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Young infants reach correctly in A-not-B tasks: On the development of stability and perseveration

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Abstract

This paper examines the development of perseverative reaching in the A-not-B task. We describe two recent models that view perseveration as a sign of developmental progress toward stability. In Experiment 1, we test the novel prediction from both models that very young infants should not perseverate in the A-not-B task whereas older infants should. We tracked infants' behavior monthly on the A-not-B task and found that infants reached correctly at 5 months, and only perseverated at 7 and 8 months of age. Experiment 2 provides further evidence on the role of motor development in the emergence of perseveration by exploring the connection between perseveration and detailed changes in reach kinematics in two infants across the first year. These data together suggest that perseveration is a sign of developmental achievement on the path to stable and flexible behavior.

Keywords: Perseveration; Motor development; Cognitive development; Object permanence

Skilled behavior – both cognitive and motor – requires stability *and* flexibility. Stability is required because similar contexts and tasks benefit from similar solutions. Adaptive intelligence, however, also requires dropping old solutions when some shift in task and context demands a change. Immature organisms, and also those suffering neurological damage, are often characterized as being inflexible (showing too much stability), as repeating prepotent or habitual behaviors in task contexts in which those behaviors are no longer adaptive (e.g., Diamond, 1985; Milner, 1963; Stuss & Benson, 1984).

One task that has been used to study flexibility in infant cognition is the A-not-B task. In its typical form, it works like this: an investigator hides a small, attractive toy in one hiding location (A). The infant, typically after a brief delay, is allowed to search and on these A trials usually does so at the A location, recovering the toy. After a number of hidings and recoveries at A, there is a shift trial; while the infant watches, the investigator hides the toy in the second location, B. When the infant is permitted to search, 8- to-ten-month-old infants typically show a perseverative response, reaching back to the original A location.

Infants perseverate in this manner in a variety of spatial tasks, not just those involving hidden objects. For example, when given two towels to pull – one with a toy on it and one with a toy behind it – infants clearly recognize the causal connectedness and pull the towel with the toy on it, thus retrieving the toy. After repeatedly pulling this towel (with the

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toy on it), infants fail to shift behavior when given a switch trial, continuing to pull the first towel even when it has no toy on it (and failing to pull the one that now holds the toy, Aguiar & Baillargeon, 2000). Similarly, when two spatially segregated objects are placed in view of an infant and attention is directed to one, the infant reaches out and takes that object. This is repeated several times and then attention is drawn to the second object. Eight- to 10-month-old infants will look at that second object but then perseveratively reach out and grab the first object (Smith, Thelen, Titzner, & McLin, 1999). Indeed, perseverative behaviors such as these appear at all stages of development but do so in different kinds of tasks (e.g., Zelazo, Frye, & Rapus, 1996). For example, while infants perseverate in tasks that require them to switch the spatial direction of an action, preschoolers perseverate in tasks that require them to shift attention from one property (e.g. color) to another (e.g., shape; Zelazo et al., 1996). The point is this: perseveration is a general property of an immature or partially developed skill.

Two recent models of the A-not-B error provide insight into why this might be the case. Both accounts understand skilled behavior as the product of processes (or memories) that operate over nested time scales. One set of processes keeps cognition tied to the specifics of the here and now; these processes have fast rise times and decay functions. The second set of processes operates over a slower time scale, bringing forward into the moment experiences from the past. Skilled cognition in general (see Clearfield & Thelen, 2001; Samuelson & Smith, 2000) and success in the A-not-B task in particular (Munakata, 1998; Thelen, Schoner, Scheier, & Smith, 2001) require a balance of these faster and slower processes. The present paper is concerned with a new prediction that results from these analyses: perseveration is a developmental achievement. The performance of very young infants should be controlled by the faster time scale processes, exhibiting ready shifts in behavior. Only later in the developmental progression, as the slower time scale memories strengthen, will perseveration occur. The final developmental step is when infants can flexibly balance between the faster and slower memory processes, thus following the cue on every trial and reaching correctly. Note that this prediction is unique to these two models; traditional explanations of the A-not-B error have attributed the error to infants' lack of object concept (e.g., Piaget, 1954) or other deficits of spatial representation (e.g., Bjork & Cummings, 1984), memory, or motor control (e.g., Diamond, 1985), all of which would result in younger infants perseverating more than older infants.

