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Vision for Action in Toddlers: The Posting Task

Sandra Y. Street, Karin H. James, Susan S. Jones, and Linda B. Smith
Indiana University

Three experiments examine 18- to 24-month-old (N = 78) toddlers' ability to spatially orient objects by their major axes for insertion into a slot. This is a simplified version of the posting task that is commonly used to measure dorsal stream functioning. The experiments identify marked developmental changes in children's ability to preorient objects for insertion, with 18-month-olds failing completely and 24-month-olds succeeding easily. In marked contrast, 18-month-olds preorient their empty hands for insertion into the same slots. This developmental dissociation between aligning hands and aligning objects to slots suggests that the key developmental change is in action with the goal of object-to-object alignment versus action on an object.

Contemporary understanding partitions visual processing into two functionally distinct neural systems: vision for action and vision for object recognition (Clark, 2009; Milner & Goodale, 1995, 2004; Ungerleider & Mishkin, 1982). This functional distinction is linked to two projection pathways in the visual cortex. The dorsal pathway, sometimes called the ''where'' or ''how'' system, is thought to process the spatiotemporal properties of visual events. Because this system also supports such actions as grasping and manipulating objects, it is also sensitive to the geometric properties of objects relevant to those actions. These object properties include some shape information, visual cues to weight, actual size, and orientation. The ventral pathway, also known as the ''what'' system, is responsible for object recognition and categorization and thus for processing the stable properties of objects, including the properties of shape that are relevant to object kind. Although vision for action and vision for object recognition involve distinct pathways with distinct processes, the two systems must work together—in coordinated and complementary ways—in everyday tasks (Graf, 2006; Jeannerod, 1997; Milner & Goodale, 1995). Major open questions at present concern the independent developmental trends in both of these domains (Mareschal & Johnson, 2003; Smith, 2009) and the nature of that integrated functional system—that is, how the two component systems may support each other in producing smooth, object-centered actions in the world.

This article presents new evidence on the development of vision for action and locates marked changes in action organized around object properties in the period between 18 and 24 months. This discovery, which is the main contribution, brings new insights into the development of the vision-for-action system, and as we conjecture in the general discussion, may provide avenues for new research into the integration of the two systems. The experiments use a simplified version of the ''posting task''—a task commonly used in the neuropsychological literature to assess dorsal stream functioning. For this reason, the present results also provide new information about early developmental changes in performance on this task.

Developmental Evidence

There is a growing literature on the development of the dorsal and ventral systems considered independently and jointly (Atkinson, 1998; Johnson, Mareschal, & Csibra, 2001; Milner & Goodale, 1995; Pellicano & Gibson, 2008). The human data derive mostly from studies of infants prior to their first birthday (Csibra, Tucker, & Johnson, 1998; deHaan, Pascalis, & Johnson, 2002; Mareschal & Johnson, 2003). These findings from young infants have been interpreted as evidence of a possible developmental lag between the two systems, with the ventral

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Correspondence concerning this article should be addressed to Sandra Y. Street, 1101 East Tenth Street PY A140, Bloomington, IN 47401. Electronic mail may be sent to systreet@indiana.edu.

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object recognition system seeming more mature (deHaan et al., 2002; Kurtzberg & Vaughan, 1977) and the dorsal, vision-for-action system showing slower development (Atkinson et al., 2003; Csibra et al., 1998; Diamond, Zola-Morgan, & Squire, 1989; Dilks, Hoffman, & Landau, 2008; Gilmore & Johnson, 1997). However, recent research on both object recognition and vision for action suggests substantial changes in both systems after the first birthday (Smith, 2009). Johnson et al. (2001) in particular conjectured that the surface information from objects (generally used by the ventral stream) may also begin to be used in conjunction with spatial–temporal information (by the dorsal stream) during this period, when infants' actions on objects become more sophisticated and more dependent on the properties of the objects themselves. More generally, they argued for significant changes in vision for action and its use of object properties in the 2nd year.

Development of vision for action seems likely to be intertwined with the development of the motor system. Infants' first reach for objects occurs at about 5 months and their manual explorations of objects become increasingly sophisticated after they are able to sit steadily (6–8 months) and thus engage in extended periods of object exploration (Soska, Adolph, & Johnson, 2009). During this period, there are incremental improvements in dorsal stream functions such as coordinating hand actions to the sizes and orientations of objects and making these adjustments prior to actual hand contact with the object (Bruner & Koslowski, 1972; Clifton, Rochat, Litovsky, & Perris, 1991; Fagard, 2000; Lockman & Ashmead, 1983; Lockman, Ashmead, & Bushnell, 1984; von Hofsten & Fazel-Zandy, 1984). Everyday observations tell us that after their first birthday, toddlers' actions on objects become increasingly complex and dependent on object shape; these include actions such as stacking objects, inserting objects into openings, and engaging in thematic play (such as pretending to feed a doll). There has been less systematic study of developmental changes in dorsal stream processes or in the object information used by the vision-for-action system in these tasks by toddlers (see also Barrett & Needham, 2008).

