Initiation of Movement and Energy Expenditure in Children With Developmental Delay: A Case-Control Study

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Background. Lower levels of physical activity in children with developmental delay (DD) usually are attributed to higher energy costs. However, there is no evidence that children with DD spend more energy on daily physical activities, such as walking.

Objective. The aim of this study was to compare energy costs during walking and movement initiation times in children with DD and children with typical development (TD) and matched for age.

Design. This was a case-control study.

Methods. Children who were 3 and 5 years old and had DD (n=12) or TD (n=12) participated in the study. Measurements included ranges of motion in the lower extremities, physiological costs of walking, and movement initiation times. A task designed to evaluate the initiation of movement (the “go play with the toy” task) was used to examine the reaction times for children’s goal-directed walking.

Results. The physiological costs of walking were similar in the 2 groups; however, children with DD walked at a lower speed than children with TD. Importantly, children with DD took more time to initiate goal-directed walking.

Limitations. The nature of the study design limited causal inference from the results.

Conclusions. Children who were 3 to 5 years old and had DD had delays in goal-directed movement that may not have been attributable to motor impairments. The findings suggest that therapists should evaluate the movement initiation ability of 3- to 5-year-old children with DD as part of the design of an overall intervention plan.
Children with developmental delay (DD) have delays in meeting developmental milestones in one or more of the physical, cognitive, psychosocial, and linguistic dimensions. These disabilities may create barriers that limit participation in functional and community activities. Indeed, studies have shown that children with DD are more sedentary and have lower levels of physical activity—defined as “any bodily movement produced by skeletal muscles that results in energy expenditure” than children with typical development (TD).

According to Newell’s model, there are 3 constraints—individual, task, and environmental—that shape people’s movements by limiting or permitting their execution (Fig. 1). Individual constraints are related to children’s diagnosis and physical and mental conditions. For example, for children with cerebral palsy, walking has a higher energy cost. A high energy cost during physical activities may cause children to become easily fatigued and preclude many physical activities.

Cognitive information processing, which consists of stimulation identification, response selection, and response programming, is critical in the initiation of movement. The speed of information processing can be determined by reaction time (RT), which is the time between the stimulation input and movement onset. Many studies have investigated the RTs of people with or at risk for DD; however, these studies had some limitations. First, the tasks used in most of these studies involved aiming or computer-based games not closely related to daily physical activities. Second, most of these studies involved children who were at risk for DD and were more than 5 years old or adults with or without DD.

Task constraints in movement execution refer to task-specific physical and cognitive demands. Environmental constraints are not task specific and include physical or social environmental factors such as temperature, light, flooring, parental attitudes toward children’s movement, and discouragement or encouragement.5

To date, only Bartlett and Palisano have investigated the role of individual constraints in motor development or skills acquisition in children with or at risk for DD. However, the role of individual constraints in the execution of well-learned or mastered skills, such as getting up from a stationary position, walking, or mov-

Figure 1. Conceptual model used in the present study and based on Newell’s model.6,7

ROM = range of motion.

The Bottom Line

What do we already know about this topic?

In children with developmental delay (DD), physical therapists usually focus on reducing energy expenditure in order to increase levels of physical activity on well-learned activities, such as walking.

What new information does this study offer?

As expected, children aged 3 to 5 years with DD have delays in goal-directed movement rather than greater energy costs of walking.

If you’re a patient or a caregiver, what might these findings mean for you?

As part of the plan of care, physical therapists should evaluate the movement initiation ability of children with DD and develop strategies to enhance this ability.
ing to reach a toy, have not been explored in young children with DD. These constraints have been suggested as an explanation for the discrepancy between motor performance (what a child actually does—eg, does not walk) and motor capacity (what a child can do—eg, can walk) in children with DD. Therefore, it is important to understand their individual effects. The purpose of this study was to investigate individual constraints in the execution of a well-learned daily physical activity in young children with DD. We compared the physical demands of walking and RTs in a goal-directed walking task in children with DD and children with TD while the task (goals, rules, equipment) and environment (space, temperature) constraints were standardized. We hypothesized that children with DD aged 3 to 5 years would have relatively more physical and mental constraints in the walking activity than would children with TD. The findings of this study may help identify factors contributing to the often sedentary lifestyle of children who are 3 to 5 years old and have DD and may assist in the development of better rehabilitation strategies, which may include fitness training or task and environment modifications.

Method

Study Design

This age- and sex-matched case-control study was conducted to understand the differences in the physiological costs of walking and RTs in a task designed to evaluate the initiation of movement (the “go play with the toy” task) in children with DD and children with TD. Walking and moving to play with toys were chosen because these are common activities for children who are 3 to 5 years old.

