier comprehension and number-knower level (Give-*n* task), we then calculated the correlation between quantifier score, number-knower level (1, 2, 3, 4, or CP), and age. Results revealed a significant correlation between quantifier score and number-knower level,  $r(18) = .53, p = .02$ . When controlling for age, the effect remained marginally significant,  $r(18) = .47, p = .05$ . To examine links between quantifier comprehension and counting skills, we calculated children's proportion of correct counting responses on the How-many task. We then calculated the correlation between quantifier score, proportion of correct counting responses, and age. Quantifier comprehension was found to correlate with counting skills even when age was controlled for,  $r(18) = .52, p = .03$ . These findings indicate that children who have a greater comprehension of quantifiers also have better (exact) number skills, independent of age.

### The relation between quantifier comprehension and approximate number skills (ANS acuity)

To assess children's Approximate Number System (ANS) acuity, we first analyzed accuracy (percent correct) on the number comparison task. On average, children responded correctly on 79% of the trials, showing above-chance performance,  $t(18) = 11.12, p = .001$ . There was no difference between area correlated and anti-correlated trials,  $t(18) = -.15, ns$ . We therefore collapsed over area correlated and anti-correlated trials in further analyses. A one-way ANOVA with factor NUMERICAL RATIO (1:2, 2:3, 3:4, and 4:5) revealed that children's accuracy decreased with increasing numerical ratio, in line with Weber's law,  $F(3,54) = 8.1, p = .001$ . We then calculated the correlation between quantifier score, ANS accuracy and age. There was no age-independent correlation between quantifier score and ANS accuracy,  $r(18) = .29, ns$ . In addition, we determined each child's Weber fraction *w* as another indicator of ANS acuity (i.e., taking into account the amount of noise in children's underlying ANS representations, see e.g. Halberda & Feigenson, 2008 for details). No significant correlation between quantifier score, Weber fraction *w*, and age was obtained,  $r(18) = -.34, ns$ . Results thus suggest that links between quantifiers and number development are rather specific. Quantifier comprehension only correlates with exact number skills but not with approximate number skills (ANS acuity).

### The relation between different quantifier types and numeral comprehension in children

In order to examine significant links between quantifier comprehension and exact number skills more closely, we distinguished between two different types of quantifiers. Quantifiers that required one single correct response (i.e., 2 for *both*) were classified as exact quantifiers, whereas quantifiers that allowed for a range of responses were classified as non-exact quantifiers (e.g. *some*). Based on these criteria (verified by adult responses), exact quantifiers were *all*<sup>1</sup>, *a*, *none*, and *both*. Non-exact quantifiers were *many*, *most* and *some* (see Table 1). We then calculated an exact quantifier score and a non-exact quantifier score ranging from 0 to 3 for each child.

When looking at the two types of quantifiers (exact vs. non-exact) separately, a t-test revealed children displayed better comprehension of exact quantifiers compared to non-exact ones,  $t(19) = 8.6, p = .001$ . Comprehension of exact quantifiers also correlated significantly with number-knower level, even when age was controlled for,  $r(18) = .52, p = .03$ . Moreover, exact quantifiers significantly correlated with counting accuracy,  $r(18) = .55, p = .02$  (age-controlled). By contrast, there was no age-independent correlation between non-exact quantifier comprehension and number-

<sup>1</sup> Although the quantifier *all* requires one exact response (e.g. 8 in a sample of 8), it is context-sensitive and depends on the total number of items. However, since the total amount of tokens was fixed in our study (i.e. 8 tokens), context-dependency was limited and *all* qualified as an exact quantifier.

knower level,  $r(18) = .24, ns$ , nor between non-exact quantifier knowledge and counting accuracy,  $r(18) = .29, ns$ . Links between quantifiers and number skills thus appear to be restricted to exact quantifiers.

## General Discussion

Overall, we found a correlation between quantifier knowledge and counting skills, even when age was controlled for. Our findings thus confirm that linguistic quantifiers and number acquisition are tightly linked. Unlike Barner and colleagues (2009a, b), we merely obtained a marginally significant age-independent correlation between quantifier comprehension and number-knower level (as assessed by the Give-*n* task). This is most likely due to the small sample size in our study. Testing further participants is thus a necessary next step to directly compare our results to those of Barner and colleagues.

