Understanding Object Exploration: The Role of Infant Temperament

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General Background

From a developmental cascades perspective, even seemingly mundane experiences can accumulate to affect development (Masten & Cicchetti, 2010). Interactions with toys and other objects (i.e., object exploration) are an important component of a young child's everyday experience. Mounting evidence suggests that object exploration in infancy facilitates learning across domains (e.g., language skills, academic achievement). Thus, object exploration is emerging as a critical, yet understudied, construct in infancy research. What are the factors that motivate and constrain exploratory behavior? Previous work has largely focused on contextual factors (e.g., SES, parenting style). In line with an ecological systems framework of development (Bronfenbrenner, 1979), which focuses on the active role of the child, we highlight the *child's* contributions to object exploration by testing links between parent-reported temperament and observed exploratory behaviors. In the present studies, we focus on one within-person factor– temperament– and its relation to infant and toddler object exploration.

Defining Object Exploration

The capacity to explore the environment is a crucial component of early childhood well-being (Zeanah & Zeanah, 2019). Exploration can occur on multiple levels, including exploration of physical spaces, objects, and people (Eckerman & Rheingold, 1974; Hoch et al., 2019). Here, we focus on *object* exploration. In the second year of life, interactions with toys and other objects are very brief (median = 9.8 seconds) but accumulate to an estimated 60% of each waking hour, representing a substantial portion of a child's awake time (Herzberg et al., 2021).

What does object exploration look like? Object exploration behaviors range from more rudimentary looking or touching behaviors to more sophisticated actions such as shaking, fingering, or rotating an object. Some authors distinguish between exploration and play, arguing that exploratory behaviors are distinct from, and actually precede, what can be called "play" (Pellegrini et al., 2007). Specifically, exploration is understood as a behavior driven by novelty and aimed at learning and information-gathering, while play involves repetition of "known" behaviors and is understood as the enjoyment of familiar objects (Keller & Boigs, 2018). However, in the present studies, we will use the word "exploration" to refer to any form of manual or oral interaction with objects.

Developmental Trajectories of Object Exploration

Throughout the first year of life, interactions with peers and caregivers increasingly incorporate toys and other objects (Bakeman & Adamson, 1984). Before 4 months of age, infants engage primarily in visual examination, mouthing, and simple manual behaviors (Gibson, 1988; Rochat, 1989). Around the onset of reaching, infants build on previously-learned skills to engage in a variety of "formal" exploratory behaviors, including mouthing, fingering (running fingers across the surface of an object), and rhythmic exploration of objects (i.e., shaking or hitting repeatedly; Belsky & Most, 1981; Lobo & Galloway, 2013). Later, as infants become more skilled at coordinating their eye, hand, and arm movements, they engage in more motorically-complex techniques such as rotating objects as they visually inspect them and transferring objects back-and-forth between their hands (Muentener et al., 2018). In general, across development, infants engage in more efficient visual exploration, more complex manual exploration, and more coordinated visual and motor actions (Muentener et al., 2018).

Object Exploration and Opportunities for Learning

Piaget posited that exploration is linked to information-gain (Piaget, 1964), and indeed, object exploration provides infants with numerous and variable opportunities for learning. When infants explore objects, they learn about object properties, elicit object labels from caregivers, and learn about the social consequences of their own and others' actions.

First, exploration is linked to learning about object properties. When infants manually engage with an object, they subsequently demonstrate more successful visual discrimination between objects in a separate task compared to those without prior hands-on experience (Woods & Wilcox, 2013). In another study, infants who engaged in more spontaneous fingering of objects subsequently demonstrated a stronger preference for images of real (vs. drawn) objects, perhaps because infants with more exploration experience had learned to attend to objects with more apparent affordances for action (Gerhard et al., 2021). Different forms of exploration are linked to learning about different kinds of object properties; for example, fingering (running fingers along object surface) provides information about texture, and rotating (turn-rotating an object with the wrist) provides information about shape (Ruff, 1984). In sum, object exploration is linked to various object-related skills, including understanding of object properties (Needham, 2000; Oakes & Baumgartner, 2012), visual prediction (Johnson et al., 2003; Kubicek et al., 2017), and mental rotation (Schwarzer et al., 2013; Soska et al., 2010).

Some evidence suggests that links between exploration and infants' cognitive abilities are causal, such that object exploration directly shapes object understanding (Slone et al., 2018; Woods & Wilcox, 2013). Woods and Wilcox (2013) found that 6-month-old infants who were given the chance to engage in multisensory exploration before an object individuation task successfully used surface feature information (i.e., striped, dotted) to visually distinguish between objects, while those without the exploration experience did not. In another study, infants who were given supported reaching and grasping practice (i.e., sticky mittens training) subsequently demonstrated enhanced mental rotation ability (Slone et al., 2018). Evidence from research with both human infants and humanoid robots suggests that exploration of objects results in the formation of rich object representations that can be applied to future interactions with objects (Ivaldi et al., 2014; Johnson et al., 2003; Kraft et al., 2010). While more work is needed in this area, these findings provide preliminary evidence that object exploration directly shapes infants' short-term learning and subsequent ability to make sense of the physical world.

Object interactions may also provide infants with unique opportunities for language-learning. When infants manually explore an object, caregivers often offer word labels (Slone et al., 2018; Woods & Wilcox, 2013). Pereira and colleagues (2014) found that the combination of verbal object labeling and object manipulation is "ripe" for infant language-learning; object manipulation brings nearby objects into the infant's clear view so that labels by a caregiver are more likely to be attributed to the appropriate object than to an unrelated one. In addition to opportunities for word-learning, object manipulation may also provide opportunities for infants to practice new forms of vocalization. For example, infants appear to engage in unique forms of vocalizations when mouthing objects (Fagan & Iverson, 2007), and many of infants' object- and people-directed vocalizations co-occur with the specific exploratory behaviors of mouthing and fingering (i.e., running fingers over the surface of an object; Orr, 2022).

In addition to opportunities for object- and language- related learning, interactions with objects may also provide infants with opportunities for social learning (van den Berg & Gredebäck, 2020). In one study, infants who were more skilled at reaching and grasping objects were better able to predict the goals of others' reaching actions (Kanakogi & Itakura, 2011). Another study indicated a link between the onset of reaching and grasping and neural underpinnings of social perception (Bakker et al., 2016).

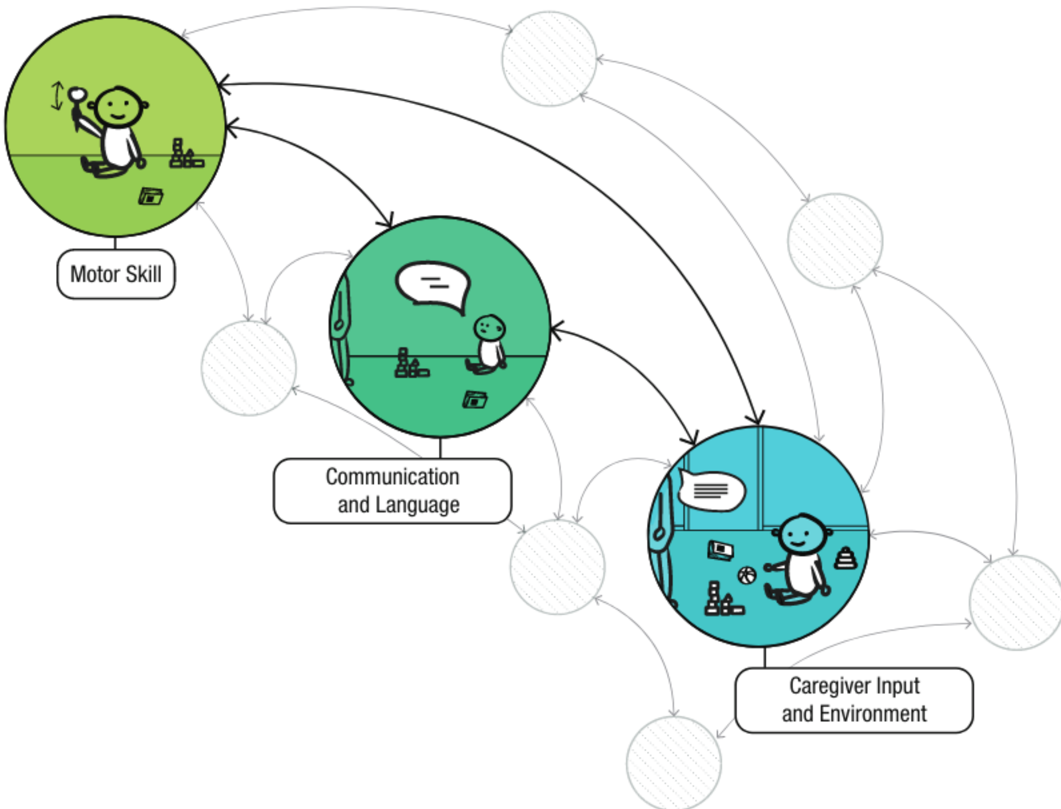
Object exploration may also provide infants with opportunities to learn about the social consequences of their actions (Hoemann et al., 2020; Iverson, 2010). Specifically, as infants develop object manipulation skills, they may have increased opportunities to learn the meaning of emotion-related cues (e.g., vocalizations, facial expressions) as they elicit more complex reactions from their caregivers (e.g., by throwing a spoon off the highchair or discovering a new function of a toy; Hoemann et al., 2020). Additionally, object play provides opportunities for joint attention with caregivers, which may reciprocally support more mature forms of object play and interaction (Bigelow et al., 2004).

