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Characterization and Intervention for Upper Extremity Exploration & Reaching Behaviors in Infancy

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Abstract

The purpose of this article is to: 1) highlight general exploration, reaching, and object exploration behaviors as key activities of daily living in infancy, 2) describe how knowledge of early warning signs for these behaviors may improve early assessment, and 3) discuss interventions that may advance performance of these behaviors. Early intervention for at-risk infants and their families should focus on improving performance of these behaviors for several reasons. First, these early, interrelated upper extremity behaviors serve an integral role in global learning and development in infancy. Second, among at-risk populations, differences have been observed in the quantity and quality of performance of these behaviors. In many cases, these differences are in turn associated with additional perceptual-motor and cognitive delays. This article fills a gap in the literature by summarizing how early assessment and intervention can target these key early behaviors in populations at risk for upper extremity disabilities, such as those born preterm, with Down syndrome, brachial plexus palsy, or arthrogryposis multiplex congenita.

Keywords

general exploration behaviors; reaching; object exploration; preterm; Down syndrome; arthrogryposis; brachial plexus palsy

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1.0 Introduction

The purpose of this article is to summarize the research related to three key categories of early upper extremity behaviors: general exploration, reaching and object exploration behaviors. Specifically, we focus on 1) how these behaviors differ between infants who are typically developing and infants ‘at risk’ for long-term impairments and functional limitations, and 2) interventions that may be used to improve early performance of these behaviors.

The first year of life is a time of significant exploration, learning, and change, and the upper extremities can serve as important tools in these processes.^{1–3} Together, general exploration, reaching and object exploration behaviors, allow curious and motivated infants to explore, gather information, and learn about their bodies, objects, and the complex relationships between them.^{4,5} We chose to highlight these behaviors because they are key activities of daily living for infants, are developmentally interrelated, and are important precursors for *future* activities of daily living including feeding, dressing, and academic activity. These behaviors are especially relevant to clinicians and families as they present differently in infants at risk, impact learning and development, and offer opportunities for targeted intervention strategies.^{6,7} Therefore, early intervention providers and medical professionals should be focused on these ‘high impact’ behaviors for early identification and treatment of delays.^{8–10} We begin this article by defining each of these categories of behaviors, briefly describing their typical development, and highlighting their interrelatedness.

1.1 General Exploration Behaviors

General exploration behaviors are the seemingly random movements infants engage in with their upper extremities when they are interacting with their bodies and surfaces around them.¹¹ Embryos begin performing these behaviors around 8 weeks in utero.¹² A variety of terms have been used to label these behaviors. For instance, these behaviors have been termed spontaneous movements because they seem not to be elicited by external triggers.¹³ A subset of these behaviors involving waving or flapping of the arms has also been referred to as pre-reaching behaviors, although these waving behaviors continue even after reaching has emerged.¹⁴ Because infants perform a variety of behaviors with their upper extremities when objects are not present, including feeling their body and surfaces, mouthing their hands, waving their arms, and looking at their hands, we refer to these behaviors here as general exploration behaviors because they provide opportunities for infants to gather information to learn about their own bodies and surfaces around them.^{15,16}

1.2 Reaching Behaviors

Reaching behaviors bring one’s hand to a target.¹⁷ Reaching for objects with the arms typically emerges between 3 and 5 months of age.¹⁸ Younger infants demonstrate reaching with their hands for parts of their bodies, such as their mouths or faces.¹⁹ They also commonly show the drive and ability to attain objects by reaching using other parts of their bodies such as their mouths or feet.²⁰

Reaching behaviors and general exploration behaviors are developmentally interrelated. The ability to reach dynamically emerges from the general exploration behaviors infants learn to perform each day.¹⁸ For instance, even before infants can successfully reach, they alter their general arm movements when objects are presented within reach.²¹ For example, in the month or two before infants reach for and contact toys, they adapt their general arm movements to become faster, smoother, and closer to toys when they are present versus without toys in view. In addition, infants learn in an individualized manner how to successfully adapt their general arm movements to contact an object without over- or under-shooting the target. Infants with slower general arm movements learn to ramp up their speed to reach a target while those with faster general movements learn to dampen their movement speed to accurately reach targets.¹⁸ Furthermore, infants' ability to perform general exploration behaviors in midline predicts the onset of successful reaching for objects.²⁰ Thus, everyday general movement behaviors serve as the behavioral repertoire from which reaching behaviors emerge.

1.2 Object Exploration Behaviors

Object exploration behaviors provide infants opportunities to gather information about the properties of objects.²² These behaviors include exploring objects with the mouth, looking at objects, and rotating and fingering objects to visually and haptically explore the surfaces of objects.²³ Humans begin performing some of these behaviors in utero or within the first months of life.^{24,25} When infants gather information about objects via exploratory behaviors they learn about causal relationships and about the affordances of objects, or how they can interact with them.^{26,27}

Object exploration behaviors also closely relate to the general exploration and reaching behaviors infants perform. For instance, when provided with objects for the first time, young infants do not immediately perform new behaviors but rather interact with those objects by amplifying and combining already existing general exploration behaviors they perform daily to explore their own bodies and surfaces.¹⁶ Therefore, like reaching, object exploration behaviors emerge dynamically from infants' ongoing general exploration behaviors.²⁸

