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Preschoolers Search For Hidden Objects

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Abstract

The issue of whether young children use spatio-temporal information (e.g., movement of objects through time and space) and / or contact-mechanical information (e.g., interaction between objects) to search for a hidden object was investigated. To determine if one cue can have priority over the other, a dynamic event was created that put these cues into conflict, with only spatio-temporal information being valid. Three-year-olds were found to use the valid spatio-temporal cue exclusively, and seemed to ignore the contact mechanical cue. Both search behavior and eye-tracking during the event support the view of a sophisticated sensitivity to the validity of a cue in indicating a target's hidden location.

Introduction

Children can use spatio-temporal and / or contact-mechanical information when predicting how objects and events will dynamically unfold in their environment (Scholl & Leslie, 1999). Contact-mechanical information provides knowledge regarding how the physical properties of objects, such as solidity and weight, influence how they interact with each other and the environment. For example, contact-mechanical information would specify that one solid object will not pass through a second solid object. Spatio-temporal information provides knowledge regarding how events dynamically unfold over space and time. For example, when watching a ball roll across the floor, spatio-temporal information such as ball's velocity, direction, and possible obstacles in its path provide cues about the eventual path and resting place of the ball.

Scholl & Leslie (1999) suggested that two distinct cognitive mechanisms subserve contact-mechanical and spatio-temporal information (Scholl & Leslie, 1999). According to their hypothesis, contact-mechanical information, such as the child's knowledge about the nature of solid objects, can be altered based on specific experiences or the discovery of new object properties. Thus, after seeing a visual illusion (e.g. a ball apparently passing through a solid

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wall), children would start to reason that perhaps rules of solidity do not apply in this situation (Haddad, Kloos & Keen, 2008). On the other hand spatio-temporal information was hypothesized to be “cognitively impenetrable” and therefore much less influenced by top-down reasoning than contact-mechanical information. In the real world, contact-mechanical and spatio-temporal information are mostly congruent but in some circumstances, such as when a moving object becomes occluded, they may become incongruent. For example, the observer’s predictions about the object’s path may not have taken into account unseen obstacles. Or, the observer may have assumed that the object’s weight was such that it would roll behind the occluder and emerge on the opposite side but its excessive weight slowed and stopped the object, preventing its emergence. This new information would influence future predictions about how this object would behave. One prediction to emerge from the Scholl & Leslie (1999) theory is that when spatio-temporal and contact-mechanical information are made incongruent the child should default to the spatio-temporal information when performing a search task (Scholl & Leslie, 1999). Essentially, the child will make choices in a search task based on what they see and ignore other conflicting visual cues because the spatio-temporal information is cognitively impenetrable and more difficult to alter. This theory has recently been supported in both primate and developmental research. For example, Santos (2004) found that macaques could find a plum that was rolled down and stopped behind an opaque panel when spatio-temporal information was provided but not when contact mechanical information had to be used (Santos, 2004). In children, Hood (1995; 1998) found that 2–3 year olds make a peculiar mistake that he termed the “gravity error”. In Hood’s task children watched an experimenter drop a ball down one of three crisscrossed opaque tubes that ended in cups. Children searched for the ball directly below the opening where the ball was dropped rather than following the tube to the appropriate cup. This finding suggests that children use a “gravity rule” to predict the spatio-temporal path of the ball rather than mechanical evidence of the tube’s constraint on the ball’s path. If the tubes were clear and children saw the ball drop through the tube, they had no problem in selecting the correct cup. Older children overcome the gravity error and use the tube to predict the ball’s path. Taken together these studies suggest that spatio-temporal information is a more primitive knowledge that is exploited by children as they attempt to predict how dynamic events in their environment will unfold. When given both spatio-temporal and contact-mechanical information, younger children appear to default to spatio-temporal information.

In a series of studies we have used dynamic search tasks to examine the developmental time course over which children are able to use contact-mechanical and spatio-temporal information to find a hidden object (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000; Butler, Berthier, & Clifton, 2002; Mash, Keen, & Berthier, 2003). In our task children watch as a ball rolls down a ramp behind either a opaque or transparent screen containing four opaque doors, one with a large visible wall placed adjacent to it. When an opaque screen is used to cover the ramp children can only use contact-mechanical information to find the hidden ball (i.e. their knowledge that the solid wall will stop the solid ball). When the ramp is covered with the transparent screen, children can either use spatio-temporal (track the rolling ball and look behind the opaque door from which the ball failed to emerge) or contact-mechanical information (look for the ball behind the door adjacent to the wall) to find the hidden ball.

