**Research Title:**

**Developmental Trajectories of Infants' Object Exploration in Socio-emotional and Physical contexts: A Micro-Genetic Longitudinal Study**

**Keywords: *object exploration, micro-genetic approach, mother-infant interaction, individual differences, dynamic systems***

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**SCIENTIFIC ABSTRACT**

Object exploration (OE) is considered a driving mechanism in infant development through which infants discover, extend, and redefine their repertoire of action possibilities with objects. Extensive research has documented the contribution of OE to infant learning. Yet, our understanding of **core aspects of the *development* of OE remains limited.** Previous research has relied on relatively long intervals between observations (e.g., several weeks); focused primarily on capturing group-level changes, with limited attention to measuring both inter-and intra-individual variability; and investigated the effects of isolated factors (such as only contingent maternal responses to the infant during joint OE or only objects’ physical features and affordances) rather than employing a multi-dimensional approach. Hence, there is little direct support for the core notion of dynamic systems approaches to development that new forms of OE emerge through continuous perception-action cycles and reflect the self-organization of various systems.

To address this gap, we will adopt a micro-genetic and multidisciplinary approach. We will use a longitudinal design with 12 dense weekly semi-structured home observations of 40 infants aged 8 to 12 months and their mothers. Each observation will include three phases: (1) *Baseline,* assessing infants’ *independent OE*; (2) *Interaction,* assessing *mother-infant joint OE*; and (3) *Retention,* assessing infants’ *independent OE post joint OE*. In each phase, *four toy objects* with unique and distinct properties and potential affordances will be *presented in a random sequence* between and within participants.

In doing so, **we will achieve our overarching aim of documenting group and individual developmental trajectories of OE from 8 to 12 months while integrating motor, interactional- communicative linguistic, and emotional aspects of OE (Aim 1).** OE development will be documented in time intervals of minutes, weeks, and months. Applying a micro-analytic coding scheme developed for this study, we will analyze the expansion of action possibilities and complexity in infants’ OE. Further novel contributions We will extend previous research by studying **the effects of the communicative-linguistic context (Aim 2)** and **mother-infant emotional availability during mother-infant joint OE on infants' independent OE (Aim 3).** The Interaction phase will be analyzed using a new micro-analytic scheme tapping communicative, linguistic, content, and motor dimensions, as well as the widely used, global Emotional Availability Scales. Finally, we will track **whether and how physical propertiesandaffordancesof objects** are perceived and **affect infant OE directly and indirectly via their effects on mother-infant joint OE (Aim 4).**

The study will advance theoretical models of OE development grounded in dynamic systems approach by documenting continuity and discontinuity while accounting for its under-studied communicative-linguistic, emotional, and object-properties aspects. The study is expected to provide the needed empirical support for a shift in future OE research and practice towards a triadic parent-infant-object perspective.

**SCIENTIFIC BACKGROUND**

**1.1 Introduction**

As infants explore the environment, they extend their repertoire of innovative behaviors and knowledge about the world1,2. Through exploration, infants experiment with and learn about “affordances” in the physical and social environment, namely, possibilities for action and interactions in and with the environment2-4. In particular, object exploration (OE) involves behaviors (action possibilities) of exploration and/or manipulation of objects and materials. As such, it plays a fundamental role in various domains of infant development1,4,5-9. The research on how infants discover affordances of objects in their environment and extend their action repertoire raises two central considerations that must be addressed the nature of developmental changes and the appropriate methodology to portray them. Developmental changes in all domains are inherently complex. They involve mechanisms of change in several interactive co-existing and co-evolving systems (e.g., motor, communicative, affective) and emerge through self-organization and continuous perception-action cycles that co-occur in multiple real-life events and environmental interactions. This complexity is likely to account for marked individual differences in the behavior in question. To portray such sensitive developmental trajectories of continuity and change in infant OE, it is imperative to go beyond extant research that examined linear models, used group averages, or examined correlations between an infant’s functioning at different time points or between specific OE skills.

**This proposed research will help close gaps in the current understanding of OE development by applying a micro-genetic methodological approach to data collection and analysis33. This approach will capture common and individual processes of change while employing a novel, multi-disciplinary perspective on OE to integrally capture motor, language, and communicative behaviors as well as their affective qualities, all as sources of meaningful information on how developmental changes in OE occur**.

**1.2 Tracing Developmental Trajectories of OE**

Research has shown that OE emerges early in life even before the onset of reaching.18 At around 6 months, OE includes exploration of individual objects in simple and undifferentiated ways, using sensorimotor behaviors and simple manual actions (e.g., mouthing, touching, and banging). With time, at around 9-12 months, OE becomes progressively diverse and complex, and exploration strategies become more differentiated, sophisticated, and accommodative to objects’ properties and in relation to surfaces.19,20 Sequences of exploration with single or multiple objects21-23 become more frequent and involve advanced manipulation strategies (e.g., relational and transforming actions, such as stacking or twisting). During the second year of life, OE evolves towards goal-directed behaviors of functional actions (i.e., use according to conventional purposes) and symbolic acts with objects24-26. These changing outward behaviors in OE that may appear to be stage-like are thought to be a reflection of a continuous process of change or stabilization in the underlying components responsible for OE behaviors, which are context-dependent, experience-driven, and self-organizing 27. Historically, the preprogrammed universal stage-like developmental trajectory view originated from the maturational theory (ref), led to, and was related to the prevalent methodology of cross-sectional OE studies, and to a lesser extent, to longitudinal studies of OE with large intervals. This theoretical framework gave way to dynamic systems theory, Gibsonian ecological, and embodied cognition perspectives. According to these approaches, developmental change arises from the dynamic interplay of many heterogeneous components and systems assembled into a cooperative unit and is constrained by internal and external factors of the individual, the task, and the environment28-30. At the micro-level, new OE skills are thought to develop through repeated and continuous cycles of perception and action, in which information received by the different perceptual systems elicits actions, and actions, in turn, provide new information to be perceived, and so on, in a reciprocal manner**2**,32. These active and embodied loops occur second by second and day-by-day over many occasions, and become integrated, yielding new developmental forms.2,3,27 As growth occurs, these dynamic, self-organizing, non-linear processes are conceptualized as generating both preferred or less preferred developmental forms (i.e., attractor states) of OE behaviors that can be observed in individual and group trajectories of the behavior (Thelen & Smith, 2006).