Despite the small sample size in our study, it is notable that we found a significant age-independent correlation between quantifier comprehension and counting skills. While our results can be interpreted in favor of close links between quantifier comprehension and number skills, they do not speak to the question of cause and effect. It is possible that better comprehension of linguistic quantifiers causes better number skills. On the other hand, our results do not rule out the opposite scenario (i.e., that number skills aid quantifier comprehension). By contrast, Barner and colleagues find more specific evidence in favor of the former option. Children's quantifier comprehension was found to mediate a correlation between age and numeral comprehension, whereas the reverse was not true (i.e., number skills did not mediate the relationship between age and quantifier comprehension). These findings suggest that quantifier comprehension may indeed support number acquisition. Additional training or intervention studies that manipulate quantifier knowledge more directly could be helpful to tackle the question of causality in the future.

While our findings confirm links between quantifier comprehension and exact number skills like counting, no such link was found for quantifier knowledge and approximate number skills. Neither children's accuracy on the ANS task nor their Weber fraction (another indicator of ANS acuity) correlated with quantifier score when age was controlled for. Unlike links between quantifier comprehension and approximate magnitude representations in adults (e.g. Shikhare et al., 2015), children's quantifier knowledge and ANS acuity may not yet be connected. It is possible this relation only develops over time.

Moreover, it seems that effects of language (i.e., linguistic quantifier comprehension) are limited to exact number abilities that may draw on verbal processes (e.g. counting). This is in line with other findings: While the absence of number words in some languages results in limitations of exact number representation, approximate number skills remain unaffected (e.g. Pica et al., 2004). In the same vein, SLI children display problems with exact numerical tasks, whereas their ANS acuity shows no signs of impairment

(e.g. Donlan et al., 2007; Nys et al., 2012). In accordance with these findings, knowledge of linguistic quantifiers does not relate to approximate number skills but only correlates with exact number abilities.

When examining the relationship between exact number skills and quantifiers more closely, we can distinguish between two different types of quantifiers (i.e., 'exact' vs. 'non-exact' quantifiers). Exact quantifiers like *all*, *none*, *a*, and *both* require a specific response (e.g. 2 items when *both* were requested), whereas non-exact quantifiers allow for a range of responses (e.g. 5-7 items when *most* were requested, see Table 1). These differences between exact and non-exact quantifiers were also confirmed by adult speakers of German. Moreover, comprehension of exact quantifiers appeared less difficult for children who displayed better comprehension of exact quantifiers compared to non-exact ones. Overall, however, children's understanding of quantifiers was not yet adult-like. In line with previous work, we found that children did not interpret quantifiers in an upper bounded way (see e.g. Hurewitz et al., 2006). This was especially true for non-exact quantifiers. For instance, when asked to put *some* of the items into the bowl, children frequently gave *all* of the items.

In addition to overall differences between exact and non-exact quantifiers, we found an age-independent correlation between knowledge of exact quantifiers and number-knower level as well as counting skills. At the same time, no corresponding correlation was obtained for non-exact quantifiers and number skills. These findings suggest that exact quantifiers may be better candidates for bootstrapping number acquisition. Since children appear to benefit from commonalities between quantifiers and numerals when learning number words, it is likely they are best served by those quantifiers that share most properties with numbers. Non-exact quantifiers – on the other hand – differ from exact numbers in a number of semantic and pragmatic features. For instance, unlike numbers – non-exact quantifiers are vague, refer to more than one entity and often require an upper bounded interpretation. These factors may make non-exact quantifiers less suitable candidates for aiding number acquisition compared to exact quantifiers. Our findings thus suggest that semantic commonalities between quantifiers and numbers (e.g. reference to one particular quantity) may represent one critical component in number acquisition.

## Conclusions

Overall, our findings confirm that quantifier knowledge and number acquisition are linked. Children who were better at comprehending natural language quantifiers also performed better on the Give-*n* task and on the How-many task, even when age was controlled for. By contrast, no age-independent correlation between quantifier knowledge and approximate number skills (i.e., ANS acuity) was obtained. When looking at exact quantifiers (like *both*) and non-exact ones (like *some*) separately, we found that children were better at comprehending exact quantifiers. Exact quantifiers

also correlated with counting skills, whereas the same was not true for non-exact quantifiers. One reason may be that exact quantifiers share more properties with cardinal numbers compared to non-exact quantifiers. Our findings therefore suggest that links between natural language quantifiers and number acquisition are rather specific: Quantifier knowledge only correlates with exact but not with approximate number skills. At the same time, this correlation appears to be solely based on exact quantifiers.

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