Balancing act(ion): Attentional and postural control strategies predict extent of infants’ perseveration in a sitting and reaching task

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ABSTRACT

This study examined the organization of attention in infancy in the context of embodied cognition. Twenty-eight 7-month-old infants, split between Stage 2 and Stage 3 sitters, participated in a modified A-not-B reaching task. Sitting proficiency, experimentally manipulated sitting surface, and whether infants employed compensatory postural control strategies predicted extent of infants’ perseveration. An independent measure of Focused Attention was related to infants’ ability to come up with balance control strategies, which, in turn, minimized infants’ attentional load and facilitated inhibition. These findings suggest a competition of resources between maintaining balance control and engaging in cognitive activity. Investigating balance control, perseverative behaviors, and the relation between the two, revealed that automatization frees attentional resources, not only for the execution of the cognitive task demands per se, but also for recognizing and executing the strategies that facilitate execution of the task.

1. Introduction

Across the lifespan, maintaining control in balance-dependent postures taxes attention (e.g., Brauer, Woollacott, & Shumway-Cook, 2002; Nascimbeni, Minchillo, Salatino, Morabito, & Ricci, 2015; Yogev, Hausdorff, & Giladi, 2008). During the acquisition of new motor skills, the effort required for infants to keep balance in a new posture hinders their concurrent allocation of attention to other taxing behaviors. For example, new crawlers reduce simultaneous vocalization and crawling during play (Berger, Cunsolo, Ali, & Iverson, 2017). In an experimental context, 13-month-old infants perseverated in a high demand motor task (stair descent), but did not do so in a comparable low demand motor task (Berger, 2004). In both high and low demand conditions, infants took a path several times to reach their caregiver at the other end. When the caregiver moved to the end of another path 90° to the original, infants were more likely to take the old, familiar path and subsequently detour around to get to the caregiver when on the stairs than when on flat ground. These studies, as well as others that investigate infants’ allocation of limited attentional resources (e.g., Boudreau & Bushnell, 2000), have demonstrated cognition-action trade-offs as a behavioral manifestation of embodied cognition,
where effortful action can impose a cognitive load (e.g., Warburton, Wilson, Lynch, & Cuykendall, 2013).

Because attentional resources are limited, the information or behavior to be attended to must be selected from all other possible alternatives (Chun, Golomb, & Turk-Browne, 2011). Several recent studies of healthy, young adults have described the process of optimizing dual task performance when task demands compete for attention. For example, adults can take advantage of experimenter-provided cognitive cues to use anticipatory postural strategies (Laessoe, Grarup, & Bangshaab, 2016), flexibly allocate attention to different task demands depending on context (Plummer, Apple, Dowd, & Keith, 2015), or selectively allocate attention to the most task-relevant information (Middlebrooks, Kerr, & Castel, 2017). Moreover, different task demands get prioritized depending on age-related ability. Young adults emphasize cognitive task demands at the expense of motor demands. In contrast, declines in strength, balance control, and agility associated with aging prompt a reversal whereby elderly adults minimize the risk of falling by allocating attention to motor demands (e.g., Krasovsky, Weiss, & Kizony, 2017; see Berger, Harbourne, & Horger, 2018; Yogev et al., 2008 for reviews). Thus, individuals allocate attention to competing motor and cognitive demands differently, depending on task demands and age-related individual differences.

Despite the increasingly nuanced understanding of embodied cognition in adulthood, and evidence that the location and timing of attention influence infants’ ability to inhibit (Watanabe, Forssman, Green, Bohlin, & von Hofsten, 2012), few studies have explored the process by which infants allocate their attention in the face of competing task demands. We tackle this question to better understand the processes driving changes in allocation of attention. Whereas adults’ skills are for the most part stable, infants’ cognitive and motor abilities are continuously in flux over the first few years making this phenomenon arguably more difficult to study. To address this gap in the literature and to examine how simultaneous change in different developmental domains shapes development, we administered a modified A-not-B reaching task where infants would have to inhibit a reach while sitting independently. In a typical A-not-B manual search task, infants watch an experimenter hide a target object at one location (A). After the infant reaches to uncover and retrieve the object several times, the experimenter hides the object at a new location (B). Infants’ ability to reach to the new location to retrieve the toy depends on their executive functioning, namely their ability to inhibit a prepotent response (e.g., Diamond, Prevor, Callender, & Druin, 1997); their motor expertise, such as reaching proficiency (e.g., Clearfield, Diedrich, Smith, & Thelen, 2006); and object permanence, or memory for a hidden object (e.g., Marcovitch, Clearfield, Swingler, Calkins, & Bell, 2016). The primary aims of this study were to ask what information newly sitting infants prioritize during a motorically and cognitively taxing task and how they arrived at their choice.