Despite this theoretical understanding, the **direct** application of system approaches in OE research, and the **empirical examination** of whether andhow new action forms appear, how infants discover and acquire new forms, and how these forms are stabilized as an integral part of infants’ OE repertoire while differentiating between individual trajectories is **scarce**.Past OE studies have typically applied a macro-developmental approach and examined how children as a group develop common patterns of OE behaviors over time(10). In addition, past studies have focused on specific aspects of OE (e.g., object construction,11,12) or on specific factors affecting OE in the infant-environment-task relationship (e.g., effects of postural control on OE14) or identified correlates or mediators of OE in infancy and specific abilities at the same age and later in development (16, 17). With few exceptions, these studies typically used cross-sectional methods with specific or multiple age groups, or involved traditional longitudinal research with few data points over relatively large time intervals (e.g.,13,19,25,34-36). These designs do not allow capturing dynamic changes in OE as a time-sensitive process that occurs at the micro and macro-level (multi-layer), leading to inter-individual variability.

Past research examined developmental changes in OE while accounting for the interrelations of overlapping and densely connected domains/systems. In this vein, studies have shown that the desire to reach for objects is part of the motivation to acquire locomotion, and this, in turn, offers infants new opportunities to learn about the environment and its properties; increasing their ability to interact socially and act on objects40. Gross motor advances drives effect on exploration, as well as on other behaviors (e.g., bimanual reaching43, motivation to move44) and abilities (language and communication17), including manual manipulations. In turn, new manual manipulations enable learning and the discovery of different possibilities of action with objects14,45. The ability to sit without support allows infants to use their hands to freely pick up objects and explore their properties. In this way, visual, manual, and oral information is linked, and infants' attention to the properties of novel objects46 is likely to improve, which may lead to advances in OE (e.g., three-dimensional object completion45). While these studies have provided *indirect* support to the notion offered by dynamic system theory, there is **a need to systematically and integratively examine how developmental trajectories in OE are self-organized and trace individual variability**. Such a close examination of the emergence of change in developmental skills was conducted in relation to early motor development (e.g., reaching, walkingref) cognitive and linguistic development (e.g., Howe & Rabinowitz, 1994; Ruhland & van Geert, 1998) but **is still lacking in the context of OE research.**

Self-organizing systems are exquisitely sensitive to aspects of their environments, because of their propensity for feedback and coupling with other systems (Lewis,2000). Maintaining an emphasis on the environment is hence vital for revealing how developmental trajectories in OE are self-organized and for tracing individual variability. This is another realm that requires further research and will be addressed in our research. It is necessary to unravel how **infants’ OE changes and whether and how it stabilizes in interaction with the environment**. Accordingly, this study will examine **the dynamic interactions between infants**’ **interests and OE-related abilities (i.e., current repertoire of actions with objects, and motor and language abilities) and** **three aspects of the infants’ environment: (1) the socio-communicative and (2) emotional environments of mother-infant joint OE** (that latter was in particular overlooked in extant research), as well as (3) **the physical properties and perceived affordances of the objects** that are targets of infants’ and mothers-infants’ exploration. Relatedly, the context in which OE is studied is important for establishing ecological validity.51 Previous OE studies were typically carried out in laboratory (e.g.,12,13,34) or in-home settings with experimenters presenting or placing objects11. Thus, they are limited in their ability to document the natural social context of exploration, namely *at home with parents*. Furthermore, mother-infant joint OE in the laboratory has shown that structured tasks and naturalistic routines yield different input patterns by the same mothers (Tamis-LeMonda et al., 2017EF). Our study will overcome this limitation and will be carried out at the infants’ homes.