One study that supports the idea that the 2nd year might be a period of dramatic change in vision for action used an object insertion task to examine 14- to 26-month-olds' ability to align and rotate differently shaped objects to fit into matching holes (Örnkloo & von Hofsten, 2007; see also Hayashi, Takeshita, & Matsuzawa, 2006). Children were presented with only one shape and one hole at a time and therefore did not have to match the shape to the hole but only had to manage to orient the object so that it would fit. Children 18 months and younger rarely oriented the object properly for insertion and rarely succeeded in fitting the objects through the holes. In marked contrast, children 22 months and older were much more successful in orienting the object with respect to the hole and in inserting it. Moreover, these older children typically made appropriate adjustments of hand shape and orientation—the adjustments necessary to grasp and rotate the object for insertion—prior to picking up the to-be-inserted object. This indicates that they were able to plan actions based on the visual processing of the relevant geometric properties of the object in relation to the opening. Thus, the developmental changes observed in this object-insertion task may signal a period of important developmental change in the vision-for-action system in its ability to adjust action to the geometric properties of objects.

The Posting Task

Insertion tasks have also been widely used in the study of dorsal stream functions in the neuropsychological literature. One commonly used task in this literature is the ''posting'' task. This task was introduced by Efron (1969) and subsequently used by Warrington (1985), Goodale, Milner, Jakobson, and Carey (1991), and Goodale and Milner (1992) in studies of adult neuropsychological patients, and more recently in studies of older children with developmental disorders thought to differentially involve the dorsal stream system (Atkinson et al., 1997; Dilks et al., 2008). In these studies, subjects are given a range of ''Efron rectangles'': flat, simple plaques that differ in their height–width ratios. The subject's task is to insert the rectangles into a slot presented at a particular orientation. The critical dependent measure is the angle of the rectangle relative to the angle of the slot just prior to insertion—a measure of whether participants orient the hand-held object to match the orientation of the slot. Adult patients with impaired dorsal stream system function can discriminate between aligned and unaligned rectangles and slots but cannot orient the hand and object to insert the rectangle into the slot (Perenin & Vighetto, 1988). Studies of children with Williams syndrome (thought to principally impair the dorsal rather than the ventral system), age-matched children, and mental-age matches using this task indicate that the posting task is particularly difficult for children with Williams syndrome (Dilks et al., 2008). No studies as far as we know have examined the development of posting in toddlers. However, Johnson et al.'s (2001) hypothesis of significant changes in dorsal stream function in the 2nd year and Örnkloo and von Hofsten's (2007) findings with the shape sorter suggest that the origins of aligning objects to slots will be found in this developmental period.

Accordingly, the experiments reported here use a much simplified version of the posting task to ask whether—given the goal of inserting an object into a slot—children appropriately align the orientation of the object to the orientation of the slot. The toddler task is simpler than the standard adult version in several ways: First, disks are used instead of rectangles so that children do not have to choose how to hold the object relative to its major axes. Second, children are required only to insert objects into either a vertical or a horizontal slot. This contrasts with the standard posting task that uses variable slot orientations and finds most errors at orientations other than horizontal and vertical. By asking the children to insert disks into a single orientation slot, we remove problems of switching between different hand movements, which might be particularly difficult for children this age (e.g., Diamond & Goldman-Rakic, 1989; Marcovitch & Zelazo, 2006). By using only horizontal and vertical slots, we hope to capture the perhaps foundational components of aligning objects to openings. In addition, in the toddler task, the object and the opening do not match in shape: That is, the objects are ''circles'' whereas the slots are rectangles. The task then is to rotate the disk so it will fit into the slot. This task requires no shape recognition per se, but does require the coding of geometric properties such as axes of elongation, size, and orientation—all of which are types of visual information thought to be processed by the dorsal stream during visually guided action.

Experiment 1 examines the performance of 18- and 24-month-olds in this simplified posting task, with the expectation that this age period will prove to be a period of significant developmental change in representing and using the geometric properties of objects in goal-directed actions. Experiments 2 and 3 provide further evidence on factors that might be responsible for the dramatic developmental differences that are observed in Experiment 1. All experiments use a lightweight head-mounted video camera as developed by Yoshida and Smith (2008) to capture the first-person view of the disks and slots.

Experiment 1

Method

Participants. The participants were twenty 18-month-olds (M = 17.4 months, range = 16.1–18.8 months) and twenty-two 24-month-olds (M = 24.2 months, range = 23.0–25.3 months). No children were excluded from the analysis. The children were recruited from a working- and middle-class population in the Midwest and had no known developmental disorders. Parents reported normal visual acuity. At each age level, half the children were assigned to a vertically oriented slot condition and half to a horizontally oriented slot condition.

Stimuli. The eight disks were 8.5 cm in diameter and 0.9 cm in thickness and were created in eight different colors. The slot was 10.5 cm × 1.5 cm, cut into a cardboard box (35 cm × 25.5 cm × 16 cm). The box was rotated to create the two conditions of a horizontally versus vertically oriented slot. The disks fit easily into the slot when properly aligned. The box and disks are shown in Figures 1 and 2.

