Journal of Cognition and Development

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/hjcd20

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Accepted author version posted online: 02 Sep 2014.

JOURNAL OF COGNITION AND DEVELOPMENT, 16(4):621–637

ISSN: 1524-8372 print/1532-7647 online
DOI: 10.1080/15248372.2014.934372

Routledge
Taylor & Francis Group

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A crucial component of numerical understanding is one's ability to abstract numerical properties regardless of varying perceptual attributes. Evidence from numerical match-to-sample tasks suggests that children find it difficult to match sets based on number in the face of varying perceptual attributes, yet it is unclear whether these findings are indicative of incomplete numerical abstraction abilities early in development or instead are driven by specific demands of the matching task. In this study, we explored whether perceptual biases would be found in data from a numerical task invoking verbal representations of number and whether these biases are moderated by verbal counting behavior. Three- to 6-year-old children classified as proficient counters (cardinal principle knowers) participated in a number cardinality task in which they were asked to identify which of 2 arrays—either perceptually homogeneous or heterogeneous in appearance—contained a specific number of animals (e.g., ''12 animals''). Results revealed an overall performance bias for homogeneous trials in this cardinality task, such that children were better able to exactly identify the target cardinality when items within the sets were perceptually identical. Further analyses revealed that these biases were found only for those children who did not explicitly verbally count during the task. In contrast, performance was unaffected by the perceptual attributes of the array when the child spontaneously counted. Together, results reveal that cardinality judgments are negatively impacted by perceptual variation, but this relationship is muted in those children who engage in verbal counting.

Early counting abilities have been found to be strongly predictive of later math achievement (Duncan et al., 2007; Geary, 2011; Stock, Desoete, & Roeyers, 2009), and thus, understanding the development of these abilities is critical for understanding the precursors to formal mathematical knowledge. Despite a wealth of research focused on how children learn to count, not much is known about the acquisition of an important and necessary component of true numerical understanding—the ability to abstract the numerosity of a display independent of its perceptual attributes (''numerical abstraction,'' Gallistel & Gelman, 1992; Gelman & Gallistel, 1978). Given that sets in real-world environments are rarely homogeneous in appearance, the ability to ignore perceptual variability when assessing number—that is, recognize that a set containing a dog, a bird, and a tree is equivalent to a set of three stars—is not only necessary for a conceptual understanding of the abstract nature of number (Cordes, Williams, & Meck, 2007), but it is also critical for appreciating numerical equivalence across sets when counting. This study

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provides a first look at how varying stimulus attributes may impact a child's ability to identify the cardinality of a set and how verbal counting may moderate this relationship.

Although children begin to count out loud as early as 2 years of age (Wynn, 1990, 1992), whether they are able to focus solely on number, independent of perceptual attributes, is an open question. While it is clear that even preverbal infants can track numerosity despite varying perceptual attributes of a display (e.g., shape, size, color, identity; Cordes & Brannon, 2008, 2009a, 2009b; Gelman & Tucker, 1975; Jordan & Brannon, 2006; Kobayashi, Hiraki, & Hasegawa, 2005; Starkey, Spelke, & Gelman, 1990; Strauss & Curtis, 1981; Xu & Spelke, 2000), the existence of perceptual biases in infancy have not been assessed. Work with preschoolers, however, has revealed systematic perceptual biases, such that children find it more difficult to match arrays based on number when arrays are heterogeneous (e.g., a mix of colors and shapes) compared with when items within (and across) arrays are identical (Cantlon, Fink, Safford, & Brannon, 2007; Mix, 1999, 2008a, 2008b; Siegel, 1973, 1974). Reports of this early childhood ''homogeneity bias,'' however, have emerged almost exclusively from numerical matching tasks, in which preschoolers are presented with a sample array and are then asked to select (from two to four choices) a second array that matches the first array in terms of number, while ignoring all other perceptual variables (item shape, size, color, or identity). For example, shown a sample array of three items (dog, cup, and ball), a child may be asked to choose between two arrays containing two (cat, house) or three (lamp, tree, fish) items. Importantly, in these tasks, the set sizes of the arrays are never labeled for the child. When performance on these heterogeneous trials is compared with homogeneous trials (e.g., three dots matched to either two or three dots), it has been shown that children are significantly less accurate when sets differ perceptually (e.g., Mix, 1999, 2008a, 2008b). These findings have been taken as evidence that ''early [numerical] comparisons require high levels of perceptual support'' (Mix, 1999, p. 294), such that children's abilities to detect numerical similarity are (at least partially) derived from perceptual similarity.

Why do preschoolers find it more difficult to attend to number when arrays are perceptually variable? Of course, one possibility is that children have yet to fully master the art of numerical abstraction and therefore rely upon perceptual variables that may correlate with number to provide additional cues (Mix, 1999). That is, a set of three stars necessarily looks more like another set of three stars than like a set of two stars, yet there are few perceptual similarities between a set containing a star, a heart, and a diamond and another set containing a square, a triangle, and a circle. In this case, children engaged in numerical tasks may simultaneously rely on multiple cues (numerical as well as perceptual) to solve the problem at hand, thereby resulting in better performance on trials in which perceptual information correlates with number.[1]

Alternatively, it may be that the specific demands of a numerical *matching* task give rise to dependence on *perceptual* matching and inadvertently foster reliance on set appearances. Previous studies have necessarily made task demands ambiguous by simply modeling correct matching behavior for the children without making any verbal reference to number or numerical values (Mix, 1999, 2008a, 2008b). Given that even human infants find perceptual properties of small sets to be at least as salient as number when task demands are ambiguous (Clearfield & Mix, 1999, 2001; Cordes & Brannon, 2009a), it is not surprising that children may be similarly

[1]A very similar account has recently been proposed in the preverbal infant literature to account for numerical discrimination failures in the small number range (''*signal clarity hypothesis*''; Cantrell, Boyer, Cordes, & Smith, 2015; Cantrell & Smith, 2013).

biased to rely on perceptual attributes under ambiguous circumstances. Moreover, even when children are explicitly told that the task is to match sets based on number, children may still be inclined to match sets on multiple dimensions, numerical and non-numerical alike. Therefore, when sets are homogeneous, correct numerical matches inevitably look more like the target set, as they match on both number *and* perceptual attributes. In contrast, when arrays are heterogeneous, correct responses match the target array based on a single stimulus attribute (number) while *mismatching* on others (e.g., color, shape), thereby requiring children to focus on number *despite* conflicting perceptual information in order to be accurate. Consistent with this account, Defever, Sasanguie, Vanderwaetere, and Reynvoet (2012) reported that children are more likely to rely on physical similarities, as opposed to numerical similarities, when engaged in a numerical same/different task that also requires children to evaluate numerical matches.

