A Narrative Review of Energy Expenditure and the Shift from Effective Ambulation to Effective Mobility in the Rehabilitation of Children with Motor Disabilities.

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Abstract

Background: In the management of pediatric developmental motor disabilities, the attainment of independent walking is often prioritized as the primary indicator of rehabilitative success. However, recent evidence suggests that this “gait-centric” approach may ignore the significant metabolic cost of movement, the long-term risk, and adult trajectories. This narrative review evaluates energy expenditure patterns in children with motor disabilities. Longitudinal studies of such children through their adulthood suggest a need fora paradigm shift of focus from “Effective Ambulation” to “Effective Mobility”—a framework that prioritizes energy-efficient, timely movement to facilitate social participation and preserve physiological reserves over the lifespan. Clinical recommendations and emerging scientific evidence emphasize early introduction of assistive technology and the adoption of the ICF framework to ensure that mobility serves as a tool for autonomy rather than a source of physical exhaustion.

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- Physiological Burnout
- GMFCS.

Introduction

The National Sample Survey (NFHS-5) analysis estimates the overall prevalence of disabilities in India at 0.93%, with household prevalence of persons with disabilities at 5.11%, and the most common subtype being locomotor disabilities at 44.73%. The burden of motor disabilities among children with disabilities was estimated at 40% [1]. The estimated prevalence of childhood non-progressive motor disabilities like cerebral palsy ranges from 2.1 to 3 per 1000 live births [2]. The occurrence of motor disabilities is more or less cumulative over the ages; the community must learn to adapt and optimize the functioning of persons with disabilities and maximize their potential.

Why is timely mobility important for children? The ecological theory of early learning states that children perceive affordances (fit) between themselves and their environment to perform actions. These perceptions and actions are dynamic and cyclically influence one another, within the premise of capabilities and environmental supports. Spontaneous exploration of alternatives and self-motivation are prerequisites to perception-action learning. A child explores by moving around. Thus, mobility is a vital behavioral function that facilitates affordance, helps children to gain control over themselves and their surroundings, and forms the bridge to achieve developmental milestones[3]. It plays a crucial role in the psychological development of children, drives self-motivation to participate in meaningful activities, and enhances overall development [4]. Children with motor disabilities switch to a mode of dependency for exploratory experiences, lose the motivation for self-reliance, which may influence their adaptive behaviors and blunt their involvement in the everyday life of education and employment [5].

In short, lack of independent mobility affects not only the gross and fine motor domains, but also the social and adaptive skills development, dampens the child's self-esteem and confidence, and hence suppresses their cognitive capabilities. Considering the ICF framework, a child's functional impairment in the community may be more severe than the disability itself, implying that a child may have an impairment, but the environment causes the disability.

The traditional approach to pediatric rehabilitation has been the achievement of effective ambulation, the ability to walk independently. This goal is pursued without thorough consideration of the child's metabolic profile and physiological costs incurred while attempting independent ambulation against odds. Newer scientific evidence and longitudinal studies of such children entering into adulthood indicate otherwise. Contemporary research focuses on the effective mobility, social participation, and functionality of individuals rather than gait-centricity.

Gap statement. This review aims to bridge the gap between metabolic theory and clinical practice by investigating energy expenditure patterns in pediatric motor disability. By exploring the high metabolic cost of ambulation and the long-term challenges faced by children who achieve walking, the article critiques the traditional clinical focus on ambulation. Furthermore, it aims to throw light on the necessity of prioritizing energy-efficient movement and 'effective mobility' to enhance the child's quality of life and longevity.

Search strategy and selection. A comprehensive electronic search across databases, including PubMed, Scopus, and Google Scholar,was conducted using the combinations of MeSH words and keywordsrelated to motor disabilities (cerebral palsy, neurodevelopmental disorders), energy expenditure (basal metabolic rate, indirect calorimetry),and mobility (gait efficiency, Functional mobility). Following screening for clinical relevance, 22 research records were selected, of which 18 articles were obtained from PubMed/Scopus-indexed journals, one from a foundational book chapter,and 3 critical grey literature sources that provided clinical frameworks for mobility. The summaryof key evidencehas been tabulated (Table 1).

Discussion

Striving for ambulation – but at what cost?

Energy expenditure analysis: A typical mature walking is a self-regulated, self-paced locomotion, which conserves energy and has the least displacement of the center of gravity during movement. An individual strides based on their set most economical walking speed. Hence, effective mobility aims at timely, least effort movement to achieve a function [6].