Reaching experience also impacts the behaviors infants use to explore objects. For example, when objects are attached to infants' hands using hook and loop material, infants mouth, look at, and finger the objects more after they have been classified as reachers than before, despite the fact they were able to perform these behaviors across all assessment points.¹⁶ In addition, infants who reach earlier and have more advanced exploratory abilities also have better performance when attempting causal learning tasks that involve object exploration such as using a switch to control a device.²⁹

Thus, these three behavioral categories, general exploration, reaching, and object exploration, can be viewed as a developmental continuum whereby the development of the latter behaviors is influenced by the development of the earlier behaviors.²⁸ This is a critically important concept for therapists because it suggests that early delays in these behaviors are likely to persist and amplify. Conversely, early interventions targeting one or more of these behaviors are likely to positively impact performance of the other behaviors and global learning and development as well.^{16,29}

Having provided definitions and evidence of behavioral interrelatedness, we will next review the general exploration, reaching, and object exploration literature for infants at risk to highlight differences from typical development in performance quality and quantity, how these differences relate to other areas of development and learning, and ways knowledge of these differences can inform our early assessments. We then review the literature to describe interventions that can potentially improve performance of these three key types of behaviors. We focus throughout on four populations of infants at risk for upper extremity disabilities: infants born preterm, with Down syndrome (DS), with brachial plexus palsy (BPP), or with arthrogryposis multiplex congenita (AMC). As we review the findings from the literature pertaining to these diagnoses, note that the amount of literature on early upper extremity development and intervention is more limited for infants with BPP and AMC.

2.0 Characteristics of Upper Extremity Behaviors Among Infants At Risk for Upper Extremity Disabilities

In reporting the atypical characteristics of upper extremity behavioral development often observed for infants at risk, we group the information to follow by behavioral characteristic rather than by diagnosis or risk factor of the child. This method of organization was chosen because the current literature suggests many of these atypical characteristics present across populations.^{6,7} With further study, it is likely even more commonalities will be revealed in these atypical characteristics across at-risk populations.

2.1 General Exploration Behaviors

Early identification of motor and associated cognitive disabilities is especially challenging in the first year of life. Assessment of general exploration behaviors is worthwhile for the potential identification of very early differences in infants' movement and information gathering techniques that can persist and broadly impact development (Table 1). Several key differences exist in the performance of general exploration behaviors for populations of infants at risk. Moreover, these differences may predict the presence of future neuromotor impairments and developmental delays (Table 1).^{12,30–32} For example, compared to preterm infants with low risk, infants born preterm with high risk, due to low gestational age, low birth weight, and/or low Apgar scores, have general exploration behaviors at one month corrected age characterized by more monotony, less variability, and less complexity.³³ Preterm infants with poorer general exploration behaviors are more likely to have poorer cognitive development and eye-hand coordination at two years.³⁰

Assessment of general movements in the first four months of corrected age using Prechtl's published methods^{34,35} has been shown to be highly sensitive and specific (71–100% and 86–97% respectively with best results at 3 months corrected age) for predicting the future development of cerebral palsy and neuromotor delay for both high-risk preterm populations and lower-risk late-preterm populations.^{36,37} Early general movements that are rigid rather than smooth and fluent and the absence of general movements that are fidgety, defined as small movements of moderate speed with variable acceleration of the neck, trunk, and limbs in all directions, can predict the future development of cerebral palsy.^{12,32} When assessed in combination with the obligatory asymmetrical tonic neck reflex (ATNR), or an ATNR the

infant does not appear able to move out of, qualitative assessment of general movements from six to twenty-four weeks of age can predict minor neurological dysfunction as far ahead as seven to eleven years of age.³⁸ Minor neurologic dysfunction is defined as dysfunction in two or more of the following: posture and muscle tone, reflexes, choreiform dyskinesia, coordination and balance, fine manipulative ability, and rarely occurring dysfunctions such as an excess of associated movements.

Assessment of infants born preterm who either a) presented with periventricular leukomalacia (PVL) in the neonatal intensive care unit or b) displayed future cognitive delays differed in their early general exploration behaviors relative to preterm infants with typical development. At 2 months corrected age, preterm infants with PVL or future cognitive delay have a more frequent startle response, defined as abrupt abduction of the shoulders, extension of the elbows, and opening of the fingers that occurs without a provocative cause.^{39,40} Preterm infants with future cognitive delays also have less frequent mouthing of their hands and perform less cyclical arm movement.⁴⁰

Infants with DS also show differences in their early general exploration behaviors. From birth through two months, their general exploration behaviors are slower, larger amplitude, less smooth, less variable, and less complex in terms of coordination of movement across the arms, legs, neck, and trunk compared to the behaviors of typically developing full-term infants. Their movement repertoire also lacks the large, fast extensor movements of the arms and legs as well as the small range movements seen in typical development.⁴¹ From 4 through 6 months of age, infants with DS kick their legs less than do infants with typical development.⁴² These differences may relate to factors such as the high incidence of muscle co-activation, low muscle tone, ligamentous laxity, and muscle weakness typically observed in this population.^{43–45}

Infants at risk for upper extremity disabilities also may demonstrate diminished isolated joint movements and increased associated movements, suggesting their coordination may already be impaired.^{32,39} For instance, at 2 months corrected age, preterm infants with PVL perform fewer isolated movements of the upper extremity and neck joints.³⁹ Similarly, infants with neonatal stroke who developed hemiplegia show less frequent independent finger movements relative to infants with neonatal stroke who did not develop hemiplegia and to healthy infants.³² Preterm infants with a neurological diagnosis or developmental delay at three years of age may have general exploration behaviors in the months surrounding their expected dates of birth characterized by lower average velocities, lower numbers of movement units, higher correlations between limb velocities, and poorer ability to dissociate movement of the arms.⁴⁶ Taken together, infants at risk for upper extremity disability may move less often, more slowly, less variably, with less complexity, and typically with their limbs mirroring one another by moving with similar speeds and paths.

