The Value of Providing Early Mobility to Infants with Motor Impairments: For Patients, Families, and Physical Therapists

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I. Introduction

Scientists have long been captivated by the concept of self-directed locomotion. While locomotion certainly serves to move an individual from one point to another, researchers and theorists have questioned whether development of locomotor skills occurs in isolation or in concert with maturation of other systems.[1,2,3] For example, the Dynamic Systems Theory suggests that early global development is a product of genetic, neural, behavioral, and social interactions.[2] This concept contributed to development of theories related to embodied cognition, which states that physical interactions with the environment and associated sensorimotor experiences are important contributors to the development of cognitive skills.[4,5,6,7] Psychologist Jean Piaget also proposed that cognitive development is reliant upon motor function.[1,3,4,5] According to these theories, locomotor development does not occur in isolation; rather, acquisition of motor skills directly affects the development of critical cognitive skills.

II. The Interaction of Motor, Cognitive, Language, and Social Development

Motor and cognitive functions share common regions of the brain, including the dorsolateral prefrontal cortex, cerebellum, and connecting structures, further validating the need to explore the relationship between motor and cognitive development. [1,3,4] As early locomotion research has emerged, evidence supporting associations between motor development and specific cognitive functions has emerged. Heineman et al[3] studied the association between motor skill acquisition during infancy and IQ at age 4. For children with delayed motor skill acquisition during infancy, the average IQ at 4 years was 8.9 points lower than infants without motor delay.[3] In a study of the effects of motor skill development upon various domains of executive function, Wu et al[5] found that gross motor abilities at age 2 were related to cognitive inhibitory control and even working memory at age 3.

Uchiyama et al[8] compared three groups of infants in a study of visual proprioception: infants with no locomotor experience, infants with locomotor experience with a walker, and creeping infants. When peripheral optic flow was induced in a room with moving walls, the authors found that infants in the two groups with locomotor experience demonstrated greater postural compensation compared to the group with no locomotor experience. Additionally, the infants with locomotor experience demonstrated more instances of emotional expressions in response to optic flow. These results suggest that the infants with locomotor experience were better able to interpret and use postural muscle activation to adapt to differences in visual and vestibular input, and were emotionally conscious of this novel scenario and its implications (i.e. risk of falling).[8]

In addition to cognitive development, the development of language skills typically occurs in a pattern parallel to motor development.[4,6] Neuroimaging has demonstrated that areas of the brain involved with language, such as Broca's area, are active during motor performance; likewise, areas involved with motor function are often active during language tasks.[4,9] When a child is able to sit, stand, or ambulate independently, his or her hands are free to manipulate and gather sensory information about a given object.[7] Because this may include motor, tactile, visual, and/or auditory information, the child is able to begin categorizing objects based upon various types of sensory input, leading to an understanding of the language construct of nouns. The concrete meaning of verbs may be learned directly through a child's actions; however, a child may also learn the meaning of abstract verbs, such as "love," through actions such as hugging.[7]

Similar to research supporting the relationship between motor and cognitive functions, recent studies have strengthened the evidence of the relationship between motor and language skill development. A longitudinal study by Walle and Campos[10] found that maturation of both receptive and expressive language skills was associated with the onset of ambulation. Bhat et al[11] observed 24 infants at risk for developing Autism Spectrum Disorders at 3, 6, and 18 months of age. The authors found that 67-73% of infants with motor delay at 3 or 6 months also presented with a communication delay at 18 months.

Salavati et al[12] studied the association between the quality and quantity of motor skills in infancy and language performance during childhood. The motor performance of each participant was assessed at 3 and 5 months of age, and then language performance was assessed at roughly 5 and 10 years of age. The authors found higher scores in motor performance during infancy were associated with higher scores in both expressive and receptive language assessment at 5 and 10 years of age. Additionally, demonstration of both smooth, fluid movements as well as fidgety movements during infancy were associated with higher expressive language scores at both 5 and 10 years of age. The conclusions drawn by these authors suggest the quality and timing of motor skills development are directly related to the acquisition of language skills.[12]

Independent locomotion can also affect social development. Independent locomotion has been associated with a greater number and a longer duration of social interactions between infants and peers or family members.[13,14,15] As the number and duration of social interactions increases, the opportunities for learning social skills, such as taking turns, also increases.[15] Additionally, infants with independent locomotor skills are more likely to initiate intentional social interactions.[14] For example, when a child attains independent walking, his or her hands are free for carrying objects. As a result, the child may choose to carry an object to a caregiver to initiate a social interaction. Infants with independent locomotion have also demonstrated greater attention, proficiency in following gaze and gestures, and ability to perceive the actions of others as intentional.[13]

Kovaniemi et al[16] studied the relationship between the timing of motor skill acquisition and parental concerns for social-emotional and behavioral development at 1 year of age. The authors found that infants whose parents reported social-emotional and behavior concerns were more likely to have achieved gross motor milestones later than infants whose parents expressed no social-emotional and behavior concerns. While the authors suggest that delayed motor development may aid in predicting risk of delayed social-emotional and behavioral skills later in infancy, these results suggest a relationship between social and motor development.[16]