We designed this type of cognition-in-action task because previous work has found individual differences in performance on A-not-B manual search tasks based on locomotor experience (Bell & Fox, 1997) and has shown that novice walkers had difficulty inhibiting in a goal-directed locomotor task, whereas age-matched expert walkers in the same task did not (Berger, 2010). We chose the development of sitting as the motor context for this study because identifying infants’ sitting expertise is fairly straightforward (Harbourne & Stergiou, 2003) and because novice sitters require more attentional resources for balance control than expert sitters do (Cashon, Ha, Allen, & Barna, 2013; Harbourne, Ryalls, & Stergiou, 2014). We experimentally manipulated the surface that infants sat on during the task to systematically explore how sitters of different levels of expertise might react to challenges to balance control. We also measured infants’ focused attention (FA) because it has been demonstrated to be related to changes in sitting postural control in children with cerebral palsy (Surkar, Edelbrock, Stergiou, Berger, & Harbourne, 2015), self-regulation in premature infants (Lawson & Ruff, 2004), and 5-month-olds’ visual search in a looking A-not-B task (Marcovitch et al., 2016). Thus, there was a strong possibility that FA might also be related to sitting ability in full-term, typically developing infants, as well as relevant for understanding how they allocate their attention when trying to inhibit. We expected to find infants’ ability to inhibit a reach to a location where they had previously reached, but which was no longer the correct location, to be a function of their sitting proficiency, the stability of the sitting surface, and their FA. Specifically, we hypothesized that the worse infants’ sitting ability, the more unstable the surface, and the poorer their focused attention in an independent task, the greater the extent of their perseveration in the reaching task.

2. Methods

2.1. Participants

Twenty-eight 6.5- to 7.5-month-old infants (14 girls; \( M = 6 \) months, 28 days; \( SD = 1 \) month, 12 days) participated in this study. All infants were healthy and born at term. Criteria for participation was being able to sit independently but not yet able to crawl. We chose this age range because the average age of crawling onset is not until around 8 months (Adolph, Vereijken, & Denny, 1998; Adolph, Berger, & Leo, 2011; Berger, Theuring, & Adolph, 2007). Families were recruited via birth announcements published in the local newspaper and recruitment drives held at local libraries and museums in Brooklyn and Staten Island. Data collection took place either in the Child Development Lab at the College of Staten Island or in families’ homes.

An experimenter interviewed parents regarding their infant’s birth history and their experience sitting and crawling. Interviewers used a strict protocol of probe questions regarding dates of events (Berger et al., 2007). Parents used ‘baby books’ or calendars to augment their memories for milestone dates. Most participants were Caucasian (71%; 18% Hispanic, 7% Black, 4% Asian) with at least one parent with college education or higher (90%) and lived in the New York City metropolitan area. Experimental procedure was explained prior to testing. All parents provided informed consent before participation. Families received a small thank-you gift and a “diploma” for participating.
2.2. Sitting skill assessment

An experimenter assessed infants’ sitting skill using a 3-stage classification system for the development of sitting postural control (Harbourne & Stergiou, 2003). Infants sat on the floor while holding a small object in their hands. Sitting was evaluated for whether and for how long infants could sit independently. Based on this observation the experimenter assigned infants to one of three possible groups. Fourteen infants (M = 7 months, 8 days old) were classified as sitting Stage 2. These infants could bring both hands up to play with a toy in sitting and stay in sitting for 10–30 seconds. They might put one or two hands down for support and quickly bring them back up. Fourteen infants (M = 6 months, 19 days old) were classified as sitting Stage 3. These infants were able to sit independently for at least 30 s without needing to use hands for support and did not fall over. No infants met the criteria for sitting Stage 1. Sitting stage groups did not differ by age, t(26) = 1.22, p = n.s.