Before 3-years of age children are unable to find the ball above chance when only the contact mechanical cue of the wall’s presence is available (Berthier et al. 2000). By 2.5 years of age children can use spatio-temporal information but not contact mechanical information to find the hidden ball (Butler et al. 2002). At 3-years of age children have a sophisticated understanding of solid obstacles. When an opaque screen eliminates spatio-temporal information of the ball’s progress, they remember the wall will stop the ball even

when the top of the wall no longer shows above the screen; furthermore, if the slope of the ramp is reversed, they understand that the ball will come to rest on the opposite side of the wall (Keen, Berthier, Sylvia, Butler, Prunty & Baker, 2008). Not until 3-years of age do children appear able to use both types of information to solve a dynamic search task (Berthier et al. 2000; Butler et al. 2002; Keen, et al., 2008). All of these studies indicate that preschoolers' utilization of contact-mechanical and spatio-temporal information develops at different times, providing further evidence that different cognitive mechanisms subserve these two types of information. In summary, children can successfully use and pay attention to spatio-temporal information before contact-mechanical information when performing a dynamic search task, suggesting that this is a more primitive and easier source of information to utilize when performing a dynamic search task.

In a recent study 3-year olds were tested to see if spatio-temporal information dominates over contact-mechanical knowledge when these two cues are put into conflict (Haddad, Kloos & Keen, 2008). Three-year-olds were tested because of their experience and depth of knowledge about solidity and how objects interact with one another (Keen, et al., 2008; Perry, Smith, & Hockema, 2008). Children were required to find a ball that rolled down a ramp when contact-mechanical and spatio-temporal information disagreed. Children first experienced trials where contact-mechanical and spatio-temporal cues were congruent (the ball disappeared and stayed behind the door with the wall). After four congruent trials, children were then shown the conflict trials. In the conflict trials, the apparatus was designed so that the ball either stopped 2-doors before or 2-doors after the visible wall. Therefore, the child could only find the ball if they ignored contact-mechanical information (which was never correct) and paid attention to spatiotemporal information (which was always correct).

It was predicted that if spatio-temporal was a more privileged, cognitively impenetrable source of information, the ability of the child to successfully find the ball should not decrease when conflict trials were introduced. Essentially, the child should default to using spatiotemporal information and simply track the ball visually as it rolls down the ramp and open the door where it failed to emerge. But in fact performance did decrease on conflict trials (Haddad et al. 2008). An analysis of eye movements revealed that children frequently fixated on the wall, suggesting they were considering the wall as a reliable indicator of the ball's location. Children did make fewer search errors in the later conflict trials compared to the earlier conflict trials, suggesting they learned the wall was no longer reliable. However, search performance never rebounded to the same level as the congruent trials. Children seemed confused about the properties of the visible wall even after they observed that it was not a reliable source of information. If contact-mechanical information had been discounted after the presentation of the incongruent trials, children should have exhibited the same level of performance observed in the congruent trials. Spatio-temporal information did not appear to be a privileged source of information that overruled contact-mechanical information.

One issue with the Haddad et al. (2008) study was that children were presented with four congruent trials before they were presented with the conflict trials. This specific experience may have led children to regard the wall as a solid object that would stop the ball's progress. However, It seems doubtful that this brief encounter with the wall as an accurate cue convinced children that contact-mechanical information was reliable since Hood (1995) attempted unsuccessfully to train 3-year-olds to attend to the tube's mechanical constraint on the ball. In Hood's (1995) study children had five trials with transparent tubes and searched correctly for the ball. Nevertheless, this experience of observing how the tube determined the ball's path did not transfer to subsequent trials with the opaque tubes. Children resorted to their spatio-temporal knowledge that dropped objects fall directly down on a vertical path.