Researchers believe that the bridge between the development of motor, cognitive, language, and social skills is environmental exploration.[1,7,14-16] For example, a child may be presented with an unfamiliar toy with a switch. He or she may process information about the toy, and then react by changing the switch. Perhaps the change in direction of the switch results in music playing from the toy; the child must re-process this change and its relationship to his or her actions. This lays a foundation for future and more complex exploratory behaviors in novel and familiar environments.[6] During this process, the child forms an awareness of his or her body in space, or body schema. The body schema then contributes to production, interpretation, and description of future movements based upon this information, demonstrating the interaction of motor, cognitive, and language development.[6] As a child's exploratory skills become more advanced, there are increasingly greater opportunities for interactions with more complex environments, reciprocal interactions, and play.[6,16]

Results from a longitudinal study by Oudgenoeg-Paz et al[6] support the role of exploration as a bridge between attainment independent sitting and walking, spatial cognition, and language. The authors found that the age of independent sitting in 59 children developing typically was predictive of spatial memory and spatial language development; additionally, the age of independent walking was associated with the development of spatial processing and spatial language.[6] Locomotion allows for exploration, and exploration results in opportunities for social interaction and the collection of sensorimotor information from the environment. Perception and processing of sensorimotor information contributes to the development of cognitive and language skills. If a child's motor function is limited, thereby limiting exploration, development of cognitive, language, and social skills will also be impaired.

III. The Problem

The existing evidence has been validated by studies of pediatric populations with motor impairments. Burns et al[17] observed the relationship between motor function at 12 months corrected age and cognitive and motor functions at 4 years corrected age in children born at extremely low birth weights (<1000 g). The authors found that motor scores at 12 months corrected age were predictive of cognitive development at 4 years corrected age in this population. Of note, even children with mild motor impairment at 12 months corrected age demonstrated impaired cognitive function at 4 years of age.[17]

Lowe et al[18] studied the association between parent-reported behavioral concerns and scores on each of the subscales of the Bayley Scales of Infant and Toddler Development - 3rd edition (Bayley III) for toddlers born extremely preterm (gestational ages 22 0/7 to 26 6/7 weeks). For every 10-point increase in total behavioral problem scores, authors found 1.16, 2.02, and 1.09 point decreases in cognitive, language, and motor scores, respectively on Bayley III subscales ($p < 0.05$).[18] A review by Oudgenoeg-Paz et al[19] supports these findings, reporting that at least through age 10, delays in motor function correlate with impaired cognitive function in children born preterm or at low birth weight.

Retrospective studies of children with autism spectrum disorder (ASD) have reported that delays in motor function often present prior to language or social dysfunction and the formal diagnosis of ASD.[20] St. John et al[21] studied executive function and motor development in infants with high- and low-familial risk for ASD at 12 and 24 months of age. Participants were then evaluated for ASD at 24 months and classified as meeting criteria for ASD, high risk but not meeting criteria for ASD, or low risk and not meeting criteria for ASD. The authors found that when evaluated at 24 months, gross motor skills were associated with working memory and response inhibition.[21]

A study of participants diagnosed with cerebral palsy (CP) compared scores on the Gross Motor Function Measure (GMFM), the Bayley Infant Development Screening Test-II (BSID-II), and the Wee Functional Independence Measure (WeeFIM).[22] Of particular interest to this review, scores on the BSID-II motor scale were associated with the GMFM and the cognitive scale of the BSID-II.[22] In a study of children diagnosed with spina bifida, Rendeli et al[23] found that ambulatory children (with or without an assistive device) with meningomyelocele demonstrated higher values of performance IQ compared to nonambulatory children with meningomyelocele. Finally, a case report by Lynch et al[24] demonstrated that powered mobility training for a 7-month-old with spina bifida resulted in improvements in driving parameters as well as cognitive, language, and fine motor skills as measured by the Bayley III. Of note, the child's age-equivalent scores "far exceeded his chronological age by the end of the training period."[24]

Despite differing diagnoses and associated motor impairments, each of the populations described above may experience gross motor impairment. As a result, exploratory behaviors are limited, decreasing opportunities for cognitive, language, and social development. Pediatric assistive mobility devices have attempted to meet this need; for example, manual, gear, power-assist, and power wheelchairs have been manufactured specifically for pediatric populations to maximize independent mobility.[25] These devices give children with motor impairments the ability to explore their environments independently, rather than being carried or pushed in a stroller.

Independent mobility via power wheelchair has resulted in improved receptive communication, functional mobility, and decreased levels of assistance required from caregivers in children with severe motor impairments.[26] Jones et al[26] observed these improvements in children as young as 14 months old. Guerette et al[27] found similar results when children with CP and associated motor impairments were tested prior to and after receiving powered wheelchairs. The authors found increases in parental perceived social skills, number of mobility activities during play, and qualitative level of outdoor interactive play. Of note, the youngest child in this study was 18 months old.[27]

Despite this evidence, third-party payers will not typically provide a power wheelchair until a child is at least two years old.[28] As a result, children with motor impairments have limited opportunities for exploration and subsequently limited opportunities for development of cognitive, language, and social skills.