2.3. Focused attention task

20 of the infants in our sample received a Focused Attention (FA) task as described in Lawson and Ruff (2001). Sustained and concentrated FA is marked as when an infant looks “steadily at the toys with a serious and intent expression, reduces the distance between toy and self for better inspection, quiets other body movements, and seems to lose awareness of self with no vocalizing and no social bids” (Lawson & Ruff, 2001, p. 297). Our version of the FA task had one important modification: because we were interested in sitting control as it related to attention, all infants sat independently upright on the floor during the task, rather than in a parent’s lap or in a high chair (e.g., Petrie Thomas, Whitfield, Oberlander, Synnes, & Grunau, 2011). Infants received 3 toys in succession to explore for 90 s each (see Fig. 1A). Toys were placed on the floor in front of the infant. Trials began when infants retrieved the toy and ended after 90 s of exploratory play. During this time, parents were not in direct view of the infant. Parents were asked to refrain from engaging with infants during trials. All sessions were videotaped for later data coding. To ensure that infants’ facial expressions, body movements, and toy manipulation were captured on video, a research assistant positioned a single camera on the floor facing participants so that their bodies filled the frame.

Behavioral measures of attention include steadiness of gaze, facial expression and affect; position of toys relative to eyes; self-consciousness; and minimal extraneous movement of all body segments, including head and extremities (Lawson & Ruff, 2001). Table 1 describes the four ways that FA was measured (Surkar et al., 2015).

2.4. Reaching task

Infants participated in a modified A-not-B manual search task. Infants reached for toys through one of two cup openings (5 in. in diameter) set in a 61 cm² wooden board. The board was positioned vertically on a stand and infants sat independently facing it (see Fig. 1B). A primary difference between this task and the classic Piagetian version was that infants had to keep their own balance in this version, rather than be supported in a caregiver’s lap. Another difference from the original A-not-B manual search task was that...
infants did not have to lift a cover to find the toy; they could see the toy in the cup once the experimenter had placed it and just had to reach their hand part-way in to grasp the toy. Previous A-not-B tasks, be they manual search or locomotor variations, have demonstrated that the memory demands resulting from having to keep a hidden object in mind are not necessary to elicit perseveration (e.g., Berger, 2010; Smith, Thelen, Titzer, & McLin, 1999). Thus, to minimize the number of potentially confounding factors, we eliminated that particular task demand.

An experimenter sat behind the board and offered toys through the opening. Each infant received 5 trials at one opening (A) and then a trial at the other opening (B) in each of two conditions. The number of A trials varies from study to study (Marcovitch, Zelazo, & Schmuckler, 2002), but we administered 5 because previous work in which memory demands have been eliminated shows that 5 A trials are sufficient to elicit perseveration on the B trial (Berger, 2004). A second experimenter sat behind the infants to spot them and to gently hold their arms between trials until it was time to reach. At the start of each trial, the experimenter behind the board flashed a small LED light to bring infants’ attention back to midline and to break any potentially lingering gaze from the previous trial.

Using a within-subjects design, infants completed the reaching task under two conditions, 5 A trials and 1 B trial in each, for a total of 12 trials. In one condition, infants sat on dense foam during the task. In the other condition, infants sat on a pliant foam during the reaching task. We varied the stability of the foam between the two conditions to examine the impact of the demands of keeping balance on reaching, tracking, and searching for a target object. Sitting on compliant foam was utilized as a mild challenge to postural control because a foam surface for balance testing is an accepted method of clinical assessment, and it has also been used in evaluating infant sitting posture (Chaikeeree, Saengsirisuwan, Chinsongkram, & Boonsinsukh, 2015; Deitz, Richardson, Crowe, & Westcott, 1996; Kokkoni, Haworth, Harbourne, Stergiou, & Kyvelidou, 2017). Both order of foam condition and location of the A trials on the left or right side were counterbalanced.