In the current study we further examined the possibility that witnessing agreement between cues before observing them in conflict would influence children's performance. We used a protocol like that of Haddad et al. (2008) except that only conflict trials were presented. If children immediately disregard the contact-mechanical information and correctly solve the search task, this would imply that such knowledge is easily updated when another cue seems more valid. As seen in Hood's (1995) data, it was difficult to shift preschoolers' biases in making predictions about objects' movements when outcomes are uncertain. If simply eliminating the experience of having both cues be correct initially results in children ignoring the invalid cue, then Haddad et al. (2008) stands as a singular example of how influential children's first experience with a new event in a novel apparatus can be. Specifically, these results would suggest that even brief exposure (a few trials) to a dynamic event can influence children's use of information regarding how events unfold in a specific task. This information may be pervasive even after future trials or events render it invalid. Such results would caution researchers about the timing of how information is presented in studies of children's knowledge objects and events.

Methods

Participants

Potential participants were identified from state birth records. A recruitment letter was then sent to parents followed by a phone call. Twenty-two 3-year-old children (11 males and 11 females; 3 years $\pm$ 2 weeks) were included in this study. An additional eight children were recruited but used in the final sample because they did not have good eye tracking data (due to excessive head movement during the session). Parents signed an informed consent form prior to the start of data collection. The University of Massachusetts Institutional Review Board approved the study protocol and informed consent form.

Apparatus

The same apparatus was used as in Haddad et al. (2008). A transparent screen with four opaque doors was placed in front of a wooden ramp. The screen could be easily removed between trials so that the child could see the wooden ramp. Before each trial a barrier that protruded several centimeters above the screen so that its top was visible to the child was placed on the ramp behind one of the four doors (see Figure 1). In all trials contact-mechanical and spatio-temporal cues were placed into conflict and the latter cue was always correct. The ball rolled down the wooden ramp from left to right (1.2 second rolling time) and was stopped by a small Plexiglas barrier that was invisible to the child. Mounted behind the participant was a scene camera that remained focused on the apparatus. Point-of-gaze was recorded at 60Hz as the ball rolled down the ramp using an Applied Science Laboratories (Model 504) eye tracker.

Procedures

Two experimenters were required in this study. The first experimenter (E1) interacted with the child and a second experimenter (E2) controlled the eye-tracking system. Upon entering the testing room, the child sat on a chair facing the apparatus and the eye-tracker was calibrated using a two-point calibration procedure. The two points were located so they matched with the upper left and lower right corners of the apparatus. After each block of four trials, the calibration was checked by placing a visually attractive toy within the child's field of view. If the child's point-of-gaze did not match the location of the toy, a linear offset was performed to correct point-of-gaze location.

After the eye-tracker was calibrated, children were shown a full view of the ramp and barrier without the screen. The ball was rolled and stopped at the barrier four times, once at each

location. The experimenter commented each time, "Look, the ball stops at the wall!" This familiarization procedure was also in Haddad et al. (2008) as well as previous studies using this apparatus (Berthier, et al., 2000; Keen, et al., 2008). The purpose is to insure that children understand that the wall rests on the ramp and can stop the ball. This familiarization procedure differed from the congruent trials used in Haddad et al. (2008) in two important ways. Firstly, the ball was always in view because the occluder was never present during familiarization. Secondly, children never used the wall as a cue to find the ball's location during familiarization. We hypothesized that the active use of the wall protruding above the occluder on congruent trials led children to make persistent errors in Haddad et al. (2008).

After the familiarization procedure, 12 test trials were performed, 6 were stop-early (SE) and 6 were violation-of-solidity trials. Trials were randomized with the restriction that no more than two trials of the same type appeared in a row. In the SE trials the ball rolled down the ramp and was stopped by the small Plexiglas wall two doors before the visible wall. Thus, when the visible wall was placed at door 3 the ball stopped behind door 1 and when the visible wall was placed at door 4 the ball stopped behind door 2 (see Figure 1a). In the VS trials the ball would roll through and stop 2 doors past the visible wall. Thus, when the visible wall was placed at door 1 the ball would stop behind door 3 and when the visible wall was placed at door 2 the ball would stop behind door 4 (see Figure 1b). Both trial types put contact-mechanical and spatio-temporal cues into conflict.