In line with this account, children's performance on other (nonmatching) numerical tasks appears either unaffected or differentially affected by perceptual variability (Cantlon et al., 2007; Petersen & McNeil, 2013), suggesting that the numerical matching paradigm may simply not be an appropriate task for examining numerical abstraction abilities because it highlights perceptual similarities (and/or dissimilarities). For example, Cantlon et al. (2007) presented 3- to 5-year-old children with two different numerical tasks in which the perceptual variability of the sets was manipulated. In line with previous studies, results of their numerical matching task revealed a homogeneity bias in responding. However, performance on their ordinal task, which required children to indicate the numerically smaller of two sets, was unaffected by the perceptual variability of the stimuli. Together, these findings could be taken as support for the claim that it is something about the demands of the numerical matching task that elicits the observed homogeneity biases. Yet, significant differences between the two tasks (in terms of task difficulty[2] and whether exact or approximate numerical judgments were required) leave open the question of whether homogeneity biases may be found in other numerical tasks involving exact numerical judgments. In particular, are homogeneity biases present in tasks relying on abstract verbal representations of number, such as when children are asked to judge the cardinality of a set (e.g., find the set with ''six'' items)? If so, this would provide strong evidence to suggest that, even in early childhood, children are still in the process of acquiring the concept of numerical abstraction.

Importantly, the present study not only addresses whether a perceptual bias is found in children's cardinality judgments, but it also expands on previous research in an important way by exploring how the use of spontaneous, explicit verbal counting may foster numerical abstraction abilities. Although a significant corpus of research has been dedicated to evaluating children's counting abilities (e.g., Le Corre & Carey, 2007; Le Corre, Van de Walle, Brannon, & Carey, 2006; Mix, Sandhofer, Moore, & Russell, 2012; Wynn, 1990, 1992), much less research has focused on whether children actually invoke verbal counting behaviors during numerical tasks. Data have revealed that children who engage in explicit verbal counting are at an

[2]Exact number comparisons (as required in the matching task) are generally more difficult than approximate number discriminations (as required in the ordinal task; Cantlon et al., 2007; Halberda & Feigenson, 2008). Although accuracy was comparable across their two tasks, the authors indicated (in a footnote, Cantlon et al., 2007, p. 435) that they made participants select the smaller number in the ordinal task because pilot data indicated ''considerably higher accuracy'' when participants were asked to select the larger number. Thus, it is possible that performance on their ordinal task was more reliant on inhibitory control processes (inhibiting an initial preference to select the larger value) than on numerical abilities, thus muting any potential perceptual biases that may have been found.

advantage in numerical tasks and outperform their silent peers (Bar-David et al., 2009; Le Corre et al., 2006). Moreover, in numerical matching tasks, verbal counting ability has been found to be predictive of performance on heterogeneous trials (Mix, 1999, 2008a, 2008b; although see Cantlon et al., 2007). In fact, one study showed that only children who knew the count word labels for the set sizes used were able to perform above chance on the most difficult heterogeneous conditions (Mix, 2008b). Thus, it may be the case that engaging in verbal counting may promote numerical abstraction by mitigating perceptual biases. However, little work has explored how perceptual variability interacts with verbal counting in children's numerical judgments.

In sum, young children's numerical matching abilities have been shown to be hindered by perceptual variation in the arrays presented, yet it is unclear whether this homogeneity bias seen in the literature is indicative of specific demands of the experimental design (numerical matching) or of immature numerical abstraction abilities. Moreover, no work has investigated how the use of verbal counting may foster numerical abstraction during numerical tasks. To address these open questions, we designed a novel numerical task (adapted from Huang, Spelke, & Snedeker, 2010) that required children to judge the cardinality of sets in the face of perceptual variability. Three- to 6-year-old children were presented with an exact numerical task, in which they were asked to identify which of two sets contained a target number of animals (e.g., ''Which set has 12 animals?''). On some trials, both sets were homogeneous (all the same animal), and on other trials, both sets were composed of a variety of animals (heterogeneous), thereby maximizing the perceptual variability of the displays. Moreover, we tracked children's spontaneous counting behaviors while engaging in our task to explore whether engaging in verbal counting behavior may mediate any observed perceptual biases.

Additionally, in contrast to previous studies, only children identified as proficient counters (i.e., cardinal principle knowers, or CP knowers; Le Corre & Carey, 2007; Wynn, 1990, 1992) who had acquired the cardinality principle (that the last word in a count represents the cardinality of the counted set; Gelman & Gallistel, 1978) were included in the study. Of note, previous evidence of perceptual biases has primarily been found in very young children (3- to 4-year-olds; Cantlon et al., 2007; Mix 1999, 2008a, 2008b; Siegel, 1973), with older children (5- to 8-year-olds) performing comparably on heterogeneous and homogeneous trials (Cantlon et al., 2007; Siegel, 1973). Because these ages also approximately coincide with the period during which children acquire the verbal count procedure (Le Corre & Carey, 2007), it is possible that demonstrated perceptual biases are a product of an immature understanding of the counting procedure. Although it is not suggested that the observed pattern of responding on previous tasks reflects an inability by these young children to accurately count the arrays—in fact, in previous studies, verbal counting was generally discouraged (or at least, not encouraged; e.g., Cantlon et al., 2007)—we hypothesize that the ability to think about number using language may help to promote successful numerical comparisons at the exclusion of irrelevant stimulus features (Hannula, Rasanen, & Lehtinen, 2007; Mix, 2008a, 2008b; Posid & Cordes, 2014). Along these lines, work with children who are still in the process of figuring out the verbal count procedure (''subset knowers''; Le Corre & Carey, 2007) has revealed that nonproficient counters may be more reliant on perceptual properties of a display when making numerical judgments (Huang et al., 2010). For example, when shown a card with three dogs and told, ''This card has *three* dogs,'' children identified as ''two knowers'' (those who can reliably produce a set of two, but not three, items) can successfully identify other cards containing the same number of dogs; however, performance drops to chance levels when the items on the card are from a novel category (e.g., sheep; Huang et al., 2010). Notably, previous studies examining the effects of perceptual variability on numerical abilities have no doubt included nonproficient counters in their sample, thereby making it impossible to determine whether the poor numerical abstraction observed may have been driven by an immature count procedure (thus resulting in greater reliance on perceptual variables). Thus, only proficient counters were included in the present study for three reasons: a) It was questioned whether an inability to use numerical language may hinder numerical abstraction abilities; b) the present investigation focused on how perceptual variation impacts *cardinality* judgments (thus requiring participants to have an understanding of the cardinal principle); and c) we were interested in assessing how verbal counting behavior (which is more likely to present in those who know how to count) may interact with perceptual biases.