This prediction of early correct reaching preceding perseveration is made both by Munakata's parallel distributed processing PDP (1998) and Thelen et al.'s (2001) dynamic field account of the A-not-B error. Munakata's (1998) model explains perseveration in terms of a competition between active (faster) and latent (slower) memory traces that are nested, such that latent traces build as a consequence of a history of active traces. In a series of simulations, Munakata found that when the active traces (in response to the immediate hiding event) are very weak, they fade quickly (potentially leading to weak responses on A trials). Critically, weak active traces should also *fail to build strong latent memories over repeated A trials*, such that the model system does not perseverate but rather appropriately shifts behavior on the shift trial. The dynamic field model also explains perseveration in terms of a dynamic competition between faster and slower memories. The faster memories (like Munakata's active traces) are in response to the specific visual events that define a trial (e.g., hiding an object at A). The slower memories are conceptualized as motor memories that build over trials with each reach. Building strong motor memories –and thus perseveration – requires repetition of a similar motor plan (and reach trajectory) over the A trials. The dynamic field model thus predicts an inverted U-shaped developmental function. Reaches by young infants are too variable and poorly controlled to build a strong motor memory, and so very young infants should not perseverate but should shift behavior appropriately in the A-not-B task.

Although these two models differ in their description of the processes that underlie the longer term memories, they are formally similar and both make the same developmental prediction: very young infants should not perseverate in the A-not-B task whereas older infants should. Experiment 1 tests this prediction. Experiment 2 provides further evidence on the role of motor development in the emergence of stability (and thus perseveration) in the A-not-B task.

1. Experiment 1

Our choice of the specific A-not-B task to be used and the ages to be studied were motivated by past research showing that the perseverative error in the traditional hidden-object version of the A-not-B task emerges in infants at around 7–8 months (see Wellman, Cross, & Bartsch, 1986 for reviews). Prior to that point, infants typically do not reach for a hidden toy (given a delay) on either A or B trials. This fact is consistent with Munakata's (1998) analysis: prior to 7 months, the active memory traces may be too weak to be maintained even on A trials given a hidden object and a delay and thus also too weak to build a perseverative response. This fact is also consistent with the dynamic field model's view of the fragility of the early motor planning process. Prior to 7 months, these processes may be too variable and too easily perturbed for a reaching plan to be maintained given a hidden object and long delay, and thus also too weak and variable to lead to yield perseveration (Thelen et al., 2001). These facts suggest that a transition from non-perseverative to perseverative responding in the A-not-B task may be found during the period from 5 to 8 months. However, to test this, one needs an A-not-B task that is easy enough that even young infants will respond on the A trials, and thus potentially build the memories that create perseveration. Accordingly, Experiment 1 uses a non-hidden-object version of the A-not-B task (Smith et al., 1999) and a brief (3 s) delay in a longitudinal design that tracks individual infants' pattern of behavior in the task from 5 to 8 months of age. Note that this non-hidden-object version of the task has resulted in identical rates of reaching on all trials and identical rates of perseveration compared to the hidden-object version (e.g., Diedrich, Smith, Corbetta, & Thelen, 2000; Munakata, 1997; Smith et al., 1999).

2. Method

2.1. Participants

Fourteen (seven males and seven females) 5-month-old (±2 weeks) infants were tested four times, once a month until they were 8 months old. Families were recruited from published birth records and were given a small gift for each visit.

2.2. Stimuli

The objects were two brown disks (9.5 cm diameter) with a brown vertical knob (4 cm high). These were placed approximately 3 cm apart (edge to edge) on a brown display box (30 cm × 23 cm × 5 cm).