Data Analysis

Two experimenters were used to score the door the child opened for each trial. There was 100% agreement between the two scorers regarding the behavioral data. Eye movements were analyzed using the protocol described in Haddad et al. (2008). Specifically, the cursor that identified the child's point-of-gaze from the eye tracker was recorded. Two experimenters scored the sequence in which the eye fixated on each of the four doors and the wall. A fixation was identified if the eye stopped at one of the four doors or the visible wall for at least 5 DV frames (about 166ms). Gaze fixations were then assessed relative to the ball's position during the rolling event and were used to determine whether or not the child appropriately tracked the rolling event. In both the VS and SE trials, visual tracking was coded as appropriate if the child's point-of-gaze remained on the ball as it rolled down the ramp, disappeared, and did not reemerge. Specifically, gaze had to be on the ball within ± 100 ms of the moment it rolled behind the correct door. For the SE trials the eye had to either pause for at least 2/3 of a second when the ball disappeared (and did not reemerge) from behind that door, or scan no more than one door past where the ball failed to emerge and immediately return to the previous door. Two-thirds of a second represented a conservative number to define the pause necessary on SE trials to ensure that the children understood that the ball had stopped progressing down the ramp (given that the ball disappeared behind each door for 250ms). For VS trials, visual tracking was scored as being appropriate if the child continued to track the moving ball beyond the barrier (as the ball apparently rolled through the wall). In the VS trials, an example of incorrect tracking would be if the child made a saccade to the wall when the ball was released at the start of the trial or looked back at the wall after the ball had apparently rolled through it. In both types of trials, all other eye behavior was categorized as inattentive. Inattentive tracking was defined as eye movements that did not appear to be influenced by either the rolling ball or the visible wall. For example, a trial would be scored as inattentive if the child looked away (as observed in the camera facing the child) during the trial. In all trials, point-of-gaze data were categorized as either a correct scan, incorrect scan, or inattentive. Each of these behaviors was then related to the search performance on the task. Two coders scored the point-of-gaze data. The primary coder and secondary coder each scored 100% of the data. There was 85%

agreement between the two coders. In the trials when the coders did not agree, a third coder made the final determination.

Results

Behavioral Data

Behavioral data are reported on all 22 children. Overall performance in this study was 74.8% correct trials. Note that this level of performance is high, considering that chance is .25 with a choice among four possible doors. Furthermore the percent correct was comparable to Berthier et al. (2000) where 3-year-olds based their choice on the wall's position alone because an opaque screen prevented sight of the ball rolling between doors. We compared performance on the congruent trials of Haddad et al. (2008) directly with the conflict trials in the current data set, as both studies used the same apparatus with a transparent screen. Putting spatio-temporal and contact-mechanical cues into conflict produced no deterioration in performance compared to the earlier study's congruent trials. The means were 74.5% correct for Haddad et al. (2008) and 74.8% for the current data ($F(1,69) < 1.0$; $p > .05$; Figure 2). Performance did not decrease when given conflict trials if the children were not first given congruent trials. These results also show that children were not fooled by the familiarization procedure performed prior to the experimental trials.

Furthermore, there was no change over trials, indicating that from the start of observing conflict trials, children based their search on spatio-temporal information. A paired sample *t*-test was performed between the first 6 and the last 6 trials (adding over trial type). The correct door was chosen 71.4% of the time in the first 6 trials and 79.3% in the last 6 trials ($t(20) = 1.48$, $p = .15$). Children's high performance did not result from learning over trials, but was there initially.

We tested whether the type of conflict had an effect on search behavior. Children opened the correct door 78.7% and 71% for VS and SE trials respectively, a non-significant difference ($F(1,21) = 2.13$, $p < .16$). Using a binomial distribution, children needed to solve at least 4 of the 6 trials (within each conflict type) for search behavior to exceed what would be expected by chance (at the $p = .05$ level). The number of children scoring above chance was 18/22 and 16/22 for the Violation-of-Solidity and Stop-Early trials respectively. These findings suggest that the majority of children were easily able to find the ball regardless of the manner in which conflict was produced.