Definition of DD

Developmental delay was defined as having a diagnosis of a condition or z scores of less than −1 (developmental quotients of <85) on the Comprehensive Developmental Inventory for Infants and Toddlers (CDIIT). The CDIIT was developed in Taiwan in 1996 and was based on a randomized sample of 3,703 children who were 3 to 71 months old. The inventory contains 343 items clustered into 5 domains: cognition, language, motor, social, and self-help skills. The CDIIT manual contains detailed item-by-item instructions to guide the administration of the instrument. The scores on the CDIIT were converted to z scores and developmental quotients to facilitate comparison with age-matched norms. The reliability and validity of the CDIIT have been well established, and the CDIIT has been used for Taiwanese children with DD.

Participants

Children who had DD and were 3 to 5 years old were referred to our study by the pediatric rehabilitation clinics of Chang Gung Memorial Hospital. Children were excluded from the present study if they could not walk independently for 500 m, had unstable physical conditions (ie, were within 3 months of having surgery, botulinum toxin injection, infection, or severe disease), had progressive or degenerative symptoms or diseases, or had a diagnosis of autism or autistic tendency. Children with TD (ie, were within the control group) were recruited from a local kindergarten and were age and sex matched to children in the DD group. Sample size was estimated from the results of a pilot study (6 children in each group). The estimated sample size for each group was 12 when the α value was set at .05 and the desired power was set at .8. Written parental consent was obtained before children participated in the study.

Experimental measurements were obtained for all 24 eligible 3- to 5-year-old children (12 with DD and 12 with TD; 6 boys and 6 girls in each group). The average developmental quotients in the 5 domains of the CDIIT for children with DD were as follows: 77 in cognition, 78 in language, 56 in motor, 87 in social, and 66 in self-help. Specifically, of the 12 children with DD, 5 (42%) had cognitive delays, 5 (42%) had language delays, 12 (100%) had motor delays, 5 (42%) had delays in social interactions, and 12 (100%) had delays in self-help skills. The children with DD were shorter and weighed less than the children with TD. However, there was no difference in the body mass indexes of the 2 groups (Tab. 1). The ranges of motion of the lower extremities were similar in the 2 groups (P < .10 for all range-of-motion comparisons).

Setting and Measurements

Body weight and height were measured before the walking test, which assessed the physiological costs of walking. The range of motion of the lower extremities (hip, knee, and ankle joints) was measured with a goniometer after the walking test. Finally, movement initiation times were evaluated. To prevent potential sources of bias, graduate students and research assistants who did not know the aims or hypotheses of the study conducted the experimental procedures.

Physiological costs of walking.

The physiological costs of walking were determined using the physiological cost index (PCI; beats per meter). The standard measurement of energy cost during an activity is determined by recording the oxygen uptake with a metabolic system. However, the face masks used to collect gas for such systems are often
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uncomfortable, and the instrumentation may be too cumbersome for young children.22,23,26 Indeed, the use of face masks has been reported to cause excessive stress for children.24 Compared with complex metabolic systems, the PCI, which is calculated by subtracting the resting heart rate (HR) (beats per minute) from the walking HR and dividing the result by the walking speed (m/min), is more commonly used in clinics for assessing the energy cost of walking.8,22,23,25,26 The PCI has been reported to be a reliable index of walking efficiency in children with TD, children with cerebral palsy, and children with cystic fibrosis.8,22,27 The reproducibility of the measurement of the PCI, as analyzed with the intraclass correlation coefficient, has been reported to be high (intraclass correlation coefficient of >.8).8 A higher PCI value indicates greater energy expenditure during the walking test. Resting HR and walking HR under steady-state conditions28 (the last 2 minutes of the resting and walking periods) were calculated with Polar ProTrainer software (Polar Electro Inc, Port Washington, New York).

The procedures for the walking test were explained to the parents and the children before an HR monitor (Polar RS400; Polar Electro Inc) that recorded HR during the walking test was fastened on the child’s chest at the level of the xiphoid process with an adjustable chest band. The child was asked to sit quietly for 5 minutes and then walk consecutive lengths of a 30-m walkway at a self-selected speed while wearing shoes for 8 minutes. During the test, an investigator (A) instructed the child to stand behind the starting line, and another investigator (B) or the parents stood at the turning line. The child took a sticker from investigator A, walked at a self-selected speed to the turning line, stuck the sticker on a board that was held by investigator B or the parents, and turned back immediately to the starting line to get another sticker. During the test, investigators reminded the child not to jog or run. The distance walked was recorded. After completing the walking portion of the test, the child was asked to sit quietly for 4 minutes. The test was completed in 19 minutes.