In conclusion, this design allowed us to assess claims of poor numerical abstraction in young children while expanding on previous literature by exploring the interaction between verbal counting abilities, counting behaviors, and perceptual biases. In particular, we explored whether young children demonstrate homogeneity biases in a novel cardinality task. By assessing spontaneous counting behavior, we were able to assess how the employment of verbal counting strategies may help to successfully mitigate the impact of perceptual variation. Furthermore, by including only proficient counters, we were able to determine whether these perceptual biases persist despite fully developed counting abilities.

METHOD

Participants

Two hundred and twenty-one 3- to 6-year-old children participated in this study and were divided into two age groups: 94 younger children (3- to 4-year-olds; $M_{age} = 3;10$, $SD = 5.42$ months; 51 male) and 119 older children (5- to 6-year-olds; $M_{age} = 5;7$, $SD = 6.51$ months; 58 male). This age range was specifically selected to directly compare findings from the present study to findings from previous tasks involving numerical abstraction (e.g., Cantlon et al., 2007; Mix, 1999, 2008a, 2008b; Siegel, 1973, 1974) and because this is approximately the age range during which young children acquire a sophisticated verbal count procedure (Le Corre & Carey, 2007). Moreover, although homogeneity biases have been demonstrated in younger children (Mix, 1999, 2008), some evidence suggests that numerical judgments in children older than the age of 5 years may be unaffected by perceptual variability (Cantlon et al., 2007; Siegel, 1973). Thus, we expected perceptual variability to either not impact performance for the older age group or to do so to a lesser degree. Because we were interested in how perceptual variation impacts *cardinality* judgments, only children identified as proficient counters (i.e., CP knowers) who could correctly produce a set of at least six items in the Give-N task (Le Corre & Carey, 2007; Wynn, 1990, 1992) were included in this study. Because participation in this study required children to be classified as CP knowers, additional children who were screened and classified as less-than-proficient counters (e.g., subset knowers) were not run in the full procedure and instead participated in other ongoing studies in the lab. Therefore, a greater number of children were screened using the Give-N task than were included in the current study. From the sample of children who participated in the full procedure, an additional 17 children were excluded from the study for failure to complete all test trials ($N = 9$) or for not performing above chance (50%) on the card task ($N = 8$).

Children were recruited from the Boston, MA, area and participated in the study during one visit to our laboratory on the main campus of Boston College or to one of two local museums (Boston Children's Museum or the Museum of Science in Boston). For those children who visited the lab, their names were obtained from local birth records and parents were contacted by either mail or phone.

Materials

Give-N Task

Fifteen 2-inch (5.08-cm) small yellow rubber ducks were used for the Give-N task, as was a round blue plastic basket that was used as the ''pond'' in which children were to place the ducks.

Card Task

The stimuli used in the Card Task were 8.5-inch × 5.5-inch (21.6 × 14.0-cm) laminated cards, picturing an array of animals. The array of animals depicted on the cards varied in spatial arrangement across trials (e.g., vertical rows, horizontal rows, triangles, etc.).

In familiarization, children saw a single homogeneous array containing the target number (either 6 or 12), followed by a secondary single array containing the same target number and then four pairs of homogeneous arrays. One card within each pair contained the target number of animals (6 or 12), and the other card (distractor card) contained 2, 3, 20, or 24 animals. The identity and size of the animals depicted within each card pair on a given trials were the same (e.g., 6 small dogs vs. 3 small dogs); however, across trials, the size and species of animals varied such that no animal was pictured more than once (e.g., dogs, horses, chickens, pigs).

In test, children saw both homogeneous and heterogeneous card pairs randomly intermixed throughout. In the ''find 6'' condition, children saw 6 vs. 4, 5, 8, 10, 12, 16, and 18, and in the ''find 12'' condition, children saw 12 vs. 4, 5, 6, 8, 10, 16, and 18. Because of concerns regarding the perceptual reliance of numerical representations in the small number range (<4 items; e.g., Feigenson, 2005; Kaldy & Leslie, 2003), we were careful to only present arrays of large sets (4 and larger). Given that discriminations of large sets are dependent on their ratio (e.g., Jordan & Brannon, 2006; Xu & Spelke, 2000), these particular values were chosen to keep the average ratio between the target set size (6 or 12) and the distractor set sizes comparable across conditions (.58 in ''find 6''; .60 in ''find 12''), while, at the same time, approximately equating the numerical sizes of the distractor sets across conditions. Thus, any difference in performance observed across the two conditions should only be attributed to differences in children's abilities to identify the size of the target value (6 or 12). Importantly, although the ratio between target set size and distractor set sizes was approximately equated across conditions, because larger set sizes are more difficult to identify by sight, it was predicted that children would find the ''find 12'' condition to be more challenging and thus would be more likely to engage in spontaneous verbal counting in this condition.

For each numerical pair, there was one homogeneous pair and one heterogeneous pair created, for a total of 14 intermixed test trials (7 Distractor Values × 2 Perceptual Variations). On homogeneous trials, the same animal was depicted on both the target and distractor cards (e.g., 6 pigs vs. 12 pigs). On heterogeneous trials, however, all animals pictured on both cards were different, such that no animal was pictured more than once (e.g., a card containing 6 animals could have a dog, pig, chicken, cow, cat, and bear). Item size varied across trials (range = 50–210 px^2), but arrays within each card pair were approximately matched for overall surface area, such that, for example, in a 6-versus-12 card pair, the size of items on a card containing 6 items was approximately twice as large as the size of items on the card containing 12 items. These controls for cumulative area were modeled after those of Huang et al. (2010) to discourage the use of non-numerical cues when identifying the target card.

Procedure

Give-N Task

Children first participated in the Give-N task (modeled after Le Corre & Carey, 2007; Wynn, 1990, 1992) to identify their level of counting proficiency. Fifteen small rubber ducks were placed on the table in front of each child and the child was instructed to make a certain number of ducks jump into a blue basket (''Can you make N ducks jump in the pond?''). The experimenter first asked the child to produce one item (''Can you make one duck jump in the pond?''). If the child successfully produced one item, the experimenter continued to ask for N + 1 item. If the child failed to produce the correct quantity, the experimenter asked the child, ''Is that N duck(s)?'' The child was given the opportunity to correct their set. If the child failed to correct their set, the experimenter then asked for N – 1 item. If the child successfully produced N – 1 item, the experimenter continued to ask for N items, with the set size increasing with each correct response; however, if the child failed to produce that quantity, the experimenter ended the game. Only those children who successfully gave up to six items (identified as ''CP knowers'') continued on to the Card Task.[3]

