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Toddler’s Problem Solving: The Importance of Dynamic Integration

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Abstract

Arguably, children’s success in problem solving tasks depends on at least two factors: knowledge about the domain, and an ability to integrate the relevant information. The current study looks at the latter point; the importance of information integration. A search task was used in which toddlers perform surprisingly poorly; They cannot find a ball that rolls behind a screen and stops at a colorful wall that remains partially visible above the screen. Can performance be improved if children are aided in their integration of dynamic events? To answer this question the wall was modified in such a way as to help children integrate the wall with the dynamic event- the ball rolling behind the screen. Indeed, toddlers showed a significant improvement in performance with this modified version of the wall, compared to the original version of the wall. Control experiments rule out alternative explanations. As a whole, they point to the importance of considering a task’s demands on integration to explain children’s performance.
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Chapter I: Introduction

Problem solving is one of the essential skills that children use to navigate the world around them. Arguably, successful problem solving depends on at least two factors: *knowledge* and *integration*. In order to accurately solve a problem, children must first understand something about underlying concepts, about a specific domain, or about rules that guide a task. Further, they must be able to detect and integrate relevant information. Interestingly, children seem to be integrators by nature. For example, even young children appear to seek out structure, detect correlation patterns, link pieces of information and group components into larger wholes (Kloos, 2007). While it is true that children sometimes integrate information well, that is not always the case. The current study investigates the importance of integration, by looking more closely at a well-known task where toddlers consistently struggle, and where the problem could be one of integration.

In toddler search tasks, children 2 to 3 years old watch as a ball rolls behind a screen. The screen contains four doors, and a wall is placed in the path of the moving ball (see Fig. 1). The wall is placed in one of four locations, each one corresponding to a different door. The top portion of the wall is visible above the screen and it is painted in a contrasting color to draw the child’s attention. After the ball rolls from the child’s sight and behind the screen it comes to rest at the wall. Children are then asked to reach through the door where they believe the ball has stopped. It would seem the wall would be cue as to the final location of the ball. Surprisingly, toddlers do not appear to use this information when searching for the ball. Even prior practice without the screen, and consistent feedback (i.e. “remember, the ball stops at the wall”) does not significantly improve their performance (Kloos & Keen, 2005). We know that even young infants can formulate expectations about where a moving ball will stop (e.g., Baillargeon, 1986; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Therefore, it is not unreasonable to expect
that toddlers could search in the correct location for the ball, given adequate cues. Why then does retrieving the ball from the correct location pose such a problem for toddlers?

Results of this and similar studies have puzzled researchers for over a decade. Because the original search task was designed to explicitly test children’s understanding of the physical principle of object solidity, toddler’s poor performance is often taken to be merely a reflection of knowledge (or in this case lack thereof). However, the current study takes a different stance, namely that performance is never just a reflection of knowledge. Rather, it is the result of a conglomerate of constraints within the immediate context, and in this particular case the problem could very well be one of integration.

Figure 1. Schematic illustration of the search-task display with the visible portion of the barrier protruding above the screen.

The toddler search task has been used repeatedly to investigate whether children know that a solid object cannot pass through another, and therefore that the wall will stop the ball in its trajectory (e.g. Berthier, DuBlois, Poirier, Novak & Clifton, 2000; Mash & Keen, 2003; Hood, Cole-Davies & Dias, 2003; Kloos & Keen, 2005; Shutts, Keen, & Spelke, 2006). While children’s failure to successfully find the ball has often been attributed a lack of understanding about object solidity, several subsequent studies speak against this possibility. For example, toddlers are in fact surprised by events that appear to violate the principle of solidity (Hood et al., 2003; Mash et al., 2006). In this particular
version of the task, toddlers were presented with the same door display. But rather than asking children to open a door to find the ball, the two doors adjacent to the barrier were opened for them. On physically consistent trials, the ball was resting to left of the barrier. On physically inconsistent trials, the ball was either missing altogether, or it was resting to the right of the barrier, as if having passed through the barrier. Toddlers indeed looked longer at physically impossible events than the physically possible events.

Furthermore, 2-year-olds can reason in advance about how the principle of solidity would affect the motion of the ball (Kloos & Keen, 2005). When the screen was removed and children had to point to where the ball would stop, they correctly predicted that the ball would stop at the wall. They were successful even when the direction of the ball’s motion was changed, or when two walls (rather than just one) were placed on the ramp. Taken together, these results speak against the possibility that the difficulty toddlers face in these tasks is the result of a lack of understanding, and point to the possibility that the problem could be one of integrating the available information in order to find the ball.

