NOW YOU SEE IT, NOW YOU DON'T: PRESCHOOLERS' SENSITIVITY TO SPATIOTEMPORAL CONTINUITY

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

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presented by Ali Pearson,

a candidate for the degree of master of arts,

and hereby certify that, in their opinion, it is worthy of acceptance.

Professor Kristy vanMarle

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

Figure/Table Page

Abstract

Previous research suggests that infants understand spatiotemporal continuity and are able to reason about continuity violations (Baillargeon, Spelke, & Wasserman, 1985; Wynn, 1992). Continuity can be violated in two ways – an object suddenly appearing or an object suddenly disappearing. Recent work with infants (Wynn & Chiang, 1998) suggests that the two types of violations are not equivalent, with infants finding discontinuous disappearances more surprising. We extend this research to preschool children by asking (1) if preschoolers are able to detect violations of continuity and, (2) if the same asymmetry found with infants will be found with young children. In Experiment 1, we used a novel paradigm in which children witnessed seemingly "magical" appearances and disappearances of objects in box and were asked to report, 'yes' or 'no', whether a magic trick had occurred on each trial. Like young infants, preschoolers successfully detected continuity violations in this task. However, unlike infants, they detected discontinuous appearances and disappearances equally well, suggesting that for preschoolers, both types of continuity violations are equally salient. Because children could have been tracking the *number* of objects and/or the *continuous extent* of the hidden set (e.g., total volume of the objects) in order to detect the violations, in Experiment 2, we pitted number against continuous extent. Under these circumstances, children successfully detected continuity violations and again were much more likely to detect "magical" number changes than "magical" volume changes. This result is contrary to previous infant research in which infants often track continuous extent better than number (Feigenson, Carey, & Spelke, 2002). There was no difference in the rates of detecting disappearances and appearances. Experiment 3 was designed to see if preschoolers could be induced to detect "magical" volume changes by providing them with familiarization events in which the correct labels ('yes' that's magical or 'no' that not) were provided. Despite this, preschoolers were no better than chance at detecting "magical" volume changes, but again detected "magical" number changes reliably better than chance. In sum, the present work suggests that, like infants, preschoolers are sensitive to violations of continuity. But unlike infants, appearances and disappearances are equally salient to young children. And finally, children's ability to

detect violations of continuity appears to be accomplished by their tracking number of objects, rather than the continuous extent of the hidden set.

Previous research in infant cognition suggests that human infants possess a small number of distinguishable systems of core knowledge that allow them to reason about entities in several domains (Spelke, 1994; Spelke & Kinzler, 2007). Here we consider the domain of physical knowledge, which provides even young babies with expectations about how objects behave in the world (Baillargeon, Spelke, & Wasserman, 1985; Wynn, 1992). It has been suggested that babies use a set of "object principles" to reason about how objects can act and interact (Spelke, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992). These object principles include solidity, cohesion, and spatiotemporal continuity. The principle of solidity states that objects are not able to pass through other objects. Two objects cannot occupy the same space simultaneously. The principle of cohesion states that objects do not fall apart when they move, and instead maintain their shape and boundaries. When object principles are violated, for example, when two objects pass though each other or when an object falls apart when it is picked up (e.g., a sand pile), infants appear to cease to consider them objects, and seem unable to reason about their behavior (Spelke & Van de Walle, 1993).

Perhaps the most fundamental principle comprising infants' core physical knowledge, however, is the principle of spatiotemporal continuity (Carey & Xu, 2001; Xu & Carey, 1996). Spatiotemporal continuity suggests that objects follow continuous paths through space and time. Objects cannot magically appear, disappear, or jump from one location to another without passing through the space in between. This idea is similar to the Piagetian idea of object permanence, which Piaget claimed to be a fundamental achievement of cognitive development (Piaget, 1954).

Violations of continuity are detectable by infants by at least 5 months of age (Baillargeon et al., 1985). In Baillargeon's seminal drawbridge experiment, infants were habituated to a screen rotating towards and away from them in a 180^{o} arc. Following habituation, infants watched an experimenter place a block behind and in the path of the screen and were then shown one of two test events. In the *possible event*, the screen rotated up to the point where it would contact the block and then stopped and reversed its motion. In the *impossible event*, the screen rotated up and through the space where the block had been seen. Infants in this experiment looked longer at the impossible test event, suggesting that they expected the block to still be there even after it was occluded by the screen. A control condition in which there was no block was also included, and infants in this case looked equally at full and partial rotation events, indicating that they were not responding to the differential degree of rotation in the possible and impossible events. This research suggests that 5-month-old infants have object permanence, and expect that objects continue to exist, even when hidden from sight.

Infants have also been shown to detect violations of continuity in the context of simple addition/subtraction events (e.g., Simon, Hespos, & Rochat, 1995; Wynn, 1992). In Wynn's (1992) classic study with 5-month-old infants, the infants in one condition were shown an object, and a screen was raised to hide the object. Next, a second object was placed behind the screen, and then the screen was lowered to reveal one of two outcomes. In the *possible event*, two objects were revealed behind the screen – just what an adult would expect. In the *impossible event*, the screen was lowered to reveal only one object – as if the other object had magically disappeared from behind the screen. In this situation, infants looked longer at the impossible than at the possible event, suggesting that they were keeping track of how many objects were behind the screen, expected them to still be there when the screen was lowered, and noticed when one of them seemed to have magically disappeared, violating continuity.

Violating spatiotemporal continuity

Although many studies have shown that infants are good at detecting continuity violations (Baillargeon et al., 1985; Spelke et al., 1992, 1994; Wynn, 1992), one study has taken this a step further and asked whether infants are equally sensitive to different types of continuity violations. Continuity can be violated by an object impossibly *disappearing* from a location or by an object impossibly *appearing* in a previously empty location. Though these violations may seem at first glance to be equivalent, previous research suggests they may not be. In work by Wynn & Chiang (1998), 8-month-old infants successfully detected magical disappearances, but not magical appearances. In the study, infants participated in one of two conditions – a disappearance or an appearance condition. Infants in both conditions saw the same two types of events – an *object-put-behind* and an *object-removed event*. In the object-put-behind event, a stage with two spatially-separated screens was set up with one object on the stage, with a second (unoccluded) object located off to the side. The screens were then raised, such that the leftmost screen occluded the first object, and an experimenter's hand pushed the second object behind the rightmost screen. The experimenter's empty hand then exited. In the *object-removed event*, both objects began in positions that made them ready to be occluded by the screens, and the screens were then raised. Next, the experimenter's empty hand entered, and then exited, taking with it the object that had been behind the rightmost screen.

After both types of events, infants in the disappearance condition watched as the screens lowered to reveal just one object. This outcome was "magical" when it followed the object-put-behind event and "expected" when it followed the object-removed event. Infants in this condition looked reliably longer at the magical disappearance than at the expected disappearance, suggesting that they were keeping track of the objects behind the screens and noticed when one seemed to have magically disappeared. Infants in the appearance condition saw the same two events (*object-put-behind* and *object-removed*), but instead of seeing a one-object outcome, two objects were revealed when the screens lowered. This outcome was "magical" when it followed the *object-removed event*, but "expected" when it followed the *object-put-behind event*. Unlike the infants in the disappearance condition, infants in this condition looked equally at both types of events, suggesting that they did not notice when an object magically appeared in the object-removed event.

Wynn and Chiang (1998) attributed infants' superior detection of magical disappearances to a mismatch between what the infants were representing mentally and the true state of the world as revealed when the screens were lowered. That is, infants in the disappearance condition were representing two objects (one behind each screen) and this expectation was violated when only one object was revealed. In contrast, infants in the appearance condition were representing one object behind the left screen, but had no expectations about what was behind the right screen (perhaps because the representational system responsible for tracking these events, e.g., object indexes or analog magnitudes, does not represent empty sets). Therefore, when the screens were lowered to reveal two objects, there was no mismatch – infants expected and saw one object behind the left screen, but had no active representation for what was behind the right screen (i.e., nothing) and experienced no mismatch.[1] Based on these results, Wynn & Chiang concluded that infants find magical disappearances more salient than magical appearances (Wynn & Chiang, 1998).