Cascading Effects of Object Exploration on Development

From a developmental cascades perspective, these early interactions with objects, and the learning opportunities they provide, accumulate across time to drive developmental change (Iverson, 2021; Masten & Cicchetti, 2010). In her 2021 paper, Iverson provides a helpful illustration of how the development of object manipulation skills may have cascading effects on infants' language development (see Figure 1). As represented by top left image in the graphic, an infant who actively explores objects elicits nearby caregivers' communication about those objects (e.g., "Oh look! You have a blue block!"). This language input directly supports infants' learning of object labels and may further reinforce the infants' exploration behaviors. Caregivers may also provide *more* objects to the infant in response to active exploration, providing even more opportunities for exploration, and thus even more opportunities for verbal interaction and language learning. Across time, these interactions between the infant, objects, and caregivers build on one another to drive related changes in both the motor and language domains.

Figure 1

Motor–Language Cascade



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An important implication of the process described above is that early variability in object exploration behaviors *matter* for development (Iverson, 2021). A seemingly small advance in exploratory skills may pre-maturely initiate this process, perhaps leading to more robust communication with caregivers, access to more complex objects to explore, and an earlier development of language skills. Manipulating infants' interactions with objects at 3 months via “sticky mittens” training (i.e., reach training with velcro mittens and velcro-lined toys) resulted in enhanced exploration and attention-focusing skills 12 months later (Libertus et al., 2016). Additionally, grasping behaviors after, but not before, sticky mittens training predicted exploration at this later timepoint (Libertus et al., 2016). These findings provide powerful causal evidence for links between early object exploration and developmental outcomes.

In fact, several studies have provided evidence for links between early variability in exploration and developmental outcomes. In an infant–parent free play task, 6-9-month-old infants who engaged in more “manual” (fine motor) and oral exploration subsequently scored higher than their peers on a 24-month IQ task and a language task, respectively. In a similar way, variability in mouthing (oral exploration) in the same sample occurred between 0% and 31% of the available time, and infants who spent more time engaging in oral exploration subsequently scored higher than their less actively-exploring peers on a language task at 24 months (Zuccarini et al., 2017).

Additionally, infants who explored *more components* of an object in the time spent exploring (i.e., rapid tempo) subsequently demonstrated larger vocabulary sizes and higher verbal comprehension scores by age three (Muentener et al., 2018). Some evidence indicates even longer-term cascading effects of rapid exploration. Infants who engaged in more rapid exploration at age 5 months went on to higher levels of academic achievement at age fourteen, controlling for numerous environmental factors (Bornstein et al., 2013b). Bornstein and colleagues (2013b) argue that exploration in early life initiates a developmental cascade that impacts various cognitive functions in childhood, which in turn impact academic achievement in adolescence. Specifically, active explorers may interact more with objects, which positions them to learn more from those objects. In this way, infants play a role in shaping their own development (Bornstein et al., 2013).

In summary, while infants– on average– spend a substantial amount of time exploring objects, some infants are more active explorers than others. Evidence suggests that this variability is relevant for development, such that small differences in exploration behavior, accumulated across the hours and days and weeks of life, may result in tangible differences in developmental outcomes.

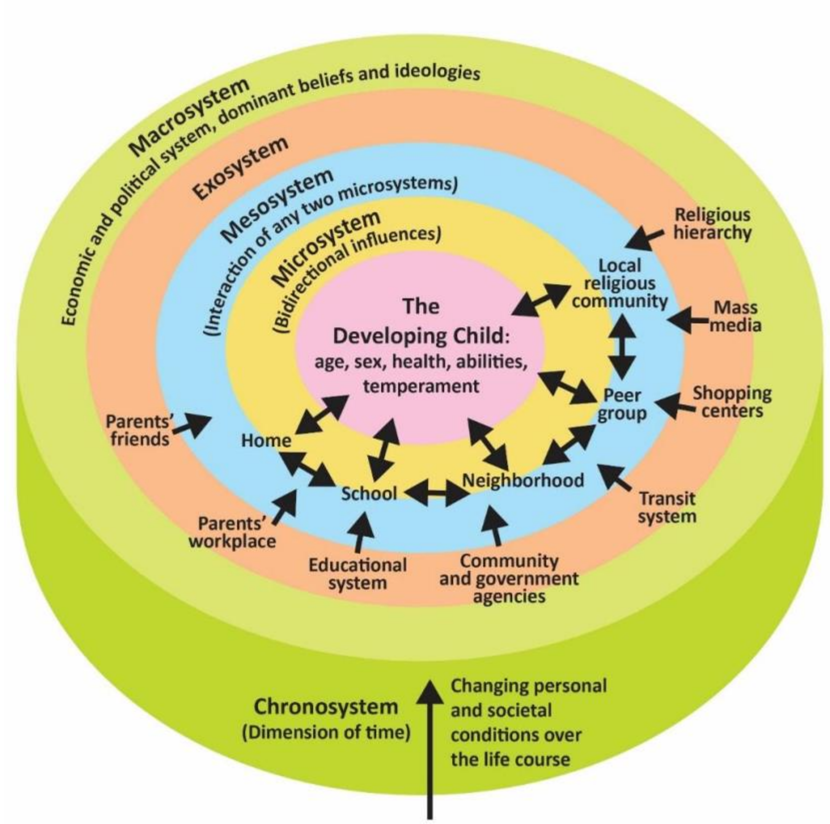
Factors Constraining & Motivating Object Exploration

Existing Literature: Contextual Factors

Given the potential positive downstream consequences of being an actively exploring infant (Iverson, 2021), it is of great interest to understand the factors that contribute to exploration behaviors. From the perspective of Bronfenbrenner's ecological systems theory (Bronfenbrenner, 1979), there are two types of influences that interact to drive development: contextual influences (i.e., existing outside of the individual) and person-related influences (e.g., sex, temperament, motor skills). See Figure 2 for a depiction of the ecological systems model. To date, much of the literature on object exploration has focused on contextual influences.

Figure 2

Bronfenbrenner's Ecological Systems Model



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At the most proximal level, several characteristics of the immediate physical environment shape infants' real-time exploratory behavior. First, providing infants with postural support (e.g., via the use of an infant seating device) facilitates exploration, perhaps by physically freeing up the arms and freeing up cognitive resources otherwise focused on postural control (Soska & Adolph, 2014; Woods & Wilcox, 2013). For example, infants who were given full sitting support (i.e., placed in Bumbo™ floor seat) engaged in more touching of a presented ball compared to those given minimal sitting support by a parent (Woods & Wilcox, 2013).

Infants' exploratory behavior also changes as a function of immediate *social* context. For example, infants engage in more sophisticated object interactions when playing with their mothers compared to when playing alone or with peers (Bakeman & Adamson, 1984; Turkheimer et al., 1989). Evidence from animal research suggest that ravens also approach novel objects differently based on the status (e.g., dominant) and sex of other nearby ravens (Stöwe et al., 2006). Infants may also explore more readily when in the presence of an attachment figure (Hazen & Durrett, 1982), perhaps because circling back to such a figure provides them with the energy and confidence they need to explore novel (and potentially threatening or fear-inducing) environments.

Additionally, we know from previous work that *caregivers' actions* play a large role in shaping infants' exploratory behavior. More specifically, caregiver scaffolding can support exploration, while overly-intrusive or directive behavior can hinder it. One study found that 6-month-old infants increased their level of play (i.e., manipulating vs. passive looking or holding) when mothers engaged in scaffolding (Landry et al., 1996); another found that maternal scaffolding was positively linked to toy engagement (Seo & Lee, 2019). On the other hand, attention-directing behaviors (i.e., attempting to re-direct the infant's attention) were negatively linked to focused toy exploration in 8-month-old infants, such that infants whose mothers engaged in more attention-directive behaviors engaged in less overall exploration (Pridham et al., 2000). Evidence from robotics research is consistent with the hypothesis that exploratory behavior depends on immediate social context: results from one study indicated that a combination of social guidance (i.e., scaffolding) and intrinsic motivation were key to building a robot that could explore and learn in social contexts (Ivaldi et al., 2014).

Researchers have also identified more cumulative influences on exploration. In one study, attachment security (secure vs. insecure) predicted toddler exploration (as measured by engagement with presented objects) at 18 and 24 months in infants who were highly irritable as newborns, such that infants who were classified as both irritable and insecurely attached explored less than other infants (Stupica et al., 2011). Main (1983) found that, compared to insecurely-attached toddlers, securely-attached toddlers demonstrated higher levels of attention to toys, longer bouts of play, and more delight in the toys (e.g., smiling or laughing about them), even apart from their caregivers.

Aside from attachment security, other measures of infant–caregiver relationship quality have been linked to exploration. For example, one group of researchers observed 2-4-month- old infants' level of eye contact with their caregivers during an interaction task (Keller & Boigs, 2018). Compared to infants whose mothers engaged in less eye contact, infants whose mothers made more frequent and sustained eye contact during this task subsequently demonstrated higher quality exploration of a novel object at two years of age, but no differences in general visual or tactile exploration (Keller & Boigs, 2018). Another study linked maternal sensitive-responsiveness (i.e., the extent to which mothers are sensitive and responsive to their infants' cues) to later exploratory behavior (van den Boom, 1994).

Several studies demonstrate links between specific early experiences and exploration behaviors. For example, infants who received early nutritional supplementation demonstrated more active exploration compared to infants who had not received the supplements (Aburto et al., 2010). Preterm infants who received "kangaroo care" (i.e., increased skin-to-skin contact in the postpartum period) intervention went on to display higher rates of exploration than their peers who did not receive the intervention (Feldman et al., 2002). Additionally, infants who receive targeted reach-and-grasp training (e.g., with sticky mittens or other approaches) during the transition to reaching show related increases in exploratory behavior (Clearfield, 2019; Libertus & Needham, 2010; Needham et al., 2002). Even observation-only experience (i.e., watching a caregiver engage in high-level exploratory behaviors) appears to encourage exploratory behaviors in 7-month-old infants with attenuated exploration skills (Kubicek et al., 2017).

