Infant Behavior During Sticky Mittens Training: What It Can Tell Us About Infant Learning

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Abstract

Infant exploratory behavior is critical for stimulating proper development and has implications on numerous developmental domains. The sticky mittens paradigm has been shown to enhance object exploration skills in infants, although the mechanism of this effect is unclear. The present study examines a short, 8-10 minute sticky mittens training session under conditions with more or less auditory feedback from the experiment conducted by Needham et al. (2017), focusing attention on interactions between the experimenter and infant. To best scaffold the infant's learning during training, analysis of data reveals that the experimenter must closely observe the infant's latency of toy contact and momentary looking behavior to provide the adequate number and timing of prompts. Results further illustrate that integration across multiple sensory modalities is an effective facilitator of infant object manipulation and learning during training sessions, especially when infants can see the success of actions that stem from their own hand.

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An infant learns about the world around them by exploring it. Exploratory behavior, whether visual, manual, or oral, forms the foundation of almost all aspects of development and has been shown to be critical to proper cognitive, motor, and social development. As an infant develops, they utilize new motor skills in their increasingly more active exploration of their environment to build the bedrock of knowledge that will support their cognitive development (Gibson, 1988).

Overview of Early Exploratory Behavior

Gibson (1988) proposed three phases of exploratory behavior during an infant's first year of life. The phases are imprecise, general parameters because progression from one phase to the next is guided by the achievement of motor milestones. The present review will focus only on the first two phases that occur prior to the onset of infant ambulation, or until approximately eight or nine months of age. During the first phase, extending from birth to approximately four months of age, infants are predominantly interested in dyadic social interactions with their primary caregiver. Here, infants are equipped with limited motor skills and a partially developed visual system. As a result, infants visually explore change and motion in their limited field of vision. While they pay minimal attention to non-moving objects, they scan their surroundings and pause to examine a moving target of interest. Other perceptual systems are active during this time; infants both explore objects orally and detect sounds that occur with events. Beginning around four or five months of age, infants coordinate among stimulus modalities such that they can integrate what they learn from visual, oral, and manual exploration (Needham et al., 2002).

At around five months when the second phase begins, infants develop the ability to reach for, grasp, and finger objects, expanding the world available for their exploration. Improvements in their manual dexterity, coupled with enhanced visual acuity and depth perception, allow them to engage in a new set of more complex interactions with their environment. Accompanied with these developing abilities is an increase in attention to objects. The ability to manipulate objects means that infants can see the consequences of their actions, enabling them to obtain more information about object qualities and features, enhancing their learning, and likely perpetuating their interest in objects. This has significant consequences for their cognitive development. Infant exploration is fundamental to their learning and cognitive development because it enables them to learn about object properties and object boundaries, in addition to their own limits and capabilities (Needham, 2000; Bourgeois, Khawar, Neal & Lockman, 2005).

Variation in Timing

It is important to note that the phases of exploratory behavior proposed by Gibson are not rigid, but highly variable for each infant. For example, differences in cultural factors, child-rearing practices, and parenting philosophies have been shown to influence the timing of various motor milestones (Adolph et al., 2010). Early experiences that encourage movement and exercise provide more stimulation for infants, supporting gains in strength and accelerating the onset of motor milestones. For instance, it is traditional for infants in Bali to be given practice holding onto a bamboo railing while learning to walk independently (Adolph et al, 2010). This extra practice accelerates the onset of independent walking for these infants. In contrast, independent sitting emerges later in cultures like the United States where infants are often seated in chairs or carefully held by their caregivers, as this provides them with less experience developing the strength to support themselves against the weight of gravity. Further, Adolph et al. (2010) noted that a commonality across all cultures is the existence of variability at the onset of each motor milestone. For example, the average age that an American infant begins to crawl is between five and eleven months (Adolph et al. 2010). This supports the view that critical periods, times during development where an infant is highly susceptible to input from its environment, are not etched in stone, but variable. In accordance with the developmental systems view, an infant's development is influenced by complex interactions between themselves and their environment.