Understanding the asymmetry

Evidence about whether children and adults more readily detect one or the other type of discontinuity is somewhat mixed. Work by Agostinelli, Sherman, Fazio, and Hearst (1986) suggests that in some contexts, adults may be better at detecting unexpected appearances than unexpected disappearances. In one experiment, college students studied line drawings for a later pattern completion task. Instead, they were given a memory test in which they had to determine whether features had been added to or deleted from the drawings. Results revealed asymmetrical performance, but contrary to the infant findings (Wynn & Chiang, 1998), adults were better at detecting appearances than disappearances. In a second experiment, however, when participants were informed of the actual purpose of the task and given time to study the line drawings they detected disappearances more readily than appearances (Agostinelli et al., 1986).

Similar research with young children suggests they detect appearances more readily than disappearances (Miranda, Jackson, Bentley, Gash, & Nallan, 1992). After studying a clipart picture for 20 seconds, they were asked to look at another picture and identify the change that had occurred. Pictures were simple scenes made with clipart and the two test pictures were identical in all respects except for the addition or deletion of a single item. In one experiment, both kindergarten and second grade children correctly identified appearances significantly more than disappearances. The same was true in a further experiment, when the items in the study picture had been explicitly named during the study period

[1] This is not unreasonable. It is computationally intractable for a mechanism to represent empty sets since there are infinitely many of them.

(Miranda et al., 1992). This advantage for appearances with clipart pictures was extended to adults, and was also found with three-dimensional objects (Nallan, Bentley, Carr, Lyons, Moore, & Underhill, 1994).

One possible explanation for the difference in the direction of the asymmetry for adults and children (appearance advantage) compared to infants (disappearance advantage) is the nature of the tasks. In Wynn and Chiang's (1998) work, infants faced a real scene in which a whole object appeared or disappeared, making the task an "object tracking" task. In contrast, the research just reviewed involved subjects looking at (or studying) two-dimensional pictures and then trying to identify when an element had been added or deleted, a task that may rely more on recognition and recall memory than object tracking. Thus, it is not clear whether the asymmetry found in that context is comparable to that found with infants.

Using a task more similar to the infant object tracking task (Wynn & Chiang, 1998) and to the task used in the present experiments, research by Subbotskii has also revealed an asymmetry in children's and adults' detection of discontinuous appearances and disappearances (Subbotskii, 1988; Subbotsky 1996). Subbotskii measured children's verbal and physical behavior when they encountered events that violated object permanence (i.e. a transformation, an appearance, and a disappearance). Children were questioned about the nature of reality and whether or not events that can happen in "fairy tales" can also happen in "real life". Then they were told a story about a magic box that was capable of making an object appear, disappear, or change into another object. In the next phase, children witnessed three different violations of object permanence, always in the same order: (1) the transformation of one type of object into another type of object, (2) the disappearance of an object, and (3) the appearance of an object. In the first trial, the experimenter showed the child a postage stamp that he claimed was created by putting a piece of paper into the box on the table. The children were then allowed to try it themselves by placing the paper into the box, closing the lid, and reopening it to find a postage stamp (i.e. a transformation). Later, the child was brought back into the room for the second part, a disappearance. The child was told that the box had a further property -- that it could change a stamp into any one of three objects.

However, when the child placed the stamp into the box and closed the lid, they found nothing in the box when they reopened it, as if the stamp had magically disappeared. In the final part, appearance, the child could close and then re-open the box to find a postage stamp where there had been nothing before, as if the stamp had magically reappeared.

Results indicated that nearly all of the children verbally acknowledged the impossibility of appearances, disappearances, and transformations in "real life". And yet, they allowed for such events within the realm of "fairy tales". In terms of behavior, the disappearance event generated substantially more search than did the transformation or appearance events (Subbotskii, 1988). This suggests that preschoolers were more inclined to engage in search behavior following the discontinuous disappearance of an object compared to both the discontinuous appearance of an object and the transformation of one object into another. This, however, does not necessarily indicate an advantage for disappearances because the likelihood of search should be greater when an object is missing (i.e., a disappearance) than when it is present (i.e., appearance or transformation). Evidence from different dependent measures, facial expression and voice was more telling. Results indicated that, compared to the appearance and transformation events, the disappearance event caused a greater degree of subjective dissonance, as measured by facial expressions of surprise (Subbotskii, 1988). Subbotskii argued that this suggests that disappearances are more salient than appearances for preschoolers in this context. Taken together, the results of this study are at least suggestive that, like infants, preschoolers may find disappearances more salient than appearances.

Subbotsky (1996) extended this work by investigating adults' reactions to violations of object permanence. Using a modified version of the “magic box” paradigm, he examined adults’ memory distortions (i.e. incorrect temporal sequencing), which he believed might reflect the strength of their belief in object permanence and any differential sensitivity to appearances and disappearances. Subjects first answered questions designed to examine the strength of their belief in object permanence. Then, they were asked to retrieve a toy that had been placed in the room, behind them. Following this, they were asked to put an object into the box, and close the lid before answering another series of questions. In the second phase, more questions were asked, including whether or not anything was unusual about the preceding events. If a subject reported noticing a disappearance or an appearance, a further set of questions was asked in order to examine their explanation(s) for the discontinuous appearance or disappearance. Next, the experimenter suggested to the subject that perhaps there was a point during the experiment when their attention was drawn away from the box. Although in every case they had retrieved the toy before any objects were ever placed into the box, Subbotsky (1996) predicted that adults would remember this retrieval task as interrupting the box manipulations in an attempt to explain the discontinuous event with which they were faced, and furthermore, that subjects in the disappearance condition would show more temporal distortions in their memory of the order of events compared to subjects in the appearance condition.

The predictions were upheld. The temporal reconstructions provided by subjects showed that they reported the incorrect temporal order of events in the disappearance condition much more often than in the appearance condition and, when confronted with a discontinuous event (appearance or disappearance), they insisted that there must have been some trick, showing their unwillingness to accept the violations of permanence they had witnessed. Importantly, the fervor with which subjects defended their belief in object permanence in the disappearance condition was greater than in the appearance condition (Subbotsky, 1996).

These results clearly suggest an asymmetry between appearances and disappearances. Subbotsky (1996) explained the direction of the asymmetry by proposing that a discontinuous appearance presents less of a challenge to one's belief in object permanence than a discontinuous disappearance. That is, a subject who has witnessed an appearance can easily explain it away by attributing it to a lack of attention on their part. These results replicate the direction of the asymmetry found by Subbotskii (1988) with preschoolers and by Wynn & Chiang (1998) with 8-month-old infants, suggesting that there may be continuity across the lifespan in the relative saliency of discontinuous appearances and disappearances.

The present study has two goals. First, we ask whether or not preschoolers can detect violations of continuity in a task that is analogous to that used by Wynn and Chiang (1998). Second, assuming they do detect such continuity violations, will they show the same asymmetry – that is, will they be better at detecting magical disappearances than appearances?

Experiment 1

Although the "magic box" paradigm used by Subbotskii (1988, 1996) was similar in many ways to the infant object tracking task in Wynn and Chiang (1998), there were several methodological differences. For instance, Subbotskii measured either children's verbal behavior and facial expressions (1988) or adults' memory distortions (1996) in response to encountering events that violated continuity, whereas Wynn and Chiang (1998) used looking time measurements. Subbotskii (1988) also permitted children to manipulate the box, whereas participants in Wynn and Chiang's (1998) experiment did not interact with the experimental stimuli. The present study was designed to be analogous to the infant task, while still being engaging to preschoolers to allow for comparison.

Participants

Participants were 24 preschool children (12 females) ranging in age from 2y 11m to 5y 6m. Five additional children were tested, but their data were excluded due to failure to cooperate (1 child), failure to complete a full set of test trials due to inattention (3 children), or response bias (1 child). A response bias was defined as giving the same answer on all 20 test trials. All participants were recruited from the greater Columbia, Missouri area. Parents provided written consent prior to their children's participation in the research.