Moving outward to more "distal" contextual influences on object exploration, researchers have identified that object exploration varies as a function of socioeconomic status (SES), such that infants from lower SES households demonstrate different patterns of exploration across development compared to their higher SES peers (Clearfield et al., 2014; Tacke et al., 2015). Specifically, high-SES infants demonstrated clear increases between 6 and 12 months in more complex techniques (e.g., object rotations and transfers), coupled with decreases in less complex exploratory techniques (e.g., mouthing and fingering). In contrast, their lower-SES peers showed overall reduced exploration and no clear changes across the same time period (Clearfield et al., 2014). In another study, infants (6-8 months and 10-12 months) from low-SES households demonstrated less selective exploration behaviors compared to their higher-SES peers (Tacke et al., 2015). Specifically, compared to their lower-SES peers, high-SES infants engaged in significantly more presses of an object onto a surface, indicating that they were using information about both the object and the surface to explore object–surface interactions (Tacke et al., 2015).

Larger cultural context may also constrain the types of exploration that infants engage in. For example, Ni-Van (Vanuatu) caregivers engage in more physical triadic engagement with infants and objects (e.g., holding the infant and making contact with the object) than U.S.

caregivers, who rely more on visual triadic engagement (Little et al., 2016). Additionally, culturally-based practices like toileting, bathing, and clothing can constrain or enable movement in such a way that shapes opportunities for exploration and movement (Adolph & Hoch, 2019). For example, in some African cultures, infants are handled and swung by their limbs or head during daily bathing in a way that can lead to earlier onsets of sitting and walking (Adolph & Hoch, 2019). An earlier onset of sitting may, for example, provide infants with increased opportunities for bimanual exploration (Soska & Adolph, 2014).

Existing Literature: Within-Person Characteristics

Sex. A core component of Bronfenbrenner's model is the "active individual" (Darling, 2007). Personal characteristics (e.g., sex, motor skills temperament) *interact* with the various contextual levels of influence to drive developmental change. First, evidence suggests that interactions with objects vary considerably by sex, even beginning in early infancy (Alexander et al., 2009; Gredlein & Bjorklund, 2000). In one study, 3-8-month-old infants showed robust differences in their visual preference for stereotypically male vs. female toys, such that male infants preferred to look at a toy truck, and female infants preferred to look at a doll (Alexander et al., 2009). In addition, evidence suggests that male infants exhibit overall higher levels of object exploration and manipulation compared to their female counterparts (Clearfield & Nelson, 2006; Dinkel & Snyder, 2020). While socialization likely plays a role, there is evidence that some of these early differences in object interactions are biologically-based. For example, biological females exposed to high levels of prenatal androgens (hormones linked to male traits) demonstrated higher levels of object-oriented play than their peers exposed to more typical levels of androgens (Berenbaumi & Hines, 1992; Cohen-Bendahan et al., 2005). Additionally, mothers with high serum testosterone levels during pregnancy were more likely to have daughters who were interested in toys and activities "typical" for boys (Hines et al., 2002). Identical sex-linked object preferences have been observed in non-human primates as well (Hassett et al., 2008), further suggesting that differences in object-focused interactions are not entirely due to socialization.

Motor skills. Changes in exploratory abilities are intricately linked to changes or developments in the motor realm (Franchak, 2020; Gibson, 1988). For example, learning to reach (Lobo & Galloway, 2008; Needham et al., 2002, 2017), sit (Marcinowski & Campbell, 2017), locomote (Oudgenoeg-Paz et al., 2016), and walk (Karasik et al., 2011) all prompt qualitative changes in exploration. Adolph and Hoch (2019) argue that motor development is inherently enabling, such that it provides infants with new perceptual experiences and new opportunities for action. New walkers, for example, are suddenly able to view more of their surroundings (Kretch et al., 2014) and more easily carry objects while they locomote (Adolph & Hoch, 2019). Importantly, results from an intervention study indicate that providing infants with postural training (i.e., gross motor training) enhanced their subsequent exploratory behavior (Lobo & Galloway, 2008), supporting the claim that motor development enables new and different exploratory activities.

Atypical Development. The presence or absence of a developmental delay or disorder can also impact infant exploration behaviors. In general, typically-developing infants engage in greater quantities of exploration than their peers with developmental delays (Muentener et al., 2018). Further, specific disorders have been linked to particular styles of exploratory behavior in infancy. For example, 6-month-old infants whose older siblings had received an ASD diagnosis (and thus considered more likely to develop ASD themselves) spent more time *looking* at objects and less time grasping and mouthing them than a group of typically-developing infants (i.e., absence of developmental diagnoses by two years of age). Additionally, while the typically-developing infants tended to show a pronounced decrease in overall mouthing behaviors between 6 and 12 months, the ASD-sibling group did not (Kaur et al., 2015). At 12 months of age, infants later diagnosed with ASD engaged in more spinning, rotating, and "unusual visual exploration" of objects (e.g., prolonged inspection and examination from unique visual angles) compared to their peers who did not go on to receive an ASD diagnosis (Ozonoff et al., 2008).

ADHD (attention-deficit/hyperactivity disorder) is another disorder linked to differences in exploration behaviors. Seven-month-old infants later diagnosed with ADHD manipulated a set of blocks less frequently than did their typically-developing counterparts (Auerbach et al., 2004). Between 3 and 24 months of age, younger siblings of children diagnosed with ADHD did not demonstrate increases in looking time to objects like their typically-developing peers did (Miller et al., 2018).

While infants with higher likelihoods of future ASD and ADHD diagnoses tend to demonstrate specific patterns of exploratory behaviors across time, infants with Down syndrome tend to exhibit overall attenuated exploratory behavior (Fidler et al., 2019). Interestingly, evidence suggests that within-syndrome variability in exploration is linked to functioning in cognitive, communication, and motor domains for children with Down syndrome (Fidler et al., 2019), suggesting that the nature of early exploratory behavior may be an important indicator of infants' general level of functioning. Together, these findings indicate that specific patterns of object exploration in infancy may both reflect and predict developmental disorders and delays and suggest the importance of evaluating patterns of exploration for the purposes of early identification and intervention.

Temperament. One personal characteristic largely absent from the exploration literature is temperament, which will be the focus of the present studies. Some researchers have proposed that temperament may moderate the types and intensities of daily activity infants engage in– including object exploration (Lawson & Ruff, 2004; Miklewska et al., 2006). This process is sometimes referred to as "niche-construction"– in which children select their own "niches" or experiences that reflect their own biologically-based preferences and tendencies (e.g., a sensation-seeking child may seek out and engage in more risk-taking behaviors; Flynn et al., 2013). For example, surgency is associated with heightened reward responsiveness (Bunford et al., 2022; Gomez et al., 2016), and highly surgent infants may engage in more exploration of novel objects, an action that can be considered intrinsically-rewarding (Oudeyer & Smith, 2016).

Temperament is defined as "constitutionally based individual differences in reactivity and self-regulation" (Rothbart & Derryberry, 1981, p. 37). The term "constitutionally-based" highlights links between temperament and biological influences. Temperament can be reliably measured via parent report as early as 3 months of age (Freund, 2019; Gartstein & Rothbart, 2003). A common measure of temperament is Rothbart's *Infant Behavior Questionnaire*, which has demonstrated scale reliability, interrater reliability, and predictive and construct validity (Gartstein et al., 2005; Gartstein & Bateman, 2008; Gartstein & Marmion, 2008; Gartstein & Rothbart, 2003; Parade & Leerkes, 2008).

Temperament is typically analyzed in one of two ways: a variable-centered approach or a person-centered approach. A variable-centered approach considers infants' scores on separate dimensions or factors. The 14 dimensions represented in the IBQ comprise three larger factors commonly used in variable-centered approaches to temperament: surgency, negative affectivity, and orienting/regulatory capacity. These three factors are considered to be independent of each other. Each of the 14 sub-dimensions can also be considered on their own (Gartstein et al., 2017).

Surgency is analogous to “extraversion” in adults. Infants rated high on *surgency* are characterized by high levels of activity, high approach behaviors, and high positive affect (Putnam et al., 2014). Measures of surgency (sometimes referred to as “exuberance”) are generally stable through early childhood (Degnan et al., 2011). Negative affectivity is analogous to “neuroticism,” and infants rated high on *negative affectivity* display high levels of negative affect and have a difficult time recovering from distress or excitement (Putnam et al., 2014). The final factor, orienting/regulatory capacity, is related to the construct of effortful control (Putnam et al., 2014). Infants rated high on *orienting/regulatory capacity* are characterized by soothability and an ability to focus for long periods of time as well. See Table 1 for a list of the dimensions that comprise the surgency, negative affectivity, and orienting/regulatory capacity factors.

Table 1

Temperament Factors and Dimensions from the IBQ

Factors	Dimensions
Surgency	Approach, Vocal Reactivity, High Intensity Pleasure, Smiling and Laughter, Activity Level, and Perceptual Sensitivity
Negative Affectivity	Sadness, Distress to Limitations, Fear, Falling Reactivity
Orienting/Regulatory Capacity	Duration of Orienting, Low Intensity Pleasure, Cuddliness, and Soothability

Note. The three temperament factors and the 14 components were taken from Putnam and colleagues (2014).