Coordination Between Sensory Modalities

Substantial evidence suggests that developmental domains are highly interlinked and coordinated. Piaget (1954) originally proposed that, by creating more sensorimotor experiences, attaining more complex motor abilities affects multiple domains of development. An infant's motor skills at a particular time in their development determine what information can be derived from their surroundings (Gibson, 1988). This relation between an infant's motor experiences and perception of their environment indicates that information gained from this domain provides the foundation for their knowledge of the world, thus playing a critical role in development.

Motor development has been shown to affect cognitive development. For example, the onset of walking abilities predicts an infant's subsequent language development, with increases in receptive and productive vocabularies for walking infants (Walle & Campos, 2014). Furthermore, motor skills and exploratory behavior at five months have been correlated to success in academics even 14 years later (Bornstein, Hahn & Suwalsky, 2013). In a longitudinal study conducted by Libertus et al. (2016) investigating the long-term effects of early motor experiences, infants who received active experience reaching for objects at three months exhibited increased exploratory behavior and improved attention focusing skills at 15 months of age. The mechanism through which these long-term effects occur is likely a developmental cascade, where an infant's early experiences in the motor domain influence their subsequent learning in other domains.

Additionally, studies have identified motor-social relations. Libertus & Needham (2011) provided three-month-old infants with the opportunity to engage in self-produced reaching experiences. Infants with active experience reaching for objects showed increased preference for faces. This exhibited connection between motor and social domains may be significant for development of triadic interactions, joint attention, and sharing with others. Engaging in self-produced action experiences has important implications on an infant's social development because it enables them to understand how they can act as agents on their surroundings to cause observable effects (Libertus & Needham, 2016). These experiences impact how an infant perceives and interprets actions (Hauf, 2007). Thus, the movements of a child's body and experiencing the consequences that result from that movement are fundamental to the development of coordinating systems. These studies suggest that manipulating an infant's early motor skills can impact their subsequent development in other domains and have lasting effects on the infant's development.

Sticky Mittens

Several studies utilizing the sticky mittens paradigm have demonstrated that self-produced reaching experiences are critical for the increased object exploration and interest in objects that normally appear around six months of age. In addition, these studies provide further evidence for flexibility in the timing of motor milestones and the potential for facilitating their advanced onset. In a landmark study, Needham et al. (2002) investigated how an infant's learning could be enhanced by manipulating their environment. An experimental group of pre-reaching infants, between the ages of around three and four months, were given Velcro gloves that allowed them to pick up toys with corresponding Velcro patches. After two weeks of experience engaging in play sessions with their parents while wearing these “sticky mittens,” these pre-reaching infants exhibited greater interest in objects, increased object exploration, and more sophisticated object exploration behavior that coordinates between different sensory modalities.

In a follow-up study, the results of active and passive training were compared. One group of infants was provided with the active “sticky mittens” experience, while another group was fitted with similar “non-sticky mittens” without Velcro patches that could not pick up toys (Libertus & Needham, 2010). This latter passive observational group only visually observed toy movement by their parents or touched the toys by parent movement of their hands. Only the active training group showed increased exploration behaviors and advances in reaching and grasping behaviors, clarifying that the enhancement of their reaching abilities was due to the physical experience provided by the sticky mittens. Additionally, these results stipulate that self-produced action experiences provide the critical information necessary to develop motor behaviors. An additional study identified that the enhanced reaching experience provided by the sticky mittens training affected the infants’ social development, as infants with the active training more closely attended to faces (Libertus & Needham, 2011). Libertus and Needham (2011) hypothesized that infants were able to gain an understanding of themselves as self-acting agents and ascertain that other people engage in intentional, goal-directed actions.

If given the appropriate mechanisms, infants’ natural inclination to explore causes them to learn what actions they can engage in and test the limits of their abilities. As infants advance in motor development and progress from sitting to crawling to walking, etc., they become informed about the possibilities of their range of motion (Adolph et al., 1997). Via their exploration, infants quickly discover what actions their current physical abilities will and will not allow them to accomplish.