Apparatus/Stimuli

The stimuli were small toy animals (approximately 2" x 1" x 2") that were each glued to a foam-core base (approximately 2" x 2") containing a magnet. In order to allow for expected outcomes and to create the illusion of magical ones, a "magic box" was built by modifying a wooden box (11"x11"x11.5"), so that it contained a false floor that could be surreptitiously rotated by means of a hidden handle. The rotating floor was covered on both sides with thin sheet metal and then covered with black felt to match the inside of the box, which was painted black. The sheet metal on the false floor allowed the stimuli to stick magnetically to the floor even when upside down. The handle and rotating floor were constructed in such a way that the turning of the floor was virtually silent.

Procedure

Participants were tested individually in a single 15-minute session in their preschool facility. Sessions were videotaped for reviewing and coding purposes. Each child was asked if they would like to play a game with the experimenter. The experimenter then explained the game to the child and they were introduced to the magic box that was said to belong to Ernie (a hand puppet), who sometimes uses his magic box to perform magic tricks.

Familiarization Phase

To check for understanding and to provide the opportunity for corrective feedback, each participant first received four familiarization trials. The first two involved a potential color/kind change. On the first familiarization trial, a small, white, stuffed baseball remained the same (expected), and on the second familiarization trial, the baseball "magically" became a small, orange, stuffed basketball (magical). The next two familiarization trials involved a potential number change involving the number zero since children have been shown to have trouble understanding it (Wellman & Miller, 1986) and might find it magical in its own right. In the third familiarization trial, the empty box remained empty (expected), and on the fourth and final familiarization trial, a small wooden block appeared in the previously empty box (magical). All children received the familiarization trials in the same order.

In each trial, the child was first shown the initial contents of the box, and then the lid was closed. On trials with magical outcomes, the box's handle was discreetly rotated while the lid was closed in order to create the illusion of magic. On trials with expected outcomes, the handle was rotated halfway and then back to its original position in order to keep the experimenter's movements and any noise constant across trial types. Since the handle was located on the back of the box, children could not readily see it, and although children frequently inquired how the magic had happened, they never suspected the handle. After this, the box was reopened, the child was shown the outcome, and was then asked, "Did Ernie do a magic trick?" The dependent measure was whether the child answered 'yes' or 'no' in response to this question. During familiarization, children were provided with feedback on their answers. If they answered correctly, they received affirmation (e.g., "You're right! That was magical! Ernie changed something!). If they answered incorrectly, they were corrected (i.e., "Actually, Ernie didn't do a magic trick. See, it's still the same thing!" or "Actually, Ernie did do a magic trick. Look, he made the ball change into a different kind of ball!")

Test Phase

Following familiarization, each child received 20 test trials – half with magical and half with expected outcomes. The procedure was identical to familiarization except that children were never corrected on test trials and were always praised (e.g., "Great job! Let's do another one!"), regardless of whether they answered the question correctly or not. The first eight test trials were *non-operation* trials in which a potential number change occurred (e.g., 1=2, 1=1). Though simpler from the trials presented to infants in Wynn and Chiang's (1998) study, non-operation events were included here to ensure that children could perform the basic task of remembering the contents of the box, noticing when something unexpected happened, and using the response labels ('yes' or 'no') appropriately. The remaining 12 trials were *operation* trials (and analogous to the events in Wynn & Chiang, 1998) in which the experimenter added or subtracted an object from the box after showing the child the initial contents and before closing the lid (e.g., 1+1=2, 2-1=2). For example, in a 2-1=2 event, the experimenter would show the child two objects inside the box and then remove one object while the child watched but was not able to see the inside of the box. This was done in order to ensure that the child would have to mentally update representation instead of being allowed to form a new representation by looking inside the box. Finally, the box was opened to reveal 2 objects – a magical appearance.

Each child received the test trials in one of two orders. The two orders were determined pseudo-randomly with the constraint that the same two events did not occur in succession. See Appendix A for a list of the all of the events and the two possible trial orders.

Results

For the initial analysis, children were divided into two age groups, older and younger, by median split. This was done to examine whether there were any age effects, similar to those found in previous research in which toddlers have been shown to fail in search tasks that are analogous to looking time tasks in which infants successfully detect violations of solidity (Butler, Berthier, & Clifton, 2002; Hood, Carey, & Prasada, 2002; Hood, Cole-Davies, & Dias, 2003). The mean age for the older group was 5 years, 2 months (Range: 4 years, 7 months – 5 years, 6 months) and the mean age for the younger group was 3 years, 7 months (Range: 2 years, 11 months – 4 years, 5 months). A preliminary 4 x 2 x 2 x 2 repeated measures ANOVA with Trial Type (expected non-operation, magical non-operation, expected operation, and magical operation) as a within-subject factor, and Sex (male or female), Test Order (Order 1 or Order 2), and Age Group (Younger or Older) as between-subject factors, revealed four significant effects. First, there was a main effect of Trial Type ($F[3,48] = 7.544$, $p < .001$). As a group, children performed better on the non-operation trials (expected: M = 87% correct, SD = 27.0; magical: M = 90%, SD = 12.8) than the operation trials (expected: M = 65%, correct, SD = 17.1; magical: M = 70% correct, SD = 26.0). None of the other factors interacted with Trial Type. Second, we found a significant main effect of Age Group, with older children performing better than younger children (older: M = 83% correct, SD = 11.4; younger: M = 71% correct, SD = 10.9, $F[1,16] = 7.096$, $p < .02$). However, both age groups performed reliably above chance (older: $t(11) = 10.83$, $p < .0001$; younger: $t(11) = 4.71$, $p = .001$)[2]. Third, there was a main effect of Sex, such that males performed significantly better than females (males: M = 84% correct, SD = 10.9; females: M = 70% correct, SD = 11.4, $F[1,16] = 8.421$, $p = .01$). Although boys outperformed girls, follow up analyses indicated that both males' (M = 85%, SD = 13.5, $t(11) = 8.876$, $p < .0001$) and

[2] This and all subsequent T-tests report two-tailed p-values.

females' (M = 72% correct, SD = 13.4, $t(11) = 5.574$, $p < .0001$) performance was reliably above chance. Finally, there was a significant three-way interaction between Sex, Order, and Age Group ($F[1,16] = 6.857$, $p = .019$). For males, younger children performed better than older children in Order 1 (younger: M = 92% correct, SD = 10.6; older: M = 79% correct, SD = 10.6), but the opposite was true in Order 2 (younger: M = 68%, SD = 10.6; older: M = 94%, SD = 10.6). For females, older children performed better than younger children in both orders (Order 1: older: M = 82%, SD = 10.6; younger: M = 60%, SD = 10.6; Order 2: older: M = 76%, SD = 10.6; younger: M = 63%, SD = 10.6). Given that there were no more than five (and as few as two) children in any one of these cells, this effect is difficult to interpret.

To follow up on the main effect of Trial Type, we performed three paired *t*-tests – operation vs. non-operation events, expected vs. magical non-operation events, and expected vs. magical operation events. These were collapsed over Age Group since the two factors did not interact ($F[3,48] = .173$, $p >$ n.s.). Only the comparison of operation vs. non-operation events was significant (operation: M = 88% correct, SD = 16.7; non-operation: M = 68% correct, SD = 18.3, $t(23) = 5.150$, $p < .0001$). The comparisons of expected vs. magical non-operation events (expected: M = 87% correct, SD = 24.4; magical: M = 90% correct, SD = 14.6, $t(23) = -.681$, $p =$ n.s.) and expected vs. magical operation events (expected: M = 65% correct, SD = 27.6; magical: M = 70% correct, SD = 23.0, $t(23) = -.808$, $p =$ n.s.) did not reach significance. (See Figure 1.) This pattern of results suggests that within each type of trial (non-operation or operation), performance did not vary as a function of whether the outcome was magical or expected. Rather, the factor driving the significant effect of Trial Type was superior performance by children on non-operation compared to the more complex operation trials.