Do toddlers struggle to find the ball, because they cannot integrate the relevant components of the task? There are three seemingly relevant pieces of information available to the children: the ball rolling along a ramp before it disappears behind the screen, the portion of the wall that remains visible above the screen, and the doors behind which the ball can be found. Is it possible that facilitating the integration of the wall with the correct door could result in improved performance? Several studies were conducted to test this possibility. For example, in one experiment, the barrier was modified to hang over the front of the screen, such that the entire front edge was visible (Keen, Berthier, Sylvia, Butler, Prunty, & Baker, 2008). In this configuration, the wall almost touched the door that children should open, decreasing the spatial distance between wall and door. Yet toddlers’ performance was no better than in previous studies.
Similarly, low performance was found when the screen was transparent above the doors (revealing a larger portion of the wall) and the doors were painted in four contrasting colors, each corresponding to a matching wall (Kloos, Haddad & Keen, 2006). To perform correctly, toddlers simply had to link the barrier to the immediately adjacent door of the same color. Eye tracking results showed that if the child broke eye contact with the ball in motion to look at the wall, attempts were unsuccessful to locate the ball in its final location.

Finally, even when the wall was visible through a window in the door, 2-year-olds performed at chance (Shutts et al., 2006). Doors were used that had a window, through which the wall could be seen. The overlapping proximity between door and wall minimized the integration necessary. Yet, when no other cue was available, children again failed to open the correct door. Taken together, these findings further confirm that 2-year-olds pay little attention to the location of the wall, and that creating a link between the wall and the correct door does little to help children in their search.

To perform successfully in the search tasks described above, children not only have to know about the importance of the wall in principle, they have to keep in mind that it intersects the path of the ball even after their attention is drawn away from the wall to focus on the rolling ball on the left of the screen. In other words, they have to keep in mind that something static and distant (the portion of the barrier protruding above the screen) has something to do with the dynamic event (the rolling ball) that happens on the bottom left of the screen. Young children might have difficulty integrating the attention-grabbing motion of the ball with a static cue above the screen. Or, they might have difficulty integrating the invisible portion of the wall with the invisible motion of the ball.

To test this theory, it was necessary to design an experiment that not only highlighted the wall that intersects the path of the moving ball, but allowed the children to integrate the wall with the dynamic event- the motion of the ball. Taking advantage of a gestalt principle that two separate objects
are perceived as a unified object if they move in concert (e.g., Johnson, 2001; Kellman & Spelke, 1983) the apparatus was modified so that children see a part of the barrier above and below the screen, and the two parts of the barrier are moved together back and forth. The assumption is that children are likely to fill in the gap between the two parts of the barrier and create a representation of a wall that intersects the path of the ball.

Figure 2 illustrates this principle. The screen with four doors hides the path of a ball and part of the barrier, the barrier (referred to as the “long-wall”) is visible both above and below the screen, and the ball is about to roll behind the screen from the left. Moving the wall back and forth, the portion of the wall visible above the screen is likely to get unified with the portion of the wall visible below the screen, and thus ease the integration of wall and motion of the ball. It might be helpful to think of integration in this case to be a coordination of two dynamic events, referred to as dynamic integration.

Children 2 - 3 years old participated in this study. The hypothesis was that if the two visible portions of the barrier move in tandem - allowing successful integration - then children will be able to successfully search for the ball in the correct location.

Figure 2: Picture of a long-wall trial in Experiment 1.
Chapter II: Experiment 1

The purpose of this experiment was to investigate whether or not toddlers – given adequate cues – can integrate relevant pieces of information and show improved performance in a task that typically poses serious issues in problem solving. The assumption is that by extending the wall to be visible both above and below the screen and showing the two parts moving in tandem, children will be able to form a virtual representation of the wall. As a result, the wall can be successfully integrated with the motion of the ball.

Method

Participants. Participants were toddlers ($n = 41$) between 25 and 40 months of age ($M = 2.9$ years, $SD = 3.7$ months). For this an all subsequent experiments, they were recruited from local daycare centers and preschools. Four additional children were tested, but were excluded from the study because of experimenter error (one child), or failure to meet participation criteria (see Procedure).

Apparatus. A ramp apparatus with a door screen was used, similar to the one used by Berthier et al. (2000). The ramp was 75cm long and at a slight incline to allow a ball to roll along its full length. The ball was 4.1cm in diameter and made out of green foam. A small groove went lengthwise along the center of the ramp to constrain the path of the ball. The screen was an opaque wooden panel (56 cm long and 17 cm wide) that could be placed in front of the ramp. It had four doors (13.5 cm high and 9.5 cm wide), spaced equally 5 cm apart. Each door had a knob on the lower part and could be opened easily. Different from Berthier et al, (2000), the ramp apparatus and screen was integrated with a table (60 cm high), such that the area below the ramp was open.