Potential mechanisms have been proposed to explain the recorded effects of sticky mittens training on infant development. It is likely that because infants themselves can move, touch, and cause observable effects on the toy as a result of their actions that they continue object exploration. Infants are easily able to detect the connection between their actions and the consequences of those actions (Thelen, 1994) and this likely plays a role in maintaining their motivation and interest in exploring and manipulating objects. Multiple studies have shown that identifying contingencies between an infant's actions on an object and the observed result is critical for development of reaching skills. For example, infants detect the connection between their leg kicking and movement of a mobile when their leg is attached to the mobile by means of a ribbon (Rovee & Rovee, 1969), indicating that infants easily learn from their own actions. Regarding the sticky mittens paradigm, infants' success in picking up objects during the training likely facilitated their understanding of how they can act as agents on objects in their environment (Needham et al., 2017). This critical exposure during the session could have potentially prolonged and extended their interest in objects in general, acting as a source of motivation and causing infants to continue attempting to reach for and explore different objects outside of the training session, progressing the onset of their next motor transition.

Research Focus

When infants develop the ability to independently interact with objects, they exhibit increased exploratory behavior. It is unclear why sticky mittens training facilitates this transition in behavior. The goal of the current study is to further investigate what precisely infants are learning as they engage in sticky mittens training. To date, all studies involving the sticky mittens paradigm have investigated differences in exploratory behavior before and after sticky mittens training sessions. However, none have analyzed the specific events that occur in the sticky mittens training session itself, which could offer useful clues about the underlying mechanism of sticky mittens training.

To address the gap in literature, the present study examines data from the experiment conducted by Needham et al. (2017), focusing on the second experiment that involves two groups of infants given more or less auditory feedback during a single 8-10 minute sticky mittens training experience. Specifically, the present study examines interactions between the experimenter and infant, closely examining the experimenter's behavior and the infant's momentary looking behavior in concordance with their object exploration behaviors. This research provides greater insight regarding the mechanism of sticky mittens as it relates to the experimenter's behavior.

Method

Participants

The study sample consisted of 18 healthy full-term infants. Infants were between the ages of 3-4 months because this age is prior to the onset of independent reaching. Using random assignment, 9 infants were placed in the *more* auditory feedback condition (M_{age} = 3 months 19 days, *SD* = 7.22 days) and 9 infants were placed in the *less* auditory feedback condition (M_{age} = 3 months 17 days, *SD* = 9.29 days). Participants were recruited and tested in a medium-sized city in the southeast, primarily in Durham, North Carolina.

Stimuli

Infants sat on their parent's lap in front of a nondescript table covered in white paper. The table was designed in such a way that the infant was surrounded by the table on all sides. Measures were taken to ensure that the infant's arms were above the table and that they had free arm movement. The experimenter sat across the table from the infant. During the training session, infants wore sticky mittens: these were mittens with Velcro patches sewn horizontally along the palm of the mitten that enabled them to grip and manipulate toys that were covered with corresponding Velcro on their sides, shown in Figure 2. The experimenter presented several toys to the infant within their reach. The toys were lightweight, of appropriate size for the infant, and chosen to allow easy manipulation while wearing sticky mittens, visualized in Figure 2 (commercially available Munchkin Sea Squirts; dolphin, octopus, turtle, pelican, and crab). The order of toy presentation was counterbalanced across trials.

There were two differences in the experimental setup between the more and less auditory feedback conditions. In the less auditory feedback condition, infants played with toys that did not make noise when moved. Infants were seated at a table covered with foam that dampened any noise that could have been made by toys. In the more auditory feedback condition, infants were seated at a table with a hard surface that was not covered with foam. Infants played with toys that had small bells inside them and mittens with small bells attached to the wrists such that moving the toys produced jingling sounds.

Pre-and Post-Training Assessments

Infants in both conditions received identical analysis of their object exploration behavior both before and after the training session. In each assessment, the experimenter presented a lightweight teether, pictured in Figure 1, to the infant by tapping it on the table within the infant's line of sight and bringing it within their reach for approximately one minute. If the infant engaged with the teether, the experimenter let go of the object, but otherwise kept it in place for the minute. The experimenter only encouraged the infant's attention on the teether at the beginning; once the infant made visual contact with the object, the experimenter ceased prompting and allowed the infant to engage with it on their own. During this time, it was important that the experimenter's face looked away from the infant (instead, the experimenter looked down at the stopwatch) as much as possible to prevent competition with the teether for the infant's attention. This aspect of the original procedure was not included in the analysis.

Figure 1. Teether used to measure exploratory behavior. This is the teether presented in pre- and post-training assessments to evaluate infants' object exploration behaviors.