2.2 Reaching Behaviors

Key differences have also been reported in the performance of early reaching behaviors for populations of infants at risk for motor and learning disabilities. Knowledge of these differences can inform early assessment practices (Table 1). Infants at risk for upper extremity disabilities often show delayed emergence of reaching behavior followed by

differences in reaching quality and quantity.^{8,47,48} For example, infants born preterm with high risk, such as low gestational age or identified brain injury, start reaching later and show poorer upper extremity control, with reaches that are jerkier, slower, and less straight than low risk preterm infants and full-term infants.^{49,50} These infants with poorer early reaching ability are more likely to demonstrate minor to moderate neurologic dysfunction and poorer fine motor skills at 6 years of age.⁴⁷ By 6 months of age, high-risk preterm infants born less than 32 weeks of gestational age, continue to have reaches that are less smooth, slower, and less straight when compared to full-term infants and these deficits are related to poorer postural control.^{48,51}

Infants with Down syndrome are also more likely to have delayed emergence and amount of reaching ability compared to typically developing infants.⁵² They are more likely to start reaching a month or two later and, once able to reach, they reach less often and with movements that are slower and less smooth than typically developing infants.^{52–54}

Infants at risk for delays not only have impairments in getting their hands to objects but they may also be less able to keep their hands at objects for extended periods, which is critical for exploration, play, and learning.⁸ For example, preterm infants reach less frequently than do full-term infants in the first half-year of life. Early intervention can increase this contact frequency but even after intervention, preterm infants may still keep their hands at toys for significantly shorter durations than do full-term control infants, suggesting they have trouble sustaining their arms raised against gravity to explore a target.⁸

Early reaching impairments can also be observed in low-risk preterm infants. For example, from 5 – 7 months of corrected age, their reaches are slower and require more adjustments to reach a target than do the reaches of full-term infants.⁴⁹ Furthermore, at 8 months of corrected age, low-risk preterm infants reach for a moving target with a hand path that is less straight than the reaches of full-term infants.⁵⁰

2.3 Object Exploration Behaviors

Differences have also been identified in the performance of object exploration behaviors for populations of infants at risk and knowledge of these differences may improve our ability to identify early motor and cognitive delays (Table 1). Less exploratory behavior with objects has been reported for those in impoverished environments, with micronutrient deficiency, with socioeconomic risk, with Down syndrome, or with preterm birth.⁷ Infants with Down syndrome show poorer ability to grasp objects they reach for from four to 6 months of age relative to typically developing infants.⁵² Infants with Down syndrome also tend to show more looking at objects without acting on them, less variability of behaviors performed with objects, shorter sequences of behaviors with objects, and poorer coordination of interaction with both people and objects.^{55,56} Because varied behavioral performance with objects is a hallmark of early exploratory learning and joint attention between people and objects is important for word learning and early language development, these early object exploration differences may broadly impact cognitive and language development for these children.^{57,58} For infants with autism, it is typical to observe performance of at least one atypical exploratory behavior with objects, such as prolonged spinning, by twelve months.⁷

In addition to less object exploration, infants born before 34 weeks of gestational age also tend to perform fewer types of exploration such as fingering, rotating, squeezing, throwing, waving, touching the body with objects, and transferring of objects between the hands. Moreover, this diminished exploratory performance has been related to poorer cognition at two years (correlation of 0.63).^{22,59} These differences are amplified in populations with lower birth weight, a history of respiratory problems, or brain injury.^{22,60} Moreover, infants born before 37 weeks of gestational age and less than 2500 grams require more time to recognize some objects as familiar and are poorer at recognizing other objects as being novel. This suggests they may not be rapidly learning to identify and classify objects via their exploratory behaviors as is typical.^{61,62}

Infants born before 30 weeks of gestational age have also been shown to have less variability in their object exploration behaviors. Variability is an important part of the typical development of perceptual-motor behaviors, such as reaching and sitting.^{63,64} Performance of a variety of behaviors allows infants to experience a range of consequences, which in turn facilitates additional behaviors ultimately providing an ever expanding behavioral repository from which they learn future functions.⁶⁵ Additionally, infants born preterm spend less time performing multi-modal behaviors, combinations of behaviors, and/or display delayed or absent ability to match their behaviors to object properties compared to full-term infants. For instance, they are more likely to wave all objects in the air rather than selectively waving a maraca in the air to elicit its sound. This suggests their early information gathering is altered and impaired relative to their typically developing peers. Moreover, infants born preterm with PVL or Grade III or IV intraventricular hemorrhage as well as infants who experience a neonatal stroke demonstrate less bimanual, midline exploration of objects.⁶⁶ Bimanual behaviors are important because infants use them to perform more complex behaviors to learn about objects, such as manipulation behaviors and fingering.

