Caroline Lynott
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Capstone Literature Review

Evidence for Early and Independent Mobility

I. Introduction

Early childhood development is marked by everyday experiences, challenges and stimuli all of which sequentially lead to independent and self-directed locomotion.[1] This array of experiences lay the fundamental building blocks for a child's motor, cognitive and social development. For children developing typically, responses to external stimuli directing achievement of motor and cognitive milestones come quite naturally with self-directed locomotion observable between ten and fourteen months of infancy.[1] However, children who experience developmental delays of any etiology rarely are able to follow the typical sequences of development, and, without proper intervention, can become fundamentally limited during infancy and toddlerhood from lack of experience, and perceptual-motor challenges.[2] Lack of early mobility and self-directed locomotion during periods of critical growth fosters a snowball effect significantly delaying advances associated with all domains of gross motor, cognitive and social development.[2,3] Although intervention and presentation of stimuli may appear different for children with disabilities, the opportunity to engage in activities that encourage motor exploration, play, interpersonal interaction and cognitive challenges is considered the "gold standard" regardless of impairment or limitation. Thus, heeding the greatest probability of developmental success as the child continues to mature.[2-4]

One of these early interventions is the introduction of augmented mobility to assist the child who is not independently mobile in independent exploration of his or her environment. Augmented mobility is a critical component to introduce when it becomes developmentally appropriate for a child to be using independent mobility, such as by creeping, but the child is displaying signs of deviation from that typical sequence of motor and cognitive development.[4] Augmented mobility can take on many forms depending on the child's mobility needs. Augmented

mobility is universally recognized as a key factor in providing the child with a movement disorder with the ability to respond to and develop from day-to-day movement experiences in the same fashion as their peers whom are developing typically. Thus, a clear understanding concerning the critical importance of self-directed locomotion for children with disabilities is essential for rehabilitative specialists whom are providing the specific interventions and family education.[4,5] This ensures that the rehabilitative intervention provides the child with an equal opportunity for independent locomotion through augmentative means, while also cultivating a level of professional competency in family and caregiver education to promote exploration and autonomy throughout the child's daily experiences.[1,4,5]

This current review of literature is therefore intended for two purposes: first to assess the evidence of the direct impact of early and self-directed mobility on physical, cognitive and psychological development; and secondly to provide considerations for rehabilitative specialists in addressing independent mobility and autonomy as children with disabilities transition into toddlerhood and preschool.

II. Physical Development Associated with Locomotion

The physical development that results following the onset of independent locomotion in children can be stratified into two categories, motor development and cortical structural changes or neuroplasticity.

Motor Development: The principles of early mobility for growth and motor development are widely recognized in pediatric practice, particularly for those children at risk for developmental delays.[4] Currently, there are ample studies investigating various motor-based interventions for enhancement of motoric development in children with functional impairments or delays. This evidence is in agreement that early, individualized motor experiences leads to improved developmental outcomes.[4-8]

Dusing, Lobo and Galloway performed a case series for early movement experience in late pre-term infants in which parents were given a specific

movement program consisting of prone play, supported sitting, head control exercises, midline hand and foot play, assisted kicking and visual tracking.[6] The parents had their child participate in this program from two weeks old (age-adjusted) to two months old, 20 minutes per day, and found significant improvements on the Test of Infant Motor Performance and Bayley Scales at each assessment point with the children achieving independent sitting at six months.[6] An additional study by Morgan trialed the GAME intervention (Goals, Activity, Motor, Enrichment) which devises custom tailored movement and parental education programs for infants at risk of cerebral palsy including interventions such as constraint-induced movement therapy, augmented sit to stand, and progressive reduction in sitting supports.[7] A total of 30 children participated from two months to twelve months with markedly significant improvements on the Peabody Developmental Motor Scales (PDMS-2) at the 12-month assessment compared to those who did not receive the intervention.[7] In fact, the standard care group had a lower PDMS-2 score at the final assessment compared to baseline from “below average” at the start of the study to “very poor” at the study’s termination.[7] An intensive movement-based aquatic therapy study by McManus found aquatic-based movement intervention to be a successful adjunct to early intervention for children with delayed functional mobility with significant improvements in the aquatic group after the 36-week study compared to those who received early intervention alone.[8] Interventions in the water included static and dynamic balance, gait training, various play positions, and resistance exercises with weighted toys.[8]

Compiling all the evidence, it is clear that physical therapists play a critical role in providing motor opportunities to accelerate developmental gains for children at risk of delay. These gains denote neuro-musculoskeletal developments such as improved postural and head control, muscle tone, muscle coordination, midline activity and advancement of motor milestones that ultimately lead to the ability to produce self-directed movement.[5-8] As these milestones typically develop at a slower rate for children with disabilities, it is essential to elicit the child’s participation in specific movement experiences both

through direct physical therapy, appropriate augmentation and parental day-to-day handling to provide the child with the greatest opportunity for self-directed locomotion with regard to improved physical function.