Mittens Training

Following object exploration with the teether, the experimenter placed sticky mittens on the hands of infants. In a series of trials, the experimenter presented the toys, shown in Figure 2, to the infant in a sequential order for approximately one minute each. Other than using toys with bells attached and a table not covered in foam, infants in the more auditory feedback condition followed the same guidelines as the less auditory feedback condition. For the first three trials, the experimenter actively demonstrated up to three times how the sticky mittens could be used to pick up toys (*M* = 2.41, *SD* = 1.28 across both conditions). There were three components to these demonstrations: guiding the infant's mittened hand to a toy, touching the mitten to the toy, and raising the infant's arm until the toy came up off the table while simultaneously attempting to sustain the infant's visual attention to the task. The experimenter always demonstrated the sticky mittens in the first trial. On the second trial, the experimenter presented the toy to the infant and briefly paused. If the infant successfully used their mittened hand to swat at the toy, the experimenter allowed the infant to engage with the object on their own and did not demonstrate how the mittens were used for any more trials. If the infant did not engage using the mittens, the experimenter again guided the infant's mittened hand to the toy, demonstrated the utility of the mittens, and continued to follow the same format for the third trial. After these first three preliminary trials, the experimenter presented a toy to the infants and verbally encouraged them to engage with the object. Across participants in the more auditory feedback condition, the average duration of the sticky mittens training session was 10 min 16 s (*SD* = 1 min 43 s). Across participants in the less auditory feedback condition, the average duration of the sticky mittens training session was 9 min 26 s (*SD* = 2 min 18 s). An average number of 9.00 toys (*SD* = 1.80) were presented to infants in the less auditory feedback condition and 9.56 toys (*SD* = 1.01) for the more auditory feedback condition.

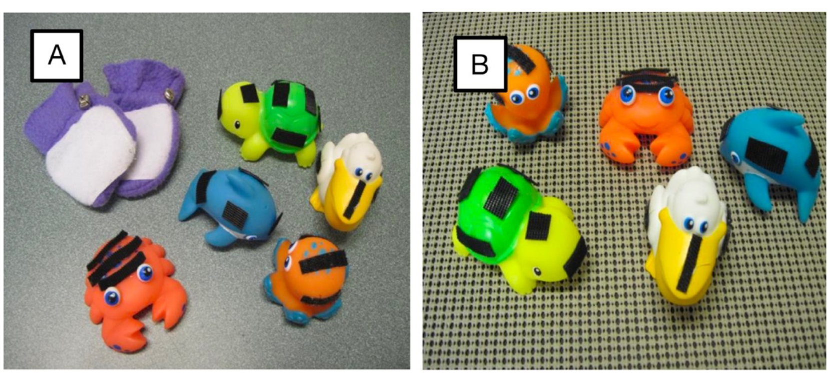

Figure 2. (A) More auditory feedback condition setup. In the more auditory feedback condition, infants sat at a table with a hard surface that was not covered with foam. Infants wore sticky mittens and were presented with toys that had small bells inside of them. (B) Less auditory feedback condition setup. In the less auditory feedback condition, infants sat at a table covered with foam to dampen any noise produced by the toys. Infants wore sticky mittens and were presented with toys without bells inside them.

Coding

Datavyu (Datavyu Team, 2014), an open-source video coding software, was utilized to code video recordings of the training session. A specified coding scheme ensured reliability between the two coders, who were undergraduate research assistants. Reliability between coders was measured.

For training measures, each trial was coded as consisting of two parts: presentation of the toy and the toy trial. The onset of each toy presentation was operationalized as the first moment when the teether was fully visible on screen. The offset of each toy presentation was operationalized as when the experimenter's hand left the toy after giving it to the infant, at which point the toy trial began. The offset of each trial was operationalized as the first moment when the experimenter touched the toy to remove it. Experimenter prompts were coded qualitatively and were not coded during toy presentations. Infant looking was coded as either directed towards the toy or mitten, at the experimenter, or other. Infant touching and mouthing were also coded. Data was exported using Ruby scripts into a .csv format for further analysis in R and manipulation in Microsoft Excel.