Card Task

The card task was modeled after Huang et al. (2010) but was modified for the purposes of exploring the impacts of perceptual variability on large cardinality identification. Following the Give-N task, children were randomly assigned to either the ''find 6'' ($N = 109$) condition (in which the target number of animals was always 6) or the ''find 12'' ($N = 112$) condition (in which the target number of animals was always 12) within each age group. Importantly, to keep task demands constant throughout the study, children were always asked to identify the same set size (6 or 12). These two conditions were included to assess varying degrees of task difficulty on perceptual intrusions in cardinality judgments. As noted previously, we approximately

[3]Although our Give-N task was modeled after Le Corre and Carey (2007), it should be noted that Sarnecka and Lee (2009) have argued that knower levels may be overestimated when set sizes are presented in ascending order (as opposed to random order). Thus, it is possible (though unlikely) that a few children included in our task may not have met Sarnecka and Lee's criterion for being classified as a CP knower and instead would have been classified as a subset knower. Conversely, however, these authors also argue that CP knowers may not consistently produce a set of six in the Give-N task, suggesting that our criterion for being classified as a CP knower may have in fact been more stringent and required a higher level of counting proficiency than Sarnecka and Lee would expect of children classified as CP knowers.

equated the ratios between the target value (6 or 12) and distractor values across conditions while, at the same time, using comparable distractor set sizes in the two conditions. Because numerical discriminations are known to be ratio-dependent (e.g., Halberda & Feigenson, 2008), this design manipulation resulted in numerical comparisons of similar difficulty across the two conditions. However, because children were not simply asked to *discriminate* set sizes (i.e., decide which is larger) but to instead *identify* the set representing a specific cardinal value (''Find the set with *6* animals''), we expected task difficulty (and correspondingly, a child's likelihood of engaging in spontaneous counting behaviors) to increase with the size of the set to be identified.

Familiarization. Children were first presented with a single card depicting the target number of animals (6 or 12) and were told, ''This card has 6 (12) animals on it!'' After two single presentations, children were then shown a pair of cards, with one card depicting the target number of animals (6 or 12) and the other card depicting a different number of animals. For each card pair, the experimenter said, ''This card has 6 (12) animals on it! But this [other] card does not have 6 (12) animals on it!'' Children were shown four different pairs of cards, and the experimenter stated which card in each pair contained the target number. Then, children were presented with the same four familiarization trial card pairs a second time, but this time, they were asked to select which card contained the target value (6 or 12). Children did not move to the test phase of the Card Task until they had correctly identified the card containing the target value in each card pair.

Test. After completing the familiarization portion of the Card Task, all children saw 14 novel card pairs and were asked to identify the card containing the target number (''Which card has 6 (12) animals on it?''). The side of placement of the target card as well as the side of placement of the card containing the larger value pseudorandomly varied across trials, such that half of the trials had each on the right. Children were always asked to select the card containing the target number, and the experimenter provided neutral but encouraging feedback regardless of the child's choice (e.g., ''Thank you!'' or ''Great job!'').

Data coding and analyses. During test, the experimenter recorded the child's response and also noted whether or not children consistently used explicit verbal counting to find the target card (as per Bar-David et al., 2009). A random subset of children (10%) was videotaped (for purposes of later data coding) while participating. Children who spontaneously engaged in explicit verbal counting during the Card Task were coded as ''counters,'' and children who did not engage in verbal counting were coded as ''noncounters.'' Two independent observers coded children's counting strategies from videotape, and intercoder reliability was 100%. Importantly, all children performed comparably on our counting assessment (Give-N task); thus, the distinction between ''counters'' and ''noncounters'' was based on whether they actually spontaneously engaged in counting behavior during the task and was not a measure of counting skill.

All *p* values reported for post-hoc tests reflect Bonferroni correction for multiple comparisons.

RESULTS

Card Task Performance

Data analyses revealed that stimulus heterogeneity negatively impacted performance on our cardinality task. A repeated-measures analysis of variance examining the within-subjects effect of stimulus type (homogeneous, heterogeneous) and the between-subjects effects of age group (younger, older) and condition (''find 6'' or ''find 12'') on percent correct revealed a main effect of stimulus type, $F(1, 209) = 4.19$, $p = .042$, $\eta_p^2 = .020$, such that children performed more accurately on homogeneous trials compared with heterogeneous trials ($M = 91.1\%$ vs. $M = 89.2\%$; Figure 1). Additionally, analyses revealed a main effect of age group, $F(1, 209) = 15.8$, $p < .001$, $\eta_p^2 = .07$, such that, despite comparable counting proficiency (as demonstrated by the Give-N task), older children outperformed their younger counterparts on the Card Task ($M = 93.3\%$ vs. $M = 87.0\%$). No other effects or interactions approached significance (ps $> .14$). Importantly, age group did not interact with stimulus type, thereby suggesting that the observed homogeneity bias did not dissipate as children aged (contrary to Cantlon et al., 2007, and Siegel, 1973). Thus, together, results suggest that children in both the younger and older age groups had greater difficulties identifying the cardinality of a set when items were perceptually heterogeneous compared with when items within the set were identical.

Counting Behavior

In sum, our findings align with those of other exact, but nonverbal, numerical tasks and reveal that children find exact numerical abstraction more difficult under perceptually variable conditions. But did verbal counting help to moderate this performance deficit in this young sample?

Although all children were classified as proficient counters in the Give-N task (CP knowers), not all children engaged in explicit verbal counting during the Card Task. Preliminary analyses revealed that approximately one third (33.3%; 71 of 213) of all children spontaneously verbally counted during the Card Task. Considering children were asked to identify the exact cardinality of a set, it is somewhat surprising that so few children spontaneously counted during the task; however, these findings are consistent with other research suggesting that children rarely count

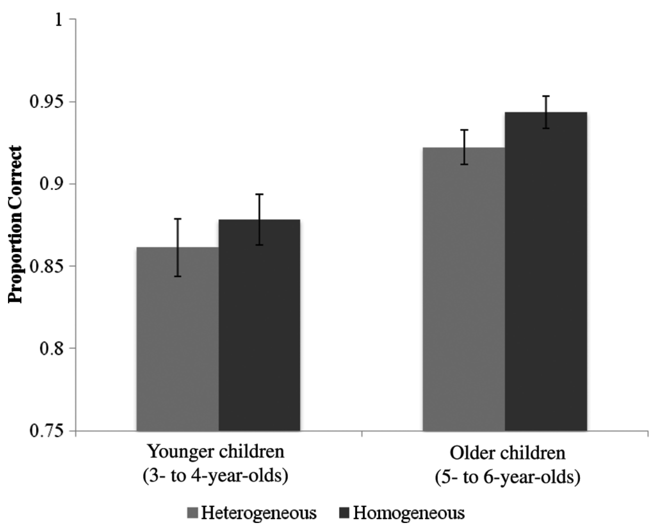

FIGURE 1 Performance on the Card Task as a function of age group and stimulus type.