Neuroplastic Development: Specific cortical structure changes have also been associated with early movement experiences in children at risk for developmental delays. In an early animal-based study, Rosenzwig found improved quality of synaptic connection both in size and density, increase in vasculature and neurogenesis in young rats with induced cortical lesions that were exposed to complex exploratory environments and given the opportunity for self-directed movement.[9,10] This animal study highlighted the importance for environmental enrichment on cortical and synaptic development and maturation.[9] Studies in children by Bell and Fox investigated the degree of intra and inter-hemispheric communication in pre-locomotor versus experienced locomotors via EEG coherence.[10,11] They found that children without locomotive abilities have increased coherence due to superfluous and immature synaptic connections, while children whom had experience in locomotion either via crawling, walking or use of a walker underwent synaptic pruning to fine tune connections between cortical lobes and hemispheres.[11] Thus demonstrating that the ability to participate in self-directed locomotion leads to neural structure and synaptic maturation from complex, enriched environments encountered with movement.[11]

III. Cognitive Development Associated with Locomotion

Links between locomotion and perceptual-cognitive advantages have been recognized for centuries, dating back to the works of Piaget and Vygotsky; however have since become more widely understood from technological advances and sound research designs comparing those with and without the ability to independently mobilize.[5] Areas of cognition highly recognized in literature associated with matured locomotion are the perception of distance, referential gesture communication, visual search strategies and socialization.

Perception of Distance and Depth: Enriched environmental interactions are shown to improve the connection between the child's visual input and position in

space. The onset of independent locomotion allows for the emergence of a three dimensional environment and processing of the ambiguous “far space” that children fail to acknowledge in static sitting.[3] Thus, the ability to move and explore allows for the perception of distance between the child and the far-off visual stimulus as well as the calibration of visual scaling of object size. An example used in a review paper by Lobo, Harbourne and Dusing is a child only accustomed to the “near” space without locomotive opportunities sees her departing caregiver as physically shrinking in size . In comparison, the child with locomotive opportunities is better able to perceive that merely the distance between themselves and the caregiver as they depart is increasing.[5] Studies such as by those by Freedman demonstrate these principles by attempting to have the child attend to distal objects in laboratory settings.[3] Only those with motor experience are able to correctly place visual attention on distal objects compared to those without motor responses who consistently focus visual attention in the “near space”.[3] This judgment of distance and depth attributable to the onset of independent movement becomes important when the child begins to navigate areas with stairs, drop offs, school hallways and begins to participate in physical and recreational activities such as ball catching and throwing.[3,5]

Referential Gesture Communication (RCG): RCG refers to the ability to correctly follow gaze and point gestures and is directly associated with the ability to mobilize independently.[3] Campos completed a study evaluating this cognitive skill amongst pre-crawling infants, and experienced crawlers or walkers.[3] The examiner used point gestures to various targets around the room with and without concomitant gaze towards the same target; those with locomotive experience consistently followed the point gesture to the target with and without the examiner’s gaze while the pre-crawlers more consistently focused their visual attention only on the examiner.[3] The same study set-up was investigated by Telzrow with children with Spina Bifida and known locomotor delays, finding similar outcomes.[3] Due to the pre-study differences between the two groups, the main association then becomes the level of independent mobility and the ability to follow point gestures.[3] This skill becomes a critical precursor in the child’s

ability to follow directions, socially reference other's body language, and successfully learn from teachers' instruction when they reach school age.

Visual Search: Infants and young children often demonstrate what is referred to as the A-not-B error, which refers to poor visual search resulting from their sole ability to process visual-spatial information in relation to themselves, also known as egocentric processing.[3,10] The task of visual search, however, requires both allocentric and egocentric processing or recognition of the relationship between two objects or between an object and its surroundings, respectively.[3,10] The A-not-B error thus refers to when a child correctly identifies an object consistently hidden behind location A, but when the object is moved to location B, the child continues to only search location A.[3,10] Studies of spatial search involving children with increased independent motor experience have found that independent mobility is directly associated with the ability to find hidden objects due to improved visual-attention strategies.[3,10] Studies specifically testing visual search in children with disabilities have found similar associations, although the time between hiding and initiation of search is generally longer than typically developing children, those having had the opportunity to independently mobilize regardless of functional limitation have better visual attention and visual search strategies.[3,10] Significant gains in these visual-spatial and searching skills provides children with the foundations to learn, read, write and interact with their peers.[3,10]