**1.3 Mother-Infant interactions during joint OE**

Social interaction is essential to the development of infants' OE skills52. Mothers place objects in infants' hands even before infants can reach them intentionally. Mothers increase infants' engagement in interacting with objects, direct their attention, demonstrate relevant actions with objects as infants’ oral and manual exploration evolve53, and use "motionese": modifying their object-related actions for closer proximity to the infant, higher interactiveness, repetition, and increased amplitude of movement55. Furthermore, mother-infant OE is reciprocal. Mothers explore objects following infants' OE to establish bouts of shared attention00. Similarly, while mothers provide clear inferences about the appropriateness of actions with objects, supporting infants' learning57,58, infants seek to share objects by showing or offering them, pointing to them, or using other gestures to get their mothers' attention to what they are doing54. So far, mother-infant joint OE has been studied along dimensions that characterize and constitute high-quality interactions in general (following00): motor, interactional, linguistic, and content. However, research gaps have arisen in each of these dimensions that must be addressed. *At the interactional level*, mothers' contingent responses are characterized by tight mirroring of infants' engagements with objects00, multimodal responses that combine physical (as gestures), auditory, and temporal properties to facilitate infants' exploration00, and different types of pragmatic categories to manage the interaction. Mothers use regulatory language to attract infants' attention, instructional language to direct infants' exploratory actions, and referential language to name objects or talk about objects' features and related actions56. However, scarce information is available on possible overlaps between the above findings, such as delving into which modality (gestures, verbally, gaze) instructional/normative language is provided and, in general, the extent of micro-changes in the triadic mother-infant-object interaction as infant's abilities develop and familiarity in the OE set increases over time. *At the linguistic level*, infants' active engagement with objects makes them salient in the visual field and elicits language input that refers to the objects and their associated properties00. Thus, mothers provide contingent labels that capitalize on infants' current attentional focus00. However, research so far has focused mainly on the labeling function, and relatively little is known about the different lexical categories, their frequencies, and diversity (e.g., types of verbs, nouns, social words) that constitute the global semantic input to which the child is exposed during the joint OE. Finally, *at the content level*, the context of mother-infant OE is an example of a daily activity that provides the contextual richness that naturally shapes the speech addressed to the infants. Participation in repetitive and therefore highly predictable routines (e.g, playing “as if”, reading books together) and "interaction formats”00 frame infants' language experiences and offer them salient cues to context-specific word meanings00,00,00. However, beyond the linguistic and interactional aspects, it is necessary to examine how the context of joint OE exposes the child to topics that may be some related to here-and-now actions while others may be more de-contextualized (for example, discussing past actions or providing options for symbolic actions). In conclusion, in order to address the research gaps in the interactional-linguistic and content dimensions, the present study seeks to delve deeper into these dimensions and examine the features across and between them. **The dense data collection and detailed analysis schemes of the proposed study (section X) will provide insights into the changes and nuances that occur on multiple time scales (both within sessions and from week to week) to better understand how joint OE is orchestrated and whether and how it relates to the development of infant OE.**

**1.4 Mother-Infant Emotional Availability in Joint OE**

Another aspect of mother-infant joint OE that may underlie the development of infant OE is the **emotional quality** of these interactions,62 particularly mother-infant emotional availability (EA). In EA interactions, mothers are sensitive to their infants (i.e., they interpret accurately and respond appropriately to infants’ signals); they express genuine positive affect, provide flexible and attuned scaffolding to infants’ exploration, and avoid intrusiveness and hostility.63,64 Infants are responsive to maternal bids (i.e., they display pleasure when interacting with the mother and follow her suggestions without diminishing their autonomy); they also involve the mother by inviting her to be an audience to their play or a source of help.63,64 Such qualities during joint mother-infant OE are likely to provide infants support and guidance in their OE, which may increase the variety and complexity of their actions with objects and contribute to their identification of more affordances. Furthermore, according to attachment theory, infants are equipped with two behavioral systems: the attachment system is activated when the infant is distressed and involves proximity-seeking with the mother; the exploratory system is activated when the infant is not distressed and it involves competent exploration of the environment. Mother-infant EA provides the infant a safe haven when distressed and facilitates activation of the exploration system, as the infant enjoys a sense of security when exploring the environment.65, Tanaka et al., 2021 Numerous studies have found that mother-infant EA is related to infants’ secure attachment and other positive social-emotional outcomes (e.g., cognitive and language development63,66 and motor development (albeit with mixed results;67,68 see review in69). Surprisingly, the notion that EA facilitates the development of infants’ OE skills during the first year of life has seldom been examined. Very few studies provide *indirect* support for this notion indicating *concurrent* links between maternal sensitivity in mother-infant interaction and infants’ exploration of more objects and display of more behavioral schemata during that interaction.62. Also increasing maternal sensitivity at 6 months improved both mothers’ sensitivity and infant quality of OE from 6 to 9 months; however, the links between the two were not examined70. Studies with *older children* showed that mothers’ attention directing and limit setting for 12-month-old infants were associated with better infant OE skills71. In addition, infants who formed secure attachments at 12 months showed longer duration and more complex OE at 21 months72 and longer object orientation and attention span at 18-24 months73. The proposed research builds on these studies **and will examine for the first time the effects of mother-infant EA during joint OE on the development of infant OE across the ages of 8 to 12 months.**

**1.5 The Physical Context of OE: Objects’ Properties and Affordances**

Infants discover and accumulate information about objects' properties, actions, and outcomes, and in turn, objects' properties influence infants' behaviors (e.g.,35,36,75). During exploration, infants discover what action possibilities an object permits or affords in relation to its properties, such as size, texture, weight, shape, color, elasticity, and novelty.10,18,36,76 For example, elastic objects elicit transforming actions such as stretching and squeezing, whereas hard objects elicit banging. Objects with moveable parts encourage bimanual exploration for transferring, turning, and rotating the object; and textural objects often involve the differentiation of the hands’ role, with one hand stabilizing the object 19,35,77-80. However, potential affordances of the object are not always perceived and discovered, but rather depend on infants’ previous experience and their motor and perceptual/cognitive capabilities at the time of exploration2,19,32. With the emergence of new abilities and skills in postural control, manual control, and object knowledge, infants become more skilled at perceiving and expanding their repertoire of exploratory actions and combinations of actions to accommodate the object’s properties18. Studies that have examined the effects of objects’ properties on infants’ OE 18, 83, 84 focused on a specific property of the object and explored its contribution to an isolated aspect of infant OE.83,84. Most longitudinal research has not examined the effects of *the properties of objects* on both infants’ independent OE and parent-infant joint OE. Research is clearly needed to unravel the dynamic processes through which infants' actions are discovered and expanded in infant-mother OE in the physical context of objects with various properties. **The proposed study will be the first to examine systematically the effects of several objects’ properties (e.g., shape, texture, parts) and action possibilities on both infant OE and mother-infant joint OE.**