An alternative to a variable-centered approach to temperament is a person-centered approach, which combines multiple dimensions for the purpose of placing individuals into categories or profiles of temperament. Interestingly, there appear to be age-related differences in type solutions, such that a 3-group solution is optimal for younger infants (3-8 months), while a larger 5-group solution is optimal for older infants (Gartstein et al., 2017). In previous work, the three clusters for younger infants included a group labeled “high negative/difficult to calm” (high on negative affect and low scores on soothability-related items), a group labeled “high positive/regulated” (high positive affect and high regulation), and a group labeled “fearless/low positive/low orienting” (low positive affect, low fear, and low duration of orienting). While the variable-centered approach can be useful for understanding linear relationships between temperament and behavior, categories developed via person-centered analysis methods (i.e., cluster analysis, LPA) may be especially useful for predicting future behavior (Belsky et al., 2020).

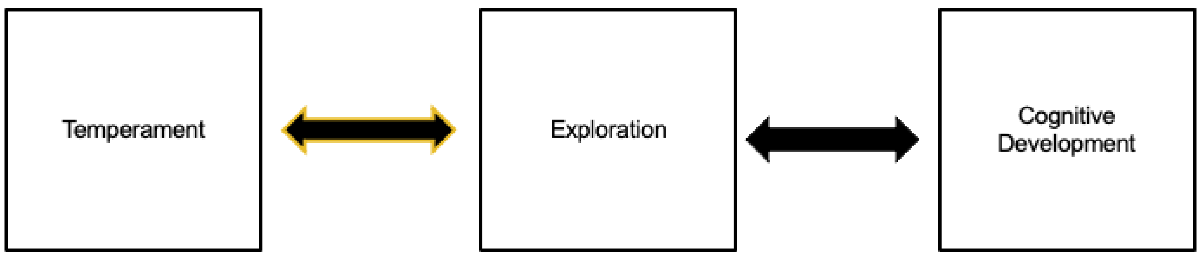
Despite theoretical motivation to do so, no research to date has directly addressed links between temperament and infants’ object exploration behaviors. Understanding exactly how temperament may shape exploratory behavior is critical to our understanding of infants’ early opportunities for learning. Additionally, it allows us to better understand the *role of the infant* in shaping and selecting their own experiences.

The Present Studies

In the present studies, we assess links between infant temperament and exploratory behavior. Specifically, we examine relations between parent-reported temperament (both from a variable- and person-centered approach) and various behavioral measures of infant object exploration. Given evidence for shifts in both temperamental typologies and in exploratory behavior by the end of the first year of life (Gartstein et al., 2017), we assess links between temperament and exploration in two different age-groups: 6-month-olds (Study 1) and 24-month-olds (Study 2). While we do not focus on cognitive outcomes in the present study, our broader theoretical model (Figure 3) includes the assumption that object exploration is closely tied to cognitive development.

Figure 3

Theoretical Model for Present Studies



Note. The yellow highlight indicates the present studies' focus on links between temperament and exploration.

Study 1

Methods

Preregistration

Study aims and basic data analysis plan for Study 1 were preregistered on OSF (https://osf.io/paefs/?view_only=f4a69bd472264239979fef78344aab42). We hypothesized that there would be a relation between three exploration variables– exploration tempo, manual exploration, and oral exploration– and two temperament variables– negative affectivity and orienting/regulatory capacity. We excluded hypotheses about temperamental surgency because it was not clear, based on previous literature, exactly how surgency might be related to object exploration. Analyses not specified in the pre-registration will be described as “exploratory.”

Participants

Participants were 96 infants and their birth mothers participating in a longitudinal pregnancy cohort study assessing early experiences, brain development, and behavior. Pregnant individuals were recruited from the Nashville, TN, area. In the present study, we analyzed data from a 6-month follow-up visit (visit when infants were approximately 6 months old). Mean infant age at this visit was 6.43 months (*SD* = 0.6 months). Infants were 50% female. Eighty-two percent of participants were White; 5% were Black; 2% were Asian; 1% were Pacific Islander; and 6% identified as “Other” (e.g., multiracial). Eleven percent of participants identified as Latinx. Income-to-needs ratios (INR) were calculated based on reported household income, number of people living in the home, and the 2020 U.S. Department of Housing and Urban Development’s low-income thresholds for the county in which the University resides. INRs ranged from 0.34 to 2.53 (*M*=1.54, *SD*=0.66), with INRs < 1.0 considered low-income.

Procedure

The 6-month visit to the lab included a filmed caregiver–child interaction task ("interaction task") and a battery of questionnaires, including the Infant Behavior Questionnaire, Revised version (IBQ-R). For the interaction task, caregivers were instructed to play with their infants as they normally in a private lab room would for 8 minutes. The lab room contained a large playmat and a toybox full of age-appropriate toys (see Figures 4 and 5). There were no restrictions on the number of toys that could be accessed at any given time. The task was filmed at three angles.

Figure 4

Overhead View of Caregiver and Child During Interaction Task

Figure 5

Playmat Used in Interaction Task

Note. In addition to the box of toys, the playmat contained objects (i.e., the fox's tail) that could be manipulated by the infant.

Video Coding

We used Datavyu software to code the videos for infant object exploration (Datavyu Team, 2014). First, if videos from multiple camera angles were available, we time-synced the videos in Datavyu. Coding occurred from when the experimenter exited the room until the experimenter re-entered the room approximately 8 minutes later. Using an external keyboard to control Datavyu, onsets and offsets of infant object contact lasting at least 1 second were recorded. Objects were defined as any object that could be lifted and displaced by the infant; however, these did not include clothing on the infant or caregivers' bodies, shoes, or pacifiers. There was only one available toy (a popup toy) that did not fit our definition of "object" because of its large size and difficulty to manipulate. To avoid a situation where infants who played with the popup toy received lower exploration scores due to their focus on the popup toy, we labeled segments of popup exploration as “no code” (i.e., they were removed from “codable” segments of the video).

Following an existing coding scheme (Zuccarini et al., 2017), we labeled each bout of object contact in Datavyu with the specific exploratory behavior observed: hold (continuous manual contact with an object not involving another type of exploration), oral (object makes contact with the infant’s lips, tongue, or mouth), rhythmic (repeated vigorous arm movement, either shaking an object or hitting it repeatedly), finger (scanning, scratching, or pinching an object’s surface with fingertips), or transfer (moving an object from one hand to the other). We originally had sixth behavior category– rotate (holding an object in view and rotating it, as if to see the other side). However, instances of rotating were not clear from the video footage, so we incorporated rotating into the “hold” category.

When a new behavior occurred, we offset the previous behavior in Datavyu and onset a new one. We recorded two behaviors (e.g., mouthing and holding) if the infants’ two hands were simultaneously engaging in two different behaviors (e.g., hold and rhythmic). Any segment in which the coder’s view of the infants’ hands was obstructed was labeled “no code.” In addition to exploratory behavior type, we recorded the specific object or objects being explored. Names of objects were pre-determined to ensure consistency within each video and between raters. Multiple objects were listed if the infant was engaging simultaneously with more than one object.

Primary coding of each video was completed either by the first author or a trained research assistant. For reliability, a randomly-selected segment of each video (comprising 25% of the total video) was double coded by both the first author and research assistant. Total durations of each type of exploratory behavior within the double-coded segments were calculated and compared between raters. Intra-class correlations (ICCs) between the two raters were 0.99 for all object contact, 0.98 for hold, 0.98 for oral, 0.91 for rhythmic, 0.84 for finger, and 0.84 for transfer. Based on widely accepted benchmark guidelines, reliability for each behavior was considered either “good” or “excellent” (Bobak et al., 2018). Disagreements between raters were discussed after reliability coding, and a final column was created to reflect any changes based on discussion. Using a pre-specified hierarchy of behaviors, entries containing more than one infant behavior were reduced to a single behavior. The list of behaviors, in order of their priority, are as follows: oral, transfer, rhythmic, finger, hold. For example, if an infant was simultaneously engaging in both oral exploration and holding (one with each hand) for a given segment of time, this segment was re-coded as “oral exploration.”

Because caregivers had the freedom to use any number (if any) of toys in the toy box, we also marked the videos for each unique object that was available to the infant throughout the interaction session. Two trained research assistants watched the videos and recorded the names of each new object made available to the infant. Availability was defined as being within reach of the infant for at least 1 second and could result either from caregiver behavior (e.g., caregiver placing an object within the infant’s reach) or infant behavior (e.g., infant rolling or crawling). See Figure 6 for a visual representation of “within reach” in the case of a seated infant. Each video was double-coded for object availability, with 96% agreement.

Figure 6

Visualizing Objects Available to the Infant

Note. Adapted from "Dynamics of the Dyad: How Mothers and Infants Co-Construct Interaction Spaces During Object Play" by Joshua L. Schneider, Emily J. Roemer, Jessie B. Northrup, and Jana M. Iverson, 2023, *Developmental Science, 26*(2), p. 6. Copyright 2022 by John Wiley & Sons Ltd.

Using Ruby, the final coding columns were exported from Datavyu and cleaned in *R* Version 4.2.0 (R Core Team, 2020). Total durations of each behavior (hold, oral, finger, rhythmic, transfer) as well as the number of unique objects contacted throughout the interaction session were calculated for each infant.

Specific Measures

Surgency, Negative Affectivity, Regulatory Capacity. Scores for surgency, negative affectivity, and regulatory capacity were calculated by averaging relevant items on the IBQ-R SF.

Gross Motor Skill. Given the relevance of motor skills for object exploration behavior, we entered infants' parent-reported gross motor skill as a covariate in analyses. Gross motor skill was assessed via the Ages and Stages Questionnaire (Squires & Bricker, 2009).

Duration of Overall Exploration. Duration of overall exploration was calculated as the total number of seconds the infant spent engaged in any type of exploration with an object.

Duration of object contact was analyzed as a proportion of codable video (i.e., the total length of the interaction task, excluding times when the coder's view of the infant was obstructed) to account for slight differences in task time between infants.