To answer the question of whether preschoolers in our task detected violations of continuity, we compared children's performance against chance. We conducted two one-sample t-tests on children's mean proportion correct (collapsed across age groups) on operation and non-operation events. Children performed reliably above chance on both (non-operation: M = 88% correct, SD = 16.68, $t(23) = 11.17$, $p<.0001$; operation: M = 68% correct, SD = 18.13, $t(23) = 4.83$, $p<.0001$).

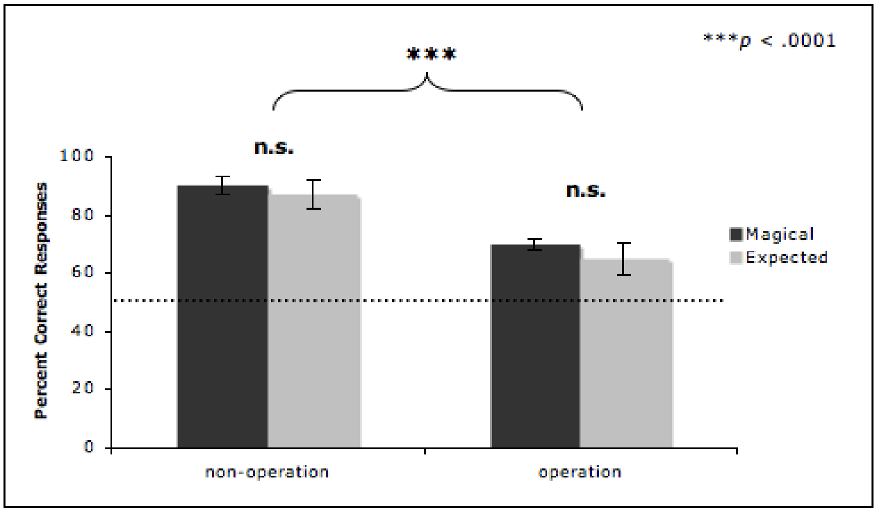

Figure 1. Mean percent correct responses on magical and expected non-operation and operation events.

To examine whether preschoolers exhibited the same asymmetry shown in infants, we compared children's ability to detect magical disappearances and appearances. These analyses were conducted on just the operation trials, because these are the events that are analogous to the events used with infants in Wynn & Chiang (1998). As a group, there was no difference in children's ability to detect magical disappearances and magical appearances, (MD: M = 72% correct, SD = 34.99, MA: M = 67% correct, SD = 31.16, $t(23) = .59$, p = n.s.). In addition, children detected both events reliably better than chance (MD: $t(23) = 3.12$, $p = .005$; MA: $t(23) = 2.6$, $p = .02$). Taken together, these results suggest that, unlike for infants, magical appearances and disappearances are equally salient to preschoolers in our task. (See Figure 2.)

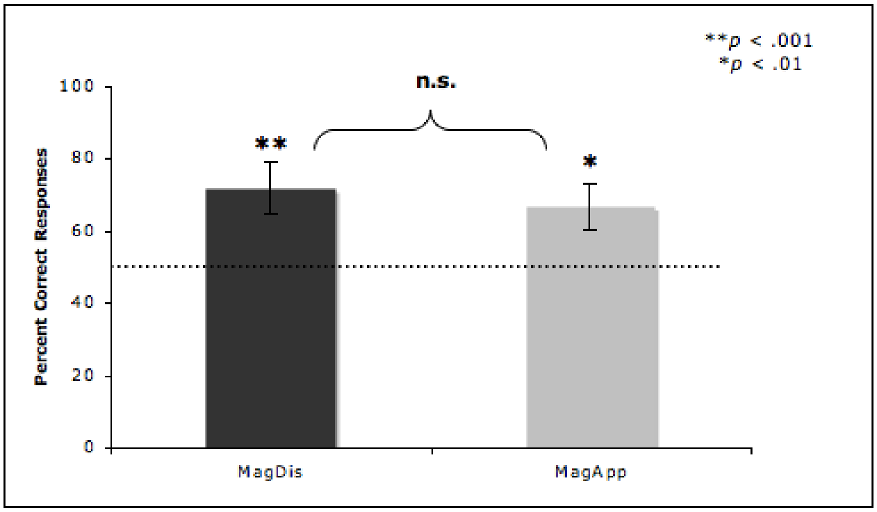

Figure 2. Children's mean percent correct on Magical Disappearance and Magical Appearance operation events.

Discussion

Overall, children performed better on non-operation events than on operation events. This is not surprising given that in order to detect the continuity violations in the operation events, children must represent the initial contents of the box, and then update this representation after an object has been added or removed. Non-operation events require only noticing whether or not something has changed and may require only perceptual memory. The fact they performed reliably above chance on both types of events, however, suggests that they were successfully detecting the continuity violations and that they were able to correctly categorize which outcomes were magical and which were not.

Unexpectedly, we did not find evidence that magical disappearances were more easily detected than magical appearances by preschoolers. Although the small difference in proportion correct favored disappearances (72%) over appearances (67%), this difference was not reliable. Thus, in contrast to the infant findings (Wynn & Chiang, 1998) and previous work by Subbotskii (1988), preschoolers did not exhibit any asymmetry in their detection of discontinuous appearances and disappearances in our task. One possible reason why we failed to find the type of asymmetry reported by Wynn and Chiang (1998) and Subbotskii (1988, 1996) is that our study required verbal responses, an explicit measure, whereas those of Wynn and Chiang (1998) and Subbotskii (1988, 1996) made use of implicit measures such as looking time, facial expression, and memory distortion.

Unexpectedly, males performed better than females overall, though both males' and females' performance was reliably above chance. This finding, while potentially important, is likely due in large part to a small sample, and it would need to be replicated before it could be considered meaningful.

Given that children successfully demonstrated knowledge of continuity in our task, one question that arises is how they detected the continuity violations. In infant looking time tasks such as that in Wynn (1992) and Wynn & Chiang (1998), it has been suggested that infants are responding on the basis of continuous extent. That is, they may be responding not to a mismatch in the *number* of objects, but instead to a mismatch in the *amount* of object stuff expected (e.g., on the basis of some continuous variable like contour length or surface area Clearfield & Mix, 1999, 2001). For example, Clearfield and Mix (1999) habituated 6- to 8-month-old infants to computer displays containing a fixed number (2 or 3) of squares of fixed sizes. In test trials, infants were shown two alternating displays. One display featured squares with the same total contour length but a different total number of squares than the infants viewed during habituation, and the other display featured the same total number of squares as the infants saw during habituation, but with a different total contour length. Results showed that infants dishabituated to displays of novel contour length and familiar number, but not to displays of novel number and familiar contour length, suggesting that they were tracking a continuous quantity (i.e., contour length) rather than number. Feigenson, Carey, and Spelke, (2002) found similar results with 6- and 7-month-old infants and live displays featuring animal-like Lego objects. The objects were identical in all ways with the possible exception of size. Infants were habituated to either one large object or two small objects, and during test trials, they were shown a display featuring a novel number of objects with a familiar surface area, or a display featuring novel surface area with a familiar number of objects. Infants in this study also responded to changes in continuous extent and not number (Feigenson et al., 2002). To examine whether preschoolers in our study were using the number of objects or amount of stuff to detect the continuity violations, we conducted a second experiment in which we controlled for continuous extent.

Experiment 2

Previous research suggests that infants' tendency to respond to either number or continuous extent depends on the nature of the stimuli. When pitted against each other, 6- and 7-month-old infants detect a change in continuous extent, but not number, when the objects in the array are identical in features (Clearfield & Mix, 2001; Feigenson et al., 2002). However, when the objects have distinct features (i.e., distinct colors and patterns), infants respond to a change in number, but not continuous extent (Feigenson, 2005). In our first experiment, older children detected continuity violations when the objects had identical features. In the present experiment, we pitted volume of the object arrays against number to see which dimension is more salient. If children, like infants, are limited to responding on the basis of extent for homogenous sets, then they should fail to reliably discriminate the magical and expected events in this experiment. If, on the other hand, they are able to respond on the basis of number, then they are expected to succeed.