during numerical tasks (Posid & Cordes, 2015). Consistent with our predictions, a greater proportion of children counted in the ''find 12'' condition compared with the ''find 6'' condition (40.2% vs. 26.4%), χ^2 (1, $N = 213$) = 4.55, $p = .033$, ΦCramer =.146, likely due to the increased demands of the more challenging ''find 12'' condition in which children would have been less confident in identifying a set of 12 items by sight. Moreover, preliminary analyses revealed that a significantly greater proportion of children in the younger age group were classified as counters compared with children in the older age group (46.8% vs. 22.7%), χ^2 (1, $N = 213$) = 13.7, $p = .000$, ΦCramer =.254 (counters, $M_{age} = 4;3$ vs. noncounters, $M_{age} = 4;10$. To verify that both condition and age predicted the likelihood of a child engaging in counting behavior, a binary logistic regression analysis was performed on counting behavior (0 = noncounters, 1 = counters) with three predictors: age group (0 = younger, 1 = older), condition (0 = ''find 6,'' 1 = ''find 12''), and the interaction (Age Group × Condition). The full model with all three predictors was significant, χ^2 (3, $N = 213$) = 24.14, $p < .001$, *Nagelkerke* $R^2 = .15$. Moreover, both age group and the Age Group × Condition interaction significantly predicted the likelihood of a child counting: age, *Exp(B)* = 0.032, $p = .002$; Age × Condition, *Exp(B)* = 1.27, $p = .029$; condition, *Exp(B)* = 0.80, $p = .163$. Although younger children were equally likely to engage in counting behavior across the ''find 6'' and ''find 12'' conditions (45.8% vs. 47.8% of counters), a significantly smaller percentage of older children engaged in a verbal counting strategy when participating in the easier ''find 6'' condition (10.3% vs. 34.4%).

Given that age significantly predicted counting behavior, to investigate the impact that verbal counting may have had on cardinality judgments in the context of perceptual variability, a Counting Behavior (counter vs. noncounter) × Stimulus Type (heterogeneous, homogeneous) × Condition (''find 6'' vs. ''find 12'') repeated-measures analysis of covariance, with age group (younger, older) as a covariate, was conducted. Not surprisingly, results revealed that children who spontaneously counted during the task outperformed those who did not count (M = 93.5% vs. M = 88.6%), $F(1, 208) = 8.18$, $p = .005$, $\eta_p^2 = .038$); however, this main effect was qualified by a significant Counting × Stimulus Type, $F(1, 208) = 8.82$, $p = .003$, $\eta_p^2 = .041$, interaction; see Figure 2. Although the main effect of stimulus type no longer reached significance ($p > .46$), the Counting × Stimulus Type interaction revealed that perceptual variability in the arrays detrimentally impacted performance, but only for those children who did not engage in verbal counting. Children who did not invoke a verbal counting strategy performed worse on heterogeneous as compared with homogeneous trials ($M = 87.6\%$ vs. $M = 91.4\%$), $t(141) = 3.12$, $p = .004$, $d = 0.27$. In contrast, children identified as counters performed comparably on heterogeneous and homogeneous trials ($M = 93.4\%$ vs. $M = 91.8\%$), $t(70) = 1.13$, $p > .2$, $d = 0.13$. Further analyses suggested that this was because verbal counting proved to be a successful strategy for overcoming the negative impacts of perceptual variability in our cardinality task. Whereas counters and noncounters performed comparably on homogeneous trials (controlling for age group, $M = 93.0\%$ vs. $M = 90.7\%$), $F(1, 212) = 1.47$, $p > .2$, $\eta_p^2 = .007$, children who spontaneously counted outperformed those who did not count on heterogeneous trials (controlling for age group, $M = 94.8\%$ vs. $M = 86.9\%$), $F(1, 212) = 14.56$, $p < .001$, $n_p{}^2 = .065$.

Moreover, a significant Counting Behavior × Condition interaction, $F(1, 208) = 6.08$, $p = .014$, η_p^2 = .028 (Figure 3) was obtained, revealing that while counting did not have a significant impact on overall performance in the easier ''find 6'' condition ($M = 89.5\%$ counters vs. $M = 91.9\%$ noncounters), $t(104) = 0.977$, $p > .14$, $d = 0.20$, it did reliably do so in the more challenging ''find 12'' condition ($M = 94.5\%$ counters vs. $M = 86.5\%$ noncounters), $t(105) = 3.39$,

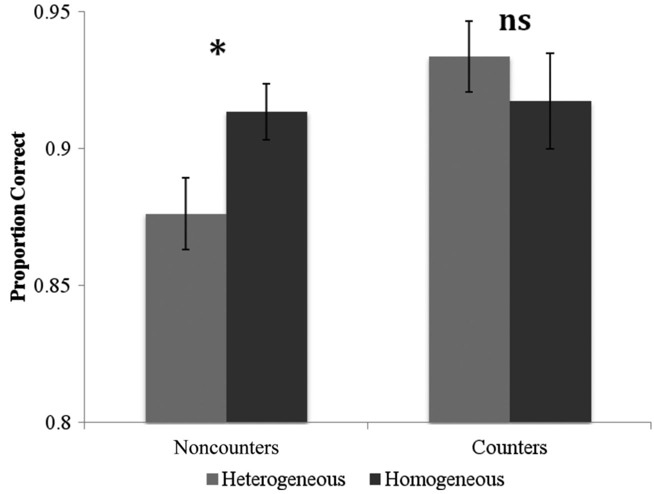

FIGURE 2 While children who did not overtly verbally count during the task (noncounters) demonstrated a homogeneity bias in the Card Task, children who spontaneously counted (counters) were unaffected by perceptual variability and performed comparably on homogeneous and heterogeneous trials.

$p = .008$, $d = 0.69$. Thus, together, the results suggest that counting led to overall greater success in our Card Task when children were most challenged—either when arrays were perceptually variable or when task demands required identification of relatively large cardinal values (12). Other than the significant covariate of age, $F(1,\ 208) = 19.27$, $p = .000$, $\eta_p^2 = .085$, no other significant main effects or interactions were obtained (ps $> .05$).

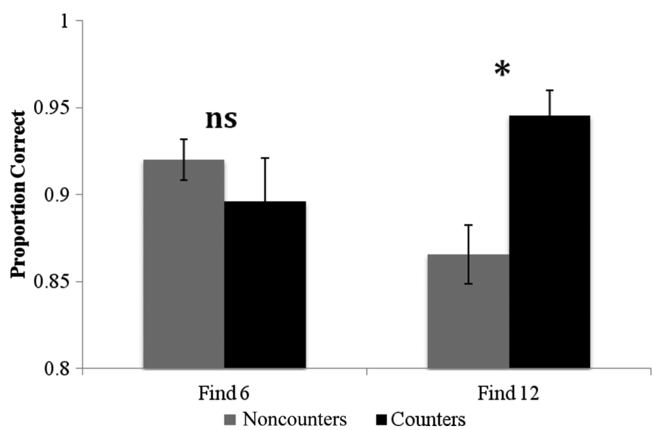

FIGURE 3 While both counters and noncounters performed comparably in the easier ‘‘find 6’’ condition, those children who verbally counted during the Card Task outperformed those who did not overtly count in the more difficult ‘‘find 12’’ condition.