In summary, previous research on OE has not applied a holistic view of interwoven dynamic systems by simultaneously examining intrinsic aspects of the infant, the social and physical context, and the task at hand (OE). The topic has been approached many times by focusing on isolated aspects of OS, without taking into account the physical and interactional social-emotional and communicative contexts in which OE occurs. In addition, studies on OE have so far been mostly conducted with long time intervals between observations, without taking into account the variability between and within participants that can occur in short time intervals of minutes and weeks. Hence, it is essential to concurrently take into account the links between the socio-communicative and emotional context of joint OE and the physical properties of objects, and make detailed observations across short time intervals in order to (a) reveal how developmental trajectories in OE are self-organized and (b) delineate individual variability, concerning both the infants’ OE and the triad of mother-infant-object exploration.

**2. RESEARCH OBJECTIVES AND EXPECTED SIGNIFICANCE**

The proposed research will apply a multidisciplinary approach to study the development of infant OE using a micro-developmental paradigm that accounts comprehensively for patterns of *intra- and inter-individual variability* and for mechanisms rooted in *socio-emotional and physical contexts* on different time scales (*minutes to weeks*). Our overarching objective is **to examine the developmental trajectories of infant OE between 8 and 12 months** and capture variability between and within infants. We aim to elucidate how infants from 8 to 12 months update and expand their repertoire of action possibilities with objects, and how new actions (spontaneous, induced, or imitational) emerge, stabilize, and become an integral part of the infant's exploratory repertoire. Considering the multidisciplinary approach taken in this study, the following three aims will complement the overarching objective:

(1) To characterize the social environment of mother-infant joint OE, focusing on mothers' communicative-linguistic input as well as motor actions, and examine their effects on infants' expansion of OE repertoire of action possibilities with objects over time. We will also examine how the development of infants' OE skills and their increased familiarity with the objects change mothers' communicative-linguistic profiles over time.

(2) To characterize the emotional environment in which developments in infant OE occur and examine the contribution of mother-infant EA to infants' OE skills.

(3) To study the effects of the physical properties and affordances of objects explored in both infant OE and infant-mother joint OE.

The results will have important theoretical and practical implications. They will enable us to **refine theoretical models** **of OE** by (1) identifying the dynamics of changes in stability, instability, and transitional phases, and revealing different forms and time frames of change, thus providing a comprehensive explanatory model for the development of infant OE during the time frame under study and delineating general and specific/individual profiles of trajectories of developmental changes in infant OE; (2) revealing social and emotional processes in mother-infant joint OE that facilitate or hinder developmental changes in infant OE. In this way, we will deepen the understanding of how different areas of child development intertwine. Finally, the results may inform clinical practice as the description of the range of typical OE trajectories could help to detect delayed and qualitatively atypical patterns of OE, identify aspects of mother-infant joint OE that are particularly beneficial (or harmful) to OE development, and shed light on properties of objects and the actions they allow that stimulate infant OE development.

**3. DETAILED DESCRIPTION OF THE PROPOSED RESEARCH**

**3.1 Working Hypotheses**

H.1. Over time and according to the literature, there will be an increase in the infant's repertoire of actions and the complexity of these actions. However, **we expect a large number of actions with large variations among infants in the first stages of the study, which will decrease in terms of the number of actions but increase in their level of complexity**. Over time, there will be a stabilization of a certain dominant repertoire of actions with a given object. Similarly, **the trajectory of OE will be dynamic**: retention is expected to occur at short intervals in the same observation, but also to fade. Only with time and increasing repetitions will new actions stabilize.

H.2. Over time and with increased familiarity with the objects, there will be a **gradual shift from interactional-oriented communication to object-oriented communication, and signs of de-contextualization and greater lexical specificity** will emerge.

H.3. **We expect that higher mother-infant EA** (namely, higher maternal sensitivity, more appropriate structuring without intrusiveness or hostility, as well as increased infants' responsiveness to maternal bids and involvement of the mother during joint OE) **will lead to an increase in the variety and complexity of infants’ exploration actions with objects and in infants’ identification of more affordances of these objects.**

H.4. **Intra-individual variability in OE will be associated with specific properties of objects' affordances**. Along with increased variability in action possibilities, it will be possible to identify similar actions across infants concerning specific object properties.

Infant temperament and mothers’ depressive symptoms will be controlled.Infant temperament, especially fear of novel stimuli, motor activity, distress to limitation, duration of orientation, perceptual sensitivity, smiling and laughter, and soothability, may be related to both infant OE73 and mother-infant EA.68 Maternal depressive symptoms are known to affect mothers’ behavior towards their infants, with consequent hampering effects on infant development.86

**4. RESEARCH DESIGN AND METHODS**

**4.1 Study design**

The study will use a micro-development longitudinal design with 12 weekly home observations of OE with a structured three-phase procedure validated in our pilot study. Phase 1 (baseline) will assess *infants’ independent OE*; Phase 2 (interaction) will assess *mother-infant joint OE*, and Phase 3 (retention) will assess infants’ independent OE post the joint OE. Each phase will last 2 minutes. In each session--consisting of these three phases—four different toys, chosen based on their *unique properties,* will be presented by the mothers to the infants. In each phase, the order of presentation of the four toys will be … (RANDOM? COUNTERBALANCED?). The point of the three phases is to enable us to examine changes in OE that occur during a single visit. By analyzing inter- and intra-session behavior, we can chart the development of OE from the initial state reflected in the first phase of the first visit (baseline), across changes in phases 2 and 3 of the first session, to the first phase of the second visit that occurs one week later, and so on repeatedly, from week to week, until the 12th session. In this way, it will be possible to examine continuity and discontinuity in data patterns at different temporal grain sizes: minutes, weeks, and months.