Head camera. As shown in Figure 1a, the head-mounted camera was embedded in a head-band that could be easily placed on the child's head. The camera was a Watec model WAT-230A (Watec Incorporated, Middletown, NY). This model has 512 × 492 effective image frame pixels, weights 30 g and measures 36 mm × 30 mm × 30 mm. The lens used was Watec model 1920BC-5, with a focal length of f1.9 and an angle of view of 115.2° on the horizontal and 83.7° on the vertical. The camera could be adjusted to ensure that it was properly aligned to the center of the visual field when the head and eyes were directed forward (see Yoshida & Smith, 2008, for further calibration and validation studies). Power and video cables were sufficiently long and supported that so that children could freely move their heads and bodies unhindered by the cords. A second camera recorded each child's activity from the side as shown in Figure 1b.

Procedure. The child sat on the parent's lap at a table and next to the experimenter. At the start of the session the child was given a highly engaging toy with buttons to push that caused animals to pop up. One experimenter distracted the child with this toy as a second experimenter placed the head camera on the head and adjusted it such that the center of the button on the toy was in the center of the head camera view when the button was being pushed by the child. When this was accomplished, the posting box was placed directly in front of and within easy reach of the child as shown in Figure 1b. One disk was then placed flat on the table

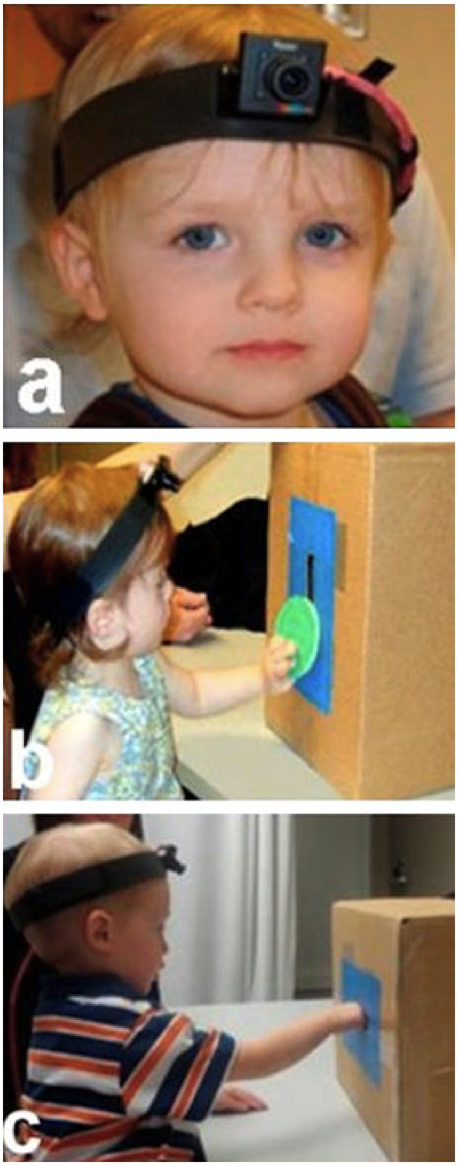

Figure 1. The experimental set-up showing (a) a child wearing a head camera, (b) the box and one disk, and (c) a child inserting his hand into the slot (Experiment 3).

between the box and the child. The instructions were simply to ''put it in the box.'' There was no time constraint: The toddlers were given as much time as they needed or wanted and were allowed to make multiple attempts until they either successfully inserted the disk or released it (dropped it, placed on top of the box, or handed back to the researcher). Any form of release ended the trial with that disk. When the trial ended, a new (identical but differently colored) disk was laid flat on the table and the child was again asked to ''put it in.'' If a child appeared to not understand the task, the experimenter demonstrated by inserting one disk. The parents were instructed not to help their child; they were allowed to verbally encourage the child to put the disk into the box but not to say or do anything that would help the child if he or she found the task difficult. There were a total of eight trials and the experimental session lasted < 15 min.

Coding. Children's performances were coded from the head camera view. The principle measure was the orientation of the disk relative to the slot at the first attempted insertion on each trial. The point at which the measure was taken on each of the eight trials was defined as the point at which the disk first touched the box (or slot). Figure 2 shows examples of aligned and nonaligned disks at this point. Initially we were primarily interested in correct and incorrect alignments and therefore grouped attempts into four basic categories: 0° (within ± 5°), 90° (within ± 5° of being perpendicular to the slot), 45° (at any intermediate orientation), and flat (placed flat against the box). This last category of responses, flat, occurred rarely, < 4% of the time for the younger children and < 1% of the time for the older children and therefore will not be considered further. Since the 45° category was large and included a variety of angles, we did a second coding of the trials that fell into that category to distinguish among intermediate angles. The second coding classified the attempts into three subcategories: 25°, 45°, and 65°. A template was made using a protractor and transparency to aid coders in judging the angles. The template could be placed over the computer screen and aligned with the slot. Coders were trained to determine if the intermediate angles fell closest to 25°, 45°, or 65° using this template. In addition, we coded the number of attempts the child made per trial prior to successful insertion and the overall proportion of success. Two independent coders each coded a random selection of 25% of the trials. Cohen's Kappas showed that interrater reliability was .86 for judgments of alignment at initial attempt on a trial (initial angle code), .83 for the second coding of angles, .81 for number of attempts, and 1.00 for number of successes.