Two walls were used to stop the ball as it rolled down the ramp, a short wall (21.5 cm high and 11 cm wide), and a long wall (25.5 cm high and 11 cm wide). Each wall had a notch (1.5 cm wide and 9 cm deep) that allowed it to slide into position on the ramp, as well as vertically along the ramp during
trials. With the four-door screen in place, both walls protruded 4 cm above the screen, and the long wall extended 4 cm below the screen (Figure 2).

The experimental program SuperLab was used to randomize the location of the wall for every trial, and to record what door the child opened first.

Procedure. Children were seated in a small chair in front of the ramp table within reaching distance of the doors. The screen was always in front of the ramp. The experiment consisted of three phases, presented in fixed order: the familiarization, the short-wall phase, and the long-wall phase. Each phase consisted of eight trials, presented in random order. Children’s task was to “help find the ball” by opening one of the doors. Feedback was given if the child opened the wrong door, and children were allowed to search until they successfully located the ball. However, only the first reach was recorded.

Within the eight trials of a phase, each of the four doors was correct twice.

During familiarization, the ball was held above one of the doors and lowered directly downward by hand. The experimenter then asked the child to open the door and retrieve the ball. To be included in the final sample, children had to open the correct door on the first try for at least five trials.

Following the first phase, children were asked to walk around to the other side of the table. They watched as the experimenter rolled the ball along the ramp. Next, the short wall was placed on the ramp in the path of the ball. The experimenter demonstrated that the ball stops when it hits the wall. The child was then asked to return to the seat and the short-wall phase started.

For each short-wall trial, the experimenter slid the short wall along the ramp behind one of the four doors. Children were reminded that the “ball stops at the wall”, and the visible portion of the wall was pointed out explicitly.

Finally, the short wall was removed and the long-wall phase started. The experimenter placed the long wall on the ramp and pointed out the visible portions of the wall both above and below the screen.
After the child acknowledged that they could see both parts of the wall, the experimenter slid the wall along the ramp to one of four positions, rolled the ball, and asked the child to search for it. Again, children were reminded on each trial that the ball stops at the wall.

Results and Discussion

The proportion of correct reaches was calculated for each child and each phase. During familiarization, when the ball was lowered from above the screen, performance was at ceiling ($M = .89$, $SD = .13$). This was not surprising, given that children merely had to follow the direction of the hand and open the door directly below it.

The important result pertains to the difference between short-wall and long-wall phase. A mixed-design 2x2 ANOVA was conducted, with condition (short-wall, long-wall) as the within-subject factor, and order (short-first, long-first) as the between-subject factor. It revealed a significant main effect for condition, $F(1,39) = 5.61$, $p < 0.01$, with long-wall performance above short-wall performance ($M_{\text{long}} = .60$, $SD = .22$; $M_{\text{short}} = .43$, $SD = .23$).

![Figure 3. Proportion of correct reaches during trials in Experiment 1](image-url)
The main effect of order and the interaction was not significant, \( (p > .18) \). In other words, children searched correctly significantly more often during long-wall trials than during the short-wall trials regardless of order. Figure 3 shows the mean proportion of correct reaches for each condition.

A simple linear regression revealed significant age effects, \( r^2 (40) = 0.17, p < .05 \), with older children performing significantly better than younger children, overall. (Figure 4 shows individual performance in each phase as a function of age.

![Figure 4](image-url)

Figure 4. Individual scores versus age in both short wall and long wall trials.

While search during both phases was above chance (assuming chance probability of 0.25, short wall: \( t(41) = 3.24, p < .05 \)), it is worth noting that of the 41 participants, 31 children searched successfully more often during long-wall trials, five of which performed at ceiling (see fig.5).
These findings show promising evidence that improved performance in a problem solving task that has previously posed problems for toddlers could be attributed to successful integration, more specifically dynamic integration. It is possible that the two visible portions of the long-wall, moving in tandem, allowed children to form a visual representation of the wall behind the screen. As a result, children were able to successfully integrate the wall with the other dynamic event - the motion of the ball. However, there are two alternative explanations. It is possible that the lower portion of the long wall, in closer proximity to the dynamic event, would be enough to draw the children’s attention to the point of intersection. Another explanation could be that the size, not the motion, of the long-wall could account for the improvement in performance.
Chapter III: Experiment 2

Is it possible that the improvement in performance is not a result of the tandem motion of the two visible portions of the long wall? Rather, could it be that the lower portion of the long wall was enough to attract the children’s attention to the wall, and thus facilitating integration? Experiment 2 was designed to test this possibility explicitly.

