

Information Processing and Motor Control in Down Syndrome

Michael Horvat^{1*}, Ron Croce² and Ashley Fallaize¹

¹University of Georgia, United States

²University of New Hampshire, United States

Abstract

Extensive research on the motor performance of individuals with intellectual disabilities (ID) and more specifically individuals with Down syndrome (DS) reflects performance deficits in physical and motor functioning. Earlier study, indicated that low levels of physical function and deficiencies in sensory processing, memory consolidation, and postural control impact their ability to acquire and perform motor skills under variable environmental contexts. In addition, indicated that movements are often uncoordinated, slower, variable and hesitant in initiation, while other researchers reported longer movements and reaction times as well as difficulties in balance and postural control. Further limitations in spontaneous or symbolic play and limited opportunities to practice motor skills were observed in school and/or community settings, primarily during their developmental years. It is apparent that these individuals display delayed motor development and atypical motor functioning, which may be attributed to structural differences in the neurological system, delayed brain development, and a compromised somatosensory system.

Keywords: Down syndrome; Motor control; Information processing; Executive functioning

Introduction

Any model of adapted physical activity must entail memory, cognition, perception, as well as motor system flexibility under changing environment situations, and variable levels of cognition [1-7]. Viewing motor performance from a functional system perspective allows clinicians to analyze deficits in motor behavior and prescribe the appropriate motor rehabilitation programs to enhance flexible and functional motor skills. It is also imperative to assess stereotypic movements that inhibit flexibility and adjustment of movement sequences. Interventions can be utilized to correct developmental lags or stereotypic movements, facilitate alternative neuromuscular mechanisms (adaptability), or modify input/output characteristics of sensory and cognitive information in order to maximize learning and performance.

Analyzing goal-directed movement from a motor control-neuropsychological perspective involves strategies for problem solving, movement initiation, and task execution in varying environmental contexts. Subsequently, the most relevant and appropriate information (sensory stimuli) from the environment aids the individual in adjusting motor responses and developing movement patterns that are flexible to external demands (such as changing the tempo and force of the movement). This the selection process facilitates the individual's ability to use this information for future responses incorporating similar movements and accessing stored memories of previous tasks. The inability to process and use relevant information to develop or access appropriate motor programs is a major concern that complicates the flexibility in movement needed to adjust and modify environmental changes. More importantly the opportunity to master developmental skills at age appropriate times is compromised.

The development of fundamental motor skills proceeds from reflexive responses reflex inhibition and rudimentary movements including head control, sitting and standing as the neurological system develops (Table 1). Locomotion and object control occurs early (2-6 yrs) in physical development and progresses as the child responds to new situations and develops cognitive responses. Defined improvements include refinement of basic movement patterns, improving motor tasks as myelination of neurons facilitates conduction

speed and automaticity of motor responses to improve motor control. In addition, the child continues to mature and develops the strength necessary to improve stability as movements become more intricate and complex. With continued maturation and practice opportunities, learned skills become more refined and adaptable to environmental changes (Table 1). In contrast, developmental disorders interfere with typical development and demonstrate variability and lack of flexibility in movement (Table 1).

The adapted physical activity program needs to address critical developmental milestones of growth and maturation for children with cognitive disorders. Tasks are learned with a minimum of cognitive involvement, becomes problematic when corrections or modifications are needed to match changes in the environment. This may be attributed to the extinction of neurological connections that negatively impact synaptic connections, which in turn can impede the ability to process information (Table 2). For example, recent data indicates that cortical thinning and atrophic dendrites in this population, as well as a lack of brain connectivity alters brain dynamics and limits the ability to integrate information from multiple brain functions that is required to initiate volitional movements [8-10]. Thus connectivity has not been established and the ability to integrate information from distant brain regions is compromised from neurological and/or developmental delays. This may be evident in the inability to initiate a change or modification of movement in response to a changing environment.