Participants

Participants were 12 (3 female) preschool children ranging in age from 4y 7m to 5y 8m. One additional child was tested, but that child's data was excluded due to failure to cooperate and to complete a full set of test trials. Since pitting number against volume potentially made the task more difficult, and since older children outperformed younger children in Experiment 1, we included only "older" children in this experiment to ensure that the results could be clearly interpreted in terms of the volume manipulation. All participants were recruited from the greater Columbia, Missouri area. Parents provided written consent prior to their children's participation in the research.

Apparatus/Stimuli

We used the same magic box as in Experiment 1, but created a new set of stimuli in order to manipulate number and volume in the event outcomes. The stimuli were small green cubes with volumes measuring two, four, or eight cubic inches. Each cube was glued to a foam-core base containing a magnet.

Procedure

Participants were tested individually in a single 15-minute session. All but five participants (who were tested in the lab) were tested at their daycare center. Sessions were videotaped for reviewing and coding purposes. The same procedure from Experiment 1 was used with a few modifications as described below.

Familiarization Phase

Each participant first received two (rather than four) familiarization trials involving a potential color/kind change. These trials were identical to the first two familiarization trials children received in Experiment 1. We did not include familiarizations involving zero. Because we controlled for volume, it was not possible to include events (here or in the test phase) that had zero either as an initial number or an outcome since outcomes of zero have no volume. As in Experiment 1, children were given corrective feedback during the familiarization phase.

Test Phase

Following familiarization, each child received 16 test trials – half with magical and half with expected outcomes in terms of numerosity and volume. The two dimensions were pitted against each other such that outcomes that were magical in terms of number were always expected in terms of volume and vice versa. The first eight trials were *non-operation* events in which a potential number change occurred (e.g., 1=2 or 1=1). The next 8 trials were *operation* events in which the experimenter added or subtracted an object from the box after showing the child the initial contents and before closing the lid, just as in Experiment 1. The initial contents of the box were always composed of either one or two cubes with total volume measuring either four or eight cubic inches. One-object outcomes always consisted of a single cube with a volume of eight cubic inches, and two-object outcomes always consisted of two cubes, each with a volume of two cubic inches (4 cubic inches total). The presentation of the events proceeded exactly as in Experiment 1. See Appendix B for a list of the all of the events and the two possible trial orders.

Results

We used proportion 'yes' responses as the dependent measure (rather than proportion correct) for all remaining analyses (Experiments 2 and 3). Since number and volume were pitted against each other, it was not clear whether children would find unexpected volume changes to be "magical". Using proportion correct (as in Experiment 1) would involve implicitly assuming that unexpected volume changes were indeed "magical" (or not) to children. Given that we did not know whether children would categorize them as magical or not, using proportion 'yes' responses provides a clearer picture of children's performance.

A preliminary 4 x 2 x 2 repeated measures ANOVA with Trial Type (non-operation number change, non-operation volume change, operation number change, and operation volume change) as a within-subject factor, and Sex (male or female) and Test Order (Order 1 or Order 2) as between-subject factors revealed two significant effects[3] -- a main effect of Trial Type (F[3,24) = 36.11, $p < .0001$), and a main effect of Test Order (F[1,8] = 6.88, $p = .03$). For both non-operation and operation events, children responded 'yes' more often when number was magical (non-operation: M = 100%, SD = 0; operation: M = 88%, SD = 16.86), than when volume was magical (non-operation: M = 8%, SD = 22.19; operation: M = 46%, SD = 31.68). Paired t-tests comparing children's tendency to respond 'yes' on magical number and volume events revealed reliable differences for both non-operation events (t(11) = 14.31, $p < .0001$) and operation events (t(11) = 4.21, $p = .001$).

To further examine children's tendency to categorize unexpected number and volume change events as "magical", we compared proportion 'yes' responses for three of the four trial types against chance (children were at ceiling on non-operation number change trials, 100% 'yes' responses, so no analysis was conducted on these events). Children's performance was significantly above chance on

[3] Note that the main effect of sex was non-significant (F[1,8] = .43, $p = .53$). However, given that the gender composition of the sample was uneven (3 females and 9 males), the validity of this insignificant result should be interpreted with caution.

operation number change trials (88% 'yes' responses, $t(11) = 7.71$, $p < .0001$), suggesting that they successfully detected continuity violations when number and volume were pitted against each other. In contrast, performance was significantly below chance on non-operation volume change trials (8% 'yes' responses, $t(11) = -6.50$, $p < .0001$) and was no different from chance on operation volume change trials (46% 'yes' responses, $t(11) = -.46$, p = n.s.), suggesting that children did not find unexpected volume changes "magical" in either context. (See Figure 3.) Note, however, that the tendency to respond 'yes' to unexpected volume changes was significantly greater for operation events (46%) than non-operation events (8%), ($t(11) = 3.76$, $p < .005$), suggesting that children may track multiple cues in operation events.

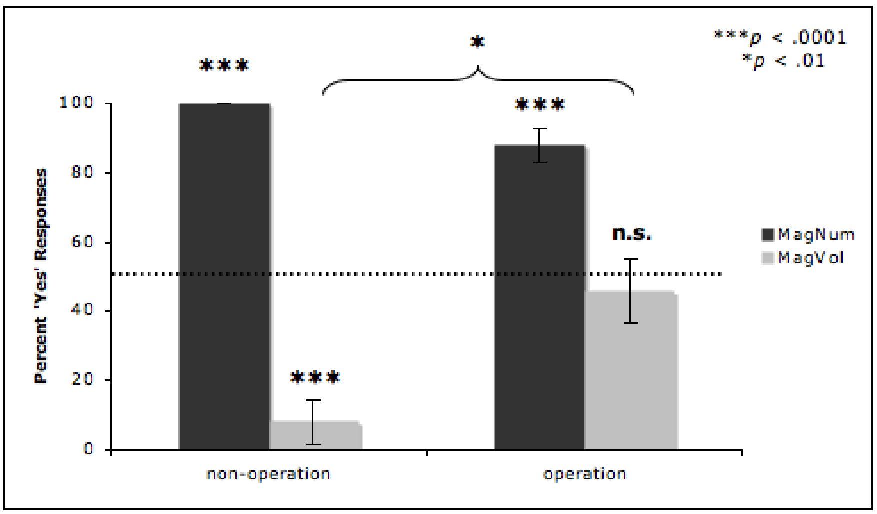

Figure 3. Children's mean percent "yes" across non-operation and operation events as a function of magical trial type.

We also examined preschoolers' performance on magical disappearances and appearances (see Figure 4) and found that children detected both event types reliably at better than chance levels (MD: M = 92% 'yes', SD = 19.5, $t(11) = 7.4$, $p < .0001$; MA: M = 83% 'yes', SD = 24.6, $t(11) = 4.7$, $p = .001$), and that there was no difference in the rates of detection of the two events ($t(11) = 1.0$, $p = .34$).

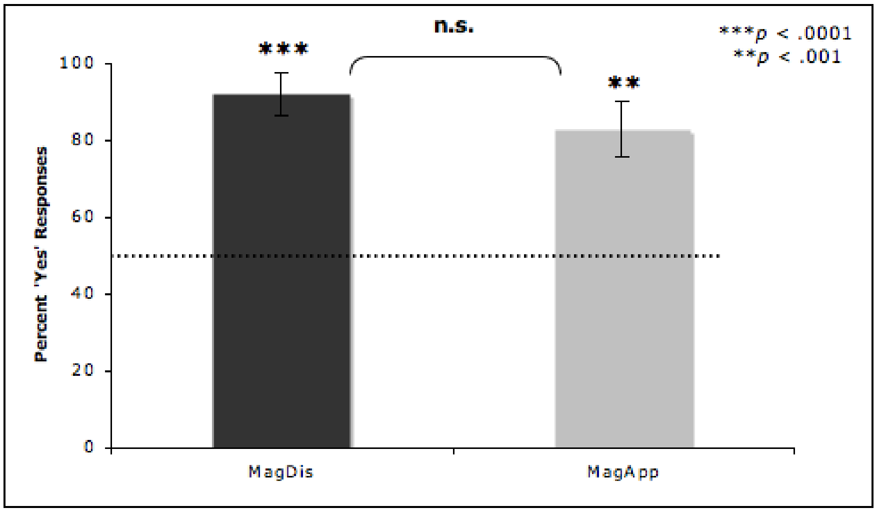

Figure 4. Children's mean percent "yes" on Magical Disappearance and Magical Appearance events.