Results and Discussion

Figure 3 shows the distributions of the angles of initial approaches on each trial, across children in the two age groups and orientation conditions. As is apparent in the figure, 24-month-olds generally oriented the disk appropriately for insertion on the initial approach (scored as 0°) in both the horizontal and vertical conditions. The younger children, in

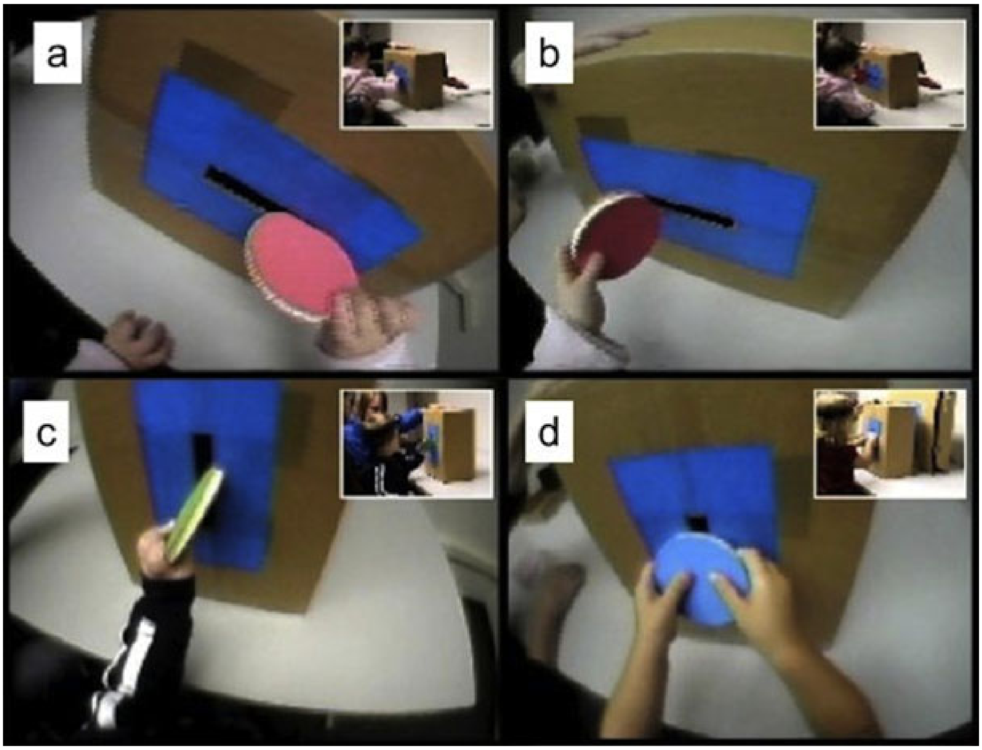

Figure 2. Head camera views of children's initial approach, scored as (a) 0° (aligned), (b) 90°, (c) 45° (any intermediate orientation), and (d) flat.

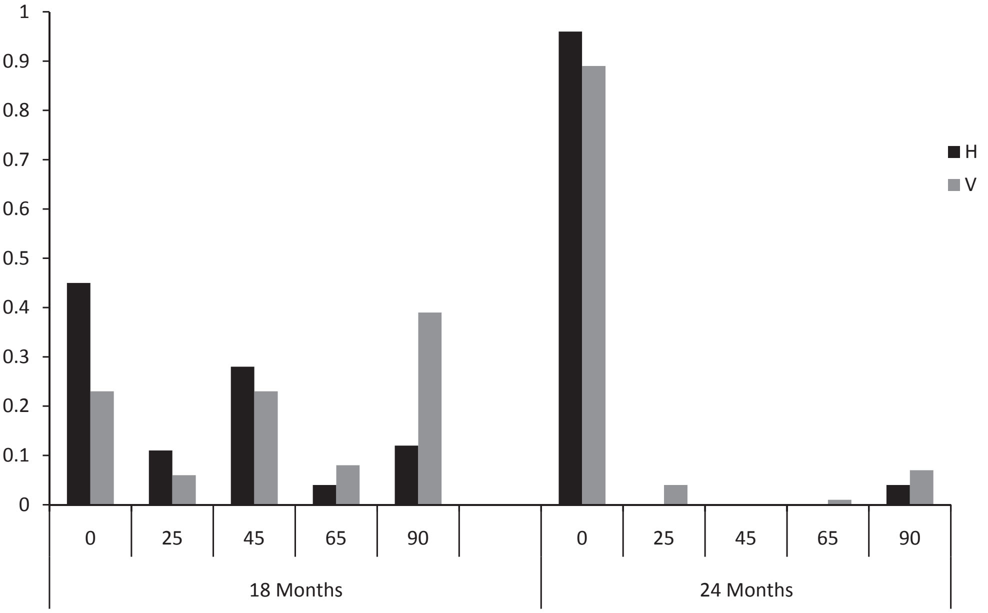

Figure 3. Proportion of initial attempts, coded in terms of the relation between the orientation of the disk and the slot as 0° (aligned), 25°, 45°, 65°, and 90° (perpendicular), for the 18- and the 24-month-olds in the horizontally aligned (H) and vertically aligned (V) slot conditions of Experiment 1.