Important to note when considering the maturation of visual-motor attention and spatial awareness is the concept of early object manipulation.[13,14] Lobo and Galloway conduct much of the research on the impact of early object interaction for future developmental gains; the researchers have observed in several studies the decreased tendency and variability of object interaction among children born preterm with and without brain injuries leading to further motor delays.[13,14] In a recent 2015 study following preterm and full-term infants in the first six months of life, Lobo and Galloway found that infants born preterm have less exploratory behaviors, less ability to perform bimanual tasks, and decreased use of visual and sensory input when interacting with objects, which translates into delayed

readiness to move, learn and play.[14] Thus, early movement-based interventions that also incorporate object manipulation are equally as important to consider in the facilitation of attention, awareness, problem-solving, perception and acquisition of general knowledge.[14]

Socialization: An additional component of cognition attributable to independent locomotor experience is the development of appropriate socialization and peer interaction. Several studies including those by Leonard et. al, associate poor motor skills with self- and parent-reported loneliness and isolation.[15,16] The mechanism by which this occurs is the cause-effect relationship between enriched environmental exploration and incorporation of various types of play, use of various objects and toys, and autonomous goal-directed peer interactions.[15,16] Children developing typically who exhibit self-directed movement, spend as much as one hour each day in direct peer-to-peer play interactions while children with disabilities without the opportunity for self-directed movement can spend as little as six minutes per day in direct play which severely limits their social development.[2] Thus, providing means for independent locomotion for children with functional limitations becomes critical in fostering healthy peer interactions and improving the child's overall quality of life.

IV. Psychological Development Associated with Locomotion

Psychoanalysts from the mid-20th century have described the onset of infant locomotion as the child's "psychological birth" and the "origin of intelligence".[3,10] In recent decades, the psychological effects of locomotion begin to appear more widely in the research due to the emergence of the Dynamic Systems Theory and Grounded Cognition.[2,3] The Dynamic Systems Theory refers to the non-linear interaction between three elements: the child's body structure and function, those that surround them, and the nature of their environment. This theory highlights the true deviation from "pre-programmed" natural history of sequential motor and cognitive development and focuses on the developmental advancements (or lack thereof) that are a direct result of individual experience.[2,3] Secondly, the theory of Grounded Cognition, refers to critical cognitive and

psychological development that occurs from participation in perceptual-motor activity and locomotion.[2,5] Inherent in both theories is the concept of activity-dependent development that strays from naturalistic maturational processes.[2,5]

Joseph Campos and his cohort on the west coast conduct much of the research linking locomotion and psychological development. Generally, Campos has overseen several studies all with "age-held-constant" designs to encompass varying levels of locomotive experience and independence among the subjects.[3] The majority of these research efforts are designed to investigate the connection between independent mobility and psychological phenomena including motivation, attachment, social referencing and "wariness of heights".[3]

Motivation: As a child has the opportunity to move between locations independently, there is an inherent response in goal-directed behavior; that is, the child is presented with auditory or visual stimuli some distance away from where they are positioned and becomes self-motivated to attend to that stimulus through independent mobility.[3] This motivation is seen as a precursor in childhood development to self-determination, autonomy and willfulness.[3]

Attachment: Locomotion also plays to the important concept of attachment, as it creates a physical distance between the child and their caregiver. Physical distance provides the child with the opportunity to self-regulate their emotions and only rely on attachment in times of fear, with evidence demonstrating experienced locomotors seeking their attachment only when presented with fearful stimuli.[3] Lack of this skill presents a great disadvantage for children whom are not given the opportunity to mobilize independently, without the physical distance from their maternal or caregiver attachment there is ultimately a delay in breaking that symbiotic relationship, interfering with further psychological, social and emotional development through decreased independent experiences.[3,17] Continued attachment into school-age fosters significant issues with participation at school and emotional self-regulation in the absence of their parent or caregiver leading to the psychological concept of "learned helplessness".[17]

Social Referencing: Autonomous mobility creates more opportunities for the child to place social references on the interaction with others.[3] Generally, as the child

explores they will receive verbal and non-verbal feedback or “distal communication” from whomever watches over them, and the child is propositioned with the task of referencing that communication with their intended actions and behaviors.[3] This type of referencing of the emotions of others is only possible with increased physical distance from their carer and the ability to independently chose their location and actions.[3]

Wariness of Heights: Another psychological phenomena or adaptation that appears widely in the literature is the “wariness of heights” which is associated directly with onset of independent locomotion.[10] This can also been seen in several consecutive laboratory studies by Campos through artificial creation of a “visual cliff” and monitoring the child’s reaction to the sensation of falling off of the fabricated pseudo-cliff.[3] They found a positive correlation between sympathetic and physical stress reactions in response to the virtual fall in experienced mobilizers including increased heart rate, visual distress and muscle stiffening compared to children having not had the opportunity to independently mobilize.[3,10] This highlights the relation of locomotion to the emergence of “safety behaviors” and deviates from previously conceived notion of safety senses being a product of classical conditioning.[3] These same results have been obtained not only for typically developing children but also children with motor disabilities and developmental delays after having received augmented mobility and the opportunity to mobilize on their own.[3] The proposed mechanism by which this occurs is through emergence of “visual proprioception” or adaptation to optic flow through movement, which does not occur if the child is in static sitting or being carried.[3] This inherent and activity-dependent emergence of safety conceptualization thus becomes critical as the child gains more autonomy and is presented with more complex environmental circumstances.