Results

Latency Calculations

To further characterize minute interactions between the experimenter and infant throughout training, the average latency of the infant's first contact with the toy was calculated for each trial, specifically as the time between when the experimenter first placed the toy on the table and when the infant first touched the toy. This analysis excluded the introductory trial because the experimenter was required to engage in a demonstration because the infant did not engage in independent actions during this time. Across all infants, the average latency of first contact with the toy showed a decreasing trend throughout the training, as shown in Figure 3. Additionally, with reference to the infant's first contact with the toy in each trial, the percentage of the infant's self-generated interactions with the toy increased throughout training, also shown in Figure 3.

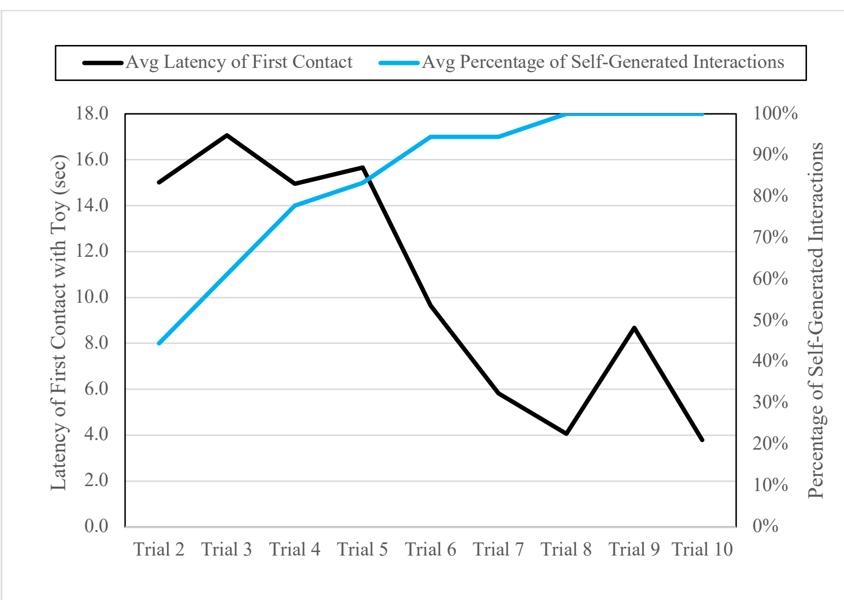

*Figure 3***.** Latency of First Contact vs. Self-Generated Interactions Throughout Training. The blue line indicates the average percentage of interactions with the toy that were initiated by the infant throughout training. The black line indicates the average latency of first contact with the toy throughout training. Both data exclude trial 1.

Despite infants in the more auditory feedback condition exhibiting a lower average latency of first contact, a t-test assuming equal variances between the groups found no significant difference between the average latency of first contact with the toy for the more auditory feedback (*M* = 8.38, *SD* = 12.77, *N* = 9) and less auditory feedback groups (*M* = 12.77, *SD* = 56.73, *N* = 9), *t*(16) = 2.12, *p* = .13.

Simple linear regression was utilized to determine if the infant's progress through the training, signified by their trial number, significantly predicted their latency of first contact with the toy. The results of the regression model indicated that the one predictor (i.e., the trial number) explained 77.53% of the variation in latencies of contact (*F* (1, 7) = 24.16, *p* = .017). These results were statistically significant at the p < .05 level.

Coders quantified the latency of toy removal to specify the duration of time that the experimenter kept the toy on the mitten before removing it. After the infant engaged in a self-generated interaction with the toy, across both groups, the average duration of time that the experimenter waited prior to removing the toy from the infant's mitten was 9.75 s (*SD* = 8.47 s). After a demonstration, the experimenter waited for an average of 11.19 s (*SD* = 12.41 s) before removing the toy for infants in both groups. There was no significant difference in the latency of toy removal for self-generated interactions between the more auditory feedback (*M* = 10.52, *SD* = 56.06, *N* = 71) and less auditory feedback conditions (*M* = 8.74, *SD* = 91.81, *N* = 54) *t*(123) = 1.16, *p* = .25.

Experimenter Behavior

Table 1 delineates the types and frequencies of experimenter prompts that were made in an effort to increase the infant's engagement with the toys. Prompts that were coded as "other" included behaviors such as clapping when the infant successfully used the sticky mittens to attach to a toy or moving the infant's hand out of their mouth.