marked contrast, did not approach the slot with the disk oriented appropriately for insertion. Although the 18-month-olds performed better in the horizontal than in the vertical condition, even in the horizontal condition they approached the slot with the disk oriented inappropriately on more than half of

Table 1
Results for 18- and 24-Month-Olds in Experiment 1

	Mean angle of initial approach			Proportion of success (over all attempts on all trials)			Number of attempts per success		
	H**	V**	Total**	H*	V*	Total**	H	V*	Total**
18 months	30.32 (19.37)	52.51 (27.93)	40.31 (25.57)	0.72 (0.35)	0.45 (0.38)	0.60 (0.39)	2.06 (0.95)	2.40 (1.33)	2.18 (1.07)
24 months	3.21 (13.61)	11.13 (26.14)	7.76 (19.22)	1.00 (0.00)	0.88 (0.33)	0.95 (0.22)	1.46 (0.20)	1.17 (0.35)	1.35 (0.46)

Note. Means and standard deviations for angle of disk relative to the slot at initial approach, for proportion of trials on which the participant ultimately succeeded in inserting the disk, and for number of attempts leading to success separately for 18- and 24-month-olds in Experiment 1, in the horizontally aligned slot condition (H), the vertically aligned slot condition (V), and across both conditions (Total).
*$p < .05$. **$p < .01$.

the trials. A 2 (age) × 2 (orientation: horizontal vs. vertical) analysis of variance carried out on just the proportions of trials on which children's orientation of the disk at initial approach was aligned (i.e., within ± 5°) found that both main effects were significant but that there was no interaction. The main effect of orientation, $F(1, 41) = 8.09$, $p < .01$, $\eta_p^2 = .18$, reflects the fact that children were more accurate with horizontal than vertical slots. The main effect of age, $F(1, 41) = 20.61$, $p < .001$, $\eta_p^2 = .36$, shows that, within a 6-month span, the ability to align a disk to the slot improves dramatically.

Other metrics of performance lead to the same conclusion. Table 1 shows the mean angle of the disk relative to the slot at initial approach, the proportion of attempted trials in which the child ultimately succeeded, and the mean number of attempts until success per trial. Separate analyses of variance—2 (age) × 2 (orientation of slot)—for each of these measures yielded main effects of age, for all measures, $F(1, 41) > 5.96$, $p < .02$, $\eta_p^2 > .15$, as well as reliable main effects of the orientation of the slot, higher scores with horizontal slots: all $F(1, 41) > 4.30$, $p < .05$, $\eta_p^2 > .10$. There were no reliable interactions in any of these analyses. Again, the task was easy for 24-month-olds by all measures and exceedingly difficult for 18-month-olds. This characterization of the developmental differences characterizes individual differences as well as the group differences. Only four of the twenty 18-month-old children scored above 70% in the initial alignment; the rest were below 50%. By contrast, only three 24-month-olds scored below 70%. Interestingly, this task did not produce a large variety of strategies for inserting the disks. The 24-month-olds were easily successful in preorienting the disks; they rarely required adjustments in their initial alignment. The 18-month-olds produced more variance in their alignment attempts over all; however, individual children did not often make productive changes in their attempts. Quite often they simply made multiple attempts with the disk in the same orientation, for example, holding the disk at a 45° angle in relation to the slot and hitting the box with it over and over without making any adjustments. A few children did make adjustments upon finding that the disk did not go into the slot; however, those adjustments often resulted in a larger angle rather than correcting the erroneous first attempt.

Children's overall better performance with the horizontal versus vertical slot could reflect their natural manner of holding disks (which might put the disk in the proper position for the horizontal but not the vertical slot) and/or could reflect motor processes related to rotating and adjusting the disk properly for alignment. Consistent with this idea, studies with younger infants find more accurate anticipatory hand shapes with horizontally than vertically aligned objects (Lockman et al., 1984). Perhaps relevant to this issue, there was a hint that experience in the task might help younger children, in that their production of aligned attempts increased slightly (although not reliably at conventional standards for statistical significance) in the second half of the trials relative to the first. Analysis of the angle of initial attempt for trials in the first and second halves resulted in the following: 18-month-olds (first half: $M = 43.17$, $SD = 24.88$; second half: $M = 30.47$, $SD = 27.73$), $t(19) = -1.89$, $p < .07$, $d = -0.46$, and 24-month-olds (first half: $M = 9.94$, $SD = 24.60$; second half: $M = 6.20$, $SD = 20.11$), $t(21) = -0.79$, $p = .44$, $d = -0.19$. Although this increase in 18-month-olds' accuracy is slight, it is interesting in that it suggests that experience with inserting things in slots may be a factor in the observed developmental differences. Overall, however, the main result is that children's performance in this simple posting task develops markedly in this period, from nearly complete failure to easy success.