2.3. Procedure

Fig. 1 illustrates the set-up for the experimental task. The infant sat on the parent's lap across a table from the experimenter. At the start of a trial, the two objects were placed on the display box in front of the experimenter. The experimenter waved the A object for several seconds, until she had captured the attention of the infant. She then placed the A object on the front edge of the display box so that it was closer to the infant than the B object. The display box was moved forward into the reaching space of the infant after a 3 s delay and the infant was allowed to reach. This procedure was repeated for the next three trials with the location of the A object progressively moved back on the display box (see Fig. 1) until it was even with the B object for trials A4–A6. The critical switch trial occurred next; the experimenter cued the B object by waving it, and then after a 3 s delay pushed the display box forward for the infant to reach. The side cued as A (left or right) was counterbalanced for each visit.

Prior to the main experiment, we also assessed infants' ability to reach for a single in view object to ensure that all infants could (and would) reach when a single object was in view. All infants did so from the very first test session.

All sessions were video-taped for later coding.

3. Results and discussion

A conventional measure of the A-not-B error is infant response on the switch trial. By this measure, perseveration increased with development. At 5 months, only 15% of infants perseverated. As shown in Fig. 2, perseveration increased with age such that at 8 months, 85% of the infants perseverated, which a binomial test revealed as significantly above chance, $p < .05$.

How one interprets this developmental trend of increasing perseveration on the switch trial depends on the infants' pattern of responses on the A trials that precede the switch. There are four possible patterns of reaches across the A and B trials: (1) infants could be correct across all A trials and reach to A on the B trial. This is perseveration. (2) Infants could also reach to the B object on some A trials, but then reach to A on the B trial. This behavior is perhaps more indicative of variability or inattention than perseveration per se. (3) Infants could also reach to the B object on some A trials, but then reach to B on the B trial. Again, this is inconsistent rather than perseverative behavior. (4) Finally, infants could reach correctly on the A trials and also shift and reach correctly on the B trial. This is correct "flexible"

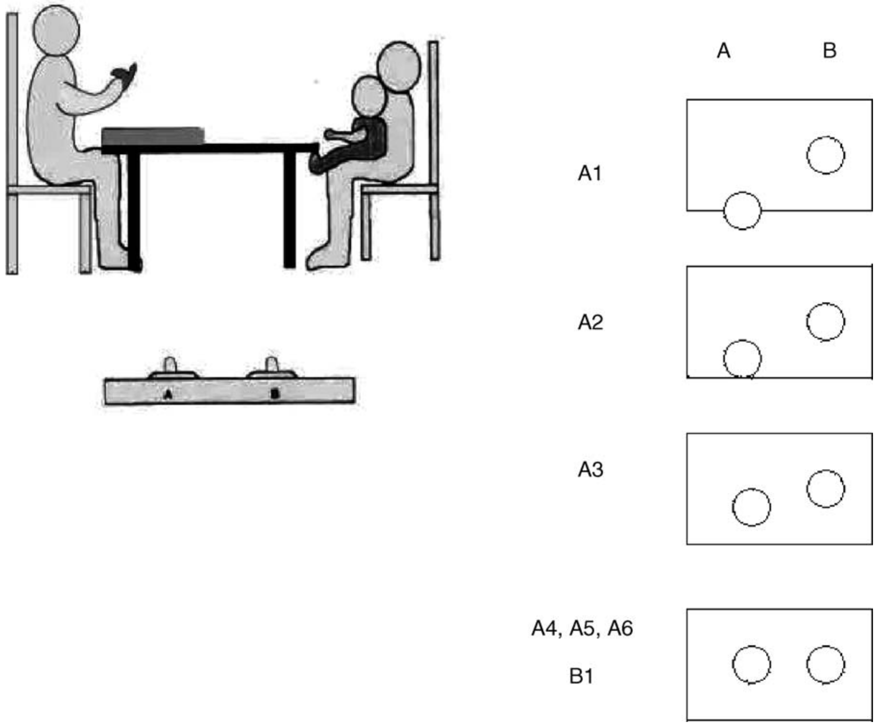

Fig. 1. The A-not-B set-up and training procedure. The left side of the figure shows the layout of the task, and the right side of the figure shows the placement of the objects on the display box across trials.

behavior. We categorized infants' performance at each session into one of these four patterns. Our criteria for calling an infant "correct on A" was at least five out of six correct reaches on the A trials.