For example, stimulus recognition is a critical component for controlling a simple task such as walking including: (1) stepping in the correct direction (2) lifting the foot to initiate the step and (3) swinging the leg to move forward. Each component must be executed

***Corresponding author:** Michael Horvat, The University of Georgia, Athens, GA 30605, United States, Tel: 706-542-4455; E-mail: mhorvat@uga.edu

Received January 27, 2016; **Accepted** March 15, 2016; **Published** March 22, 2016

Citation: Horvat M, Croce R, Fallaize A (2016) Information Processing and Motor Control in Down Syndrome. J Down Syndr Chr Abnorm 2: 107. doi:10.4172/2472-1115.1000107

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Typical Period of Development										
Age	2	4	6	8	10	12	14	16	18	20
Development	Infancy/Early Childhood		Pre-adolescence			Adolescence			Young Adult	
Typical Growth Rate	Rapid Steady Growth Spurt Consolidation									
Training Adaptation	Neural/Ther Distribution- Neural-hormonal changes, fat free mass									
Physical Adaptation	Reflex Inhibition Rudimentary Skills			Locomotor/Objectcontrol Fundamental Movement Patterns			Function Skills; Sport Specific Patterns			
Developmental Adaptations	Stability: Posture Control			Mobility			Functional Strength/Endurance		Speed/Power	
Moment/Development	Unstructured Play			Body Weight			Coordination		Proficiency	

Table 1: Typical Period of Development.

	Birth/Infancy	Adolescence/Adult
Biological	<ul style="list-style-type: none"> Neurological impairment Brain size reduced Cortical thinning Dendrites stop growing, becoming atrophic 	<ul style="list-style-type: none"> Immature development connectivity and ability to integrate information from distant brain regions
Cognition	<ul style="list-style-type: none"> Impaired attention Delayed development 	<ul style="list-style-type: none"> Impact on flexible cognition Attention delay Problem solving abnormalities Learning and memory difficulty
Myelination	<ul style="list-style-type: none"> Impaired myelination in temporal lobes 	<ul style="list-style-type: none"> Synaptic connections reduced Delayed myelination and information processing
Movement	<ul style="list-style-type: none"> Low muscle tone Constrained low motor functioning Passive information seeker and restriction in growth 	<ul style="list-style-type: none"> Impaired/delayed motor processing; Slower muscle responses Delayed myelination and low muscle functioning

Table 2: Neurological and Movement Development in Cognitive Disorders.

in the appropriate sequence and with the proper velocity and force for smooth execution. This will only occur by retrieving the appropriate motor program and making the suitable adjustment to ensure that the basic locomotor program can be applied properly in changing environmental contexts. Memory retrieval continually occurs as the movement progresses so that the task can proceed efficiently and correctly. The lack of a proper and flexible “motor memory” may be a primary cause, or at least a contributory factor, of the movement delays observed in DS. This may be apparent as individuals with cognitive disorders generate a functional motor pattern with walking but have difficulties in performing in more challenging environmental situations, including avoiding objects or changing speed and direction. Thus, inappropriate movement patterns are performed and interfere with overall development.

Likewise, the most adequate movements for walking may require spatial changes in the length or width of the stride or temporal components such as base of support or speed of movement. Cortical motor areas such as the premotor and motor cortices, and subcortical motor areas such as the basal nuclei and cerebellum program the initiation of these movements. Movement execution requires establishing a stable postural base and transcending movement patterns such as speed and direction for successful execution, all of which are dependent on functioning neurological and established connections. As the movement is generated, feedback is generated from various sensory systems and integrated by the cortex to update the motor response. Overall, goal formation and planning, and successful implementation of goal-directed movements are dependent on the interaction of multiple areas of the CNS [11,12].

If research is accurate, there is a lack of typical neurological development that effects sensory integration and connectivity in the brain, then movement responses are delayed or compromised by the lack of developmental changes in the brain to facilitate movement. Overall, three forms of task engagement form the basis of successful motor skill learning and performance: (1) acquisition or movement efficiency (encoding), (2) retention or durability (consolidation and storage), and (3) transfer or generalization to other situations and types of skills (retrieval). Each of these have a neurological basis and function when the performer has the ability to integrate various information from multiple brain regions that facilitate problem solving, learning and memory retention.

Impact of Multitasking and Executive Function on Motor Performance

Both research and clinical evaluations of individuals with intellectual disabilities lag behind significantly in typical development in both motor and cognitive functions (Table 1). This affects their ability to acquire and perform motor skills and places serious constraints on control and coordination [13]. Multitasking and executive functioning (EF) have profound implications for the motor performance of individuals with DS. Although the impact of increased information processing on basic motor skill execution has been investigated extensively in the non-disabled [14], and other populations with disabilities (e.g., Parkinson Disease [15]), it has not been thoroughly addressed in individuals with developmental disabilities.