To maintain this economy, children with motor disabilities move more slowly. The greater the abnormal gait pattern, the greater is the energy expenditure, and the use of aids for ambulation (crutches,etc.) slows them down further while increasing the energy requirement. The speed of free walking in children with meningomyelocele who walked without aids was only 36% of the speed of free walking of a typical walker without deficits; also, they required maximal aerobic capacity to achieve that speed [7].

Economical walking speed increases with age in typical individuals, but children with motor disabilities (non-progressive conditions like cerebral palsy) show,at best, maintenance of speed or more often slowing with increasing age. The energy expenditure also follows an inverse relation in typical children (reaching the optimum level), while in disabled children, it shows an increasing trend with age [6].

Even children with Gross Motor Function Classification System (GMFCS) level I showed significantly greater energy expenditure when compared to typical children, owing to impairment in strength and spasticity of muscles, less efficient gait patterns, and altered transference of energy among body segments [6]. The energy cost of ambulation progressively increased with increasing levels of GMFCS.

Researchers report that children who walk between classes using crutches/ walkers in school had a high mean heart rate that exceeded 60-75% of maximum heart rate. While these children have great determination to function in school like any other student, this exertion hampers their academic performance; in addition to co-existing morbidities such as learning disabilities or visual-perceptual difficulties [7].

Adult trajectory of children with developmental motor disabilities: When these children transition into adulthood, management of their ageing is a new challenge [8]. The natural history of a child with cerebral palsy shows an initial period of rapid rise in gross motor functions up to 5-7 years of age, followed by a plateau phase, then decline at the adolescence or early adulthood stage as per the peak and decline model of gross motor development. Although the age of decline differs based on the severity of motor deficits, several articles affirm this decline [9]. Research estimates that about 25-30% of adults with cerebral palsy exhibit a decline in gross motor function in comparison with their childhood functioning, at an age as early as 20-30 years. This decline restricts their daily functioning and mobility, resulting in secondary morbidities. [10]

Physical activity may deteriorate in adults with Cerebral palsy, with GMFCS shifting to a higher level. This implies that the family must provide greater assistance and support over the coming years [11]. Adults battle with severe pain, premature decline of mobility, and chronic fatigue, in addition to frequent cardio- pulmonary, metabolic morbidities, reducing their quality of life.A review of databases by Kumar et al [10] estimated that 80% of the adults with cerebral palsy experienced progressive and severe pain and fatigue. The spectrum of walking among persons with cerebral palsy ranges from some children never walking, to teenagers consuming extraordinary energy for walking, to physiological burn-outs in early adulthood, to painful joint deterioration in the forties [7].

When persons with disabilities perform tasks beyond their functional capacities over prolonged time periods, there is a secondary deterioration of motor function known as “physiological burnout”. Individuals with mild motor impairment who have achieved independent walking experience a decline due to musculoskeletal deterioration by around 45 years of age, which cannot be corrected. A Japanese study has stated that cerebral palsy cannot be considered a non-progressive condition, given the significant decline in gross motor functions. The management is instead focused on the reduction of limitations and enhancing the functions of daily living and activities [7, 12, 13].

The role of neurodevelopmental interventions and increased habitual physical activity in childhood in enhancing the gross motor functions in adulthood is debatable; the evidence shows mixed results. A meta-analysis study supporting significant improvement in gross motor functions in children with cerebral palsy argues that the type of exercise (task-oriented, aerobic) matters more than a general label of physical activity. [18].A Cochrane study revealed a low to very low quality of evidence supporting the benefit of physical activity in children with respect to improvement in gross motor function and gait speed. [14, 15, 16, 17].

What is the Contemporary approach to effective mobility?

The conventional neuro-maturational theory that encompasses therapies aimed at achieving and maintaining the normal walking patterns has been challenged in children with motor disabilities due to weak evidence of enhancing functional motor gains among these children [3]. Our literature evidence reveals a critical disconnect between short-term ambulation goals and long-term metabolic sustainability.

The focus is now on dynamic systems theory, which emphasizes effective functionality, active exploration, and social participation rather than normalizing the walking and motor patterns in children. The contextual and environmental factors, adaptations, and modifications act as mediators for therapeutic effectiveness. The spotlight is on normalizing effective mobility rather than ambulation, provision of adequate leisure-time, behavioral management of children to build motivation and exploratory instincts, and encouraging independence and social participation.

The paradigm has shifted from motor disability to developmental disability, from remediation of impairment to bypassing of the impairment, from achievement of effective ambulation to effective mobility. [5, 7]

Achievement of effective mobility

The ICF framework given by WHO describes any health condition under 3 main domains of bodily functions and structural impairment, limitation of activities, and restrictions in participation in community and life experiences, which are dynamically affected by environmental and personal barriers and support systems. The objective of management of motor disabilities should focus on bypassing and reduction of structural impairments, provision of aids to enhance functional activities, removal of barriers, and establishing environmental and personal supports to encourage independent functioning in the community and maximization of potentials, and assist in fluid transition into adulthood [19, 20].