In addition to the main effect of Trial Type, we also found a main effect of Test Order ($F[1,8] = 6.88$, $p = .03$), reflecting a reliable difference in the average overall rates of responding 'yes' between the children in each of the two test orders. Children in Order 1 responded 'yes' 68% of the time (SD = 11.5), while children in Order 2 responded 'yes' 53% of the time (SD = 5.23). This difference, though significant, may not be particularly informative, as there is no immediately obvious explanation for it. In our opinion, the only striking difference between the two orders is whether the first trial was unexpected in number or volume. Children in Order 1 received the former, while children in Order 2 received the latter. It is possible, though we think unlikely, that the differential salience of the unexpected change (either highly salient in the case of number changes, or less salient in the case of volume changes), affected children's initial response (most often 'yes' in Order 1, most often 'no' in Order 2) and set the stage for later responding. It cannot be the case that the initial response set up a response *bias*, since children in Order 2, most all of whom responded with 'no' on the first test trial, said 'yes' and 'no' almost an equal number of times over the course of the experiment. Rather, it might be possible that children who responded 'yes' on the first test trial became more inclined to do so, eventually saying 'yes' 68% of the time, a value that is significantly above chance, (*t*(5) = 3.78, $p < .02$. Note however, that there were only six children in each order. Consequently, we do not wish to place too much emphasis on this result unless proven replicable.

Discussion

Preschool children overwhelmingly responded to violations of continuity when number was pitted against volume, suggesting that number is more salient than volume in this task. This is contrary to previous studies with infants suggesting that continuous extent dominates children's responses in these types of events (e.g., Clearfield & Mix, 1999, 2001; Feigenson, et al., 2002, Mix, Huttenlocher, & Levine, 2002). It is possible that infants do find continuous extent more salient than number, and that there is a developmental shift that occurs by around age 5 such that number becomes more salient than continuous extent. However, recent research by Cordes and Brannon (2009) failed to replicate Clearfield and Mix's (1999) result that infants respond to continuous extent and not number, showing instead that infants respond to both continuous extent and number with small sets of objects. Thus, it is possible that our finding reflects a much less dramatic shift, where number and continuous extent are initially equally salient, and then over time, number becomes relatively more salient, even for small sets of identical objects, as was used in our experiment.

Preschoolers again detected magical number outcomes better on non-operation events than on operation events, though they were more likely to respond to magical volume outcomes on operation events than on non-operation events, suggesting that they may have been attending to and encoding volume and using it to reason about events in which the remembered set underwent a hidden transformation.

As in Experiment 1, preschoolers detected both magical disappearances and magical appearances at reliably better than chance levels, and there was no difference in the rate of detection of these event types. This replicates the finding in our first experiment and suggests that preschoolers may not find magical disappearances more salient than appearances, at least not as measured by their explicit verbal categorization of these event types.

Although these results are suggestive, two limitations led us to conduct a third experiment. First, we felt that because the sample size was relatively small, the findings should be replicated with a larger sample. Second, the outcome on every trial was “magical” in terms of either number or volume. The absence of “catch” trials in which no change occurred (i.e., the number and volume were both correct) would have helped determine what children’s baseline rate of responding ‘yes’ was in this experimental context and provide a metric for determining just how “magical” unexpected number and volume really were.

Experiment 3

Since children in Experiment 2 very clearly detected magical number changes, but not magical volume changes, Experiment 3 was designed to try to induce children to detect and categorize unexpected volume changes as “magical”. Previous work by Mix and her colleagues suggests that both infants and young children attend preferentially to continuous amount (e.g., surface area, contour length), and that attention to number develops later than attention to continuous quantities (Mix et al., 2002). We therefore were interested to see whether children could be made to respond on the basis of volume in our task. To accomplish this, we manipulated the nature of the familiarization children received so that some of the children received feedback explicitly showing them that unexpected volume changes should be labeled as “magical”. In addition, we included “catch” trials in which outcomes were expected in terms of both number and volume to obtain a baseline measure of children’s tendency to categorize an event as “magical” when nothing has changed.

Participants

Participants were 24 (12 females) preschool children ranging in age from 4y 8m to 5y 9m. We again tested only “older” children because the events are potentially difficult and we wanted the results to be directly comparable to Experiment 2. One additional child was tested, but the data were excluded due to failure to cooperate and to complete a full set of test trials. All participants were recruited from the greater Columbia, Missouri area. Parents of all participants provided written consent for their child's participation prior to testing.

Apparatus/Stimuli

We used the same magic box as in Experiments 1 and 2, and we used the same green cubes as in Experiment 2 for the test trials. The stimuli for the familiarization trials included the toy objects from Experiment 1 as well as two newly-constructed blue Lego cubes measuring two and four cubic inches, respectively.

Procedure

Participants were tested individually in a single 15-minute session. All but six participants (who were tested in the lab) were tested at their daycare center. Sessions were videotaped for reviewing and coding purposes. The same procedure from Experiment 1 was used except as noted below.

Familiarization Phase

Each participant first received four trials in which they were familiarized with either to non-quantity related changes (Kind Fam) or quantity-related changes (Amount Fam). An equal number of children (n=12) participated in each familiarization condition. In the Kind Fam condition, preschoolers were familiarized with potential color/kind changes, just as in Experiment 2. In the Amount Fam condition, preschoolers were familiarized with both potential number changes (i.e., two ducks turning into one duck or remaining as two) and potential volume changes (i.e., a blue Lego block with a volume of 2 cubic inches turning into a blue Lego block with a volume of 4 cubic inches or remaining 2 cubic inches in volume). There were two different familiarization orders in each of the two familiarization conditions, which differed in the order in which children saw the various stimuli used in the familiarization trials. For example, in the Kind Fam, children would either see trials involving a duck and a frog before trials involving a baseball and a basketball or vice versa. In the Amount Fam, children would either see trials involving a potential number change before trials involving a potential volume change or vice versa. In all cases, children received familiarization trials in which the correct answer sequence was 'no', 'yes', 'yes', 'no' (i.e., expected, magical, magical, expected). As in Experiments 1 and 2, children were given corrective feedback during the familiarization phase.

Test Phase

Following familiarization, each child received 12 test trials – four "catch" trials in which the outcome was expected in terms of both number and volume, four trials whose outcomes were magical in terms of number, but expected in terms of volume, and four trials whose outcomes were magical in terms of volume, but expected in terms of number. The first six trials were *non-operation* trials in which a potential number or volume change occurred (e.g., 1=2 or 1=1). The final six trials were *operation* trials in which the experimenter added or subtracted an object from the box after showing the child the initial contents and before closing the lid, just as in Experiments 1 and 2. The initial contents of the box were always composed of either one or two cubes with total volume measuring either four or eight cubic inches, respectively. With the exception of the "catch" trials in which the initial contents of the box remained unchanged, one-object outcomes always consisted of a single cube with a volume of eight cubic inches, and two-object outcomes always consisted of two cubes, each with a volume of two cubic inches (4 cubic inches total). The presentation of the events proceeded exactly as in Experiments 1 and 2. See Appendix C for a list of the all of the events and the two possible trial orders.