In Haddad et al. (2008) the conflict trials lowered performance significantly compared to congruent trials. To test whether performance on conflict trials differed between Haddad et al. 2008 and the current data set, we compared VS and SE trials across the two studies (Figure 2). Because the Haddad et al. (2008) study had different groups of children receiving VS and SE trials, and the current data set featured a within subjects design, we compared trial types separately. Thus, correct performance for the SE trials of the current study were found to be significantly higher ($M = 71\%$) than for the SE group in the Haddad study ($M = 46\%$; $F(1,44) = 9.42$, $p < .004$). Likewise for the VS trials in the current study children had higher correct performance ($M = 79\%$) than children in Haddad et al ($M = 60\%$; $F(1,45) = 6.74$, $p < .013$).

Eye-tracking Data

Eye-tracking data was obtained for 60% of the trials (159 out of 264 trials). Data from 40% (105 out of 264 trials) had to be discarded due to excessive noise or an unexplained loss of the eye image. Of the 105 trials that were discarded, 53 were from the VS group and 52 were from the SE group. In the trials with good eye data (a stable point-of-gaze position was present throughout the ball rolling event), children tended to track the ball correctly in 63%

(100 out of 159) of the trials (i.e., they tracked the ball in a way that ensured they witnessed the hiding event). These data were virtually identical to the congruent data in the Haddad et al. (2008) study, where the child exhibited correct eye-tracking in 69% of the trials. Eye movements in both studies predicted which door got opened. In the current study children chose the correct door in 92% (92 out of 100) of the trials when they had correctly tracked the ball which was nearly identical to the congruent data in the Haddad et al. (2008) study, where, correct tracking preceded correct door choice in 90% of the trials. Thus, similar to the behavioral data, the eye-tracking data in this study closely resembled the congruent trials from the Haddad et al. (2008) study.

In contrast eye-tracking on conflict trials in Haddad et al. (2008) differed from the present study in that children frequently looked at the wall, which may have reflected their consideration of it as a cue for the ball's hiding place. In the current study children only looked back at the wall on 5 trials during the rolling event. When children tracked incorrectly, they tended to look away from the rolling event and missed seeing the ball's failure to emerge from behind one of the doors. In these trials they tended not to open the door adjacent to the barrier. To conclude, children in the current study look infrequently at the wall and it appeared not to influence their search behavior when they erred in choosing a door.

Discussion

In the dynamic event shown to 3-year-olds in this study, different cues about where to search for the hidden object were available. The spatio-temporal information was provided by sight of a ball rolling between a set of four opaque doors. The correct action was to select the door where the ball last disappeared. The other cue in this rolling event was contact-mechanical; a solid wall protruding above one of the doors indicated an obstacle in the ball's path. For this cue to be used, the child must reason about the outcome of a two solid objects coming into contact with one another. Previous research has shown that spatio-temporal information can be used by rhesus macaques in searching for desired objects (Santos, 2004) by 3-year-old children (Haddad et al. 2008) and to a certain extent by 2.5-year-olds (Butler et al., 2002). On the other hand contact-mechanical information does not appear to be used by non-human primates (Santos, 2004) or children younger than 3 years of age (Berthier, et al., 2000; Keen et al., 2008).

Both the ontogenetic and phylogenetic data point to the priority of spatio-temporal information to guide search. In the current study when these cues gave different messages about the ball's location, children ignored the presence of the wall and based their judgments solely on sight of the ball's movement. In fact their performance in the presence of conflicting cues did not differ from that with a single cue available as in Berthier, et al. (2000). Eye-tracking data showed that on most trials children actively tracked the ball to its disappearance, and then opened the correct door. Because the spatio-temporal cue was always correct in the current situation, these results may appear totally expected, but Haddad, et al. (2008) found that these same conflicting cues lowered performance significantly. Why did putting the cues into disagreement affect performance in one case but not the other?