Method

Participants. Participants were toddlers (n =10) between 26 months and 41 months old (M = 3.0 years, SD = 5.2 months ). Two additional children were tested, but were excluded from the study because they did not wish to participate, or because they failed to meet participation criteria (see Procedure, Experiment 1).

Apparatus. The same apparatus from Experiment 1 was used in this experiment. However, an additional short wall was used to intercept the path of the moving ball. The new short wall (21.5 cm high and 11 cm wide) protrudes 4 cm below the screen (see fig 6).
Procedure. The procedure was identical to Experiment 1, except that children were never shown the long wall. Instead following familiarization (phase 1), children had eight trials using the short wall visible from above (“short wall above”) and eight trials using the new wall (“short wall below”).

Results and Discussion

The proportion of correct reaches was determined for each child and each phase by taking the number of correct reaches divided by number of trials (8) per condition. Figure 7 shows the proportion of correct reaches per trial. A within-group t-test revealed that performance during short-wall above trials ($M = .43, SD = .14$) was not significantly different than during the short wall below ($M = .46, SD = .19$), ($t(9) = .58, p > .05$). A 2x2 ANOVA was conducted with wall (short wall, other wall) as the within-subject factor and Experiment (1, 2) as the between-subject factor. It revealed a significant main effect for wall, $F(1,49) = 9.0, p < 0.01$ and a moderate interaction for Experiment, $F(1,49) = 3.55, p = 0.06$.

Overall, there was no improvement between short wall above trials and short wall below trials. These findings suggest that the proximity of the visible portion of the wall to the dynamic event has little, if any, effect on how well children perform in this task. This further demonstrates that creating propinquity between the wall and the motion of the ball, or the doors is simply not enough to help children integrate the wall with what is happening behind the screen. It is possible, however, that the sheer size of the long-wall (and not necessarily the motion) is so attention grabbing that it highlights the wall, thus allowing children to integrate it with the motion of the ball.
Chapter IV: Experiment 3

Could it be that the size of the long wall, regardless of the motion, was enough to improve performance? The purpose of this experiment was to rule this possibility out, and to further demonstrate that only the dynamic event of the long wall (the two visible portions moving in tandem) allows the children to create a visual representation of the wall behind the screen, thus helping integration with the other dynamic event— the motion of the ball.

Method

Participants. Participants were toddlers \( n =12 \) between 24 months and 39 months old \( (M = 2.8 \) years, \( SD = 4.2 \) months ). One additional child was tested, but was excluded from the study because of failure to meet participation criteria (see Procedure, experiment 1).

Apparatus. The same apparatus from Experiment 1 was used in this experiment.

Procedure. The procedure was identical to Experiment 1, except that rather than moving the walls vertically along the ramp prior to search, the walls remained static for all trials. To achieve this, the experimenter would simply pull the wall toward him or herself, removing it from the ramp and then re-position the wall in the new location by sliding directly forward into place.

Results and Discussion

The proportion of correct reaches was determined for each child and each phase by taking the number of correct reaches divided by number of trials (8) per condition. Figure 7 shows the proportion of correct reaches per trial. A within-group t-test revealed that performance during short-wall trials \( (M =.40, SD =.20) \) was not significantly different than during the long wall trials \( (M =.41, SD =.22) \), \( t(11)=.56, p> .05 \). In fact, only 4 children \( (v. 8) \) searched correctly more often during the long wall trials. A 2x2 ANOVA was conducted with wall (short wall, other wall) as the within-subject factor and
Experiment (1, 3) as the between-subject factor. It revealed a significant main effect for wall $F(1,51) = 10.22, p = .01$ as well as a significant interaction for Experiment, $F(1,51) = 6.14, p = .01$.

Poor performance in both conditions of this experiment suggests that without the motion, the visible portions of the long wall provide no more information than the short wall. Further, performance did not improve in Experiment 1 as a result of the extension of the size of the long-wall. These findings show promising evidence that the tandem motion of the two visible portions of the long wall was vital in successful performance.