Although there have been no formal studies documenting general exploration, reaching, or object exploration behaviors in infants with AMC or BPP, these infants typically present with contractures, muscle weakness, and muscle coordination impairments that significantly limit their ability to move one (BPP) or both (AMC) of their arms to engage in these behaviors.^{67,68} Studies have documented the existence of significant upper extremity and general developmental disabilities in children with AMC from the age of 2 through 18 years and in children with BPP that required surgical intervention from the age of 1 through 4 years.^{69,70} These findings suggest upper extremity behavioral differences exist for infants with AMC and BPP but need to be formally documented.

2.4 Implications for Early Assessment

As described above and in Table 1, a variety of early differences in general exploration, reaching, and object exploration behaviors may be identified during infancy for those at risk of future delays. Identification of these differences may serve as an important alternative or adjunct to existing standardized assessments to enhance early detection of impairments. There is a need for better early assessment techniques since many commonly used standardized normative assessment tools have been shown to poorly identify delays in the

first years of life.⁵⁸ We propose that in order to successfully identify these differences, early intervention professionals must first be trained to recognize the high amount, intensity, and variability with which typically developing infants perform these behaviors. This training is most likely effective in the form of extended, focused observation of typically developing infants in natural, social play settings.

Early intervention professionals must recognize the interplay between diagnosis and the early impairments described in Table 1. Infants born preterm or with Down syndrome should be monitored to identify whether they are moving and engaging with objects less often, less variably, less often in midline, and with more monotonous, less complex behaviors.⁵⁹ Because early behavioral differences have been noted across all populations of preterm infants studied, caregivers and health care providers of late and early preterm infants with low or high-risk, should be taught to look for these behavioral differences.^{34,49}

The literature reported has been heavily weighted towards infants with preterm birth or Down syndrome but similar early impairments are likely to also exist in other populations. For instance, infants with AMC have a known paucity of general exploration movements in utero and throughout infancy.^{67,71} Because general exploration movements form the foundation for reaching and object exploration behaviors, these three categories of behaviors should be a focus of early assessment and intervention for this population. These infants also have profound weakness that impairs their ability to lift their arms against gravity, which makes them likely to have other key early impairments in behaviors such as bringing toys to the mouth, into the field of view, or to the other hand for extended time periods.⁶⁷ Each of these behaviors can be a focus of early assessment and intervention.

These same early signs should be a focus of early assessment and intervention for infants with unilateral injuries such as BPP.⁷² However, even in these populations, behavioral performance should be assessed looking at both upper extremities because impairments such as weakness have been identified in the contralateral upper extremity for children with unilateral injuries.⁷³ Therefore, early intervention providers need to have a strong understanding of typical development, of early warning signs of atypical development, and of the interplay among diagnosis and early general exploration, reaching, and object exploration behavioral development.

3.0 Potential Interventions to Improve Upper Extremity Behaviors for Infants At Risk for Developmental Delay

Now that we have highlighted key differences in the performance of general exploration, reaching, and object exploration behaviors in at-risk infants, the relationship among these behaviors and future neuromotor dysfunction and cognition, and early warning signs to focus on in assessment, we will discuss potential interventions supported by the literature to address these differences.

3.1 Potential Interventions for General Exploration Behaviors

Techniques supported by the literature to improve early general exploration performance involve positioning and/or the use of toys to elicit these behaviors (Figure 2). Two recent

articles support the use of positioning interventions. The first measured general exploration behaviors of preterm infants (born at 25–31 weeks of gestational age and between 685 and 1650 g) when they were positioned supine without support and when they were positioned supine in a “nest”.⁷⁴ The nest was a soft, shell-shaped support created by surrounding the infant with an oval consisting of two rolled blankets. When in the nest, preterm infants showed a more flexed posture with greater shoulder adduction, greater elbow flexion, and the head more often in midline. This position is thought to be important to promote hand to mouth behavior and optimal musculoskeletal growth, for instance by preventing the development of malalignment of the shoulder girdle. This position is thought to also be important to counteract the excessive scapular adduction with shoulder elevation and external rotation that accompanies the extended posture high-risk infants often assume. This extended posture, if not addressed, may potentially lead to future difficulties performing midline arm movements, reaching, maintaining a supported prone position, and rolling.⁷⁵ Preterm infants in the nest also showed more wrist movements involving rotation, more movements of the hands toward and across midline, fewer abrupt movements and less time with the limbs stationary.⁷⁴

The second study was a longitudinal positioning study in the neonatal intensive care unit (NICU).⁹ It compared a preterm positioning group that received two to four weeks of positioning intervention with a preterm control group that received standard of care in the NICU. Preterm infants in this study were born between 25 and 32 weeks gestational age, weighing 811 to 1562 g. The positioning program requested that caregivers position infants in three positions: 1) prone, flexed and wrapped with a nest for stability, 2) supine, wrapped in a nest as described above, and 3) sidelying, also wrapped in a nest and with a towel between the arms to support the upper arm. Results suggested that positioning infants brought their hands to and across midline more frequently, and displayed greater variability in their movement velocity. At one month after the positioning program ended, positioning infants performed general exploration behaviors that were more similar to full-term infants.