Results

A preliminary 6 x 2 x 2 x 2 x 2 repeated measures ANOVA with Trial Type (non-operation catch, non-operation number change, non-operation volume change, operation catch, operation number change, and operation volume change) as a within-subject factor, and Sex (male or female), Familiarization Condition (Kind Fam or Amount Fam), Familiarization Order (Order 1 or Order 2), and Test Order (Order 1 or Order 2) as between-subject factors revealed only one significant effect, a main effect of Trial Type ($F[5,40] = 25.18$, $p < .0001$). No other main effects or interactions were significant (all p's > .05). Note that we again found no main effect of Sex ($F[1,8] = .30$, $p = .60$), suggesting that the difference seen in Experiment 1 was likely spurious.

To follow up on the effect of Trial Type, we performed six independent samples t-tests against chance (50%) – non-operation catch, operation catch, non-operation number change, operation number change, non-operation volume change, and operation volume change. On the catch trials, preschoolers reported that a magic trick had occurred (i.e., answered "yes") significantly less than chance on both non-operation (M = 8%, SD = 19, $t(23) = -10.72$, $p < .0001$), and operation trials (M = 21%, SD = 33 $t(9) = -4.37$, $p < .0001$). On unexpected number change trials, preschoolers said 'yes', that a magic trick had occurred, significantly more often than chance on both non-operation (M = 96%, SD = 14, $t(23) = 15.91$, $p < .0001$) and operation trials (M = 79%, SD = 29, $t(23) = 4.90$, $p < .0001$) trials. Finally, on unexpected volume change trials, preschoolers tendency to report 'yes' was significantly *below chance* for non-operation events M = (31%, SD = 41, $t(23) = -2.23$, $p = .04$), and was no different from chance on operation events (40%, SD = 39, $t(23) = -1.31$, $p = .20$). (See Figure 5.)

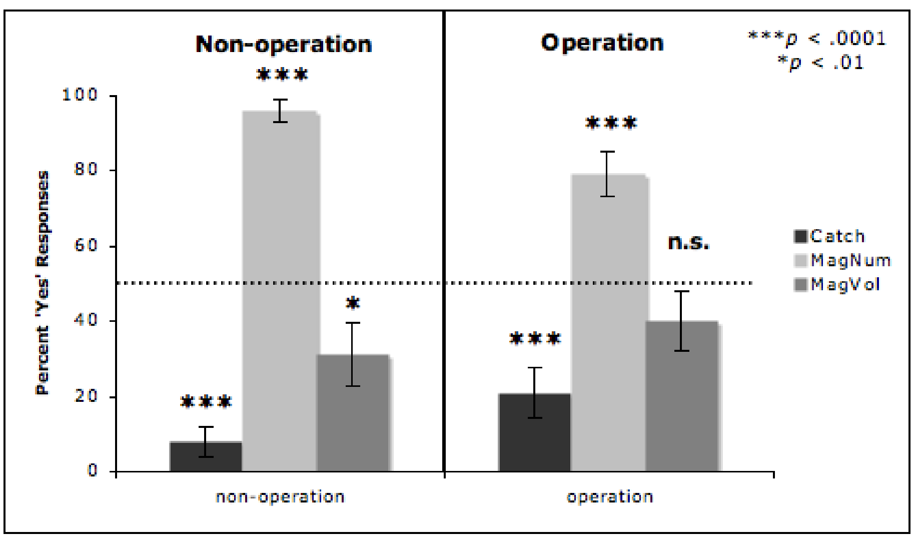

Figure 5. Children's proportion 'yes' responses on the six trial types.

Next, we performed two paired t-tests comparing performance on unexpected number and volume changes separately for non-operation and operation events. In both non-operation ($t(23) = 7.369$, $p <.001$) and operation ($t(23) = 5.000$, $p <.001$) events, preschoolers were significantly more likely to say that magic had occurred in a number change event than in a volume change event. This was the case even for children who were in the Amount Fam condition, who received explicit feedback directing their attention toward the possibility of magical volume changes and who were aware that such events should be labeled as “magical”. In fact, the rates of responding ‘yes’ to the various events was very similar across the two familiarization conditions (all *t*s (22) < 1.5, all *p*s = n.s.). (See Table 1.) This suggests that even under supportive conditions, preschoolers did not find magical volume changes salient or compelling enough to label them as “magical” any more often than when no explicit support was given, a finding supported by the fact that the main effect of Fam condition was far from significant. (F[1,8] = .14, p = .72).

	Non-operation			**Operation**		
	“Catch”	***Number Change***	***Volume Change***	***“Catch”***	***Number Change***	***Volume Change***
Kind Fam (N=12)	**4%** (14%)	**100%** (0%)	**33%** (44%)	**17%** (33%)	**88%** (23%)	**42%** (42%)
Amount Fam (N=12)	**13%** (23%)	**92%** (20%)	**29%** (40%)	**25%** (34%)	**71%** (33%)	**38%** (38%)

Table 1. Mean percent ‘yes’ responses (SDs in parentheses) for catch trials, number change events, and volume change events as a function of familiarization condition.

Finally, we conducted a paired t-test to compare preschooler’s responses on magical disappearance and magical appearance events, and again found no difference in their ability to detect magical disappearances and magical appearances (t(23) = .901, p = n.s.).

Discussion

Children again detected continuity violations, even when number and volume were pitted against each other. They performed well on catch trials, labeling these events as “magical” significantly less often than chance. This indicates that even in the face of unexpected number and volume changes, they were able to correctly identify when nothing had changed, and when values along both dimensions were expected. Preschoolers again overwhelmingly responded to number when number was pitted against volume, replicating the finding from Experiment 2, but with a larger sample. They responded to magical number changes at levels significantly above chance on both non-operation and operation events, but were below or at chance on both types of volume change events. This strongly suggests that in this task, number is the more salient dimension when pitted against volume. We again replicated the finding from Experiment 1 in which children detected both magical disappearances and magical appearances at better than chance levels, and as before, there was no difference in their rates of detection of the two event types.

General Discussion

Three different samples of children in three different experiments successfully detected continuity violations in a task analogous to that used by Wynn and Chiang (1998). However, we found no evidence that preschoolers are any more sensitive to impossible disappearances than to impossible appearances. This was found to be true both when number was confounded with continuous extent (Experiment 1) and when number and continuous extent were pitted against each other (Experiments 2 and 3). One possible reason why we failed to find the type of asymmetry reported by Wynn and Chiang (1998) and Subbotskii (1988, 1996) is that our study required verbal responses, an explicit measure, whereas those of Wynn and Chiang (1998) and Subbotskii (1988, 1996) made use of implicit measures such as looking time, facial expression, and memory distortion. Given that the direction of difference was consistent in all three experiments (greater detection of magical disappearances compared to appearances), our explicit measure may just not be sensitive enough to detect a difference.

Alternatively, it is possible that there is a genuine developmental shift between infancy and early childhood in which children become more sensitive to magical appearances, becoming equally sensitive to them by around 5 years of age. On Wynn and Chiang's (1998) account, the asymmetry apparent in 8-

month-old infants can be attributed to processes that underlie the representation of sets (e.g., analog magnitudes or object tracking processes). Specifically, they suggested that magical disappearances are detected when there is a mismatch between what is represented and the true state of the world. The failure of infants to detect magical appearances, they suggest, may be due to these processes failing to represent empty sets (Wynn & Chiang, 1998). In other words, the analog magnitude system and/or the object tracking processes do not actively represent the empty locations and when an object is revealed in a previously empty location, no mismatch is detected. Our results suggest a possible developmental shift in which these processes become able (in some way) to detect these mismatches.

Our results are not readily reconcilable with Subotskii's (1988, 1996) findings in which preschoolers and adults seemed to detect magical disappearances more readily than magical appearances. However, the dependent measures used in his work were quite different from our own. We might have seen more of an asymmetry if we were able to accurately measure children's facial expressions in our task. Nonetheless, our results are consistent with this previous work in that in both studies, children successfully detected both types of events. Therefore, the differences may not be qualitative, but more a matter of degree. Future experiments should include implicit measures such as facial expressions in order to further examine whether children's reactions to magical appearances and disappearances are similar or different in the two studies.