IV. The Solution

In recognition of the gap between the need for assisted mobility and the lack of powered equipment until age 2, researchers and clinicians have studied the use of modified ride-on toy cars in young children with motor delay.[28] This process involves purchasing a ride-on car from a local or online toy store, and using supplies from a hardware or department store to create adaptations such as an activation switch and/or supportive seating.[28,29] The GoBabyGo! program, developed by Cole Galloway at the University of Delaware, has provided many modified ride-on cars to children with motor disabilities through this process.[28,30] Additionally, this program has sparked research of specific outcomes such as the impact of modified ride-on cars on independent mobility, language, and socialization.

Logan et al[31] followed 3 children over the course of 3 months after receiving a modified ride-on car. The children were 29-, 12-, and 21-months old with diagnoses of spastic quadriplegic CP, 16p 11.2 microdeletion and cortical vision impairment, and microcephaly, strabismus, and limited extraocular movements, respectively. The authors found that each child was able to drive his or her car independently; additionally, two of the three children demonstrated improved mobility scores as measured by the Pediatric Evaluation of Disability Inventory (PEDI).[31]

Huang et al[32] performed an observational study of 10 children ages 1 through 3 years old with diagnoses including cerebral palsy, Down syndrome, and developmental delay. After 2-hour training sessions were held 2 days per week for 9 weeks, all participants were able to drive the cars independently, stop at a target, and intentionally drive to a toy or an adult for interactions. As the intervention progressed and independent mobility increased, all children required less visual attention to the control switches of the cars.[32] Two case reports involving a 21-month-old with spastic quadriplegic CP and a 13-month-old with Down syndrome demonstrated similar improvements in mobility as well as socialization, vocalization, independence with self-care, and emergence of new behaviors and interactions.[33,34]

A two-group design including children ages 1 through 3 compared an intervention using ride-on cars with combined social training to a home education program alone.[35] Diagnoses of participants included CP and developmental delay. Outcomes of interest in this study were mobility (measured by the PEDI), social function, and caregiver stress levels. While both groups demonstrated improvements in mobility and social function, the group using ride-on cars had significantly greater improvement in social function, caregiver stress levels, and achievement of program goals.[35] A similar two-group study compared use of modified ride-on cars to conventional therapy alone (physical, occupational, and speech).[36] The group using ride-on cars showed significantly greater improvement in mobility, social function, and parent stress levels, whereas the group receiving conventional therapy improved in social function alone.[36]

Modified ride-on cars certainly are realistic for clinic use from the standpoint of adaptability. Switch activation via head or limb movement can be created, and seating systems can be modified and re-modified based upon an individual child's needs and progression. In a recent study of 4 infants with Down syndrome, ride-on cars were modified to have both sitting and standing modes.[37] In order to activate the car in standing mode, the children were required to pull themselves from sitting to standing. Ride-on cars have also been adapted to accommodate respiratory ventilators for children with complex needs either in the trunk of the car or by way of a trailer pulled behind the car.[28] Another positive consideration of modified ride-on cars is accessibility; as mentioned previously, these toy cars can be purchased from local or online stores, and are modified using common materials such as polyvinyl chloride (PVC) pipe, swimming kickboards, Velcro, and carriage nuts and bolts.[29,37]

Modified ride-on cars are also relatively easy for a family or caregiver to manage. Maintenance typically only requires charging a battery, and the cars are lightweight and transportable in most family vehicles.[29] The cars are socially and aesthetically pleasing to both the child and family, in contrast to many other forms pediatric adaptive equipment. Finally, the out-of-pocket cost is significantly reduced compared to that of a powered wheelchair. The cost of the toy car alone ranges from $200 to $400, and modifications are often less than $150 as compared to a cost of $150 to $1500 for most power wheelchairs.[28,29,38]

V. Conclusion

Early mobility has been associated with cognitive, language, and social development in children developing typically. Children with motor delay are more likely demonstrate deficits in cognitive, language, and social skills than children developing typically. Research has shown that these deficits often parallel the degree of motor impairment. While powered mobility has proven an effective and feasible option for these children, powered wheelchairs are not available commercially or financially until a child is at least 2 years of age.

Programs such as GoBabyGo! have produced modified toy ride-on cars for young children with motor impairments in order to bridge this gap.[30] While the research surrounding these cars is relatively limited, results thus far have demonstrated improvements in independent mobility, language, and socialization. The most important piece remains independent mobility, which acts as a springboard for other critical components of development.

Modified ride-on cars are "adaptable in real-time, durable, relatively low-cost, and easily obtained."[28] While these cars are low-cost compared to powered wheelchairs, third-party payers will not provide reimbursement for their use. This places the $200 to $400 purchase of the car itself, as well as modifications, on a child's family or caregivers. As a supplement to this literature review, a PowerPoint presentation has been developed to summarize the evidence discussed and to provide useful information for requesting funding support for modified ride-on cars.

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