Positioning interventions may not only be effective at promoting general exploration behaviors for infants born preterm and in the early months of life, but they may also be helpful at promoting these behaviors for infants with other diagnoses. For instance, positioning sidelying in a nest may help promote bimanual activity, hand to mouth behavior, and looking at the hands for infants with DS, AMC, or BPP.⁷⁶ Experience moving across a wide variety of positions is important for early learning and motor development for all infants, those with typical development and for those at risk for delays.^{77,78} Therefore, properly supported prone, sidelying, and supine positioning should be a focus of intervention across populations.

The use of activities whereby infants receive pleasing feedback from a toy in response to increased general movement of their arms may also serve as effective interventions to promote general exploration behaviors.^{29,79} Since reaching and object exploration behaviors emerge from general arm movements, the promotion of general exploration behaviors may also serve to advance these future behaviors.⁸⁰ For example, one may softly tether an infant’s wrist to an overhead mobile or toy so that movements of the arm result in pleasing movement of the toy.^{79,80} This in turn excites the infant to elicit further general

movement.⁷⁹ By using electronic goniometers, accelerometers, or infrared technology, instrumented play environments can be designed whereby infants must elicit specific patterns of movement in order to receive feedback from the toy.^{81,82} This type of tool could help infants increase their amount of general exploration, improve their movement variability and improve their ability to dissociate movement across joints within and across limbs. It could also be used to tailor interventions to meet the individual needs of infants with AMC or BPP who often have muscle imbalances and contractures that can lead to maladaptive movement patterns that can result in future secondary impairments. For instance, specific movements into shoulder or elbow flexion could be rewarded with toy activation while movement of the arm initiated from the trunk or scapula would not be rewarded.

Play activities that use toy movement and sound production to reinforce general exploration behaviors can be an effective, inexpensive way to encourage increased movement in the first year of life (Figure 2).⁵⁸ Parents can be easily be involved in helping their children engage in these activities by using a soft ribbon to tether their wrist(s) to a helium balloon, overhead mobile, or any toy that will move when the arm moves.⁷⁹ These activities can be performed in a variety of positions such as a) supine, sidelying, or prone in commercially available play gyms; b) in reclined sitting, such as in commercially available bouncy seats, c) in upright sitting such as in a booster seat. Through these activities, infants can have relatively high dose movement experiences that are varied with respect to task constraints and the role of gravity.^{57,83} We propose that these play activities should be a focus for any populations known to have diminished early movements, such as infants born preterm or with DS who tend to have general exploration behaviors of lesser amount and poorer quality, infants with AMC who have diminished movements that persist after 8 weeks in utero, and infants with BPP who have diminished movements in the affected upper extremity after birth.^{67,72}

3.2 Potential Interventions for Reaching Behaviors

Techniques supported by the literature to improve the emergence of reaching in at-risk populations involve increasing general exploration behaviors, handling and positioning techniques, and task-related interventions with objects (Figure 2).^{8,29,80} Because infants build upon general exploration behaviors to perform their emerging reaching behaviors, activities that promote increased general movement behaviors can advance reaching behavior.⁸⁰ Two-month-old infants who had each limb tethered to an overhead toy, 5 minutes for each hand and foot, had improved reaching ability after just one to two weeks. Specifically, these infants increased the number of foot- and hand-toy contacts and spent more time holding the feet close to a toy relative to a control group that did not receive movement training. This reinforces our earlier proposal that activities to increase general exploration performance may also improve future reaching.

Reaching can also be advanced by educating caregivers in Western cultures on new ways to handle and position their infants (Figure 2).^{29,84} Attainment of motor milestones is typically advanced in cultures with parental handling and positioning techniques that challenge infants, for instance by providing them less support for their heads and trunks, relative to the practices in Western cultures.^{85,86} Educating caregivers to handle and position their infants

differently in the first month or two of life may effect behavioral changes. Studies have included education that encourages: 1) increased play in prone in a variety of contexts, such as on the floor, being held like an “airplane”, or on the caregivers’ legs or stomach; 2) pull to sit activities, 3) time moving in and out of the base of support in supported sitting and supported standing; and 4) play activities and positioning to encourage midline hand movement, such as scaffolded hand clapping play and sidelying positioning.²⁹ Throughout the activities, the appropriate level of assistance should be provided to support yet challenge the infant.

These types of activities can advance head and trunk control within just two weeks when provided within the first month or two of life.⁸⁷ This is important because head and trunk control play a critical role in reaching and other manual behaviors for the maintenance of balance and for the visual location and attendance to targets.⁸⁸ These activities can also advance the emergence of reaching, can improve infants’ ability to contact objects more frequently and for longer periods of interaction, and can increase the amount of bilateral reaching through five to six months of age even when the activities were prescribed for only a few weeks at two months of age.²⁹ Therefore, caregivers of infants at risk for impaired or delayed reaching behavior, such as those born preterm, with DS, AMC, or BPP, should be educated on how they can safely and appropriately use handling and positioning practices to challenge their infants throughout each day before infants are able to demonstrate more independent mobility and transitions.