![Figure 7. Proportion of correct reaches for Experiment 1 (Short Wall v. Long Wall), Experiment 2 (Short Wall Above v. Short Wall Below) and Experiment 3 (Short Wall Stationary v. Long Wall Stationary)](image-url)
Chapter V: Discussion

The goal of the current set of experiments was to investigate the importance of integration in a problem solving task that typically poses problems for toddlers. The hypothesis was that children’s success depends on the degree to which integration of relevant pieces of information is supported in the immediate task context. In this task, I argued that the relevant pieces of information pertained to (1) the dynamic motion of a ball rolling behind a screen, and (2) a wall intersecting its motion. In support of my hypothesis, I manipulated the degree to which the wall was perceived to intersect the dynamic motion of the ball. Indeed, 2-year-olds performed better in the condition in which the wall apparently intersected the trajectory of the ball (long-wall trials) than in the condition in which this was not the case (short-wall trials). Findings show that two visible portions of the wall moving in tandem above and below the screen were crucial for successful performance. Toddlers search correctly for the ball behind the screen nearly 60% of the time.

Alternative explanations of improved performance in long-wall trials could be that the lower portion of the long wall, in closer proximity to the ramp, was very attention grabbing. Thus, it could have highlighted the wall in such a way that children were able to more easily locate the ball. Experiment 2 was designed to explicitly test this possibility. A new wall (visible only below the screen) was designed to replace the long-wall. Results from Experiment 2 speak against the possibility that the lower portion of the wall accounted for children’s improved performance during the long wall trials in Experiment 1. Performance in trials using a wall that was only visible below the ramp was not different than trials where the wall was visible above the screen.

Another possibility is that the sheer size of the long wall - and not the motion - highlighted the position of the wall and thus the location of the ball. In order to rule this possibility out, it was necessary
to remove the motion cue. The results of Experiment 3 ensured that these findings were not due to the size of the long wall. In other words, the mere presence of a wall protruding above and below the screen did not improve children’s search. Instead, children’s performance during stationary long-wall phases was near 40%, and not significantly different than performance during stationary short wall trials.

One could argue that the long wall merely highlighted the correct door: A barrier extending below and above the screen might ease integration of the wall and the door behind which the ball can be found. However, previous findings speak against this possibility. Despite rather obvious measures of decreasing the distance between wall and correct door, children’s search performance did not improve (e.g. Keen et al., 2008; Kloos et al., 2006; Shutts et al., 2006). The results from the current study suggest, instead, that the motion of the long wall highlighted the intersection of wall and the moving ball, and thus highlighted the location of the ball for children.

Note that nothing in the display gave away the answer about the position of the ball. Our manipulation merely created a dynamic event that potentially highlighted the wall’s role for the motion of the ball, and as such potentially helped children integrate (or coordinate) it with the other dynamic event. However, it is also possible that the highlighted wall grabbed the children’s attention and led them to open the door at that location, with little regard to the physical principle of solidity. After all, the experimenter reminded the child on every trial that the ball stops at the barrier. It was therefore not necessary for children to utilize any physical knowledge about solidity. In other words, our results do not speak directly to the question of whether toddlers know something about solidity, or whether they can form expectations about hidden events.

Along the same lines, the results of this experiment do not directly address the question of learning. In fact, the results of Experiment 1 indicate that children did not learn during this task. Overall, children perform poorly in all short wall trials regardless of order. Although the purpose of this task was
not to explicitly help children ‘learn’ where the ball would stop on future trials, per se, it was surprising to find that even children who received the long–wall trials first performed poorly during short wall trials. These findings indicate that while scaffolding integration may lead to successful problem solving, the transfer of information from one context to another may pose additional problems for children.

In sum, the current study does not answer the question of whether or not problem solving is contingent upon knowledge or cognitive/developmental maturity. Nor does it indicate the degree to which integration can facilitate learning. Rather, results from the current study show that facilitating the integration of the pertinent cues resulted in remarkable improvement of performance and that sometimes integration can be quite complicated when one component of the task is more attention grabbing than another component.

These results lend further support to the argument that a child’s performance reflects a conglomerate of constraints that operate in the immediate task context, constraints that help or hinder integration of the relevant pieces of information (e.g., Smith, Thelen, Titzer & McLin, 1999; Van Orden, Pennington & Stone, 1990). Finding that small changes in the immediate context result in successful performance in some trials, but not others, supports the notion that performance is not a mere reflection of certain knowledge, or lack thereof. Instead, it might demonstrate the degree to which constraints guide children’s attention to coordinate events (or tasks components) in one way or another. If so, it would be important to better understand the kinds of constraints that operate in this task. For example, is it possible that children would still look for the ball next to the long-wall if the wall had a large gap allowing the ball to pass through? In other words, if the wall was no longer a relevant cue, would children still attempt to integrate it with the motion of the ball?
References