DISCUSSION

The present study investigated whether perceptual variability impacts young children's numeric comparisons in a novel cardinality task. Findings from the present study confirm data from previous work suggesting that young children's numerical judgments are detrimentally impacted by perceptual variability and extend previous findings of a homogeneity bias found in studies employing numerical match-to-sample tasks (Cantlon et al., 2007; Mix, 1999, 2008a, 2008b; Siegel, 1973, 1974). In these tasks, performance relied heavily on non-numerical stimulus attributes, resulting in performance decrements when sets were perceptually variable. Interestingly, this pattern holds in our novel cardinality task, where children relied on an abstract verbal representation of number when responding. Thus, even when children were not asked to make a numerical similarity judgment (as in a match-to-sample task), perceptual biases are found, suggesting that it is not the specific task demands contributing to this documented pattern of results. Moreover, our data are the first to demonstrate a clear homogeneity bias for exclusively large-set cardinality judgments in children identified as proficient counters, suggesting that this pattern of findings cannot be accounted for by perceptual biases for small sets and/or by immature counting abilities. Instead, the findings suggest that numerical abstraction, at least in the context of tasks requiring cardinal numerical judgments, may not be fully developed as late as 6 years of age, despite mastery of the verbal count procedure.

In line with findings from recent studies, these findings suggest perceptual attributes of a display are particularly salient to young children. It has been suggested that perceptual richness increases children's attention to the items displayed and directs their attention to those objects in a non-numerical manner (McNeil, Uttal, Jarvin, & Sternberg, 2009; Petersen & McNeil, 2013). In particular, when items are familiar (e.g., animals), perceptual variability may redirect attention toward item-specific information (e.g., the type of animal and other corresponding information) and away from numerosity, thereby resulting in poorer performance overall. In contrast, a recent study reported that when items were unfamiliar to children, children were better able to focus on number (Petersen & McNeil, 2013). Together with our data (also revealing poorer performance on heterogeneous trials involving familiar items), results suggest that it may be difficult for children to view the items to be enumerated in terms of their numeric meaning or purpose within the task, thus decreasing their ability to abstract numerical properties appropriately.

Notably, although previous studies have suggested that this perceptual bias may dissipate with age (Cantlon et al., 2007; Siegel, 1973), our data revealed a homogeneity bias present in even our oldest participants. Thus, it is an open question as to when children become able to ignore perceptual attributes of an array when enumerating a set without the use of verbal counting. Some evidence suggests that perhaps we may never overcome these biases, with even adults incapable of pure numerical abstraction resulting in homogeneous sets being estimated as more numerous than heterogeneous sets (Redden & Hoch, 2009). However, whether this difference in numerical estimates is indicative of compromised numerical processing or instead simply reflects altered, yet intact, numerical perception is an open question. Regardless, our data suggest that further work is needed to clarify the developmental progression of these numerical distortions to determine how children and adults engage in both verbal and nonverbal enumeration in real-world contexts in which arrays are rarely perceptually homogeneous.

Results of our secondary analysis revealed that those children who engaged in overt verbal counting performed more accurately overall and were better able to overcome the challenges presented by a perceptually variable display, regardless of age. That is, whereas children who did not overtly count demonstrated a homogeneity bias, those who did count performed comparably on heterogeneous and homogeneous trials. Importantly, analyses revealed that verbal counting boosted performance specifically on heterogeneous trials, indicating that verbal counting allowed children to overcome the impacts of perceptual variability in the context of a cardinality task. Although some previous studies with older children and adults have revealed verbal counting to *benefit* from array heterogeneity (e.g., Frick, 1987; Towse & Hitch, 1997; Trick, 2008; but see Miller & Baker, 1968), our data did not reveal this, suggesting that perhaps young children may require further experience with counting to use perceptual variability to their benefit.[4] Regardless, findings confirm that verbal counting facilitates numerical abstraction in young children faced with perceptual variability.

Given that all children who participated in our task had been identified as proficient counters (CP knowers), what made some children invoke successful counting strategies while others did not? One possibility is that counting behavior reflected greater maturity and/or experience with numerical tasks. However, this did not appear to be the case. Post-hoc analyses confirmed that children who spontaneously counted during our task were significantly younger than those who did not count, thereby making it less likely that differences in maturity, counting skill, or counting experience drove children to count. In fact, because they were older, noncounters were likely more mature and were more likely to have had more practice counting items and greater fluency with the count procedure—all factors that should have contributed to better performance on the task overall. Instead, it is possible that children who relied on externalized counting behaviors may have done so because they had a *less* developed representation of number and thus less confidence in their ability to solve the task at hand.

The distinction between children who did or did not count more likely reflects a distinction in strategy choice, perhaps driven by differing levels of confidence with numerical tasks altogether (Geary & Brown, 1991; Kamawar et al., 2010). Consistent with this account, research reveals that children's confidence in the numeric task to be solved may determine what strategy—and the sophistication of that strategy—children choose to employ. For example, Geary, Brown, and Samaranayake (1991) found that typically developing first and second graders were less likely to rely on counting strategies when solving difficult arithmetic problems during a 10-month period, whereas age-matched peers identified as math-disabled (thus presumably less confident in their arithmetic abilities) continued to rely heavily on counting strategies throughout the same period. Similarly, the pattern of counting behavior observed as a function of age and condition in our task also suggests that confidence played a role in determining whether a child engaged in verbal counting. Although our ''find 6'' and ''find 12'' conditions were designed to approximately equate the average ratio of target number to distractor pairs while keeping the

[4]Only one study has investigated whether a similar pattern is observed in young children who have recently mastered the count list (Schaeffer, Eggleston, & Scott, 1974). Although data from that study were in line with a heterogeneity bias for counting, it should be noted that their heterogeneous arrays were constructed such that they contained contiguous subgroups of items (e.g., three tigers, two buttons, and three cars), and importantly, children used these subgroups to guide their counting behavior, such that 95% of children counted items within subgroups in sequence (counting all tigers, followed by all buttons, etc.)—a strategy that does not apply to counting arrays in which all individual items are distinct. Moreover, recent evidence suggests that adults enumerate sets that can be parsed into subsets in a distinctly different fashion than standard heterogeneous sets (Cordes, Goldstein, & Heller, 2013; Redden & Hoch, 2009), thus leaving open the question of how young children's counting would be affected by perceptual variability.