Experiment 2

Experiment 1 required the children to take an unaligned disk and align it. In Experiment 2, we provide the object properly aligned to the slot for the younger children so that all they need to do is to grasp and insert it into the box. If the younger children's principal difficulty was in knowing to and knowing how to align the object—and not simply in holding the disk properly for insertion—then they should perform well when the alignment is done for them.

Method

Participants. The participants were 22 children with a mean age of 17.7 months (range = 16.3–19.3 months). One child was excluded due to making no attempts to insert the disks. The children were recruited from a working- and middle-class population in the Midwest and had no known developmental disorders. Parents reported normal visual acuity. Half of the children were assigned to the vertical-slot condition and half to the horizontal-slot condition. None of the children had participated in Experiment 1.

Stimuli. Experiment 2 used the same posting box and disks described in Experiment 1.

Procedure. The procedure was identical to Experiment 1, except that the experimenter demonstrated inserting the disk prior to each of the child's trials, and after the demonstration, the disk was handed to the child correctly oriented to the slot and approximately 1 in. from the opening. The toddler needed only to grasp the disk and insert it into the slot. The experimental session lasted < 15 min.

The videos were coded from the head camera perspective as in Experiment 1 and again two independent coders each coded a random selection of 25% of the trials yielding agreements using Cohen's Kappa of .85 for number of attempts on each trial, .82 for angle of the disk relative to the slot, and 1.00 for number of successes.

Results and Discussion

The children in this experiment exhibited significantly greater success than the 18-month-olds in Experiment 1. Figure 4 shows the distributions of initial approaches on each trial. The children maintained the experimenter-provided orientation of the disk (within ± 5° of the slot at initial approach) on 64% and 51% of the trials in the horizontal and vertical conditions respectively. The difference between the two orientations was not statistically significant: $t(20) = 1.3$, $p > .10$. The overall proportion of aligned initial insertions in Experiment 2 (.57) compares favorably to that of the 18-month-olds in Experiment 1 (37), $t(40) = 2.85$, $p < .05$, $d = 0.47$. That is, aligning the disks for the children helped them to insert the disks on the initial attempt and did so equally well in the horizontal and vertical conditions.

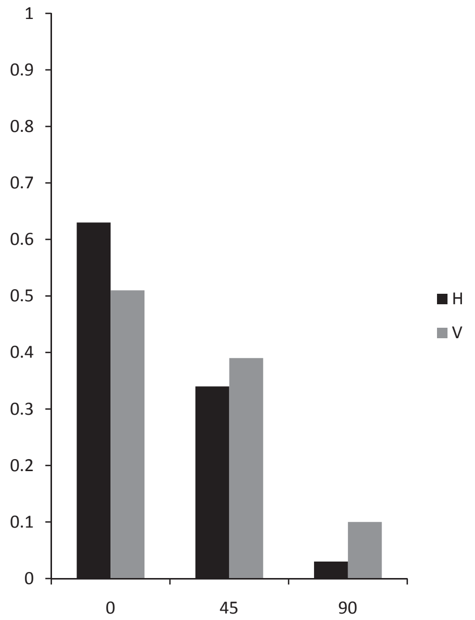

Figure 4. Proportion of initial attempts, coded in terms of the relation between the orientation of the disk and the slot as 0° (aligned), 45° (oblique), and 90° (perpendicular), for the 18-month-olds in the horizontally aligned (H) and vertically aligned (V) slot conditions of Experiment 2.

The children in this experiment might have been even more successful if they had not occasionally taken the properly aligned object as given and then played with it prior to insertion, essentially putting themselves into Experiment 1 in which they had to align the object for themselves. On 16% of the trials, children actively moved the disk out of alignment prior to attempting insertion. Their initial attempt at insertion on these trials was *mis*aligned 63% of the time, consistent with the findings of Experiment 1. The children who performed particularly poorly in this task were the same children who on a high percentage of trials (above 60%) took the object and played with it prior to attempted insertion resulting

Table 2
Results for 18-Month-Olds in Experiment 2

Mean angle of initial approach			Proportion of success (over all attempts on all trials)			Number of attempts per success		
H	V	Total	H	V	Total	H	V	Total
17.90 (12.45)	26.98 (19.78)	22.24 (16.59)	0.79 (0.27)	0.73 (0.29)	0.76 (0.27)	1.37 (0.26)	2.25 (1.59)	1.79 (1.17)

Note. Means and standard deviations for angle of disk relative to the slot at initial approach, for proportion of trials on which the participant ultimately succeeded in inserting the disk, and the mean number of attempts to success for 18-month-olds in Experiment 2, in the horizontally aligned slot condition (H), the vertically aligned slot condition (V), and across both conditions (Total).

in a misaligned disk rather than the prealigned disk provided by the experimenter.