Table 1 provides operational definitions for the range of perseverative behaviors. Each infant received a perseveration score that was the sum of the individual measures of perseveration. We used this measure, rather than the more common dichotomous measure of reach to A vs. reach to B on the B trial for two reasons. First, previous work has demonstrated the richness and variability in infants’ perseverative behaviors in locomotor versions of the A-not-B tasks (Berger, 2004, 2010) and we wanted to determine whether this range of behavior was also observable in a reaching task. Second, because this was not a strict replication of the classic A-not-B manual search task, we captured infants’ behavior as broadly as possible in the event that their perseverative behavior also did not strictly correspond to previous observations. Our Extent of Perseveration score allowed us to capture subtle perseverative behaviors and vacillation between locations, as well as the more formal definition of reaching to where the target object is not.

To address the primary aim of understanding infants’ behavioral priorities during an embodied cognition task, we also coded infants’ postural control strategies during the reaching task. We identified whether any of 4 possible postural control strategies, high guard, light touch, propping, and falling, occurred on each trial—from the video frame when infants were first free to reach to the video frame when they first made contact with the toy. These postural control strategies were chosen because they are easily identifiable, do not require specialized equipment, and capture a range of functions. High guard removes the hands from a support surface or the toy area and describes postural instability during sitting in numerous standardized infant assessments. High guard is associated with frequent loss of balance in sitting, rather than independent stable sitting (Harbourne & Dusing, 2017; Kubo & Ulrich, 2006; McGraw, 1943; Piper & Darrah, 1994). Both high guard and light touch facilitate keeping balance, but high guard is a characteristic of immature sitting (Bly, 1994) and may reflect a regression to an earlier posture, whereas light touch may generate somatosensory information for controlling posture (e.g., Barela, Jeka, & Clark, 1999; Barela, Jeka, & Clark, 2003; Metcalfe et al., 2004). Propping with the arms is notable in studies of sitting development as an aid to maintaining upright posture (Harbourne et al., 2018; Harbourne et al., 2014; Soska & Adolph, 2014; Wickstrom, Stergiou, & Kyvelidou, 2017). Propping and high guard reflect extreme postural control—leaning the whole body on the arm or freezing arms up the way a tightrope walker holds their arms out to rigidly control balance. High guard classification in this study reflects shoulder abduction and retraction of the arms away from the play or work surface. When not engaged in these postural coping strategies infants sat with their arms relaxed, such as lightly resting on their legs or in their laps.

Table 1
Operational Definitions of Primary Outcome Measures.

<table>
<thead>
<tr>
<th>Focused Attention Task</th>
<th>Longest FA - longest bout of sustained attention for each toy</th>
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<tr>
<td></td>
<td>Total FA - duration of total FA, summed for 3 toys</td>
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<td></td>
<td>Frequency of FA - number of FA bouts for each toy</td>
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<td></td>
<td>Global FA - qualitative 5 pt. scale, ranging from no interest in objects to long bouts of FA and reduced extraneous behaviors. GFA may capture several relevant variables in a single score</td>
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<table>
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<tr>
<th>Reaching Task - Extent of Perseveration</th>
<th>Looking - toy located at B, but infant looks at A</th>
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<td>Direction Shifts - number of perseverative vacillations between locations</td>
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<tr>
<td></td>
<td>Return to A - reached to A after successfully retrieving toy at B</td>
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<tr>
<td></td>
<td>Reach to A - reached to A when toy is at B</td>
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<tr>
<td></td>
<td>Extent of Perseveration - sum of 4 perseveration measures</td>
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<tr>
<th>Postural Control Strategies</th>
<th>High Guard - any position of the arms that included shoulder abduction with external rotation; no differentiation between high, medium or low guard</th>
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<tr>
<td></td>
<td>Light Touch - brief, light touches to reaching board for stability</td>
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<td></td>
<td>Propping - sustained propping with at least one hand on the floor or the legs as a support surface to add stability</td>
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<td></td>
<td>Falling - lose balance control, caught by spotter</td>
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Operational definitions for postural control strategies can also be found in Table 1. To address the aim of capturing infants’ decision process, we coded the amount of time infants spent at different phases of the trial. From video, we coded how long it took infants to make visual contact with the toy once it was offered in the reaching board, latency to reach for the toy once they saw it, and how long it took infants to reach from the time they started moving their arm(s) until they made contact with the toy.