More task-related interventions have also been shown to improve early reaching performance (Figure 2). For instance, educating caregivers to present objects within reach and to scaffold, or assist, early reaching attempts starting in the first month or two of life can advance the emergence of reaching.^{8,29} These experiences can improve infants’ abilities to contact objects more frequently, to keep their hands at objects for longer periods to interact with them, and to bring both hands to objects.²⁹ A larger level of assistance may be needed at first as infants learn to control their arm movements and learn that in addition to being interesting to look at, objects are also interesting to manually explore. Short-term task-related reaching interventions have been shown to improve early reaching ability for infants born preterm.⁸⁹ Four minutes of scaffolded midline reaching for objects can increase number of object contacts. Therefore, early reaching intervention programs should not only include activities to increase general arm movements and to alter early handling and positioning experiences. They should also include task-related experiences that allow infants to interact with objects so they learn more about the behaviors they can perform with objects and grow their motivation to more independently retrieve desired objects.

Interventions that combine the above techniques are likely to be the most effective. Most of the studies we have mentioned to advance reaching have focused on advancing reaching using one type of intervention. In contrast, one recent longitudinal intervention study involved a hybrid home training program with preterm infants less than 33 weeks gestational age.⁸ The intervention included a hybrid of the aforementioned general movement and task-related activities provided by caregivers. They included tethering the arm to toys to encourage increased general exploration behaviors and task-related reaching experience with toys with appropriate levels of assistance from caregivers starting at 8 weeks of corrected

age.^{29,80} Preterm infants who received the training improved the onset of reaching, number of reaches, and duration of reaches relative to preterm infants who did not receive training.⁸

3.3 Potential Interventions for Object Exploration Behaviors

There are a variety of techniques supported by the literature for improving object exploration performance (Figure 2). For example, kangaroo care, or the promotion of skin-to-skin contact, has been shown to improve object exploration abilities for infants born preterm before 33 weeks of gestational age and with low birth weight.⁹⁰ This intervention involves daily skin-to-skin contact between the infant and caregiver and is especially effective when provided in the NICU environment when infants are connected via tubes to a variety of medical devices and might otherwise be lacking this type contact. When provided for just two weeks in the NICU for one to two hours daily, this type of intervention can improve object exploration at six months of age.^{10,90,91} This is evidenced by improved maternal-infant-object interactions, with mothers handing toys more frequently to their infants and engaging in joint object manipulation more often. It is also shown by longer periods of sustained exploration relative to a preterm control group. Interestingly, this type of intervention has also been shown to have additional benefits for preterm infants, including improvement of sleep-wake cycles, self-regulation, respiratory function, and maternal attachment behavior in the first year of life.⁹⁰ Furthermore, it has been shown to have benefits, such as more organized sleep cycles, improved cognition, and improved stress responses, that last throughout the first decade of life.⁹²

The use of sticky mittens, or mittens of hook and loop fabric, during play with objects before the emergence of reaching has been shown to improve object exploration behaviors for typically developing infants and may be a potentially effective intervention for at-risk infants (Figure 2).⁹³ This was evidenced by changes such as increased looking at objects, increased time exploring objects, and greater number of switches between looking and mouthing allowing for comparison of information. This intervention involves daily play with caregivers using “mittens” or hand straps made of soft fleece with hook and loop covering to play with a variety of objects that are also covered with hook and loop material so they adhere to the mittens easily. This can allow infants with poor grasp to maintain contact with objects for more prolonged periods of exploration and information gathering. Hand straps that allow for maximal exposure of the fingers and hands can allow infants to gain useful tactile information. This can be achieved by simply looping the soft loop strap of the hook and loop material around the infant’s wrist and palm.¹⁶

Caregiver training on handling and positioning techniques as described above for the advancement of reaching has also been shown to advance object exploration behaviors for infants with typical development and to serve as an effective intervention for infants at risk (Figure 2).^{29,84} When performed for just a few weeks in the second month of age, these activities can advance the emergence and performance of a range of behaviors from reaching, mouthing, fingering, and transferring objects hand to hand through crawling and walking.

Caregiver training to provide daily object-oriented experiences has also been shown to advance object exploration behaviors for infants with typical development and may serve as

an effective intervention for infants at risk (Figure 2).^{29,80} These activities involve providing daily experiences for assisted play with objects involving reaching for, grasping, feeling, and mouthing a variety of objects. When these activities are provided for a few weeks at 2 months of age before the onset of reaching, they can not only improve early reaching and object exploration abilities but they also improve future problem-solving abilities.

For older populations with upper extremity impairments that are unilateral or are asymmetrical with one limb affected more than another, there are also a variety of intervention techniques that have been shown to be effective at improving upper extremity function.^{94,95} There is a need to study the feasibility and effectiveness of these interventions for infants and young children, such as those born preterm with hemiplegia or those with BPP. For example, constraint induced movement therapy (CIMT) where the unaffected limb is constrained, via hard constraints like casts or soft constraints like puppets, and individuals are encouraged to use their affected limb for tasks has been shown to result in improvements in unilateral and bimanual function that can last for months after intervention for children with hemiplegia and adults after stroke.^{94,95} Intensive bimanual upper extremity therapy has been shown to have similar benefits as CIMT for these same populations, but the functional benefits from bimanual training tend to be greater.^{94,95} Recent case reports using these interventions for infants born preterm or with neonatal stroke at 7 to 18 months corrected age suggest CIMT and bimanual training are feasible to provide during infancy and can improve motor function.^{96,97} A combined protocol of CIMT and bimanual training called COMBIT has been proposed for use for individuals with hemiplegia.⁹⁸ And a randomized controlled trial of CIMT for infants with unilateral upper extremity impairment was recently initiated.⁹⁹ Other potential interventions that have been shown to improve upper extremity function for older populations but need to be tested in younger populations are mirror therapy and robotic therapy.^{100–102}