Table 2 shows the other metrics on performance and again they lead to the same conclusions. The mean angle of the disk relative to the slot at initial approach (averaged over scores of 0°, 45°, and 90°), the proportion of attempted trials on which the child ultimately succeeded, and the mean number of attempts before success on a trials all compare quite favorably to the 18-month-olds' performance in Experiment 1, and indeed look more like the 24-month-olds' level of success in Experiment 1, results for attempts per success and proportion of success were not significantly different, $F(1, 36) < 4.00$, *ns*. Moreover, none of the analyses shows a reliable effect of orientation of slot, all $t(40) < 1.00$, *ns*.

The results of Experiment 2 suggest that the younger children can hold the disk properly and insert it, both in the horizontal and vertical conditions. When given the disk properly aligned, 18-month-olds are generally successful. Thus, their problem appears to be either recognizing the need to, or knowing how to rotate the disk so that it is aligned with the slot.

Experiment 3

To align the disk to the orientation of the slot, children have to be able to perceive the different orientations, they have to know that orientation matters (that horizontally aligned disks cannot, e.g., fit into vertical slots), and they have to know how to rotate the object to align it to the slot. The final experiment provides evidence that the younger children do perceive the different orientations of the slots, that they know that orientation matters for inserting at least *one class of objects* into the slots, and that they know how to rotate that class of objects for insertion. In the testing of children in Experiments 1 and 2, we noticed that children sometimes put their hands into the slots, as illustrated in Figure 1c, but we never saw any misaligned attempts at hand insertion. Experiment 3 confirms this observation and a developmental dissociation in aligning hands versus objects.

Method

Participants. Participants were 14 toddlers aged 16–18 months (M = 17.34 months, range = 16.1–18.5 months). Two toddlers were excluded due to nonparticipation in the task; they made no attempts. The children were recruited from a working- and middle-class population in the Midwest and had no known developmental disorders. Parents reported normal visual acuity. Half of the children were assigned to the vertically aligned slot condition and half to the horizontally aligned slot condition. None of the children had participated in Experiments 1 or 2.

Procedure. Experiment 3 made use of the same posting box as in the previous experiments but this time no disks were involved. The box was placed in front of and within easy reach of the child. The experimenter first demonstrated putting her hand in the box so that the child understood the task. The instructions were to ''put your hand in the box.'' If the child needed additional motivation to engage in the task or seemed to not understand, the experimenter reached in from the back of the box, letting her fingers peek out of the slot briefly and asked the child to reach in and touch the experimenter's fingers. Figure 1c shows a child participating in this task.

The videos were coded from the head camera perspective as in Experiments 1 and 2. Again, two independent coders each coded a random selection of 25% of the trials, yielding reliability based on Cohen's Kappa of .87 for correct hand orientation.

Results and Discussion

Consistent with our casual observations, the children were highly successful, aligning their hand either horizontally or vertically on initial approach (and thus prior to actually trying to fit the fingers in) on 80% of the trials, mean proportion aligned .88 in the horizontal condition and .74 in the vertical condition, $t(10) = 0.71$, $p < .50$. Interestingly, all but 3 of the children (2 in the vertical condition and 1 in the horizontal) aligned the orientation of their hand to the slot on their first approach on more than 75% of trials. Thus, for most of these young children—children the same age as those who seem not to know to, or know how to align the orientation of a disk to a slot—aligning hand orientation was a trivially easy task. This result shows that these younger children *perceive* the orientations of the slots and something about the implications of slot orientation for inserting fingers. However, that knowledge appears specific to hands. Put another way, rotating hands appeared easy for 18-month-olds but rotating objects in hands was not. In sum, the problem for 18-month-olds appears to be about aligning *objects* (not body parts) to slots. This task, inserting hands, is different from the task used to assess the perception of slot orientation in neuropsychological patients. In that literature (Milner & Goodale, 1995), patients are asked to determine if a hand is oriented so it is aligned to the slot, but not to actually insert their hand. To the best of our knowledge, a hand insertion task like the present one has never been used. Thus, it is not known whether dorsal stream patients who, like young children, cannot align disks to put into slots, would succeed or fail in orienting their hand in order to insert that hand.

General Discussion

The experiments yield two main results. First, they show marked developmental change in children's ability to align an object's orientation to a slot in an insertion task. In the 6-month period between 18 and 24 months, children go from arrant failure to easy success. Second, these changes concern aligning objects but not hands. Even the youngest children tested oriented their own hands properly to reach into slots, but they did not orient their hands accurately when those hands were holding objects. These results suggest that the developmental changes leading to success concern the integration of object properties into planned actions.