Coding infants’ independent OE and infant-mother joint OE will involve a multi-disciplinary approach that will capture *motor, linguistic, and communicative behaviors,* as well as their *affective quality*. Data will be analyzed using multilevel modeling (MLM) to reveal the effects of socio-emotional and physical contexts on infant OE while taking into consideration the interplay between infants’ OE behaviors across different dimensions of motor, language, communication, and socio-emotional.

GRAPH: We did not decide yet whether to insert here a graph illustrating the design

**4.2 Participants**

Forty healthy, full-term, single-born infants aged 8 months and their mothers will participate and they will be followed up until the age of 12 months. This age range was chosen because major advances in gross and fine motor skills (e.g.,43,48), communication,49 representational abilities50, and the ability to integrate visual, manual, and oral modalities14co-occur during this period. Only infants who can sit without support will be included to exclude the effect of gross motor constraints (e.g., postural control) on OE. Mothers will have at least a high school education. Single mothers and mothers with significant diagnoses (e.g., depression or ADD) will be excluded. The proposed sample size is acceptable (Lewis et al., 1999), as the large number of measurements per infant (a minimum of eight observations X three phases in each observation; see section 4.3) significantly increases the power of this design. The inclusion of 40 infants will yield a minimum of 320 observations and 960 phases. Even with some attrition, expected to be up to 10%, the number of data points will be large enough to guarantee sufficient statistical power to find medium and large effect sizes (i.e., at least .20 or .3087-89). The estimations of the required sample size were based on longitudinal studies employing similar methods with 30-50 participants but with less dense sampling90-92, and on the “sample size mixed” function in the sjstats package for R software.93

**4.3 Procedure**

The procedure was developed based on OE literature and our preliminary findings (see section 4.7). Consistent with previous studies, OE will be assessed with infants in a sitting position in a highchair, thus allowing them to explore freely with their arms and coordinate visual information with manual exploration.34,45,94. Two cameras will be placed to capture infant and mother behaviors, one facing the infant and one from the side. After a brief warm-up, infants will be placed in the highchair, and mothers will be asked to sit on a chair in front of them.

At the beginning of each session, all four objects (arranged together on a tray) will be presented simultaneously for 30 seconds to examine OE preference. Since each session will open with this procedure, we could observe situational and sustained preferences. The toys will be taken away and the baby will be given a bottle of drink to give a pause before starting the main observation.

Each observation will include the following three sequential phases.

*Phase 1 - Baseline: Infants’ free exploration.* The infants will play with each of the four toys. Their mothers will not intervene, except to draw infants' attention to a new object given to them (e.g., “Look at this one!”) or to minimally encourage infants to continue the exploration (e.g., "Nice!").

*Phase 2 - Interaction: Joint OE, with mothers as fully active participants*. Mothers will be invited to play with their infants with each toy in the context of joint natural play, as they would normally do (e.g., they may model actions; instruct the infants on how to manipulate objects; and name, explain, or perform a variety of actions on the objects). After a 15-minute break, the third and final phase begins.

*Phase 3 - Retention: Infants’ free exploration*. As in phase 1, the infants will be allowed to explore each of the objects in turn, with only minimal input from their mothers.

In each of these three phases, the four objects will be delivered to the infants by their mothers, one at a time, but the order delivery will be counterbalanced both between participants and within each participant over time, to avoid order effects and also in case of fatigue or lower attention to the last object presented. Each phase will last 6 min (2 min for each object). The time-lapse of OE (2 min) is consistent with previous studies examining OE with several objects18 and is based on our pilot study (see section 4.7). Written guidelines will be provided to mothers prior to the start of the study to clarify their roles in the various phases, in particular, to differentiate between phases in which they are less active (phases 1 and 3) and the phase in which they are invited to be active (phase 2). The decision to propose a semi-structured design of joint OE at home, as detailed above, was made based on research showing that maternal language inputs to 13-month-old infants during structured play were consistently dense from minute to minute, with no breaks, in contrast to naturalistic routines, which reveal striking fluctuations interspersed with silence. Tamis-LeMonda et al. (2017)

Information on infants' motor and communicative abilities will be gathered at the beginning of the study and once a month thereafter. In addition, mothers will complete online standard questionnaires on infant temperament and maternal depression after sighing a consent form and before the first home visit.

**4.4 Objects**

The following set of four toys was chosen for this study in light of their unique properties (texture, shape, size) and affordances (e.g., rotational movement, rational actions): an elastic rubber cube; two solid blocks; a plastic egg that splits to two parts; a car with a driver figure; see toys’ pictures in Table 1). This number reflects a balance between introducing objects with varied features and infant attention span and tiredness (see our preliminary results).

**4.5 Measures**

Infant OE, mother-infant joint OE, and infant motor and communication development will be rated by independent blind coders. Inter-rater reliability of each measure will be based on 20% of observations.