4.0 Conclusions

General exploration, reaching, and object exploration behaviors are three key sets of behaviors that should be a focus of early assessment and intervention for infants at risk for delays. In this paper, we reviewed the literature to demonstrate: 1) why these are important early behaviors, 2) how they present differently in at-risk populations and can therefore inform early assessment practices, and 3) interventions that may improve performance of these behaviors and learning in infancy. These behaviors individually have been shown to be important for early learning and development and to relate to future neuromotor and cognitive outcome.^{22,29,31} However, what is even more interesting and important for clinicians is to recognize that these behaviors are highly interrelated and impact one another dynamically in early development.^{16,80} Thus intervention to address future developing skills such as object manipulation skills *should not wait* until infants are older or have begun to show delayed performance of these skills. On the contrary, by understanding the foundational behaviors from which these behaviors emerge, intervention providers can begin to impact development proactively, starting very early with the aim of maximizing future motor and learning abilities.¹

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Highlights

- General exploration, reaching, and object exploration behaviors are key activities in infancy.
- Knowledge of early warning signs for these behaviors can improve early assessment.
- Early intervention activities can be provided to advance these behaviors.
- By advancing these behaviors, infants are better equipped to explore and learn.

Figure 1.

A) Depiction of the developmental progression of the amount and variability of general exploration, reaching, and object exploration behaviors during awake, alert periods throughout the first year of life in typical development. B) For infants and children with upper extremity impairments, these trajectories may be narrower and stretched out across time, reflecting reduced amount and variability as well as delayed performance of these behaviors.

Intervention Activity	Suggested Provision Timeline	Visual Examples
<p>Positioning in Nests: Use rolled towels or other soft and safe supports to encourage flexed, midline positioning of the limbs in supine, prone, and sidelying.^{9,74}</p>	Should begin in the neonatal intensive care unit
<p>Kangaroo Care: Encourage skin-to-skin contact between caregivers and infants^{10,91}</p>	Should begin in the neonatal intensive care unit
<p>Prone Positioning: Provide frequent, varied opportunities for infants to move and play in prone when they are awake, for example prone on the floor, on a caregiver's chest or lap, or held in prone.^{29,84}</p> <ul style="list-style-type: none"> • Level 1: Simple weight bearing in prone • Level 2: Use social interaction and objects to encourage the infant to push up on the arms 	Should begin within the first days of life if stable
<ul style="list-style-type: none"> • to lift the head and trunk • Level 3: Encourage the infant to shift weight side to side, to pivot, and to unweight one or both arms for reaching and object play. • Level 4: Encourage mobility in prone via crawling and creeping as well as transitions among prone, quadruped, and sitting. 		
<p>Variable Positioning and Play: Provide infants opportunities to learn to move their bodies in a variety of positions, such as supine, prone, sidelying, semi-reclined, and sitting</p> <ul style="list-style-type: none"> • Social interaction and music may be used to encourage infants to increase their amount and pattern of movement.¹⁰³ • Tethering infants' limbs to overhead toys such as helium balloons or mobiles so that their movement causes movement and sound from the toy may also be used to increase their amount of movement.^{79,80} 	Should begin within the first days of life if stable
<u>Midline Play:</u> Encourage midline hand activities using social and object play activities ²⁹	Should begin within the first days of life
<u>Pull to Sit:</u> ²⁹ <ul style="list-style-type: none"> • <u>Level 1:</u> support the infant semi-reclined on your legs, place your hands on the infant's trunk, and raise/lower the infant to/from an upright position using your finger(s) to support the infant's head as needed • <u>Level 2:</u> support the infant semi-reclined on your legs, hold the infant's hands, and raise/lower the infant to/from an upright position • <u>Level 3:</u> place the infant in supine on a comfortable surface, place your hands on the infant's trunk, and raise/lower the infant to/from an upright position using 	Should begin within the first month after expected date of birth if stable

<p>your finger(s) to support the infant's head as needed</p> <ul style="list-style-type: none"> • <u>Level 4</u>: place the infant in supine on a comfortable surface, hold the infant's hands, and raise/lower the infant to/from an upright position • <u>Notes</u>: Give the infant a couple of short pulls before beginning the movement to allow the infant to contract his/her muscles. Move slowly throughout. 		
<p><u>Sitting Activities</u>: Provide infants opportunities to hold their heads and trunks upright while interacting with people and toys in sitting, providing them as much assistance as necessary. Start by holding infants at the head and shoulders. Move your hands lower as they show the ability to hold their heads and trunks upright. Then challenge them by tilting their trunks slowly forward, backward, and laterally, allowing time for infants to adjust their head and upper body positions as they are moved.²⁹</p>	<p>Should begin within the first month after expected date of birth if stable</p>

<p>Standing Activities: Provide infants opportunities to hold their heads and trunks upright and to bear weight through their legs while interacting with people and toys in standing, providing them as much assistance as necessary. Start by holding infants in their axillae. Move your hands lower as infants show the ability to hold their heads and trunks upright and bear more weight. Then challenge them by tilting their trunks slowly forward, backward, and laterally, allowing time for infants to adjust their head and upper body positions as they are moved.²⁹</p>	<p>Should begin within the first month after expected date of birth if stable</p>
<p>Play With Toys: Present safe toys within infants' reach to provide frequent opportunities for them to look at objects, to reach for them, to hold them, and to feel them with their hands and mouth.^{29,80}</p> <ul style="list-style-type: none"> • Assist infants in these activities as needed to encourage and support them. • Allow infants to play in a variety of positions, including supine, prone, sidelying, sitting, and semireclined. • For infants with poor or emerging grasp ability, hook and loop bands can be used to help them maintain contact with objects for longer periods of play and exploration. 	<p>Should begin within the first month after expected date of birth</p>
<p>loop bands can be used to help them maintain contact with objects for longer periods of play and exploration.</p>

Figure 2.