Fig. 3 shows the number of infants fitting each pattern as a function of age. At 5 months, more infants reached correctly across all trials than any other pattern. This means they reached to A on the A trials and to B on the B trials. At 6 months, this pattern changed. Correct reaching on both A and B dropped to 8%, and remained low throughout the remainder of the sessions. The majority of infants at 6 months of age were incorrect on the A trials, and random on the B trials. By 7 and 8 months of age, true perseveration emerged. That is, the majority of infants were correct on A, but also reached perseveratively back to A on the switch trial.

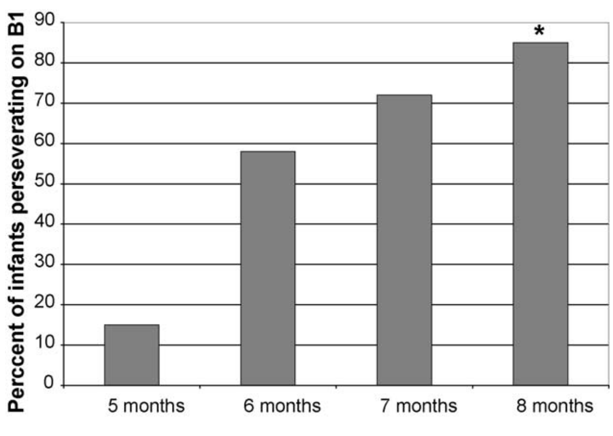

Fig. 2. Percentage of infants that perseverated on the critical switch trial (B1).

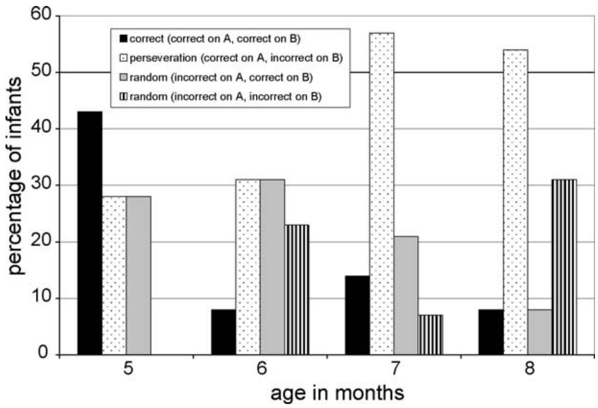

Fig. 3. Percentage of infants reaching correctly or perseverating on the A-not-B task.

These results provide strong support for the common idea in both Munakata's PDP model and the dynamic field theory's account of the A-not-B error. Apparently, infants must achieve a certain level of stability before perseveration can emerge. The fact that these two accounts make the same prediction is not surprising because at a formal level, the two are fundamentally similar (Smith & Samuelson, 2003). However, there are two important differences. First, Munakata's (1998) model is built with a bias to be correct on all A trials, whereas the dynamic field theory allows for reaches to B on the A trials. Indeed, the results here demonstrate that infants do reach to B on the A trials, especially at 6 and 7 months. Moreover, whereas Munakata (1998) has focused on the processes underlying the growing stability of visual representations, the dynamic field model has concentrated on processes underlying the growing stability of the motor plan to reach. In all likelihood, both sets of processes increase in their stability during this time and contribute to the emergence of perseveration (see Smith et al., 1999; Thelen et al., 2001). In Experiment 2, we provide evidence that stabilization of processes relevant to executing a reach play a role in the emergence of infant perseverative behavior in A-not-B tasks.