2.5. Data coding

All sessions were videotaped for later data coding. A primary coder scored all focused attention, perseveration, and postural control variables using Datavyu digital video coding software (datavyu.org). This system allows the coder to view the videotaped sessions frame by frame, via keyboard control, and to record durations and frequencies of behaviors of interest. In the reaching task, infants contributed 12 trials each, yielding 336 trials. In the focused attention task, infants explored 3 toys each, yielding 84 trials. To ensure inter-rater reliability, a second coder coded 27% of all outcome measures. For duration and frequency variables, Pearson correlations ranged from .95 to 1.0, p-values < .01. For categorical variables, inter-rater agreement ranged from .94 to 1.0, p-values for all Cohen's kappa coefficients < .01.

3. Results

3.1. Extent of perseveration

Perseveration can only be with respect to the prior behavior. In this case, perseveration on the B trial is only valid if infants reached to A on the A trials. This was the case. Out of 280 A trials (5 A trials x 2 conditions x 28 infants), infants reached to B only 3 times.

A 2 × 2 ANOVA with condition (dense vs. pliant) as a within-subjects factor and sit stage (Stage 2 vs. Stage 3) as a between-subjects factor on the extent of infants’ perseverative behaviors on the B trial revealed a significant interaction between condition and sit stage, $F(1, 26) = 6.72, p < .02$; partial $\eta^2 = .21$; observed power = .70 (see Fig. 2). Post hoc Scheffé tests revealed that the interaction was driven by significantly more perseveration by Stage 2 infants in the pliant foam condition than in the dense foam condition, $t(13) = 2.40, p < .04$, and by Stage 3 infants perseverating to a greater extent than Stage 2 infants in the dense foam (control) condition, $t(26) = 2.27, p < .04$. Pearson correlations between age and extent of perseveration in dense and pliant conditions were not significant and we did not find any order effects for condition.

3.2. Postural control strategies

A series of 2 × 2 ANOVAs with condition (dense vs. pliant) as a within-subjects factor and sit stage (Stage 2 vs. Stage 3) as a between-subjects factor on each of the postural control strategies revealed no main effects for sit stage or condition on the B trial for high guard, light touch, or falls. In contrast, there was a significant interaction between condition and sit stage for propping, $F(1, 26) = 7.31, p < .02$; partial $\eta^2 = .22$; observed power = .74 (see Fig. 3). A post hoc Scheffé test revealed that the interaction was driven by Stage 3 infants using a propping strategy significantly more often than Stage 2 infants in the pliant foam condition, $t(13) = 2.28, p < .05$.

To examine individual differences, we ran a Fisher’s exact test of the distribution of infants who propped over the two foam conditions. Table 2 shows that most infants were propped on both B trials or did not prop on either B trial. Infants who switched between conditions were more likely to prop in the challenging foam condition than in the dense foam (control) condition ($P = 0.011$). 60% of the infants (12 of 20) who never propped or only propped in the pliant foam condition were Stage 3 sitters. 75% of the infants (6 of 8) who always propped or propped in the dense foam (control) condition were Stage 2 sitters.

![Fig. 2. Extent of perseverative behavior according to sitting stage and sitting surface. Error bars denote standard error.](image-url)
3.3. Time to complete the task

A series of 2 × 2 ANOVAs with condition (dense vs. pliant) as a within-subjects factor and sit stage (Stage 2 vs. Stage 3) as a between-subjects factor on how infants spent their time on the B trial during the reaching task revealed no main effects or interactions for sit stage or condition for time to visual contact, latency to reach, or reach duration. Although not statistically significant, Fig. 4 shows a trend in which Stage 3 sitters were faster to see the toy in the reaching board than Stage 2 sitters; both groups were faster to start their reach after seeing the toy and reached faster in the dense foam (control) condition than when sitting on pliant foam; and both groups took more time to complete a trial when sitting on pliant foam than when sitting on dense foam.