Subsequently Horvat et al. [2,16] compared spatial and temporal movement parameters on responses to five dual-task conditions of increasing complexity that involves greater information processing and attention. Using similar components of gait yielded information that young adults with DS had inferior performance compared to age-matched non-disabled peers in all spatial and most temporal variables measured and decreased walking ability as task complexity increased. It was concluded that there was an inability in individuals with DS to extract relevant information that was task specific for complexity. As the dual-task included more cognitive involvement, the ability to walk was impeded, signaling more complexity for cognitive involvement and impeding the performance. Data from both experiments led the authors to conclude that although adults with DS had difficulties in postural control, they can perform a typical walking pattern that is less efficient and adaptable to changing environmental contexts. When attention is divided, or too much sensory information is encountered, additional demands are placed on their ability to process sensory information and control the movement response. This is characterized by the inability to extract relevant environmental information and reliance on a default movement setting that establishes a more secure environment as well as lack of vital brain connections. It also demonstrates the effect of dysfunctional development of the brain that delays movement responses, impair processing and integrating

information from distant brain regions including cortical thinning, atrophic dendrites, immature connectivity impaired myelination, slower processing and low muscle functioning (Table 2).

Differences in temporal and spatial aspects of walking are consistent with previous research indicating that individuals with DS experience improvements in walking patterns and motor functioning during adolescence and adulthood but experience difficulties in multitask events and modify movements to enhance control and safety [17-20]. Latash and Anson [21] speculated that “adaptive choice”, is used in unexpected situations or those requiring increased executive functioning to enhance security and stability. According to these authors, while movements produced by individuals with DS appear uncoordinated and clumsy, their movements can be viewed as adaptive reactions of choice due to changed priorities within the central nervous system (CNS). Instead of developing a coordinated motor program or pattern that can be replicated, individuals with DS select a safer alternative that can be adapted to their situation. This indicates that they revert to a default movement, which is safer and secure rather than extending their limits such as their increasing movement speed. Under unexpected circumstances, these individuals generate solutions to provide movement outcomes beneficial for themselves -- such as increased reciprocal muscle co-contraction patterns, which are viewed as abnormal in the non-disabled population to increase stability [22]. However, with extensive practice of simpler movements, these individuals can adopt a more normal tri-phasic pattern of contraction, which favors the notion that co-contraction is a choice made by them in light of CNS adaptability. Although this “adaptive choice” is mechanically suboptimal, it does offer more security to these individuals and reflects insecurity in the postural control system to generate appropriate universal postural reactions [6].

Likewise, Kubo and Ulrich [19] compared joint stiffness and forces in adolescents with and without DS by analyzing motor performance on a treadmill at different velocities showing the same adaptation mechanism, that participants increased their joint stiffness and forces. However, the primary difference between individuals with and without DS was explained as being relative to goals for their increased stiffness and force application. Individuals with DS triggered this adaptation as a compensatory strategy to maintain stability overcome joint laxity and/or reduced muscle tone. On the other hand, individuals without DS primarily optimized metabolic efficiency. Moreover, Kubo and Ulrich [23] found that when comparing toddlers with DS to a control group, toddlers with DS showed wider step widths but not a larger mediolateral displacement. They explained this finding by speculating increases in step width contributed to mediolateral stability by creating a wider base of support. Nevertheless, toddlers with DS cannot allow their burgeoning walking system to rock side-to-side more than minimally without losing balance and control. Similar to the results found by Horvat M, et al. [2,16,23] also found increased step widths and increased step lengths were utilized as a way to improve stability. This was an adaptive choice to enhance stability under varying environmental circumstances over that which is deemed as biomechanically correct [21,24], but not adaptable to changing environmental or cognitive tasks [2].

Current research on executive functioning (EF) in individuals with DS also support the notion that qualitative motor performance and EF are inextricably intertwined. Therefore, besides being impaired qualitatively in motor skills and performance, individuals with DS additionally are impaired in higher order cognitive functions such as EF, and that are interrelated with motor control [8,25-30]. Skills such

as goal formation and planning, and successful implementation of goal-directed movements are dependent on the interaction of several areas of the CNS, and are the basis for coordinated movement (Table 2).

Executive functioning in nondisabled individuals with intact neurological brain development has been linked not only to the prefrontal cortex, but distributed neural networks connecting parietal and temporal cortices. In contrast, individuals with DS encounter abnormal development of the prefrontal which may be fundamental for normal EF and a major factor in their EF deficits [31,32]. Investigators have shown that motor and cognitive processes use identical brain structures and tend to support the notion that the cerebellum is at the heart of the relationship between motor performance and EF and that the cerebellum is involved in both motor learning and cognitive learning [33,34]. This is observed most vividly during novel-tasks or when EF is highly relied upon under dual-task or dual-switching conditions that present movement difficulties for individuals with DS.