Duration of Oral Exploration. Duration of oral exploration was calculated as the total number of seconds the infant spent with the object touching their mouth or lips. Duration was analyzed as a proportion of codable video (i.e., the total length of the interaction task, excluding times when the coder's view of the infant was obstructed) to account for slight differences between infants.

Duration of Fine Motor Exploration. Fine Motor duration was calculated as the total number of seconds the infant spent engaging in either fingering or transferring of objects. Duration was analyzed as a proportion of codable video (i.e., the total length of the interaction task, excluding times when the coder's view of the infant was obstructed) to account for slight differences between infants.

Exploration Tempo. Exploration tempo, referred to as "efficiency" in previous work, was calculated by dividing the total number of unique objects contacted by the infant by the total duration of time the infant spent engaged in any type of object exploration. If an infant contacted three objects (e.g., a ball, a rattle, and a block) throughout the full interaction session and spent a total of 4 minutes (240 seconds) engaging in object exploration behaviors, we assigned the infant a score of 0.01 (240/3). This variable is a unique combination of the overall *breadth* of exploration as well as the pace at which infants explore.

Number of Available Objects. The number of available objects was defined as the total number of unique objects available to the infant throughout the interaction session. A given object was counted only once, even if it was taken away and later returned to the infant.

Data Analysis

Variable-Centered Approach. To reduce undue influence of outliers present in our exploration variables, we conducted Spearman's correlations between exploration measures (oral, fine motor, and tempo) and temperament factors from the IBQ-R (surgency, negative affectivity, and orienting/regulatory capacity).We did not pre-register hypotheses about relations between surgency and object exploration. Post-hoc power analyses indicated power of .85 to detect a Spearman's correlation of 0.3 (moderate association) at the alpha .05 level (Puth et al., 2015).

Person-Centered Approach. Using a k-means method of clustering, infants were placed into cluster groups based on scores on each of the 14 individual IBQ-R dimensions (activity level, distress to limitations, approach, fear, duration of orienting, smiling and laughter, vocal reactivity, sadness, perceptual sensitivity, high intensity pleasure, low intensity pleasure, cuddliness, soothability, falling reactivity/rate of recovery from distress). Cluster analyses were conducted in R using the *k-means* function in the *stats* package (R Core Team, 2020). The three clusters were then compared on object exploration metrics (oral, fine motor, and tempo) using Dunn tests, a multiple-comparison technique that compares the mean rank of different groups (Kassambara, n.d.).

Results

Descriptives

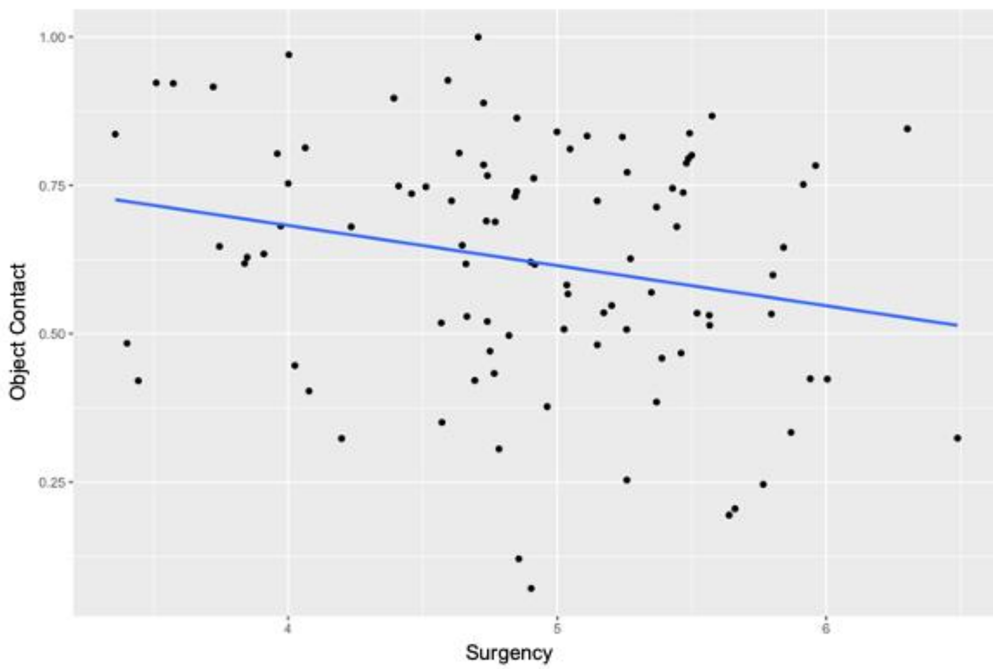
Mean temperament ratings were 4.90 (SD = 0.69) for surgency, 3.18 (SD = 0.72) for negative affectivity, and 5.29 (SD = 0.59) for orienting/regulatory capacity. On average, infants spent 62% of the time engaged with objects, which is consistent with the estimated 60% found for older infants in previous work (Herzberg et al., 2021). Infants spent 45% of the time holding, 10% of the time mouthing, 3% of the time engaged in rhythmic play, and 4% of the time engaged in fine motor exploration (2% fingering and 1% transferring). Surgency and negative affectivity were not significantly correlated, $r_s = .07$, $p = .53$; surgency and orienting/regulatory capacity were significantly correlated, $r_s = .40$, $p < .001$; and negative affectivity and orienting/regulatory capacity were significantly correlated, $r_s = -.35$, $p < .001$.

Variable-Centered Approach

Spearman's rank-order correlations were used to account for non-normal distribution of variables and to reduce the influence of outliers. Infants rated higher in surgency spent significantly *less* overall time interacting with objects ($r_s = -.21$, $p = .036$) and engaged in a faster tempo of exploration ($r_s = .27$, $p = .009$) compared to infants rated lower in surgency. See Figure 7 and Figure 8 for scatterplots of the raw data. The number of objects available to the infant was highly correlated with exploration tempo ($r_s = .70$, p < .001). However, using partial Spearmans' correlations, the correlation between tempo and surgency remained statistically significant when accounting for the number of objects available to the infant ($r_s = .20$, $p = .04$). The correlation between surgency and tempo also remained statistically significant when accounting for infants' gross motor skill ($r_s = .245$, $p = .009$). Effect sizes between negative affectivity and orienting/regulatory capacity and metrics of exploration were small and not statistically significant.

Figure 7

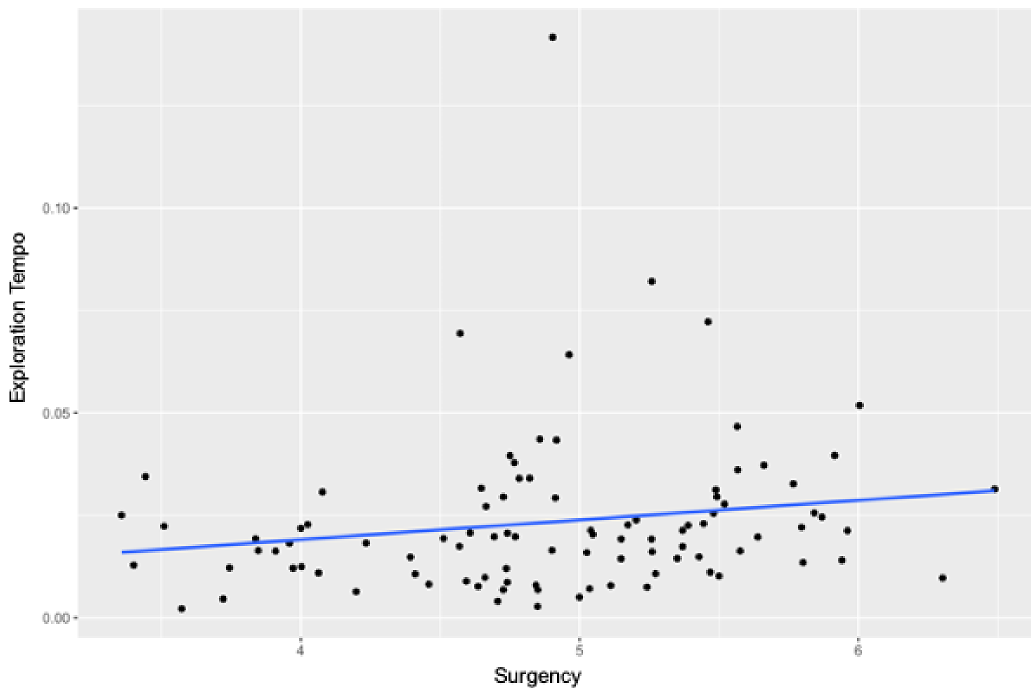
Scatterplot of Surgency and Object Contact



Note. Object contact was analyzed as a proportion of total coded task time. For visualization purposes, the raw values are plotted. A blue line was included to display the fitted regression line.

Figure 8

Scatterplot of Surgency and Exploration Tempo



Note. Exploration tempo was calculated as the number of unique objects contacted by the infant divided by the total number of seconds spent engaged in any form of object contact. For visualization purposes, the raw values are plotted. A blue line was included to display the fitted regression line.

Person-Centered Approach

Previous research has supported a three-cluster/profile solution for infants age 3-8-months based on the same IBQ dimensions used in the present study. All 14 temperament dimensions from the IBQ were entered as variables in the cluster analysis, and a silhouette method supported a 3-cluster solution. Cluster 1 ("High Positive/Low Negative") was characterized by high levels of positive affect, low levels of negative affect, and average activity levels. Cluster 2 (“Active/High Positive/High Negative”) was characterized by high levels of both positive and negative affect as well as high levels of activity. Cluster 3 (“Low Active/Low Positive/Low Negative”) was characterized by below-average levels on nearly all 14 subfactors. These clusters roughly mapped onto the 3 clusters found previously in a similar age group (Gartstein et al., 2017). See Table 2 for the mean values of each temperament factor by cluster.