4. Experiment 2

Five-month-old infants' reaches are poorly controlled: often jerky, with a tortuous path to the target (Thelen, Corbetta, & Spencer, 1996; von Hofsten, 1991). By the dynamic field theory, these poorly controlled reaches should be too unstable for the formation of a strong motor memory. In contrast, reaches by 8-month-olds are relatively straight, smooth, and reliable and thus should build strong motor memories and perseveration. In Experiment 2, we build on a prior study by Thelen et al. (1996) to provide preliminary evidence for the idea that the stability of reaching plays a role in the development of perseverative responding. Thelen et al. (1996) used a case study approach to track the week-by-week development of reaching in four infants with the goal of capturing each infant's first reach as well as the emergence of controlled reaching. We use a similar longitudinal method to track the emergence of controlled reaching and perseveration in the A-not-B task in two infants. This case study method, while limiting generalizability, enables one to document in individuals the temporal relations between distinct developmental achievements.

5. Method

5.1. Participants

The participants were two male infants (KD and GB); one began the study at 8 weeks of age, the other at 12 weeks of age. The goal of starting the infants in the study at such young ages was to ensure that we capture their first reach to an object. They were observed every week until 30 weeks of age and then every other week until 52 weeks.

5.2. Apparatus and procedure for measuring controlled reaching

Reaching was measured at each visit. The infants were seated in an infant seat, reclined 30°, with a supportive torso strap, which permitted free arm movement yet provided the necessary head and neck support. An Optotrak motion analysis system tracked the movements of infrared light emitting diodes (IREDs) taped to the wrist and hand at the third metacarpal. These motion analysis systems provide high resolution three-dimensional (3D) coordinates of marked positions. Parents or experimenters presented the infants with a variety of small attractive toys at midline, shoulder height and just at the edge of their reaching space. The infants reached for a single toy attached to a dowel. Coordinates were recorded at 150 Hz and all sessions were also videotaped using a split-screen generator to capture both a lateral and frontal view. For more details, see Thelen et al. (1996).

Reaches were measured in terms of the kinematics (time–space parameters) of the endpoint of the reaching limb (hand or the wrist, depending on IRED visibility). Movement segments were identified and a fourth-order Butterworth filter was used to smooth the data. An interactive computer program matched the 3-D velocity profile of the hand with the start of the reach as coded behaviorally from videotape (see Corbetta & Thelen, 1995). The kinematic variables assessed were:

(1) *straightness*, defined as a ratio of the virtual path length (a straight line between the 3-D coordinate of the hand at the start of the reach and at toy contact) and the actual path length. A ratio of 1 indicates a perfectly smooth reach, similar to most simple adult reaches.
(2) *movement units*, defined as one unit of acceleration and deceleration. Mature smooth movements typically consist of one (or sometimes two) movement units.
(3) *contact* velocity, the speed at target contact.
(4) *average* velocity, the average three-dimensional speed from the onset of the reach to target contact.

Stable controlled reaches are straight, have few movement units, and have consistent (and often relatively slow) velocities.

5.3. Stimuli and procedure for the A-not-B task

Infants were administered the same A-not-B task as in Experiment 1 at 1 month intervals beginning after the first reach. This test was administered monthly rather than weekly to replicate the procedure in Experiment 1 and to limit possible learning effects over the course of the experiment.

6. Results and discussion

Infant KD made his first reach at 18 weeks and so was administered the A-not-B task at 5–9 months. He refused to reach during the A-not-B task at 5 months. After this point, his pattern replicated that observed in Experiment 1. He reached correctly to A on the A trials and to B on the switch trial at 6 months of age and then showed the perseverative pattern (correct reaches to A on A trials and to A on B trials) at 7–9 months. Infant GB did not reach until 24 weeks and was administered the A-not-B task at 6–9 months. This infant also showed the same developmental pattern as infants in Experiment 1, reaching correctly to A on the A trials and to B on the switch trial at 6 months, reaching inconsistently to A and B on the A trials at 7 and 8 months, and then showing the perseverative pattern at 9 months.

Figs. 4 and 5 show the week-by-week kinematic data for each infant while reaching for a single visible object. Both infants show the same pattern of development as reported by Thelen et al. (1996). Early reaches are less straight, with more stops and starts, and more variable speeds and later reaches are straighter, smoother and more stable. Also marked on Figs. 4 and 5 are the monthly measures of performance in the A-not-B task. Overall, perseveration in the A-not-B task emerged when reaches became more highly controlled and stable. For infant KD, this is especially apparent in his contact velocity, which spikes up and down from 18 weeks until 26 weeks, the week at which he reached correctly on the A-not-B task (see Fig. 4). His movement units also spike up and down during this time, along with some variability in the straightness of his reaches. It is precisely when his reaches stabilize (most dramatically evidenced in his contact velocity), that he consistently perseverated on the A-not-B task. Similarly, for infant GB, his early reaches to a single target were less straight but faster at contact during the time when he reached correctly on the A-not-B task.