***Infant OE.*** Micro-genetic coding of infant OE across phases will use ELAN software (EUDICO Linguistic Annotator, the Language Archive; https://tla.mpi.nl/tools/tla-tools/elan/), a frame-by-frame annotation tool for audio and video recordings.95 Every infant action with each object will be coded using a coding scheme that we designed for this study. The coding was adapted from25,26,34,80,96 and expanded according to our observations in our pilot study (see section 4.7). If necessary, it will be further refined at the preparation stage of this proposed study. The coding scheme includes the duration of exploration; the number of new actions; frequency of action; and type of action, namelycomplexity level of manipulation strategies (simple vs. complex), bimanual vs. unimanual manipulation, and multimodality (see section 4.7). This coding scheme will enable us to document changes in action possibilities in terms of the emergence of new actions with each object between phases and between sessions.

***Mother-infant interactions:*** Mother-infant joint OE in phase 2 will also be coded using ELAN. The micro-coding will include four dimensions: Interaction (adapted from60), language, and content (the latter two dimensions developed for the present study). ***The interactional dimension*** includes: *structure*: initiation/response, *modality* (uni/multimodal: verbal, physical), and *type*: object-oriented / interaction-oriented. *Object-oriented* includes referential language (mother provides or requests information about objects or motor actions), instructional assistance (mother provides modeling and explains how to explore and manipulate the object), and symbolic (mother suggests performing symbolic action “as if” with objects). *Interaction-oriented includes* attention-getting and encouragement. For the ***Linguistic\Lexical dimension*,** we will examine the mothers’ total number of words (tokens), the number of different words (types), and lexical diversity (VOCD) using the Computerized Language Analysis (CLAN) program. (MacWhinney, 2000) The analysis of the ***Content dimension*** will allow us to differentiate between contextualized (here-and-now) and decontextualized language, and references to object properties and actions with the object or the other person. The above micro coding will allow us, on the one hand, to delve deep into each of these dimensions and, on the other hand, to cross-check and examine interface points and differences between the three dimensions.

***Mother-infant*** ***emotional availability***. Mother-infant joint OE in phase 2 will be coded using *Emotional Availability Scales – 4th Edition*97, a widely used and well-validated measure.63,67,68,98 Four scales tap maternal behavior: sensitivity, which includes assessment of creativity and positive affect, as well as accurate perception of infant signal, appropriate structuring, non-intrusiveness, and non-hostility. Two scales reflect infant behavior: responsiveness, which includes assessment of positive affect towards the mother, and involvement of the mother as a source of help or as an audience for infant OE. Scales range from 1 to 7; higher scores reflect higher EA.Coders will be trained by PI Sher-Censor, an expert EA coder. EA scales were successfully used by us to analyze 2-min mother-infant interactions90 in our pilot study (see section 4.7).

***Control Variables. Infant motor and communicative development.*** Motor development will be observed using *Alberta Infant Motor Scale* (AIMS99), a well-validated, normed tool for motor performance from birth to 18 months. AIMS is sensitive to motor changes in a one-week window and has beenused previously in Israel (e.g.,44,68). Communication development will be rated using the *Pre-Verbal Communication Schedule* (PVCS100), translated into Hebrew and adapted for use in Israel by Dromi.101 PVCS rates four levels of pre-verbal communication: conditions preceding communication, pre-verbal communication, verbal comprehension, and expressive language (based on maternal reports of the number of words used by the child). **Infant temperament** will be assessed with the widely used *Infant Behavior Questionnaire-Revised Short Form* (IBQ-R-SF102)*,* validated in Israel.68 Mothers will rate the observed frequency over the previous two weeks of 94 temperament-related behaviors using 7-point scales from 1 (never) to 7 (always), with X as non-relevant. **Maternal depression.**will be measured using the depression scale of the *Depression Anxiety Stress Scale 21* (DASS 21103) prior to the first data collection meeting. Mothers will be asked to rate the extent they experienced 7 symptoms of depression over the past week on a 4-point Likert scale from 0 (does not apply) to 3 (applies very much). The scale is widely used and was validated among Israeli mothers (e.g.,104). Mothers with scores above the clinical cut-off score of 21 will be excluded from the study and encouraged to discuss their distress with their physician.

**4.6 Data analysis**

We will conduct growth curve modeling analyses fitted in Mplus (version 8.1105) using a multilevel modeling (MLM) framework. MLM was chosen given its flexibility and ability to easily handle repeated measures of the same outcomes where time points moderately vary across participants and to allow the inclusion of subjects with missing data at certain time points.106,107 Multilevel growth modeling will enable us to examine individual behavior, pattern rate, and shape of change of each infant's developmental trajectory and to identify both time-varying (i.e., variables change over time) and time-invariant (i.e., variables do not vary over time as they are either inherently stable or are measured once) predictors of developmental patterns of change.107,108 Given the rich longitudinal data we expect to gather, we will model and predict growth patterns (linear and non-linear) using three models according to the three research hypotheses. To examine hypothesis 1, a growth model will be fitted for the development of OE, and the variables of language and motor development will be used as predictors of the model parameters (i.e., intercept and slope), which may be one of the sources of variability between infants. We will test if growth spurts are visible following periods of transition in other developmental domains. To examine hypothesis 2, we will use the variables of mother-infant contingent responsiveness and mother-infant EA (as measured during the second phase when infant-mother interactions are observed) as predictors of growth model parameters of the same growth model of OE fitted for hypothesis 1. To examine hypothesis 3, we will use the characteristics of the objects and joint mother-infant actions as predictors of model parameters. In sum, Multilevel growth modeling is a sound and rigorous modeling approach that will enable us to examine intra- and inter-individual developmental trajectories of exploration across time and the factors that promote or hinder it.