Table 2

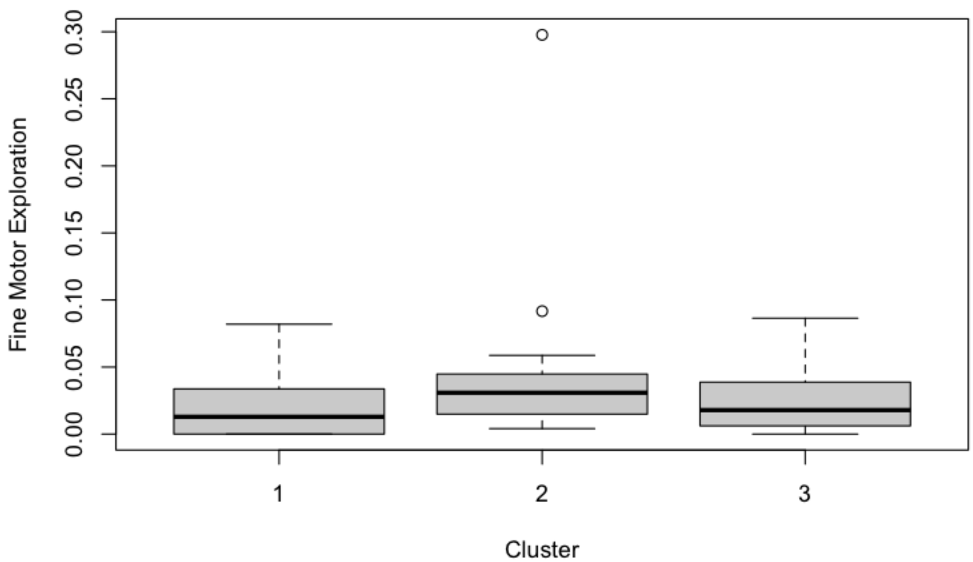
Mean Values of Temperament Factors by Cluster

	Cluster 1 (n = 37)	Cluster 2 (n = 28)	Cluster 3 (n = 31)
Activity Level (M = 4.39, SD = 0.96)	4.40	5.06	3.76
Approach (M = 5.57, SD = 0.72)	5.73	5.81	5.14
Vocalization (M = 4.86, SD = 1.01)	5.44	5.19	3.89
Smiling (M = 4.58, SD = 1.07)	5.29	4.72	3.61
High Intensity Pleasure (M = 5.76, SD = 0.74)	6.10	5.93	5.20
Low Intensity Pleasure (M = 5.52, SD = 0.89)	6.04	5.48	4.93
Soothability (M = 5.77, SD = 0.81)	6.32	5.25	5.58
Sadness (M = 3.52, SD = 0.97)	3.00	4.16	3.56
Distress to Limitations (M = 3.69, SD = 0.93)	3.17	4.58	3.50
Fear (M = 2.68, SD = 1.15)	2.29	3.47	2.43
Cuddliness (M = 5.94, SD = 0.64)	6.12	5.76	5.90
Perceptual Sensitivity (M = 4.23, SD = 1.45)	4.59	4.60	3.48
Falling Reactivity (M = 2.85, SD = 0.87)	2.30	3.60	2.82
Duration of Orienting (M = 3.96, SD = 1.14)	4.59	4.06	3.13

A Kruskal-Wallis rank sum test indicated at least one significant difference between clusters on fine motor exploration, χ^2=7.84, p=.02. A Dunn’s test (*dunn_test.R*) of multiple comparisons indicated that infants in Cluster 2 (“Active/High Positive/High Negative”) spent twice as much time engaged in fine motor exploration (i.e., fingering and transferring; M = .04 or 4% of the time, *SD* = .05) than did infants in Cluster 1 ("High Positive/Low Negative"); M = .02 or 2% of the time, *SD* = .03), *z* = 2.79, *p* = .005. See Figure 9 for a visualization of differences between clusters. Dunn’s test ranks all values across clusters and compares mean ranks between groups; thus, it is insensitive to the outliers observed in Cluster 2 (Figure 9).

Figure 9

Boxplot Depicting Fine Motor Exploration by Cluster



Notes. Fine motor exploration was analyzed as a proportion of total codable time in the interaction task video (e.g., a score of .05 indicates that fine motor exploration occurred for 5% of the codable time in the video).

Discussion

Exploration Tempo

We did not find significant links between our two preregistered temperament variables– negative affectivity and regulatory capacity– and any of the three exploration variables (tempo, oral exploration, and fine motor exploration). However, exploratory analyses indicated a correlation between surgency and exploration tempo, such that infants rated higher on surgency engaged in a more rapid tempo of exploration. Existing literature on surgency sheds light on potential reasons for the observed link between surgency and exploration tempo. First, evidence suggests that surgency is associated with reward sensitivity and responsiveness (Bunford et al., 2022; Gomez et al., 2016). In youth, positive emotionality (a large component of surgency) is linked to enhanced reward sensitivity, such that individuals rated high on positive emotionality demonstrate higher neural levels of sensitivity to reward (Bunford et al., 2022). In infancy, this higher sensitivity to reward may manifest itself in more rapid exploration of a variety of objects, presumably to maximize the reward inherent in exploring novel objects.

Highly surgent infants may also engage in a more rapid tempo of exploration simply because they experience more positive affect. According to Fredrickson’s Broaden and Build Theory (Fredrickson, 1998), experiences of positive affect broaden behavioral repertoires, encourage discovery, and promote skill-building (Stifter et al., 2020). In fact, the experience of positive affect has been causally linked to enhanced cognitive performance (Blau & Klein, 2010). Perhaps an infant prone to “smiling and laughter” (a surgency subscale item on the IBQ) is motivated to “discover” and broaden their reach, as evidenced by moving relatively quickly through multiple objects or components of objects.

The paradox of surgency is that it is associated with both adaptive (e.g., sociability) *and* maladaptive (e.g., impulsivity) characteristics and outcomes (Degnan et al., 2011). Components of surgency– specifically, high positive affect and approach behavior– have been linked to impulsivity (Fox et al., 2001; Pfeifer et al., 2002; Stifter et al., 2008). Highly-surgent infants' rapid tempo of exploration may reflect this impulsivity, such that they tend to act on immediate impulses to interact with or explore other objects in their field of vision, even if they had just begun exploration of the first object.

It is important here to consider what a rapid tempo of exploration might *mean* for an infant or toddler. On the one hand, rapid exploration of objects (i.e., more objects in a given amount of time) may present infants with more varied opportunities for learning. For example, a highly surgent infant may make contact with more objects over the course of a given day compared to a less surgent infant. Over time, these moments of contact with objects may accumulate to produce meaningful differences in learning opportunities. For example, a rapid explorer may hear more object labels from caregivers than their peers who explore less rapidly. This idea is supported by evidence that rapid tempo is longitudinally associated with higher IQ and educational attainment (Bornstein et al., 2013a; Muentener et al., 2018). On the other hand, a rapid tempo of exploration may reduce the likelihood that infants engage in exploratory strategies (e.g., fingering, transferring) that require extended focus on a single object. One potential consequence is that infants may "miss out" on a depth of learning made possible by extended focus on an object.

Fine Motor Exploration

Person-centered analyses reveal links between overall temperament profile and fine motor exploration, such that infants in the "Active/High Positive/High Negative" cluster (Cluster

2) engaged in more fine motor exploration than infants in the "High Positive/Low Negative" (Cluster 1) category. What potential temperamental differences between Clusters 1 and 2 might explain observed differences in fine motor exploration? Compared to infants in Cluster 1, infants in Cluster 2 were substantially more active. The two fine motor behaviors assessed– fingering and transferring– require relatively complex motor movement and a higher level of attentional focus compared to more basic actions such as mouthing and holding. Specifically, transferring requires the infant to simultaneously coordinate the movement of both hands to "pass" an object from one hand to another. Fingering (i.e., running fingers along the surface of an object) typically requires the infant to hold an object steady with one hand while coordinating finger movement with the other. Infants with high levels of activity may simply have more energy to devote to such complex movements compared to infants with lower levels of activity.

The second major difference between clusters 1 and 2 was the level of negative affectivity. On average, infants in Cluster 1 were reported to display low levels of negative affect, while infants in Cluster 2 were reported to display higher levels of negative affect. Infants in Cluster 1 may simply have been more content to engage in more basic behaviors (e.g., mouthing, holding, rhythmic) for longer periods of time. Additionally, infants with higher levels of negative affect may be overall more *sensitive* to stimulation from the environment, which may also make them more likely to engage in behaviors that provide more detailed information about objects. For example, infants tend to use fingering strategies to gain information about object texture and transferring to gain information about object weight (Ruff, 1984).

What are the developmental implications of engaging in high levels of fine motor exploration? Fine motor exploration at 6 months of age has been linked to 24-month cognitive performance on a standardized test (Zuccarini et al., 2017). Fingering (or "haptic scanning") may be especially important for infants' object perception (Gerhard et al., 2021). Thus, the particular combination of high activity level, high positive affectivity, and high negative affectivity may motivate an exploratory behavior that is closely tied to cognitive development.

Comparing Variable- and Person-Centered Approaches

The variable and person-centered approaches to temperament each provide their own unique insights into human behavior. The variable-centered approach allows us to consider a single dimension and variation along that dimension in relation to variables of interest. By contrast, a person-centered approach considers multiple relevant variables, which allows us to understand how different dimensions interact to shape behavior. Based on findings from Study 1, surgency may be more useful for understanding broader characteristics of exploration (e.g., tempo and total duration of object contact) but less so for understanding more fine-grained behaviors like fine motor exploration. Likewise, temperament clusters (comprised of the 14 dimensions of the IBQ) may be more useful for understanding more fine-grained behaviors, but less so for understanding broader exploration characteristics.