Table 1. Frequency of each type of experimenter behavior according to condition.

Prompt	More Auditory Feedback	Standard Deviation	Less Auditory Feedback	Standard Deviation
Demonstration	3.78	2.77	2.78	1.72
Shaking the toy	10.00	9.66	0.44	1.01
Moving the toy	14.89	8.98	19.33	8.25
Tapping or pointing	3.33	4.24	3.22	3.42
Other	0.44	1.01	3.67	3.16

Excluding the first introductory trial for the same reason stated above, the average number of experimenter prompts provided to the infant prior to their first engagement with the toy showed a decreasing trend as the training session progressed, shown in Figure 4.

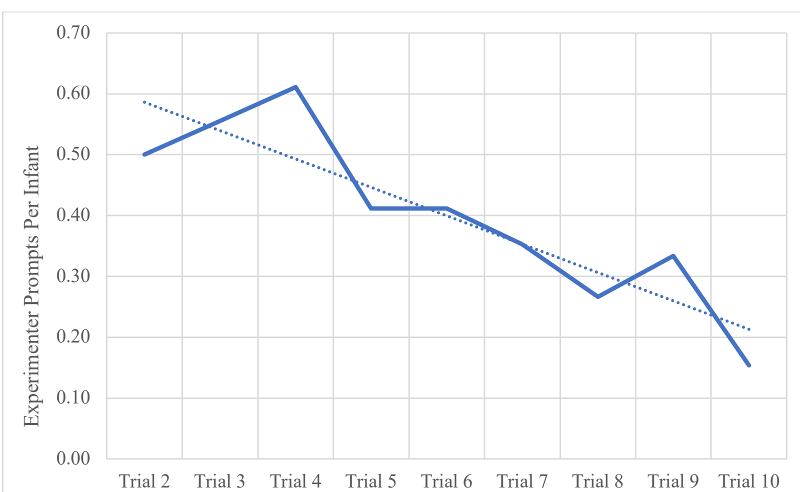

Figure 4. Average Number of Experimenter Prompts Prior to First Contact. The line shows the average number of experimenter prompts that were provided prior to the infant's first contact with the toy. This number is reflected per trial and per infant. For example, in trial 2, there was an average of 0.50 prompts given to one infant before their first contact with the toy, or every two infants received a prompt.

Redirection of Attention

A one sample t-test was conducted to compare, per individual trial, the average frequency that infant looking was redirected to the toy after looking at the experimenter or elsewhere. Infants in the more auditory feedback condition (M = 6.67, SD = 0.23) showed a significantly greater number of attention shifts back to the toy in comparison to the less auditory feedback condition (M = 3.79, SD = 0.06), $t(16) = 16.07$, $p < .001$. These results were statistically highly significant at the $p < .001$ level.

Discussion

The purpose of this study was to examine in greater detail the minute interactions that occur between the experimenter and the infant during a short, 8-10 minute sticky mittens training session under conditions with more or less auditory feedback. The study's goal was to obtain greater insight into the mechanism by which sticky mittens increases exploratory behavior.

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Scaffolding and the Bidirectional Nature of Training Sessions

The dynamic relationship between the infant and the experimenter during sticky mittens training is crucial for infants to learn about the contingency of their actions. It is up to the experimenter to provide the proper amount of scaffolding to facilitate the infant's learning. Each infant is different: while some visibly express excitement when they see the connection between their hand movements and the toy's movements, it is more difficult to catch the attention of other infants who are slower to respond or produce behavior that is more difficult to interpret. The experimenter is highly attentive to the infant's behaviors and must learn from the cues that they provide through abrupt shifts in their looking behavior. In this context, an effective experimenter reads the infant's social and behavioral signals to determine their engagement level and adjusts their guidance to fit the infant's current performance level.

While there were more prompts given to scaffold the infant's first contact with the toy in the first few trials, the frequency of these prompts decreased over time as the infant engaged in a greater number of self-generated interactions with the toy. If the infant was not sustaining increased looking at the toy or engaging in independent actions with the toy, the experimenter would provide more prompts. Combined with the fact that the infant's initial contact with the toy required fewer prompts from the experimenter throughout the training, this evidence highlights the important decisions that the experimenter makes when guiding the infant's behavior. This interaction is likely important for the infant's learning during the session.