Suggested activities caregivers and early intervention providers should encourage infants to engage in for a continuum of care to facilitate the development of key early upper extremity behaviors. Because the development of general exploration, reaching, and object exploration behaviors are interrelated in infancy, these activities aim to facilitate them as a group.

Table 1

Warning signs to look for in early assessment of general exploration, reaching, and object exploration behaviors for infants at risk for upper extremity movement disabilities. Note that a strong understanding of typical development is required for clinicians to identify these differences and that there is a need for future research to better quantify performance of these behaviors in typical and atypical development.

Category of Behavior	Suggested Time Frame to Assess	Early Warning Sign for Future Disability
General Exploration Behaviors	Birth through 9 months corrected age	Movements that are very monotonous or repetitive. Infant does not perform a variety of combinations and types of movements of the arms, legs, neck, and trunk. These movements should include different patterns of arm waving, leg kicking, mouthing one's hands, feeling one's own body and surfaces, and a variety of movements of the wrist and fingers.
		Movements that appear too rigid and not smooth.
		Diminished amount of fidgety movements after 6 weeks corrected age. Fidgety movements are the small movements infants perform continually with their arms, legs, neck, and trunk when they are awake.
		Presence of an obligatory asymmetrical tonic neck reflex after 6 weeks corrected age.
		Diminished mouthing of the hands
		Diminished cyclical waving of the arms
		Diminished isolated movements and increased associated movements. This could manifest as less frequent movement of the wrist, elbow, or shoulder alone, or of one finger alone. It could also manifest as mirroring behaviors within and among the arms. For instance, within an arm, the shoulder and elbow may most often flex and extend in unison. Across limbs, the arms may appear to be mirroring one another in their movement directions and speeds most often.
Reaching Behaviors	After 3-5 months of age	Reaching onset delayed after 5 months corrected age
		Infrequent number of contacts with objects after the onset of reaching, either due to diminished number of reaching attempts or due to reaching attempts characterized by lack of contact with the target object.
		Inability to keep the hands at objects for extended periods (more than 4-5 seconds at a time) to explore and play with them. Contacts may even be frequent but will be short like the infant is swatting at the toy.
		Reaches where the arms move in a manner that is jerky, slow, and less straight .
Object Exploration Behaviors	After birth	Decreased overall amount of interaction with objects. Infants may have atypical delays in starting their interactions with objects that are presented. They may also seem to interact with objects less intensely.
		Less variability in the behaviors performed with objects. Infants may perform the same behaviors repeatedly rather than switching among a range of behaviors.
		Diminished performance of combinations of behaviors and multimodal behaviors (looking while acting on objects). Infants may be more likely to look at objects while holding them stationary and not performing other actions on them. They may also be more likely to perform one behavior at a time, such as fingering objects alone or mouthing objects alone, rather than performing behaviors in combination, such as fingering objects while mouthing them.
		Diminished performance of bimanual midline behaviors. Infants may be more likely to interact with objects using only one hand at a time and in areas that are more lateral.
		Diminished ability to match exploratory behaviors to the properties of objects. Infants may have their routine of exploratory behaviors that they perform across all objects presented regardless of how these behaviors inform the infant about the objects. For instance, they may cyclically wave all objects in the air. This is typical behavior and is informative for objects that make sound when moved. It is less typical and informative for objects that have textured surfaces and do not make sound. Infants should learn to finger and feel these types of objects and this learning may be impaired.
		Diminished touching of the body with objects. Infants may spend less time especially in the first 6 months of life, touching their faces, trunks, arms, and legs with objects they are holding.

Category of Behavior	Suggested Time Frame to Assess	Early Warning Sign for Future Disability
		Diminished waving of objects. Infants may cyclically wave objects in the air when they are being held, especially in the first 9 months of life.
		Diminished fingering of objects. Infants may spend less time holding objects in one hand and feeling their surfaces with the fingers of the other.
		Diminished rotation of objects. Infants may spend less time holding objects and turning them to reveal their different sides.
		Diminished squeezing of objects. Infants may spend less time squeezing objects with one or both hands to experience the density and material properties of the objects.
		Diminished transferring of objects. Infants may pass objects from one hand to the other less often.
		Diminished throwing of objects. Although infants may drop objects because they are difficult to hold, they may less often engage in throwing games where their arm movements, facial expressions, and vocalizations suggest they are purposefully throwing objects for play.
		Performance of atypical behaviors with objects. Infants may engage in the performance of atypical behaviors with objects, such as prolonged spinning or visually exploring them primarily using peripheral vision.