3.4. Focused attention

Eight infants did not provide FA data either due to experimenter error or because they were too fussy to complete the task. Of the 20 babies for whom we have FA measures, independent sample t-tests revealed no differences in Global FA, longest FA, total FA, or frequency of FA bouts based on sit stage or on whether infants propped up their own weight during the dense foam (control) condition. In the pliant foam condition, infants who propped had a significantly higher mean Global FA score ($M = 2.97$) than those who did not ($M = 2.41$), $t(18) = 2.75, p < .02$, but there were no differences in the other FA measures.
4. Discussion

Twenty-eight new sitters participated in a modified A-not-B manual search task. This version of the task differed in 4 main ways from the classic Piagetian version: 1) infants sat independently, rather than in a parent’s lap or in an infant seat, 2) they reached forward into a reaching wall, rather than down onto a table surface to retrieve the target objects, 3) the toys were partially occluded when they were placed into cups for retrieval, but were never completely hidden from view, and 4) the surface that infants sat on during the task varied to experimentally manipulate challenge to balance. Based on an embodied cognition account, we hypothesized that the more attention infants had to devote to maintaining balance, whether due to their natural proficiency or to experimental manipulation, the fewer attentional resources available to devote to the cognitive demands of the task, specifically inhibition on the B trial.

As expected, Stage 2 sitters perseverated to a greater extent in the pliant foam condition than in the dense foam (control) condition. When the Stage 2 sitters were in the pliant foam condition, they were pushed to their limits for keeping balance: they were less proficient sitters coming into the study, they were taxed with an unstable sitting surface, and then taxed further when they had to inhibit on the switch trial. Allocating attention towards maintaining their sitting posture (Harbourne, Lobo, Karst, & Galloway, 2013) did not also allow infants to devote sufficient attention to inhibiting their reach to the familiar location. They maintained their balance, but at the expense of inhibition (Berger, Harbourne, Horger et al., 2018).

Surprisingly, we found the opposite pattern for the Stage 3 sitters. These infants perseverated to a greater extent in the dense foam (control) condition than in the pliant foam condition. Ostensibly, the more advanced sitters were faced with fewer challenges to balance when sitting on the more stable surface. In studies of the role of expertise on adults’ attentional control during skill acquisition, experts’ performance may be negatively impacted when attention is explicitly drawn to the performance of an automatized skill. In contrast, less proficient individuals may benefit when they focus their attention on executing the new skill (Beilock, Wierenga, & Carr, 2002). In the dense foam (control) condition, it may be that the Stage 2 sitters benefitted from a taxing task that prompted close attention to how to carry it out. For the more proficient Stage 3 sitters, however, keeping balance while sitting independently may have drawn too much attention to solving the problem, which in turn resulted in sub-optimal performance.

The pattern of postural control strategies that infants employed to cope with challenges to balance while sitting independently during the task also helps to explain these unexpected findings. Stage 3 sitters rarely propped their own weight in the dense foam (control) condition. Without an obvious challenge to balance, Stage 3 sitters were not prompted to use compensatory balance control strategies. They maintained mature, independent sitting, but were more likely to perseverate. Stage 3 sitters did prop frequently in the pliant foam condition. The proprioceptive feedback provided by the pliant surface highlighted challenges to balance for the Stage 3 sitters (Gibson et al., 1987) and they compensated for the attempted experimental increase in motor demands by employing their own strategies to decrease motor demands (e.g., Berger, Chin, Basra, & Kim, 2015). By alleviating the motor demands of the task, the Stage 3 sitters made the task easier for themselves and decreased the extent of their perseveration (Berger, 2004; Berger, Harbourne, & Lliguichuzha, 2018).