absolute values of the distractor values comparable, it is clearly more difficult to assess the cardinality of a set of 12 (compared with a set of 6) items just by sight (i.e., without counting), making this condition slightly more challenging. In line with our predictions, children were more likely to count in the ''find 12'' condition than in the ''find 6'' condition. Importantly, however, the difference in the proportion of children who counted in the two conditions varied as a function of age such that younger children were equally likely to count in each condition whereas the older age group was notably less likely to adopt counting strategies in the ''find 6'' condition (relative to the ''find 12'' condition) with age. This systematic pattern of counting behavior as a function of age group and condition suggests that a child's confidence in being able to perform the task played a role in determining whether the child chose to verbally count; that is, confidence increases both as children age and as they engage in easier tasks, thus reducing the likelihood that they engage in verbal counting. Some studies have shown a qualitative distinction in performance and strategies among children classified as CP knowers (Davidson, Eng, & Barner, 2012; Le Corre & Carey, 2007). For example, Le Corre and Carey (2007) identified ''CP mappers'' and ''CP nonmappers'' and argued that the former have a richer, qualitatively different understanding of the counting principles that are more stable. Our data are suggestive of a similar distinction in performance for those children who, when confronted with a challenging cardinality task, are less confident in their abilities and opt to invoke verbal counting.

Because our secondary analysis focused exclusively on *spontaneous* verbal counting on the part of the child, it was impossible for us to randomly assign children to the counter or noncounter groups. Thus, it is possible that other variables that we did not assess, such as individual differences in IQ and/or counting experiences (including differences in the rate that caregivers may model counting behavior), may have correlated with a child's propensity to overtly count, thereby leaving open the question of whether it was solely the child's confidence and/or one of these other variables that may have been the driving force behind their tendency to verbally count. Given that counting behavior was associated with successful numerical abstraction in our task, future research should further examine how individual differences (e.g., IQ) and experiences (e.g., modeling counting through training studies) may promote (or hinder) the likelihood of spontaneous counting behaviors and, in turn, whether the promotion of counting behavior continues to result in greater success in numerical tasks (see Posid & Cordes, 2015). Engaging in counting behavior is likely crucial to the acquisition of counting proficiency; thus, these studies may prove important for facilitating the count acquisition process and, in turn, impacting early math achievement (Duncan et al., 2007; Geary, 2011; Stock et al., 2009).

In conclusion, our results extend previous findings of an inherent homogeneity bias in numerical judgments to a novel cardinality judgment task and suggest that the ability to ignore perceptual variation and attend exclusively to number may be an ability that is still developing well into early childhood. However, our data suggest that when children choose to verbally count, they are able to overcome the obstacles presented by perceptual variability, and they outperform those who do not count in a challenging numerical task and demonstrate true numerical abstraction. Moreover, the results are consistent with previous studies suggesting that attaining the level of CP knower may not be the final level in proficiency with the count procedure but that, instead, children invoke differing strategies with age and task difficulty. And sometimes the strategy employed by older children (i.e., attempting to identify cardinality of large sets without verbally counting) is less successful than the strategy employed by their younger counterparts, perhaps mediated by their overconfidence in solving the problem at hand. Together, findings suggest that when attending to number in real-world settings, in which sets are rarely perceptually homogeneous, even children who have mastered the counting routine may be at a disadvantage. Consistent with data revealing that children who are encouraged to count outperform controls (Posid & Cordes, 2015), these results indicate that a greater emphasis should be placed on getting children to engage in verbal counting to maximize success on numerical tasks, especially in the context of perceptually variable displays.

ACKNOWLEDGMENTS

We would like to thank the members of the Boston College Infant and Child Cognition Lab, especially Alison Goldstein, Brynn Huguenel, Erica Tavares, Cara Picano, and Allyse Fazio, who assisted in data collection, as well as Michelle Hurst and Ursula Anderson, who provided statistical help. We would also like to thank the Boston Children's Museum and the *Living Laboratory* at the Museum of Science in Boston, as well as all of the families who participated in our study.

FUNDING

Funding was provided by an Alfred P. Sloan Foundation Fellowship to SC.

REFERENCES

Bar-David, E., Compton, E., Drennan, L., Finder, B., Grogan, K., & Leonard, J. (2009). Nonverbal number knowledge in preschool-age children. *Mind Matters: The Wesleyan Journal of Psychology*, *4*, 51–64.

Cantlon, J., Fink, R., Safford, K., & Brannon, E. M. (2007). Heterogeneity impairs numerical matching but not numerical ordering in preschool children. *Developmental Science*, *10*, 431–440.

Cantrell, L., Boyer, T. W., Cordes, S., & Smith, L. B. (2015). Signal clarity: An account of the variability in infant quantity discrimination tasks. *Developmental Science*.

Cantrell, L., & Smith, L. B. (2013). Open questions and a proposal: A critical review of the evidence on infant numerical abilities. *Cognition*, *128*, 331–352.

Clearfield, M. W., & Mix, K. S. (1999). Number versus contour length in infants' discrimination of small visual sets. *Psychological Science*, *10*, 408–411.

Clearfield, M., & Mix, K. S. (2001). Amount versus number: Infants' use of area and contour length to discriminate small sets. *Journal of Cognition and Development*, *2*, 243–260.

Cordes, S., & Brannon, E. M. (2008). The difficulties of representing continuous extent in infancy: Using number is just easier. *Child Development*, *79*(2), 476–489.

Cordes, S., & Brannon, E. M. (2009a). Crossing the divide: Infants discriminate small from large numerosities. *Developmental Psychology*, *45*, 1583–1594.

Cordes, S., & Brannon, E. M. (2009b). The relative salience of discrete and continuous quantity in young infants. *Developmental Science*, *12*, 453–463.

Cordes, S., Goldstein, A., & Heller, E. (2013). Sets within sets: The influence of set membership on numerical estimates. *Journal of Experimental Psychology: Human Perception and Performance*, *40*(1), 94–105.

Cordes, S., Williams, C. L., & Meck, W. H. (2007). Common representations of abstract quantities. *Current Directions in Psychological Science*, *16*, 156–161.

Davidson, K., Eng, K., & Barner, D. (2012). Does learning to count involve a semantic induction? *Cognition*, *123*, 162–173.

Defever, E., Sasanguie, D., Vandewaetere, M., & Reynvoet, B. (2012). What can the same–different task tell us about the development of magnitude representations? *Acta Psychologica*, *140*, 35–42.

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., … Japel, C. (2007). School readiness and later achievement. *Developmental Psychology*, *43*, 1428–1446.