The two variants of the task—inserting hands and inserting an object held in the hand—are at least superficially similar, in terms of hand orientation, in terms of how the hand has to rotate, and in terms of assessing the orientation of the slot. However, by one task analysis, inserting an object requires what may be a critical advance in the development of vision for action. Just inserting a hand into a hole is like picking up an object, in that the child only needs to coordinate the action of the body part to one object. Prior research shows that young children before their first birthday are quite good at adjusting hand shape to an object to be acted upon (von Hofsten & Fazel-Zandy, 1984). Experiment 3 in the present study shows that young children are also quite good at adjusting their hand orientation to bring it into alignment with a hole. The task of inserting the disk into the slot, however, requires more than adjusting a body part to a single object. Instead, the child has to use the body part to adjust one object (the disk) to bring it into alignment with a second object (the slot). The psychological importance of the object-to-object alignment in the present task is highlighted by the fact that the child could succeed in the disk task just by ignoring the disk in his hand and orienting the hand (holding the disk) as if he was going to insert the hand. A small number of previous studies have reported similar observations of young children's difficulties in spatially orienting one object to another (Matsuzawa, 200; McCarty, Clifton, & Collard, 2001).

The hand–disk difference may also reflect differences in amounts of experience. Children have been using their hands and inserting them into different kinds of openings for months. Children have had less experience putting objects into openings, and probably very little experience with disks and slots. However, this difference also means that what children know about orienting hands so that they are aligned to openings does not transfer to the task of orienting disks. This is reminiscent of Adolph, Eppler, and Gibson's (1993) finding that knowledge about inclines in the task of crawling did not transfer when the task was upright walking. Clearly, a next step in this program of research is to examine the role of specific experiences with specific kinds of objects. The experiential differences between disks and hands in children's everyday life may also be related to observations in the neuropsychological literature of a dissociation in adults between transitive and intransitive actions. Neuropsychological studies of apraxia (Dumont, Ska, & Schiavetto, 1999; Rapcsak, Ochipa, Beeson, & Rubens, 1993) as well as functional imaging studies of normal adults (e.g., Kosslyn, Digirolamo, Thompson, & Alpert, 1998; Vingerhoets et al., 2001; Windischberger, Lamm, Bauer, & Moser, 2003) indicate that actions involving objects and actions involving only body parts recruit distinct neural systems.

Thus, one useful experimental window into the development and integration of these neural systems may be the study of goal-directed actions that do and do not involve objects. Pertinent to this idea, Robinson, McKenzie, and Day (1996) found that 10-month-old infants aligned hands appropriately to grasp vertically extended versus horizontally extended objects but did not align their hands appropriately for inserting their hands into horizontal versus vertical slots. The present study shows that 18-month-olds can do this but cannot align an object to a slot so as to insert that object, an action that requires both grasping the object and relating the object to the slot. Other insertion studies also suggest growth in relating a held object to an opening. Shutts, Örnkloo, von Hofsten, Keen, and Spelke (2009) reported significant changes between 15 and 30 months in children's ability to select objects by size and shape for insertion into holes, with one key component skill involving children's ability to match three-dimensional object shape to a two-dimensional hole shape. These findings complement those of Örnkloo and von Hofsten (2007) who did not require children to match shapes to holes but only to adjust held shapes to fit into holes, a skill that did not emerge until 22 months. Critically in that study, the older children made appropriate adjustments of the object to match the hole prior to initial insertion which suggests that the children were attending to the relation between the object and the hole. Finally, in a related study not involving object insertion, McCarty et al. (2001) reported protracted developmental changes in children's ability to orient tools such as hairbrushes and spoons with respect to self and others. Just after their first birthday, most children could orient the objects to act on themselves—that is, to brush their own hair or feed themselves with the spoon. However, it was not until late in the 2nd year that children appropriately held the objects to perform the same actions on another person. All of these results along with the present findings suggest that children become increasingly skilled in relating objects to other objects, a skill that may depend on the in-task integration of dorsal and ventral stream functions. Certainly, this is a developmental period and these are tasks that warrant systematic study with respect to these questions.

To conclude, the posting task is generally understood to be a dorsal stream task, and the object properties relevant to solving that task are generally understood to be distinct from the object properties involved in object recognition (a ventral stream function). There is nothing in the present evidence that is contrary to that characterization. However, the key development observed in this study, occurring between 18 and 24 months, is about acting in a way that requires the child to relate the geometric properties of two objects, and the key property concerns the major axes of the objects. Studies of object recognition (a function of ventral stream processes) in 18- to 24-month-olds also suggest equally dramatic changes in the use of geometric object properties, and one property central to visual object recognition is the object's major axis of elongation (Biederman, 1987; Marr, 1982). The developments observed here in acting on objects and the developments in early visual object recognition may be separate developments. However, by one recent interpretation of evidence from adult cognitive neuroscience experiments, the geometric properties of three-dimensional objects processed in the dorsal stream may feed into object recognition processes in the ventral stream (Farivar, 2009). Current efforts in adult cognitive neuroscience are directed toward a better understanding of how the dorsal and ventral systems exchange information about objects; a developmental perspective on the same issue may be crucial to understanding both developmental changes in vision for action and in object recognition. Certainly, the fact that there are marked developmental changes in both functions in the period from 18 to 24 months argues for their joint study (Smith, 2009).

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