**4.7 Preliminary Findings**

We conducted a pilot study to determine the feasibility of data collection, refine the study procedure, develop coding schemes for infant OE and mothers’ contingent responsiveness, and to provide initial evidence of the utility of these coding schemes and the EA to achieve the research aims.

***Data collection*.** Participants were 5 mothers and their infants aged 8 months (1 female, 1 male), 10 months (1 female, 1 male), and 11 months (male). The latter 3 were observed *twice* over *a two-week* period. Observations were videotaped, transcribed, and coded.

***Study procedure*.** During the first two pilot sessions, we took methodological notes and refined the following: (a) *Logistics*– the position of the two cameras facing the mother and infant and the most appropriate setting for introducing the objects (i.e., infant high-chair); (b) *Procedure*– the optimal number of objects, duration of exposure to each, and duration of breaks between phases that would allow observation of a wide range of motor actions but not lead to infant boredom or impatience. The duration of infant OE with each object (1.59-1.90 min) and infant tiredness when introduced to 5 objects led us to include only 4 objects and allow 2 min exploration with each object in each phase; (c) *Objects* - choosing the most appropriate objects to allow a wide variety of motor actions while taking into consideration infants’ chronological age and motor, communication, and emotional development (see Table 1); (d) *Instructions* provided to mothers in each phase.

***Micro-analytic coding schemes*.** The literature on infant OE (e.g.,80) and joint mother-infant interactions with objects (e.g.,109,110) informed the generation of an initial list of primary coding categories. We expanded and refined it based on the observed behaviors of participating dyads. For example, the coding process revealed that at 10 months, infants gestured with objects to communicate with their mothers (see Figure 1). Such action constitutes a bridge between infant OE and mother-infant communication. We added it to the coding scheme and labeled it “motor action for communication”.

![A picture containing text, person, indoor

Description automatically generated]()A picture containing text, person, indoor

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Figure 1: Mother-infant joint OE

***Utility of infant OE, mother-infant contingent responsiveness, and EA coding systems*.** We coded OE for all 5 infants. Contingent responsiveness and EA were rated for the 8-month-old boy, the 2 sessions of the 10-month-old girl, and the 2 sessions of the 11-month-old boy. We conducted frame-by-frame coding of the onset and offsets of infant OE and mothers’ contingent responsiveness using ELAN software. Inter-coder reliability between two coders (graduate students trained by PIs Atun-Einy & Yifat) was performed in 2 sessions (for different infants). Coders achieved an average agreement of 83.5%. Differences were discussed until a consensus was reached. Mother-infant EA were rated using the EAS by an experienced EA coder (PI Sher-Censor). Data analyses indicated the following:

(1) We found *substantial variability in infants’ and mothers’ variables across objects and phases*. For example, infants showed 10 to 82 OE behaviors in each phase, with median scores of 49, 38, and 32 in phases 1 to 3 respectively. EA scores in phase 2 ranged from 4 to 7. The description of the variables were similar to those obtained in low-risk samples63.

(2) We observed the following *trends in infant OE and maternal behaviors across age and phases, supporting the formulation of the hypotheses for the proposed research*: First, simple OE was more frequent than advanced OE. The former decreased and the latter increased with age. This suggests the proposed research has the potential to document the nuanced developmental trajectories of infant OE from ages 8 to 12 months in terms of infants’ expansion of action possibilities and OE complexity. Second, all infants showed a decrease in simple OE behaviors from phases 1 to 2 and from phases 2 to 3 in both session 1 and session 2. This may be related to mothers' scaffolding and modeling of advanced motor actions in phase 2. Third, mothers adapted their actions to the abilities of the infants and showed more complex motor actions when interacting with older infants, indicating their contingent responsiveness to infant OE developmental skills. Fourth, all mothers used fewer simple actions than their infants. However, mothers did not refrain from performing simple motor actions. They adapted themselves to the infant but at the same time offered a variety of complex motor actions, including actions the infant did not perform. Fifth, regardless of infant age, mothers used more object-oriented language than interaction-oriented language (see Figure 2), suggesting the instructions provided were clear. Sixth, the analysis of the sub-categories of object-oriented language showed mothers of younger infants used referential and instructional language with similar frequency, while mothers of older infants used instructional language more frequently. Interestingly, only mothers of older infants used symbolic language, supporting the notion of the effect of infant development on maternal behavior (see Figure 3). In the proposed study, we will identify the profiles of mothers, to examine longitudinally inter-individual variability and changes in the use of language types and their associations with infants' OE.

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Figure 2: Frequency of mothers' object-oriented language vs. interaction-oriented language per infantChart, bar chart

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Figure 3: Frequency of sub-categories of mother object-oriented language per infant

(3) *Coding mothers’ contingent responsiveness (i.e., motor behavior and language) and EA provided distinct information*. Nonparametric tests (e.g., Gamma; *p* < .05) revealed the following. First,these *scores only partially overlapped***.** Mothers’ motor behaviors were associated with maternal interaction-oriented and object-oriented language. Maternal EA was associated with mothers’ more frequent motor behaviors but not with mothers’ language. Second,*each aspect of maternal behavior was associated with* *unique aspects of infants’ OE*.

*Associations in phase 2*: Mothers’ frequency of motor actions, interaction-oriented language, and EA were each associated with a higher frequency of infants’ total OE behaviors, whereas mothers’ object-oriented language was associated with a higher frequency of complex OE.

*Associations between maternal behavior in phase 2 and infant independent OE in phase 3*: Mothers’ motor actions, interaction-oriented language, and EA were each associated with a higher frequency of *total i*nfant OE behaviors; mothers’ object-oriented language was associated with more frequent *complex* OE behaviors of the infant.