V. Rehabilitation Considerations

The evidence makes it clear that the role of the physical therapist is to provide specific locomotor opportunities for children with disabilities or developmental delay through direct intervention and mobility augmentation. Charlene Butler, a widely recognized researcher by the American Academy for Cerebral Palsy and Developmental Medicine, defines augmented mobility as "all techniques and aids that supplement or enhance ambulation".[17] General indications for physical therapists for employment of augmented mobility can be stratified in the following loose diagnostic categories: children who may never walk, children with inefficient mobility and children with the loss of independent mobility.[17] Thus, specific diagnoses that may be appropriate to introduce augmented mobility might include spastic or athetoid quadriplegia, multiple limb deficiency, spinal cord injury, several forms of cerebral palsy, myelomeningeocele, juvenile rheumatoid arthritis, trauma, infection and progressive disorders such as Duchenne Muscular Dystrophy and Spinal Muscle Atrophy.[17] Generally, means of augmentation can be stratified into ambulatory aids (walkers, crutches, canes) and non-ambulatory aids (wheeled mobility), both of which involve careful, multi-faceted consideration in order to provide the child with the most efficient means of mobility.[17]

The most widely recognized construct for determining if augmented mobility is warranted is the International Classification of Functioning, Disability and Health (ICF).[5] The therapist must be competent in the use of the ICF model for the simultaneous recognition of several elements, not just the child's level of impairment, but also daily activity requirements, mobility goals, energy expenditure, preferences, financial limitations, as well as cultural and religious beliefs.[5,17] Keeping in mind the critical developmental advantages of independent mobility, the therapist can thus rely on this model for determining the most appropriate means of mobility for each individual child.

Augmentative means of locomotion must be child-centered. Early intervention (EI) and strategies for locomotion in infancy and early toddlerhood may present as caregiver positioning and handling education, supported seating devices for

improved reaching and object manipulation, and most recently modified ride-on cars for independent exploration.[18-20] Recent studies have emerged that provide evidence for the benefits of modified ride-on cars for children between 12 and 36 months and their findings directly correlate with the more general evidence of the impact of independent locomotion on development.[19,20] Huang and Chan found after children with disabilities of varying etiologies are trained in use of the modified ride-on cars, they demonstrate marked improvements in self-regulation of emotion, socialization behaviors, visual-attention and appropriate forms of communication and perception.[19,20]

As modified ride-on cars are not appropriate recommended means for locomotion at school, augmented mobility begins to appear more like the mobility aids used by adults once the child reaches school-age.[17,21] These mobility aids will be those that allow for efficient and safe mobility throughout the classroom and school environment including either ambulatory or non-ambulatory aids or a combination, depending on the child's level of mobility.[21] This is likely the stage where the therapist, child and family begin to consider introduction of wheeled mobility to offset the physiological toll of abnormal or inefficient ambulation.[17] It is at this stage where the physical therapist plays an integral role in working with equipment vendors and choosing appropriate equipment, as well as ensuring the child's safety and mobility while using it in the classroom, home and community.[21]

Although interventions appear differently between EI and school-age, the continued role of parental education and encouragement of self-directed movement and autonomy remains present.[1,2,5,21] Perhaps more importantly in school-aged children, advising limited use of strollers and carriers is a critical component in facilitating locomotive success with the child's augmented mobility aids. In return, the child will be better prepared for environmental and interpersonal interactions for advancement of physical, cognitive, social and physiological skills and self-regulation.

VI. Conclusion

In summary, self-directed locomotion creates a unique and unmatchable shift in the relationship a child has with his or her environment. The onset of independent mobility marks significant changes in motor, cognitive and psychological development that are entirely experience-dependent. Children with disabilities often are limited in their ability to independently explore their environment beginning at a very early age, which significantly hinders their growth and development. Rehabilitative specialists such as physical therapists play a crucial role in working with children and families throughout various stages of childhood development for physical intervention, education and introduction of appropriate augmented mobility. Rehabilitative efforts thus grant equal opportunity for the developmental gains that emerge with self-directed locomotion and active participation in enriched and complex environments for children who would otherwise be significantly limited.

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