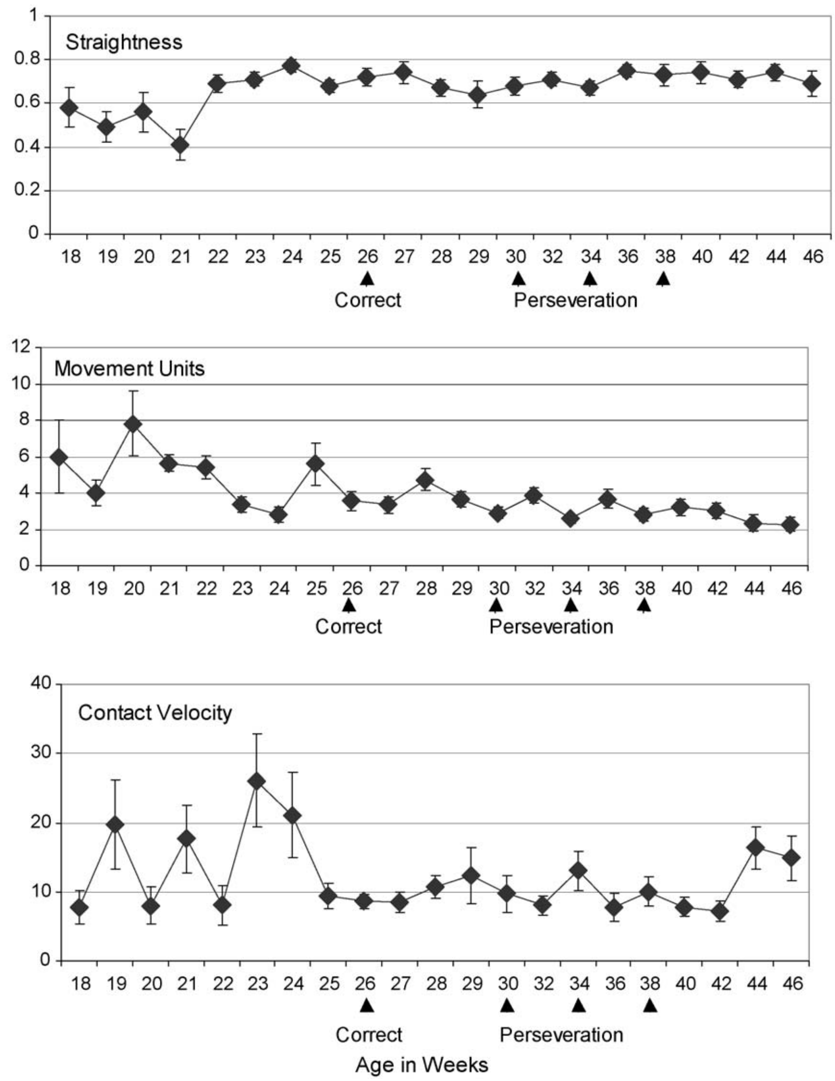

Fig. 4. Changes in reach kinematics in infant KD across the first year.

His variability spike in contact velocity (and to a lesser extent in straightness) coincided with inconsistent behavior on A-not-B, and it was only when these two variables achieved stability (around 39 weeks) that he perseverated on the two-target task.