Limitations

It is important to note that findings regarding temperament and exploration may differ based on the demographic make-up of the sample. We have reason to suspect that infant expression of temperament, as well as parents' perceptions of infant temperament, varies based on cultural context (Super et al., 2008). For example, caregivers in the U.S. value characteristics related to infant surgency (e.g., high activity level) more so than caregivers in Israel (Klein & Ballantine, 1991). As a result, the highly surgent infant in the U.S. may elicit very different responses from caregivers than the highly surgent infant in Israel, which may moderate the effects of temperament on child outcomes (Zentner & Shiner, 2012). Thus, future work should seek to address whether cultural context moderates the relationship between temperament and exploration.

Another limitation of Study 1 is that we did not directly code the caregiver's behavior, and thus it remains unclear whether and how caregiver's behaviors may relate to an infant's expression of temperament and how these behaviors shape the infant's exploration. Future studies should explore real-time interactions between infant temperament and caregiver behavior. Additionally, although the interaction task allows us to capture naturalistic interaction between infants, caregivers, and objects, we recognize that seated play with toys may occur relatively infrequently in day-to-day life. Thus, it may represent only a small proportion of the activities infants and caregivers typically engage in.

Study 2

Methods

Participants

Participants for Study 2 were 35 toddlers and their caregivers, who were a part of a longitudinal study (N=50) assessing the effects of early perceptual-motor experiences on the development of tool-use skills. Before their first visit to the lab, infants were randomly assigned to either an experimental or a control group. The experimental group received two weeks of at-home, parent-led "sticky mittens" training between infant ages of 2.5 and 3.5 months. Infants returned to the lab for follow-up assessments at 3.5 months, 8-9 months, 14-15 months, and 23-24 months. In the present study, we use data from the 24-month visit to assess links between temperament and exploration, collapsing across study conditions. A total of 15 participants were excluded from analyses: 2 dropped out of the study; 2 moved out of state before the 24-month follow-up visit; 6 were not comfortable completing the 24-month visit due to COVID-related concerns; 1 family did not complete the questionnaires for the 24-month visit; one child could not complete the 24-month visit due to fussiness; and one participant had a twin participating in the study. Mean age at this visit was 24.13 months (*SD* = 1.38 months). Infants were 51% female. Eighty-eight percent of participants were White; 2% Black; 5% Asian; and 5% indicated more than one race. Five percent of participants identified as Latinx.The sample was highly educated, with 94% of primary caregivers reporting a bachelor's degree or higher.

Procedure

The 24-month visit consisted of several short behavioral tasks and a battery of questionnaires– including the ECBQR-VSF– for the caregiver. In the present study, we analyzed data from the "Activity Ball" free play task. For this task, toddlers sat on their parents' lap at the edge of a rounded study table (see Figure 10). After a warm-up task, the experimenter said "*look what I have!*" and presented the infant with an activity ball toy. After the presentation, the experimenter turned her back and pretended to be occupied by paperwork. Caregivers were asked before the session to refrain from interfering with their infant's actions– they were only permitted to briefly acknowledge the toy if their child turned to show it to them. Toddlers were given 30 seconds to explore the activity ball however they wished before the experimenter turned around to retrieve it. This task was filmed by a four-way video camera for later coding.

Figure 10

Overhead Camera View of Free Play Task

Note. A clear plastic barrier was placed between the experimenter and the child to reduce the spread of germs during the COVID-19 pandemic.

Video Coding

Prior to coding, we named each moveable component of the Activity Ball toy (e.g., purple ring, blue caterpillar). A trained research assistant watched the video of the task and checked off each Activity Ball component as the toddler manipulated it. Each component was only marked once, even if the infant manipulated it multiple times. In order for a component to count, the infant had to move or rotate it. This information was used to calculate the total number of components each infant contacted. The first author double-coded 20% of the videos, with an average percent agreement (on the number of components contacted) of 96%. We used Datavyu to mark the onsets and offsets of infant engagement with the activity ball (Datavyu Team, 2014). Engagement was defined as any physical contact with the ball.

Specific Measures

Surgency, Negative Affectivity, and Orienting/Regulatory Capacity. The three super-factors were calculated by taking the means of relevant items on the Early Childhood Behavior Questionnaire, Very Short Form.

Exploration Tempo. Exploration tempo was calculated by dividing the total number of unique activity ball components contacted by the total number of seconds the infant spent engaged with the activity ball. For example, if the infant contacted 5 different components of the activity ball and spent a total of 25 seconds engaged with the object, a score of 0.2 was assigned.

Data Analysis

To prevent undue influence of outliers, we conducted Spearman's rank-order correlations between exploration measures (oral, fine motor, and tempo) and temperament factors from the IBQ-R (surgency, negative affectivity, or orienting/regulatory capacity). We did not conduct person-centered/cluster analyses on this sample given the smaller sample size. Additionally, the "very short" version of the ECBQ did not allow for the analysis of fine-grained dimensions of temperament.

Results

Descriptives

On average, infants spent 26.18 seconds (*SD* = 7.00) engaged with the activity ball and contacted 3.80 components of the activity ball (*SD* = 1.95). We did not expect experimental conditions to differ on exploration tempo; and a Wilcoxen rank sum test confirmed a non-statistically significant difference between experimental and control groups on exploration tempo, $W = 119$, $p = .27$. Surgency and negative affectivity were not significantly correlated, $r_s = .04$, $p = .84$; surgency and orienting/regulatory capacity were not significantly correlated, $r_s = .18$,

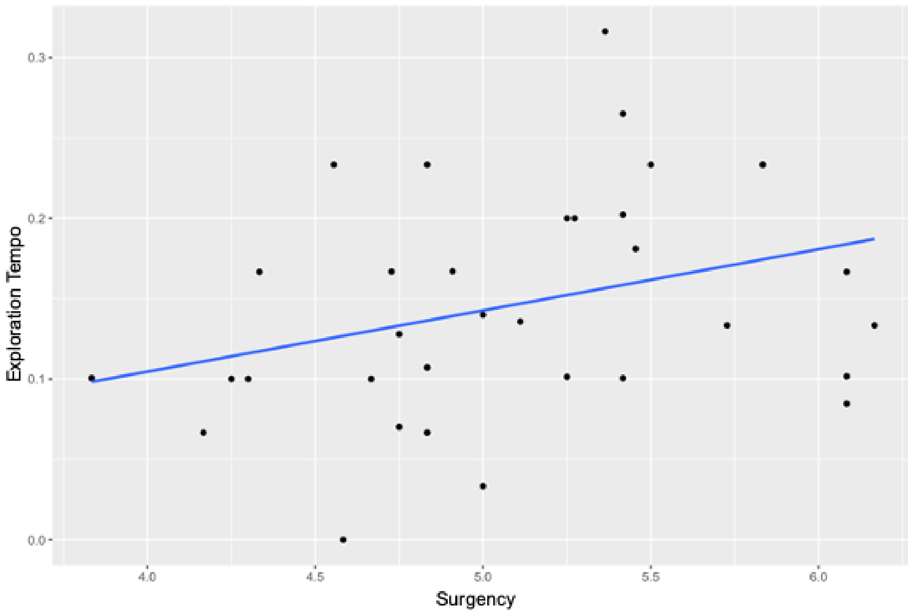
p =.29; and negative affectivity and orienting/regulatory capacity were significantly correlated, r_s = -.48, p < .003.

Temperament and Exploration

Spearman's rank-order correlations between exploration tempo and each of the three temperament factors revealed a medium-size and significant correlation between parent-reported surgency and our concurrent metric of exploration tempo. Higher levels of surgency were associated with more rapid exploration of the activity ball, r_s = 0.41, p = .015 (see Figure 11 for a scatterplot of the raw data). Negative affectivity was also significantly correlated with exploration tempo, such that toddlers rated higher in negative affectivity demonstrated less rapid exploration of the activity ball, r_s = -.35, p = .037 (see Figure 12 for a scatterplot of the raw data).

Figure 11

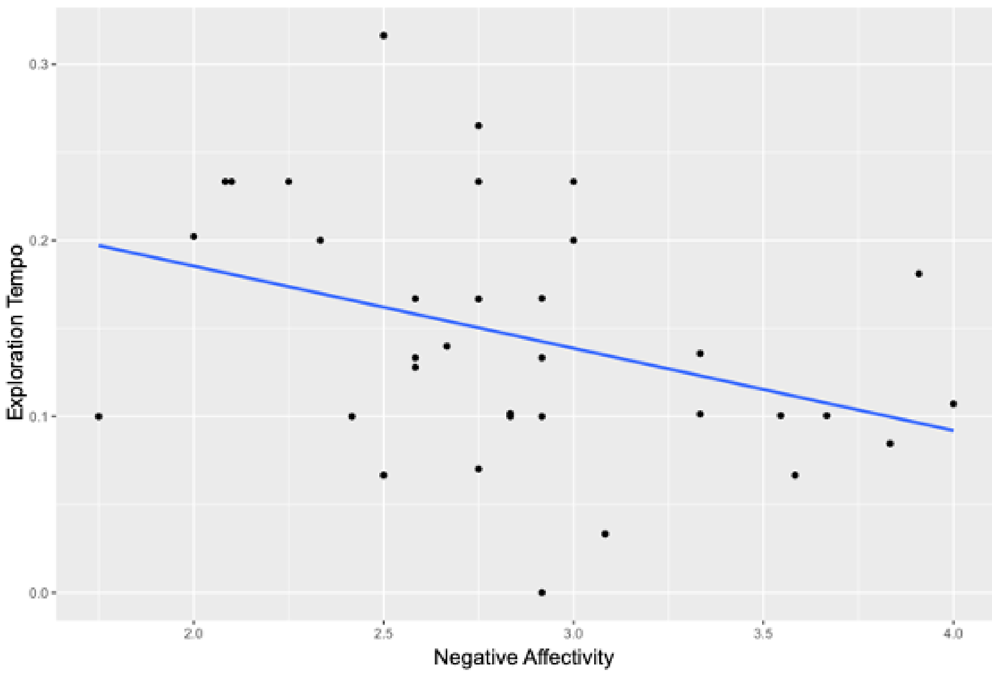
Scatterplot of Surgency and Exploration Tempo



Note. Exploration tempo was calculated as the number of unique toy components moved by the infant divided by the amount of time spent engaged with the object in seconds. For visualization purposes, the raw values are plotted. A blue line was included to display the fitted regression line.