Self-Generated Actions and Coordination Between Sensory Modalities

Comparing between the two conditions, infant attention was redirected back to the toy after looking elsewhere more frequently for the more auditory feedback group. The fact that this was statistically highly significant follows a logical pattern: the toys in this condition had small bells inside them and the table was not covered with foam, so interactions with the toy would produce loud sounds that did not occur in the less auditory feedback group. A considerable amount of literature indicates that feedback from various sensory modalities simultaneously facilitates learning (Bahrick & Lickliter, 2002, 2012; Gibson, 1988; Piaget, 1954; Rochat, 1989). Infants in both conditions experienced intersensory redundancy, which refers to receiving the

Commented [NE2]: I would leave out this word same perceptual input from multiple sensory modalities at the same time. However, there was more intersensory redundancy available to infants in the more auditory feedback condition because these infants received input from three sensory modalities (manually, visually, and auditorily) in comparison to two (manually and visually). Bahrick & Lickliter (2000; 2002) proposed that receiving this amodal information in temporal synchrony is beneficial for learning about objects and their properties. Because infants in the more auditory feedback condition showed greater increases in object exploration post-training (Needham et al., 2017), we suggest that infants in the more auditory feedback condition were better able to link up experiences across modalities and learn from the sticky mittens training because they could hear, see, and feel the results of their own actions on objects. The high saliency of this multi-modal input likely assisted the infant's understanding of the contingency between their hand actions and the toy's subsequent movements.

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Furthermore, infants showed an increase in the frequency of self-generated interactions with the toy and became faster at initiating this interaction throughout the training session. This supports the hypothesis that infant object manipulation and learning is accelerated because infants learn during sticky mittens training how to manipulate objects by seeing the effects of actions that stem from their own hands, and this is greatly enhanced when feedback is provided from multiple sensory modalities. When infants can see the success of their own actions at an age earlier than they would have without intervention, this can jumpstart their object exploration skills and have cascading effects on numerous areas of development (Malachowski & Needham, 2023).

Limitations

There are several limitations of the present study that should be noted. Firstly, the number of participants analyzed in the present study was notably less than the sample in the experiment conducted by Needham et al. (2017). While the original experiment consisted of 18 participants in the more auditory feedback condition and 18 participants in the less auditory feedback condition, data from 18 infants were excluded from analysis in this study due to lost data (n = 5), extensive experimenter error (n = 4), and time constraints (n = 9). This is important to note because a limited sample size decreases the power of the study and could potentially undermine the validity of findings.

Secondly, there were likely inconsistencies in coding the videos. One infant was seated far from the table so that their arms kept falling off, often while attached to the toy. This resulted in the experimenter moving the toy, which was incorrectly coded as experimenter prompts. Additionally, it is possible that demonstrations of the toys were coded incorrectly because various experimenters did not raise the infant's arm above the table after attaching the infant's mitted hand to the toy. Also, the sticky mittens fell off the hands of several infants during training; when the experimenter adjusted their mitten, this was occasionally coded as an experimenter prompt in the "other" category. Some experimenters (n = 2) clapped their hands when the infant successfully swatted at a toy, which was coded as an experimenter prompt, but because the experimenter was not fully visible in the video, this was only occasionally coded. Lastly, some participants did not engage in a full sticky mittens training session of ten toys due to fussiness, causing further reduction in the data.

Conclusion

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Since the training portion of the sticky mittens paradigm has never before been analyzed in such detail, the present study reviews data from the second experiment in Needham et al. (2017) consisting of a short, 8-10 minute sticky mittens training session under conditions of more or less auditory feedback, with the goal of better understanding the mechanism by which sticky mittens training operates. The current findings highlight the dynamic relationship between the experimenter and the infant, including how the experimenter's decisions dictate the extent to which the infant can learn during the sticky mittens training session. The infant's latency of toy contact and momentary looking behavior dictate the timing and number of experimenter prompts or interactions that ultimately scaffold the infant's learning. These findings additionally support the hypothesis that integration across multiple sensory modalities promotes infant object manipulation and learning during training sessions, and this is enhanced when infants view the success of actions that stem from their own hand.

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