This correspondence is also shown in Table 1. We divided the kinematic data into three categories bounded by the observed developmental transitions in the A-not-B task: correct performance, inconsistent performance, and perseveration. Prior to the first session in which KD showed a perseverative response in the A-not-B task, his reaches in the one-object reaching task were significantly less straight, comprised of more movement units, faster, and more variable than were reaches during the period in which he perseverated on switch trials in the A-not-B task. Similarly, developmental changes in the kinematics of GB's reaches for a single in-view object are also temporally linked to developmental transitions in the A-not-B task. A shift from correct to inconsistent responding and from inconsistent to perseverative responding in the A-not-B task aligns with statistically increasing straightness and slower more controlled velocities of reaches in the single-target reaching task.

The partitioning of the kinematic data by performance in the A-not-B task is, admittedly, post hoc, but nonetheless these data suggest an association between increasing stability in the reaches themselves and perseveration in the A-not-B task.

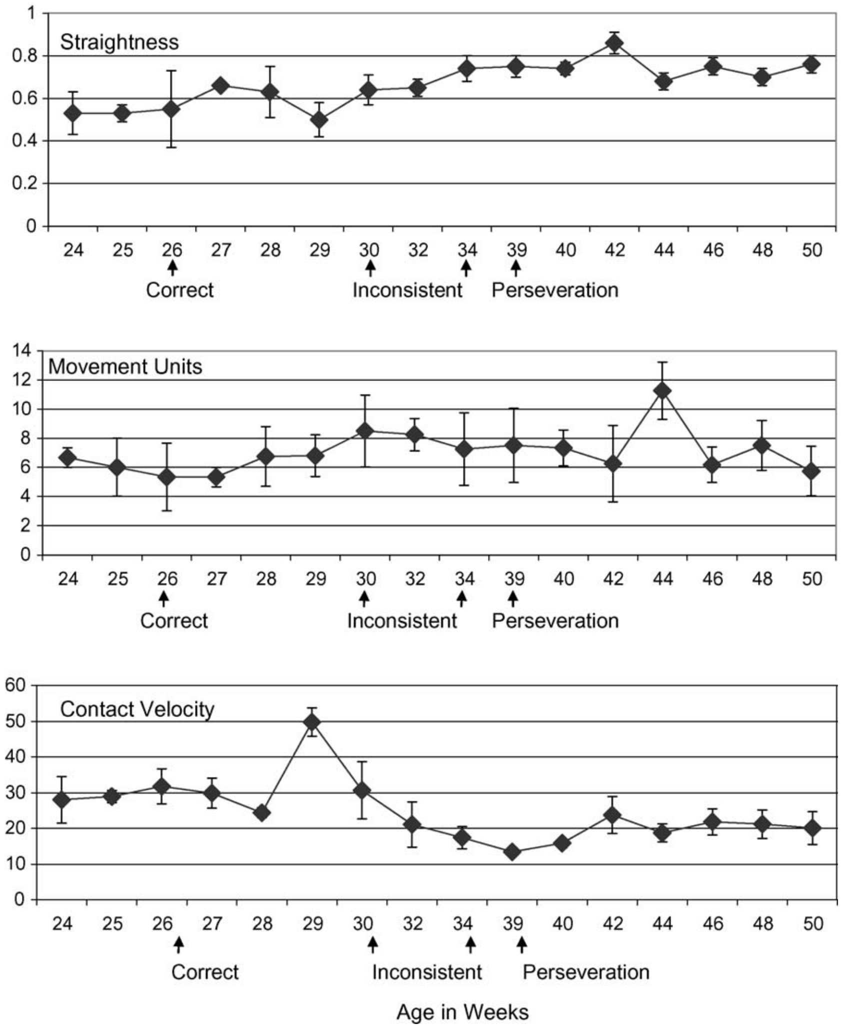

Fig. 5. Changes in reach kinematics in infant GB across the first year.