*Associations between maternal behavior and changes in infant OE across phases*: None of the maternal behaviors predicted changes in infants’ OE scores from phase to phase, except for maternal motor actions; when mothers showed more motor actions, the decrease in infant OE from phase 1 to 2 was lower, suggesting *mothers’ motor action with the objects helped to maintain infants’ engagement in OE*. Taken together, these preliminary findings indicate the examination of the associations of mother-infant contingent responsiveness and EA with infant OE has the potential to reveal the role of social-emotional context in infant OE development.

(4) Object affordance*: The type of infants’ OE behaviors varied by object*, as shown in Table 1.

Table 1:Sum of Infants’ Simple and Complex OE Across Phases and Sessions by Object

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Action types** | | **Icon  Description automatically generated**  **Elastic Cube** | **A picture containing indoor, toy, decorated  Description automatically generated**  **Blocks** | **A picture containing indoor, helmet  Description automatically generated**  **Car and animated ball** | **Egg that split in two** | **sum** |
| Simple actions | Mouthing | 85 | 89 | 56 | 99 | 329 |
| Banging | 29 | 14 | 25 | 16 | 84 |
| Tossing | 40 | 26 | 18 | 9 | 93 |
| Waving | 11 | 7 | 4 | 0 | 22 |
| Fingering | 8 | 13 | 26 | 11 | 58 |
| Rubbing | 11 | 4 | 5 | 4 | 24 |
| Transferring between hands | 3 | 0 | 1 | 0 | 4 |
| Dividing parts | 2 | 6 | 4 | 3 | 15 |
| Hitting | 4 | 6 | 11 | 17 | 38 |
| **Sum of simple OE** | | **193** | **165** | **150** | **159** | **667** |
| Advanced | Multimodal exploration | 2 | 7 | 10 | 12 | 31 |
| Communication actions | 10 | 1 | 1 | 0 | 12 |
| Advanced- Transforming | Squeezing | 36 | 0 | 0 | 0 | 36 |
| Breaking | 38 | 0 | 0 | 1 | 39 |
| Twisting or bending | 4 | 0 | 0 | 0 | 4 |
| Rotating | 20 | 14 | 29 | 14 | 77 |
| Flipping | 3 | 1 | 9 | 0 | 13 |
| Advanced- Functional | Scooting/moving movable parts | 4 | 3 | 45 | 2 | 54 |
| Advanced-relational | Stacking/building | 0 | 3 | 0 | 0 | 3 |
| Combining | 0 | 4 | 4 | 8 | 16 |
| De-attaching | 0 | 0 | 0 | 2 | 2 |
| **Sum of advanced OE** | | **117** | **24** | **121** | **39** | **301** |
| **Total OE actions** | | **310** | **189** | **271** | **198** | **968** |

**4.8 Conditions Required for Conducting this Research**

The study will be conducted at Haifa University, where there are suitable research provisions for the PIs (i.e., a laboratory equipped with cameras; undergraduate and graduate student research assistants). The PIs belong to different departments – Physical Therapy, Communication Sciences and Disorders, and the School of Psychological Sciences - yielding the interdisciplinary and integrative expertise needed to conduct the study. The PIs have rich experience in the areas of early motor development (both gross and fine), socio-emotional and communicative development, and the application of longitudinal and micro-genetic methodologies and research tools (e.g.,67,111,112). They have already established a meaningful research collaboration (e.g.,113). Our consultant, Dr. Ora Oudgenoeg-Paz, is a leading expert in the research of infants’ object exploration 11,47,92. She has extensive experience in conducting longitudinal studies and in using the specific advanced statistical analyses planned for this proposed study.

**4.9 Expected results and pitfalls**

We expect the results will reveal a range of exploration levels for each infant within each phase and between sessions, with a progression in the complexity of infants' action possibilities and better identification of objects' affordances within and between sessions. We also expect individual differences in mother-infant contingent responsiveness and EA and in infants’ OE despite the common guidelines given to the mothers. We expect the results will meet our working hypotheses and reveal individual trajectories in infants’ OE associated with motor and communication development, mother-infant contingent responsiveness, and mother-infant EA. The rich dataset that results from our study will allow for additional novel secondary research to be conducted. For example, the bi-directional links between infant OE and mother-infant EA can be investigated, as well as the employment of Machine Learning technologies for assessing complex patterns of changes in infant OE.

Although there are potential difficulties with the recruitment and retention of participants for an intensive longitudinal study, our expertise in conducting similar research projects has equipped us with strategies for coping with these issues. ~~It may be difficult to recruit mothers who commit to an intensive, long-term project~~. In addition, data collection with very young infants may be delayed due to unforeseeable or changing situations. Based on previous research, we expect a possible dropout of about 10%. We will try to avoid problems by building rapport with mothers during weekly visits, being in close but non-invasive coordination with mothers, and showing sensitivity to everyday situations. We also intend to provide toys and/or infant books each month, as appropriate compensation, which was useful in retaining participants in our pilot study. As data collection is planned in waves, if dropouts occur, we will continue data collection longer to compensate. Because the study has an innovative and intensive methodology, the time spent on data collection and coding is critical and involves intensive training and labor requirements. Therefore, we piloted the procedures and methods of analysis and carefully planned the project to overcome obstacles as much as possible. Finally, even if COVID-19 is not resolved by fall 2023, our experience with data collection in home visits over the past two years suggests our ability to recruit families and collect data will not be significantly affected.

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