It is also apparent that motor performance and EF have several underlying processes in common that are related to planning, monitoring, and error detection, and that they all involve such processes as forward planning, response inhibition, and working memory [2,30,35,36]. Further, problems in EF exhibited by this population most likely are the result of their characteristic cognitive and brain development [26] and is supported by recent neuroimaging studies [8,32]. It appears that the pathophysiology of EF deficits in this population is complex and multifaceted and probably not limited to a single cortical region [26,37]. Recent research (Table 2) has demonstrated that individuals with DS have impaired myelination [38], have fewer cortical connections, and display abnormal brain symmetry patterns [8]. The pathophysiology of EF deficits in this population is complex and multifaceted and probably not limited to a single cortical region [26,37]. A more in-depth study of this area is needed to further explore some of the mechanisms involved in EF formation and why individuals with DS show deficiencies in this area and potential intervention techniques that facilitate function.

Overall, evidence strongly suggests synaptic plasticity is severely impaired in individuals with DS. What is not known, is how these differences impact on development of cortical and subcortical neural networks during motor learning and performance. Future research needs to determine if differences do exist and, if so, how they might impact on motor processes. At the moment, it appears that these problems can be augmented through increased participation in movement activities which have been observed in learning-induced changes in functional brain connectivity across key cortical areas [39].

Therefore, we believe that the keys to successful motor training programs should not be based on outdated theories of central nervous system integration, but rather lie within motor learning theories based on years of empirical research [40,41]. Likewise, some of the motor or physical issues such as low muscle tone or strength are linked to neurological development. According to Virgil-Babul and Latash [9], muscle responses are slower due to nervous system immaturity while postural control is inadequate or delayed. Our research, has consistently noted difficulties in many developmental components along with increases in function when opportunities and instruction are provided [5,42,43]. We also have noted a rapid drop in functioning when the intervention procedure ceases which emphasizes the need for ongoing programs and opportunities to participate especially the early years of development to initiate and develop cortical connections. Overall, the literature supports the position that systematically applied principles of motor learning can improve motor skill acquisition and performance

of individuals with DS; however, learning responses in this population are not as “robust” as that found in the non-disabled population while studies investigating motor learning in the DS population have been parsimonious in number and scope.

Therefore, individuals with intellectual and cognitive deficiencies should be exposed to developmentally appropriate motor training programs based on theories of motor control and learning that not only facilitate movement, but require increased attention during performance [1,40,44]. There may be a hierarchy of skill and/or control development that requires learning movement patterns from guided control or prompts in the early stages to processing visual and auditory cues and sequencing one or more movements into a motor pattern. Developmentally, children with DS are not generally exposed to variations in play and other movement experiences that the non-involved child experiences. Basic patterns like walking may be learned but not expanded to situations that require different movement responses in variable practice situations. The addition of a supplementary task then divides attention and decreases the flexibility of movement solutions.

More specific feedback paradigms should be established to provide individuals with DS vital cues to learn and to modify tasks under variable settings to encourage cognitive engagement. Increased learning opportunities should be provided in early stages of development in order to promote gross motor programs (GMP) and strengthen connections within the brain. In this context it is expected that individuals with cognitive involvement would maximize individual capabilities to facilitate development and apply relevant information. This avoids reverting to a default motor pattern that compromises task efficiency. The literature supports an interrelationship between cognition and movement, and that individuals with DS can improve their motor behaviors by focusing on attention and cognitive engagement. It is important for practitioners to understand that persons with DS are not inherently clumsy and un-trainable, but have a vast potential for improving their motor performances [45]. It is imperative that aggressive models of learning and feedback be used during the early stages of development to challenge individuals with DS. In this manner, individuals can be more efficient movers and able to transfer motor skills to a variety of environmental demands and to be more flexible in motor responses. With the use of basic principles of motor learning and control, practitioners can positively influence the motor behavior of these individuals.

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Citation: Horvat M, Croce R, Fallaize A (2016) Information Processing and Motor Control in Down Syndrome. *J Down Syndr Chr Abnorm* 2: 107. doi:[10.4172/2472-1115.1000107](https://doi.org/10.4172/2472-1115.1000107)

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