Figure 12

Scatterplot of Negative Affectivity and Exploration Tempo



Note. Exploration tempo was calculated as the number of unique toy components moved by the infant divided by the amount of time spent engaged with the object in seconds. For visualization purposes, the raw values are plotted. A blue line was included to display the fitted regression line.

Discussion

Consistent with Study 1, toddlers rated higher on surgency by their parents were more rapid explorers. The consistency of findings between the two studies is notable given that the two studies differed in many ways methodologically. First, Study 1 assessed temperament and exploration in a sample of 6-month-olds, while Study 2 assessed temperament and exploration in a sample of 24-month-olds. Consistent findings across this broad age gap suggest that temperament's role in exploration is not limited to particular points in development. Rather, temperament may motivate exploration in both premobile infants and the fully mobile toddler.

Another major difference between Study 1 and Study 2 was the actual nature of the object exploration task. In Study 1, infants and caregivers were free to interact with each other and any number of toys in a toy basket. While they were instructed to remain in the study room, there was substantial flexibility and room for variability in both infant and caregiver behavior during this task. In Study 2, the caregivers' influence on child behavior was heavily restricted. While caregivers were present for the Activity Ball task (toddlers sat on their caregiver's lap), they were asked to avoid participating in their child's activity. Thus, while Study 1's free play task was unstructured and interactive by nature, Study 2's free play task was, in many ways, a solo and highly structured exploration activity. Additionally, only one object was presented to the toddler in Study 2, and this object remained the same across all infants. These important differences in methodology increase our confidence in the link between the temperamental dimension of surgency and exploration tempo that moves beyond specific context.

We also found a statistically significant correlation between negative affectivity and exploration tempo, such that toddlers who display more negative affect (e.g., fear, sadness) demonstrated a slower tempo of exploration. Toddlers with higher levels of negative affectivity may have experienced higher levels fear or frustration in the novel lab setting, resulting in attenuated exploration. For toddlers prone to negative affectivity, this "strange" lab experience (seated in a caregiver's lap, facing an experimenter) may have resulted in negative emotionality (and thus attenuated exploration) in a way that playing freely with a caregiver in a private room (as in Study 1) did not.

One limitation of Study 2 is that the free play task was likely not representative of a typical activity for a toddler. The child was seated at a special table on a caregiver's lap, but the caregiver was instructed to avoid communicating with their child. Additionally, we are limited in our ability to draw firm conclusions from Study 2 given the very small and homogenous sample. However, the consistency of findings across studies 1 and 2 provides some level of confidence in the observed effect.

General Discussion

Summary of Findings

Across both studies (Study 1 and Study 2), the temperamental dimension of surgency– characterized by high levels of activity, approach, and positive affectivity– was positively and significantly associated with exploration tempo (i.e., number of unique objects contacted divided by the amount of time spent engaged in exploration). Effect sizes between the other two temperament factors– negative affectivity and orienting/regulatory capacity– and our metrics of exploration were small and statistically non-significant. In Study 1, we also conducted cluster analyses based on the 14 subfactors present in the short form of the Revised Infant Behavior Questionnaire. While fine motor exploration was rare overall, infants rated higher in activity, positive affect, and negative affect ("Active/High Positive/High Negative") engaged in twice as much fine motor exploration (fingering and transferring) as did infants with lower levels of activity and negative affect.

Understanding Object Exploration

We return here to our quest to understand the various factors that constrain and motivate infant object exploration. As discussed in the General Background, previous work has indicated several contextual factors relevant for exploration, including SES, caregiver behavior, and postural support. A small number of personal characteristics have also been noted, including sex at birth and motor skills. Findings from the present study add "temperament" to this list. While continued research assessing links between temperament and exploration is needed, the present study suggests that some components of temperament are relevant for understanding infants' exploration of objects; namely, surgency for understanding exploration tempo, and combinations of activity level and affectivity for understanding variability in the more fine-grained behavior of fine motor exploration (fingering and transferring).

Implications for Research on Object Exploration

These findings linking temperament to object exploration have important implications for research involving the assessment of object exploration ability. In standard, lab-based object exploration tasks, infants are presented with novel objects to explore. Infants' behaviors during these tasks are considered exploration "skills." However, it is important to consider that these tasks may be capturing what infants *tend to do* in novel situations (perhaps based on temperament) and not necessarily what they are *capable of doing*. This highlights the importance of recent efforts to capture infant behavior via naturalistic, home-based observation in order to capture what infants *really* do in their day-to-day lives (de Barbaro, 2019).

Interactions Between Temperament and External Influences

The various factors related to object exploration may be best understood in the larger context of Bronfenbrenner's ecological systems theory, in which personal characteristics (i.e., temperament, sex) and varying levels of external factors (i.e., immediate context, family context, neighborhood context, etc.) interact to shape behavior and development. In other words, just as external influences and personal characteristics may directly shape a child's behavior, characteristics of the child (e.g., highly active) may elicit particular responses from caregivers that, in turn, shape infant behavior and further reinforce said personal characteristic (as in a developmental cascades model; Iverson, 2021).

One challenge for future research is to tease apart the relative contributions of temperament and contextual influences on infant exploratory behavior. In Study 1, the number of objects available to the infant was a strong and significant predictor of exploration tempo, highlighting the influence of contextual factors on exploratory behavior. However, we did not find evidence that temperament interacted with this particular contextual factor (correlations between temperament dimensions and the number of available objects were small and non-significant). The number of unique objects available to the infant may have been a “crude” proxy for caregiver behavior, so future studies should seek to capture more nuanced aspects of caregiver behavior during infant play with objects.

Implications for Development

From a developmental cascades perspective, different “styles” of object exploration (e.g., rapid tempo vs. slower tempo, more or less fine motor exploration) have meaningful implications for developmental trajectories. When accumulated across the minutes, hours, days, and weeks of an infant’s life, seemingly small differences in the tempo of object exploration may result in widely different opportunities for learning about objects (Franchak, 2020). Infants who explore more rapidly may also elicit more frequent feedback from caregivers, resulting in more frequent opportunities for learning language, for example.

The Active Infant

More broadly, the findings of the present studies emphasize the role of the child as an active agent in the environments. This sharply contrasts with theories, both historical and current, that emphasize or *over*-emphasize the role of the environment. The Tabula Rasa (“blank slate”) theory of child development, first posited by John Locke in the 18th century and popularized by B. F. Skinner in the 20th century, positions the infant as a largely passive receiver of stimulation. In other words, all that infants come to know and do later in life must be taught. Today, this line of thinking continues in what some authors call "radical environmentalism," or the tendency to over-emphasize the influence of the environment when explaining or predicting behavior (Lilienfeld, 2010; Lykken, 1991). According to Lilienfield (2010), the problem with this stance is that an exclusive focus on experiences can cloud more nuanced perspectives on the complex interplay of the individual and the environment throughout development. Thus, if our goal is to accurately explain and predict human behavior, we must not forget the crucial role of individual difference factors, including temperament.

Our findings linking temperament to infant object exploration can also be understood in the context of developmental niche-construction theory (Stotz, 2010). Based on the idea that human cognition extends "beyond the brain" into the physical world, developmental niche-construction theory highlights the active role of the organism in shaping or modifying its own environment and the role of the environment in shaping cognitive development (Stotz, 2010). Highly surgent infants exploring at a rapid tempo is one example of an organism shaping environmental input. The level of stimulation received and information gained from a rapid tempo of exploration is different from a non-rapid tempo of exploration– in this way, surgency may result in the accumulation of different *kinds* of input, both directly (i.e., via their own behavior) or indirectly (i.e., by influencing the behavior of their caregivers). For example, on a given day, more surgent infants may come into contact with more objects, providing more opportunities for learning about objects directly as well as more opportunities for caregivers to provide verbal feedback.

Broader Implications

The present studies merge two broad domains of infant development not previously considered together: the motor domain (object exploration) and the affective domain (temperament). Our findings support a developmental cascades framework in which developments in one area are intricately connected to developments in other areas (Masten & Cicchetti, 2010; Oakes & Rakison, 2019). In the case of the present studies, early expressions of temperament may play a role in the development of behavioral patterns related to object play. Future research might consider how temperament shapes other important sources of cognitive stimulation in infancy (e.g., language input, caregiver scaffolding). Overall, our findings indicate that early learning experiences may depend on the specific behavioral styles and sets of preferences that infants bring into the world. This understanding points to the complexity of early development and the importance of examining both contextual and within-person factors when seeking to explain and predict behavior.

Conclusion

Findings from the present studies indicate a link between parent-reported temperament and components of object exploration in infancy and toddlerhood. This provides us with a better understanding of the factors that motivate and constrain exploration in early life. More importantly, these findings highlight the role of the child in shaping early opportunities for learning.

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