Although not statistically significant, we did find trends toward differences in how infants spent their time during the task that speak to how they made their reaching and postural control strategy choices. At the start of each trial, Stage 3 infants tended to be quicker at visually spotting the toy in the reaching board and they started reaching sooner than the Stage 2 infants. Having better balance control in sitting likely freed up attention that they could devote to other task demands (Cashon et al., 2013; Harbourne et al., 2014). In the pliant foam condition, both groups were slower to begin their reach once visual contact was made and slower to execute the reach once the reach was started than in the dense foam (control) condition, suggesting that they modified their movements to take into account the challenge to their balance posed by the pliant foam. In combination with the extent to which infants perseverated, these findings are even more edifying. The conditions under which infants perseverated most (Sit Stage 2 pliant, Sit Stage 3 dense) were the same conditions when infants were slowest to begin a reach. Infants were relatively quick to spot the toy in the reaching board in these conditions, but then needed additional time to take into account the switch in toy location. The time they spent reaching was also longer, likely capturing some of the time spent reaching back to the A location or vacillating between A and B locations before eventually making contact with the toy. Future work is already underway to examine whether more sensitive tools, such as eye-tracking to capture infants’ gaze, can better differentiate the subtleties of how infants’ allocated their attention over the course of solving the inhibition task.

We also discovered individual differences in how infants solved the problem of juggling motor and cognitive demands when they were pushed to the limits of their abilities—sitting independently, with an additional challenge to balance, and in combination with inhibition. Under those circumstances infants who employed a strategy to minimize postural demands had higher Global Attention scores and were more likely to inhibit. Infants who were better able to maintain attention had the wherewithal to come up with compensatory postural strategies which, in turn, relieved infants’ attentional load and facilitated inhibition. Previous work on embodied cognition in adults has demonstrated that augmenting movement with support can yield cognitive benefits and the same pattern seems apparent in this context with sitting infants (Warburton et al., 2013). Reciprocally, the attention allocated to executive functioning associated with inhibition reduced the attentional resources available to maintain sitting. We observed a cognition-action trade-off as a result, where infants who could not reduce the motor demands of sitting were more likely to perseverate.

We found no differences in the independent measure of focused attention based on sit stage, but it remains unclear how to interpret that lack of difference. Patterns of FA associated with cognitive skill change over the course of infants’ first year. At first, shorter looking is associated with faster information processing. Later that first year, however, shorter looking is associated with worse self-regulation (Kannass & Oakes, 2008) and may indicate difficulty with maintenance of attention (Colombo & Cheatham, 2007). It could be that the age of our participants, right in the middle of that first year, obscured attentional differences if the sample
was composed of infants for whom looking durations meant different things. In addition, differences in planning or means-ends problem solving based on motor proficiency may not be detected unless infants are pushed to the limits of their motor ability (Berger & Adolph, 2003). It could be that Stage 2 and 3 sitters were too similar in motor skill to elicit differences in focused attention as the scale designed to identify sit stages uses fairly subtle distinctions in sitting ability. It is also possible that our design to test infants’ attention while they sat independently could have masked differences. Previous studies of FA in infancy have typically tested infants when they were sitting in supportive seats or high chairs (e.g., Lawson & Ruff, 2004; Oakes, Tellinghsuen, & Tjebkes, 2000; Petrie Thomas et al., 2011), but our version without postural support may have pushed infants’ to their attentional limits. Future work may want to include a comparison group of Stage 1 sitters tested in a supported sitting position to tease apart whether more pronounced differences in motor ability would elicit attentional differences. Moreover, subsequent studies should hold sit stage constant and allow age to vary to address age-related changes in the meaning of looking time.

A limitation of the study is that we used behavioral coding only for assessment of postural stability. Although more quantifiable methods are available, such as using the center of pressure (COP) from a force platform, the dynamic nature of the task was not conducive to the COP technique, which requires either quiet, static sitting to assess postural sway, or a standardized and well-timed reach, not possible with infants performing a reaching task (Harbourne & Stergiou, 2003; Harbourne et al., 2013). A related limitation, the identification of stages of sitting (2 & 3), is a somewhat arbitrary distinction; and, although easy to describe behaviorally, is likely to be a continuum of skill rather than a clear demarcation of change.

In sum, these findings speak to embodied cognition in infancy, specifically an indication of a competition of resources between maintaining balance control and engaging in cognitive activity, such as executive functioning. Upon skill acquisition, motor demands are prioritized, likely to minimize risk of falling, similar to the strategies that elderly adults use in dual tasks. Investigating balance control, perseverative behaviors, and the relation between the two, revealed that automatization frees attentional resources, not only for the execution of the cognitive task demands per se, but also for recognizing and executing the strategies that facilitate execution of the task.

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