Unlike the current study where children saw only conflicting cues, the Haddad et al. (2008) study initially presented children with four trials in which the cues agreed on the correct answer: the ball rolled behind the door with the barrier and stopped. This procedure appeared to reinforce children's expectations that the wall would stop the ball, and they subsequently found it difficult to disregard that information. The eye movement data in the Haddad et al. (2008) study supported this interpretation. Even after correctly tracking the

ball to disappearance, children would sometimes look back at the wall as if they were surprised it did not stop the rolling ball. This may have caused them to lose track of the door where the ball disappeared. On other trials the child would fixate on the wall and not continue to track the ball as it passed through and beyond the door. Because they were fixating on the wall, they did not witness the ball's final disappearance. In contrast, when the congruent trials were omitted children almost always ignored the wall during the rolling event. They rarely looked at the barrier, which suggests they did not use it to provide information regarding the location of the ball. Unlike the previous study, search errors were not made because the wall provided an inaccurate source of information. Rather, search errors were typically due to children looking away from the rolling event and missing the ball's failure to remerge from behind one of the doors.

The effect of "training" trials was also seen in Perry, et al. (2008). In that study, which used an apparatus and search task very similar to ours, children were exposed to the ball moving at different speeds. Their subsequent search was influenced by this prior experience, such that children who were familiarized with a fast-moving ball opened doors further down the track than a group exposed to slow-moving balls (Perry et al. 2008). The Perry, et al. (2008) and Haddad, et al. (2008) studies support the view that young children modify their beliefs and strategies when given new information in a specific context. It is notable that children did improve performance after several conflict trials in Haddad, et al. (2008), although not to the same levels as before the conflict trials were presented. The exposure to the early congruent trials continued to influence search behavior in the later trials.

The behavioral and eye data from the current study suggest that when contact-mechanical cues are shown to be invalid from the start, children immediately adopt spatio-temporal cues to solve the search task. There were no differences in search behavior between the early and late trials; children quickly defaulted to using spatio-temporal over contact-mechanical information when these two cues were in conflict. Such flexibility is the hallmark of creative thinking and is surprisingly sophisticated in these preschoolers.

We conclude that by 3-years of age children can use multiple cues in a search task, and are sensitive to each cue's validity in indicating a target's hidden position. The question these data do not answer is whether spatio-temporal information truly has priority over contact-mechanical information, as some have suggested (Santos, 2004; Scholl & Leslie, 1999). To answer this question, the cues should be put into conflict but with contact-mechanical information being correct. If children still default to spatio-temporal information even when it is incorrect, strong evidence would be provided that this information is privileged and impenetrable when children witness novel events. If however, results from such a study show children use the correct contact-mechanical information over the incorrect spatio-temporal information, neither source of information would appear to be privileged. Rather, such a finding would suggest children are able to extract the correct and relevant information when cues regarding the outcome of a novel event are incongruent. Procedurally it would be more difficult to falsify spatio-temporal information, and no theory predicts that contact mechanical information is dominant. Still, the question of cue dominance should be resolved empirically, and is important because it informs us about how young children predict and interpret moving object events in their environment.

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Figure 1.

Schematic of the apparatus and the eye-tracking equipment during an a) violation-of-solidity trial and b) stop-early trial. The eye-tracking system consisted of an eye and a head-tracking camera, placed under the apparatus to record an unobstructed eye image during the ball-rolling event. While the ball was rolling down the ramp, the apparatus was placed out of reach of the child (approximately 95cm) to accommodate the eye-tracking equipment and so the child would not attempt to prematurely open one of the doors. When the apparatus was pushed forward to allow the child to open a door, the eye camera became obstructed and no point-of-gaze data was obtained. Point-of-gaze data were therefore only collected during the rolling phase of each trial and not when the child was opening a door. Mounted directly to the left of the eye camera was an optic head tracker. Using known landmarks on the face (e.g. eyes and nose) the head tracker was able to determine head rotations made by the child. The eye camera would then use the head position information to change its orientation in an attempt to maintain an eye image. Mounted above the apparatus (not shown in the schematic) was a video camera that was focused on the child. The view from this camera was superimposed on the video from the eye-tracker using a picture-in-picture video mixer. This camera view was used to determine if the child was attentive during each trial. The video signals from the ASL control box and from the camera facing the child were recorded simultaneously onto a standard 30Hz Sony DV video deck using a picture-in-picture video mixer.

Figure 2.

Proportion of trials where the correct door was chosen in the current study and the Haddad et al. (2008) study. No congruent trials were performed in the current study.