7. General discussion

The developmental trend from non-perseveration to perseveration observed in both experiments suggests that perseveration is not merely a deficit, the sign of some neurological immaturity or deficiency. Rather perseveration is also a sign of developmental progress. Perseveration is the consequence of a system that builds stability by bringing its own past activity into the present. This is the central idea in both the PDP and dynamic field theory accounts of the A-not-B error. Young infants, by both accounts, do not bring their own recent past activity (perceptual or motor) strongly forward into the present. Instead, their responding is tightly tied to the here and now and thus shifts with shifts in input. Young infants, then, are not so much flexible as variable, very much in the current moment. Skilled behavior, in contrast, would seem to benefit from being modulated by (and pulled to) the just previous activity of the system. Indeed, this perseverative aspect of human cognition is everywhere, evident in such fundamental phenomena as priming and assimilation (e.g., Arbuthnott, 1996; Martin, Roach, Brecher, & Lowery, 1998). The ubiquity of these phenomena in human cognition and behavior – the pulling of the immediate present to the just previous past – suggests their importance to cognitive coherence and a healthy stability.

However, too much stability is also not adaptive. In the A-not-B task, 8-month-olds but not 5–6-month-olds generate memories that stabilize behavior to the detriment of performance when there is a shift in task demands. Truly

Table 1
Results from the A-not-B task and the single-target reaching task for infant KD and GB

	Prior to perseveration, $N = 75$	Perseveration, $N = 109$	t-Value, d.f. = 221
Infant KD			
A-not-B task	Correct at 6 months	Error at 7, 8, 9 months	
Straightness	.74 (.03)	.82 (.01)	1.99[*]
Number of movement units	1.79 (.15)	1.44 (.08)	3.11[**]
Contact velocity	10.34 (1.2)	9.26 (.63)	1.94[*]
Variability in average velocity	.84	.62	11.84[**] (Levene test)

	Reach onset up through, correct performance $N = 27$	Inconsistent[a], $N = 12$	Perseveration, $N = 62$	F-value, d.f. = 100
Infant GB				
A-not-B task	Correct at 6 months	Inconsistent at 7 and 8 months	Error at 9 months	
Straightness	.53 (.04)	.67 (.03)	.74 (.02)	15.67[**]
Number of movement units	6.22 (.7)	8.0 (1.12)	7.6 (.7)	.89
Contact velocity	34.28 (3.25)	23.05 (3.63)	20.57 (1.35)	10.85[**]
Variability in average velocity	3.73	1.67	.68	38.8[**] (Levene test)

N, number of reaches per developmental period, which varies based on the number of reaches per week and the number of weeks in each developmental period.

[a] Inconsistent was defined as at least 2 reaches to B on the A trials.

[*] $p < .05$.

[**] $p < .01$.

skilled performance requires both the efficient use of the regularities generated by previous activity and the flexible adjustment of behavior to changing context. Both the PDP and dynamic field models capture this dependence of skilled behavior on a dynamic *balance* of faster processes tied to the immediate input and slower, stabilizing, processes that build over a history in the task. In this regard, both models provide insight into the development of stability and flexibility beyond infancy and beyond the A-not-B task. The PDP model has been successfully applied to (and generated new predictions about) perseveration and flexibility in preschool children's attention (Munakata & Yerys, 2001) and the dynamic field model has been applied to both spatial cognition and action in older children and adults (Schutte, Spencer, & Schoner, 2003; Spencer & Hund, 2002). The same developmental increase in perseveration has also been observed in very young children's lexical access with strengthening memories of individual words (Gershkoff-Stowe & Thelen, 2004). We suspect that progress in any skill domain may follow the same universal course: instability (and a too tight dependence on the here and now) followed by growing stability and thus perseveration, followed by behavior that is both stable and adapted on line to relevant changes in context.

From this perspective, it seems likely that a variety of component abilities will contribute to developing stability and flexibility. The results of Experiment 2 suggest an interesting avenue for future research, that one component relevant to the emergence of perseveration in the A-not-B task could be the stability of the reach itself (see also Diedrich et al., 2000). As reaching becomes more highly controlled and less variable, each reach in a task context may build on the just previous reach, creating strong memories of the reach and thus perseveration. This may be a temporary aspect of reaching behavior, in that as reaches become more flexible and less perseverative, they may be less likely to create the strong motor memories that create perseveration. We conclude with the general idea that perseveration may be the product of processes that are fundamentally adaptive and, like lexical priming, build coherence from moment to moment. But there can be too much of a good thing. This may be the main lesson to be drawn from infant perseveration in the A-not-B task.

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