In Experiments 2 and 3, when number was pitted against volume, preschoolers still reliably detected violations of continuity. In contrast to results obtained with infants (Clearfield & Mix, 1999, 2001), preschoolers found number changes more salient than volume changes in both non-operation and operation events in our task. Preschoolers do appear to be influenced by volume changes more in operation events than in non-operation events, though they overwhelmingly respond to changes in number in both types of events. It could be that preschoolers are representing and keeping track of multiple cues (i.e., number and continuous extent) and that socialization at home and/or school has taught them to respond primarily to number, especially in an educational setting such as a preschool or laboratory, and in the context of a perceived educational game. Research by Cordes and Brannon (2009) lends support to the idea that preschoolers may be keeping track of multiple quantity cues. Their recent research with infants suggests that infants do in fact continue to represent number even when a representation of continuous extent is sufficient for reasoning in a task. This research also provides evidence that infants may not respond to a change in continuous extent more than to a change in number (as suggested by Clearfield & Mix (1999, 2001)). According to Cordes and Brannon (2009), numerical representations are more sensitive/precise than are representations of continuous extent. Perhaps by preschool age, children have learned (implicitly or explicity) that this is the case and tend to rely on their representations of number over continuous extent.

In Experiment 3, it was found that differential familiarization did not affect performance on number change or volume change trials. There were no differences in performance between children familiarized to the possibility of number/volume changes and children who were not. Indeed, children were *even less* likely (though not reliably so) to correctly categorize magical and expected volume changes when familiarized to the possibility of such events and after having received feedback (i.e., in the amount familiarization condition). It is possible that children did not spontaneously notice the size change during familiarization and that the feedback they received had the effect of confusing them more than alerting them to the notion that impossible volume changes are magical.

Overall, preschool children's ability to detect continuity violations in a task analogous to that used with infants (Wynn & Chiang, 1998) suggests continuity in the development of spatiotemporal continuity. Though we failed to replicate the asymmetry between magical disappearances and magical appearances found by Wynn and Chiang (1998) and Subbotskii (1988, 1996), it should be noted that, in all three experiments, children did detect magical disappearances slightly better than magical appearances, and perhaps with a larger sample size, the results would reach significance. Additionally, though our results with respect to the relative salience of number vs. volume were found to be inconsistent with the work of Clearfield and Mix (1999, 2001), they are in line with those obtained by Cordes and Brannon

(2009), suggesting that there is continuity in the saliency of discrete and continuous quantity from infancy to early childhood.

The present results can potentially inform early education initiatives in that understanding of number may be more easily taught than understanding of continuous quantities such as volume. The brief familiarization we provided children did not substantially increase their attention to volume, however, it remains possible that more rigorous protocols could have some effect. Future research could explore this further, examining the conditions under which children may be led to attend to volume.

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Appendix A.

Experiment 1

Sequence One	Sequence Two
1=1 (expected)	1=0 (magical disappearance)
2=2 (expected)	2=1 (magical disappearance)
2=1 (magical disappearance)	1=1 (expected)
1=1 (expected)	1=2 (magical appearance)
1=2 (magical appearance)	2=2 (expected)
0=1 (magical appearance)	0=0 (expected)
1=0 (magical disappearance)	0=1 (magical appearance)
0=0 (expected)	1=1 (expected)
2-1 = 1 (expected disappearance)	0+2 = 0 (magical disappearance)
0+2 = 2 (expected appearance)	0+1 = 1 (expected appearance)
2-2 = 2 (magical appearance)	1-1 = 0 (expected disappearance)
0+1 = 0 (magical disappearance)	2-1 = 2 (magical appearance)
1-1 = 1 (magical appearance)	1+1 = 1 (magical disappearance)
1+1 = 2 (expected appearance)	2-2 = 0 (expected disappearance)
0+2 = 0 (magical disappearance)	2-1 = 1 (expected disappearance)
0+1 = 1 (expected appearance)	0+2 = 2 (expected appearance)
1-1 = 0 (expected disappearance)	2-2 = 2 (magical appearance)
2-1 = 2 (magical appearance)	0+1 = 0 (magical disappearance)
1+1 = 1 (magical disappearance)	1-1 = 1 (magical appearance)
2-2 = 0 (expected disappearance)	1+1 = 2 (expected appearance)

Appendix B.

Experiment 2

Sequence One	Sequence Two
2=1 (4&4 = 8) (magical disappearance)	1=1 (4=8) (expected number)
1=1 (4=8) (expected number)	1=2 (4 = 2&2) (magical appearance)
2=2 (4&4 = 2&2) (expected number)	2=1 (4&4 = 8) (magical disappearance)
1=2 (4 = 2&2) (magical appearance)	2=2 (4&4 = 2&2) (expected number)
1=2 (4 = 2&2) (magical appearance)	2=2 (4&4 = 2&2) (expected number)
2=2 (4&4 = 2&2) (expected number)	1=2 (4 = 2&2) (magical appearance)
1=1 (4=8) (expected number)	2=1 (4&4 = 8) (magical disappearance)
2=1 (4&4 = 8) (magical disappearance)	1=1 (4=8) (expected number)
1+1 = 1 (4+4 = 8) (magical disappearance)	2-1 = 1 (4&4 – 4 = 8) (expected disappearance)
2-1 = 1 (4&4 – 4 = 8) (expected disappearance)	1+1 = 1 (4 + 4 = 8) (magical disappearance)
1+1 = 2 (4+4 = 2&2) (expected appearance)	2-1 = 2 (4&4 – 4 = 2&2) (magical appearance)
2-1 = 2 (4&4 – 4 = 2&2) (magical appearance)	1+1 = 2 (4 + 4 = 2&2) (expected appearance)
1+1 = 1 (4 + 4 = 8) (magical disappearance)	2-1 = 1 (4&4 – 4 = 8) (expected disappearance)
1+1 = 2 (4 + 4 = 2&2) (expected appearance)	2-1 = 2 (4&4 – 4 = 2&2) (magical appearance)
2-1 = 1 (4&4 – 4 = 8) (expected disappearance)	1+1 = 1 (4 + 4 = 8) (magical disappearance)
2-1 = 2 (4&4 – 4 = 2&2) (magical appearance)	1+1 = 2 (4 + 4 = 2&2) (expected appearance)

Note: Events are first described in terms of their numerical elements, and then characterized in terms of volume in parentheses.

Appendix C.

Experiment 3

Sequence One	Sequence Two
2=1 (4&4 = 8) (magical disappearance)	1=2 (4 = 2&2) (magical appearance)
1=1 (4=4) (catch)	2=2 (4&4=4&4) (catch)
2=2 (4&4 = 2&2) (expected number)	1=1 (4=8) (expected number)
1=2 (4 = 2&2) (magical appearance)	2=1 (4&4 = 8) (magical disappearance)
1=1 (4=8) (expected number)	1=1 (4=4) (catch)
2=2 (4&4=4&4) (catch)	2=2 (4&4 = 2&2) (expected number)
1+1 = 2 (4 + 4 = 4&4) (catch)	2-1 = 1 (4&4 – 4 = 4) (catch)
2-1 = 2 (4&4 – 4 = 2&2) (magical appearance)	1+1 = 1 (4+4 = 8) (magical disappearance)
1+1 = 2 (4 + 4 = 2&2) (expected appearance)	1+1 = 2 (4 + 4 = 2&2) (expected appearance)
1+1 = 1 (4+4 = 8) (magical disappearance)	2-1 = 2 (4&4 – 4 = 2&2) (magical appearance)
2-1 = 1 (4&4 – 4 = 4) (catch)	1+1 = 2 (4 + 4 = 4&4) (catch)
2-1 = 1 (4&4 – 4 = 8) (expected disappearance)	2-1 = 1 (4&4 – 4 = 8) (expected disappearance)

Note: Events are first described in terms of their numerical elements, and then characterized in terms of volume in parentheses.