Feigenson, L. (2005). A double-dissociation in infants' representations of object arrays. *Cognition*, *95*, B-37–B-48.

Frick, R. W. (1987). The homogeneity effect in counting. *Perception and Psychophysics*, *41*, 8–16.

Gallistel, C. R., & Gelman, R. (1992). Preverbal and verbal counting and computation. *Cognition*, *44*, 43–74.

Geary, D. C. (2011). Cognitive predictors of achievement growth in mathematics: A 5-year longitudinal study. *Developmental Psychology*, *47*, 1539–1552.

Geary, D. C., & Brown, S. C. (1991). Cognitive addition: Strategy choice and speed-of-processing differences in gifted, normal, and mathematically disabled children. *Developmental Psychology*, *27*, 398–406.

Geary, D. C., Brown, S. C., & Samaranayake, V. A. (1991). Cognitive addition: A short longitudinal study of strategy choice and speed-of-processing differences in normal and mathematically disabled children. *Developmental Psychology*, *27*, 787–797.

Gelman, R., & Gallistel, C. R. (1978). *The child's understanding of number*. Cambridge, MA: Harvard University Press.

Gelman, R., & Tucker, M. F. (1975). Further investigations of the young child's conception of number. *Child Development*, *46*, 167–175.

Halberda, J., & Feigenson, L. (2008). Developmental changes in the acuity of the 'number sense': The approximate number system in 3-, 4-, 5-, and 6-year-olds and adults. *Developmental Psychology*, *44*, 1457–1465.

Hannula, M., Rasanen, P., & Lehtinen, E. (2007). Development of counting skills: Role of spontaneous focusing on numerosity and subitizing-based enumeration. *Mathematical Thinking and Learning*, *9*, 51–57.

Huang, Y. T., Spelke, E., & Snedeker, J. (2010). When is *four* far more than *three*? Children's generalization of newly acquired number words. *Psychological Science*, *21*, 600–606.

Jordan, K. E., & Brannon, E. M. (2006). A common representational system governed by Weber's law: Nonverbal numerical similarity judgments in 6-year-olds and rhesus macaques. *Journal of Experimental Child Psychology*, *95*, 215–229.

Kaldy, Z., & Leslie, A. M. (2003). Identification of objects in 9-month-old infants: Integrating 'what' and 'where' information. *Developmental Science*, *6*, 360–373.

Kamawar, D., LeFevre, J., Bisanz, J., Skwarchuk, S., Smith-Chant, B., Fast, L., … Watchorn, R. (2010). Conceptual knowledge of counting: How relevant is order irrelevance? *Journal of Experimental Child Psychology*, *105*, 135–145.

Kobayashi, T., Hiraki, K., & Hasegawa, T. (2005). Auditory-visual intermodal matching of small numerosities in 6-month-old infants. *Developmental Science*, *8*, 409–419.

Le Corre, M., & Carey, S. (2007). One, two, three, four, nothing more: An investigation of the conceptual sources of the verbal counting principles. *Cognition*, *105*, 395–438.

Le Corre, M., Van de Walle, G., Brannon, E. M., & Carey, S. (2006). Re-visiting the competence/performance debate in the acquisition of the counting principles. *Cognitive Psychology*, *52*, 130–169.

McNeil, N. M., Uttal, D. H., Jarvin, L., & Sternberg, R. J. (2009). Should you show me the money? Concrete objects both hurt and help performance on mathematics problems. *Learning and Instruction*, *19*, 171–184.

Miller, A. L., & Baker, R. A. (1968). The effects of shape, size, heterogeneity, and instructional set on the judgment of visual number. *American Journal of Psychology*, *81*, 83–91.

Mix, K. S. (1999). Similarity and numerical equivalence: Appearances count. *Cognitive Development*, *14*, 269–297.

Mix, K. S. (2008a). Children's equivalence judgments: Cross-mapping effects. *Cognitive Development*, *23*, 191–203.

Mix, K. S. (2008b). Surface similarity and label knowledge impact early numerical comparisons. *British Journal of Developmental Psychology*, *26*, 13–32.

Mix, K. S., Sandhofer, C. M., Moore, J. A., & Russell, C. (2012). Acquisition of the cardinal word principle: The role of input. *Early Childhood Research Quarterly*, *27*, 274–283.

Petersen, L. A., & McNeil, N. M. (2013). Effects of perceptually rich manipulatives on preschoolers' counting performance: Established knowledge counts. *Child Development*, *84*, 1020–1033.

Posid, T., & Cordes, S. (2015). *How high can you count? Probing the limits of children's counting*. Manuscript submitted for publication.

Posid, T., & Cordes, S. (2014). The small–large divide: A case of incompatible numerical representations in infancy. In D. Geary, D. Berch, & K. Mann-Koepke (Eds.), *Evolutionary origins and early development of basic number processing* (pp. 253–276). San Diego, CA: Elsevier Academic Press.

Redden, J. P., & Hoch, S. J. (2009). The presence of variety reduces perceived quantity. *Journal of Consumer Research*, *36*, 406–417.

Sarnecka, B. W., & Lee, M. D. (2009). Levels of number knowledge during early childhood. *Journal of Experimental Child Psychology*, *103*(3), 325–337.

Schaeffer, B., Eggleston, V. H., & Scott, J. L. (1974). Number development in young children. *Cognitive Psychology*, *6*, 357–379.

Siegel, L. S. (1973). The role of spatial arrangement and heterogeneity judgments on numerical equivalence. *Canadian Journal of Psychology*, *27*, 351–355.

Siegel, L. S. (1974). Heterogeneity and spatial factors as determinants of numerical ability. *Child Development*, *45*, 532–534.

Starkey, P., Spelke, E. S., & Gelman, R. (1990). Numerical abstraction by human infants. *Cognition*, *36*, 97–128.

Stock, P., Desoete, A., & Roeyers, H. (2009). Master of the counting principles in toddlers: A crucial step in the development of budding arithmetic abilities? *Learning and Individual Differences*, *19*, 419–422.

Strauss, M. S., & Curtis, L. E. (1981). Infant perception to numerosity. *Child Development*, *52*, 1146–1152.

Towse, J. N., & Hitch, G. J. (1997). Integrating information in object counting: A role for a central coordination process? *Cognitive Development*, *12*, 393–422.

Trick, L. M. (2008). More than superstition: Differential effects of featural heterogeneity and change on subitizing and counting. *Perception and Psychophysics*, *70*, 743–760.

Wynn, K. (1990). Children's understanding of counting. *Cognition*, *36*, 155–193.

Wynn, K. (1992). Children's acquisition of number words and the counting system. *Cognitive Psychology*, *24*, 220–251.

Xu, F., & Spelke, E. S. (2000). Large number discrimination in 6-month-old infants. *Cognition*, *74*, B1–B11.