The functional level and potential for mobility of the child, is assessed based on the GMFCS classification system as follows: can the child achieve (a) independent walking (provide child with assistive devices, powered mobility, and periodic physiotherapy for gait and balance), (b) mixed mobility (child needs wheeled devices, and continued physiotherapy till 7-8 years for walking), (c) independent via powered mobility (provide powered mobility devices, physiotherapy is aimed at balance and deformity prevention) or (d) is the child is caregiver dependent (needs substantial assistive devices and supportive equipment to promote independent functioning, physiotherapy mainly for deformities management). [5- 7, 13, 14, 16, 18-20].

Emerging evidence recommends the use of powered mobility devices, not as a last resort when all interventions have failed, but as a powerful assist device for social inclusion and active participation. The recent framework called "On Time Mobility" advocates early access to powered motor devices to children with motor disabilities, at the time corresponding to the child's developmental stage of ambulation [21]. Lack of opportunities to play and explore causes decreased motivation, low self-confidence, dependency, and frustration, resulting in a cycle of deprivation that further reduces learning opportunities and achievement of milestones. [22]. The Japanese study by Toru F and Tomoaki S showed that the ambulant group with independent walking who used a powered wheelchair from their adolescent age group did not develop secondary deterioration, but the group of independent walkers who went long distances of self-ambulation, avoiding use of powered devices, developed physiological burnout and secondary functional deterioration, which does not have effective solution [12].

The various powered mobility devices are electric-powered wheelchairs, standers, powered scooters, Electric Train for preschoolers ®, modified ride-on cars, Permobil ® Mini-explorer, powered kids' electric vehicles, Wild Things by Sealth products ®, Bugzu by Meru ®, Weebot ®, Wizzy Bug ®, to name a few. Indian companies obtained through a preliminary web search include Morecare Mobility, Rehamo, and Neomotion, which can provide customized devices. Research shows evidence that even toddlers can quickly learn to drive powered mobility devices and commute safely with sufficient practice [21]. Assist devices have been introduced to children as young as infants, with promising results (prerequisite of adequate cognition) [7].

The concerns that early use of a powered mobility device might hamper the child's motor skill acquisition have been disproved by various studies. In fact, there is greater and more sustained motor development, as well as faster acquisition of skills in other domains of development in these children, improving their active self-confidence, self-motivation, and social participation [4, 7, 22].

Conclusion

While children with motor disabilities may achieve different degrees of walking, the energy cost of walking across GMFCS levels is significantly higher than that of a child with no disabilities, which affects their daily activities and social participation. The long term impact of pursuing 'conventional walking' among these children can cause secondary deterioration and increased dependency on caregivers at very early adulthood, crippling them further. The newer perspective is providing means and devices for timely, effective mobility.

Table-1: Summary of key evidence and research articles.

Clinical Domain	References	Key Evidence / Clinical Implication
Epidemiology & Indian Context	Pattnaik et al. [1], Ramanandi& Shukla [2]	High prevalence of CP in India (NFHS-5) identifies socio-demographic barriers to rehab access in Gujarat.
Foundational Development	Gibson & Pick [3], Motor Dev. Review [9]	**Ecological Theory:** Movement is the driver of perceptual learning; motor skills must support intellectual exploration.
Metabolic Cost of Movement	Johnston et al. [6]	**The GMFCS-Energy Link:** Direct correlation between GMFCS level and increased oxygen cost of walking.
Natural History & Aging	Blair et al. [8], Kumar et al. [10], Yi et al. [11], Furui& Shimada [12], Park & Kim [13]	**Physiological Burnout:** Inefficient childhood walking leads to secondary orthopedic decline, chronic pain, and loss of mobility in adulthood.

Clinical Domain	References	Key Evidence / Clinical Implication
Efficacy of Activity Interventions	Reedman et al. [14], Bloemen et al. [15], Gorter [16], Ryan et al.[17], Yang et al. [18]	**The Controversy:** Cochrane reviews show low-quality evidence for gait speed gains, but task-specific exercise significantly improves GMFM scores.
Transition to Effective Mobility	Butler [7], Sabet et al. [21], Perelló-Díez et al. [22], Vassbø&Mørk [4]	**Mobility Equity:** Rationale for early powered mobility; movement must be "efficient" to be "effective."
Participation & ICF Framework	Huang [5], Noten et al. [19], Chagas et al. [20]	**The Goal:** Mobility (by any mode) is a tool for social participation and autonomy as defined by ICF Core Sets.

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