“Go play with the toy” task. We designed the “go play with the toy” task to examine children’s RT, focus time (FT, the time spent focusing on the target), and movement time (MT, the time between movement onset and reaching the target). Participants were taken to a room with a child’s chair, a table, a digital camera, and a white cloth covering a toy train on the table. A toy train with a railway track was used in the test because all of the children chose it as their favorite toy. We let the children select their favorite toy to minimize the possibility of differences in motivation affecting outcome measurements in the task. The chair and the table were 3 m apart. In the beginning of the test, the child was instructed to sit on the chair with hip and knee joints flexed at 90 degrees and both feet on the ground. The tester sat behind the table with the train that was covered by a white cloth. After the child sat still for 10 seconds, the tester removed the cover and pressed a button on the toy train that caused it to move and make sounds. If the child did not stand up and walk toward the toy, the tester gave verbal prompts (“Would you like to play with the toy train?” and “Go and get it!”) after 2 minutes. The test was video recorded until the child touched the toy (Fig. 2).

The video recordings of the “go play with the toy” task were analyzed by a trained investigator with the computerized video analysis system Observer XT (Noldus Information Technology, Wageningen, the Netherlands). The time between the toy being revealed and movement by the child (RT), the time between the child standing and reaching the table with the toy (MT), and the time the child spent focusing on the target toy while sitting in the chair (FT) were measured (Fig. 3). The interobserver reliability of this test in our pilot study with 6 children in each group was high. The intraclass cor-

Table 1.
Demographic Characteristics of Children With Developmental Delay (DD) and Typical Development (TD)\(^a\)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Children With DD (n=12)(^b)</th>
<th>Children With TD (n=12)(^b)</th>
<th>(P^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>3.6 (0.4)</td>
<td>3.8 (0.4)</td>
<td>.37</td>
</tr>
<tr>
<td>Height, cm</td>
<td>95.7 (6.7)</td>
<td>104.2 (7.3)</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>14.7 (2.3)</td>
<td>17.2 (2.9)</td>
<td>.03</td>
</tr>
<tr>
<td>Body mass index, kg/m(^2)</td>
<td>16.0 (1.9)</td>
<td>15.8 (1.0)</td>
<td>.71</td>
</tr>
<tr>
<td>Diagnosis (no. of children)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DD without a defined etiology</td>
<td>5 NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Down syndrome</td>
<td>1 NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>Preterm with DD</td>
<td>3 NA</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>DD with congenital heart disease</td>
<td>3 NA</td>
<td>NA</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)NA—not applicable.  
\(^b\)Data are reported as mean (standard deviation) unless otherwise indicated. 
\(^c\)Determined with an independent t test. \(P\) values of less than .05 indicate significant differences.
relation coefficients for RT, MT, and FT were 1 ($P < .001$), .99 ($P < .001$), and .93 ($P < .001$), respectively.

Data Analysis
Data are presented as means (standard deviations). Independent $t$ tests and chi-square tests were used to examine the differences between children with DD and children with TD according to continuous and categorical variables. Separate $t$ tests were used for RT and MT in the “go play with the toy” task because RT and MT are different, and the lengths of RT and MT were independent of each other in the task. Effect sizes were calculated with the Cohen $d$; 0.2 to 0.3 was considered a small effect, 0.5 was considered a medium effect, and 0.8 was considered a large effect. Pearson product-moment correlation coefficients were used to examine the relationships between continuous variables. SPSS 10.0 (SPSS, Chicago, Illinois) was used to analyze data statistically, and the significance level was set at .05 (2-tailed).

Role of the Funding Source
This study was supported by the Chang Gung Medical Research Program (CMRPD190181) and the National Science Council of Taiwan (NSC99-2314-B-182-002, NSC99-2314-B-182-017-MY2, NSC99-2320-B-182-001, and NSC101-2314-B-182-006-MY3).

Results
Comparison of Physiological Costs During a Walking Activity
We found that the PCI values were similar in children with DD and children with TD. However, children with DD walked more slowly than children with TD ($P = .01$), and this result had a large effect size (Cohen $d = -1.12$) (Tab. 2). The distance covered in 8 minutes of walking by children with DD was 12.4% shorter than that covered by children with TD. To evaluate whether the body

Figure 2.
Setting and procedure for the “go play with the toy” task. (A) Setting of the test. (B) The test starts with the tester removing the cover and pressing a button on the toy train to cause it to move and make sounds. (C) The test ends when the child touches the toy. (D) The tester gives verbal prompts if the child sits for more than 2 minutes after the toy is revealed.
height of the children influenced walking speed and distance, we used Pearson product-moment correlations. We found no significant correlation between body height and walking distance \( (r = -0.04, P = 0.84) \) or between body height and walking speed \( (r = -0.04, P = 0.86) \).

Comparison of RT and FT in the “Go Play With the Toy” Task

Children with DD had longer RTs and FTs but not MTs (Tab. 2). In other words, children with DD spent more time sitting (Cohen \( d = 1.11 \)) and looking at the target toy (Cohen \( d = 1.16 \)) before starting to move toward the toy. The walking speed (the inverse of MT) and the percentage of time the children spent focusing on the target toy while sitting (FT/RT) were not significantly different in children with DD and children with TD (Tab. 2). Five children (42%) in the DD group did not move until the prompt was given, whereas all children with TD moved toward the toy before the prompt was given.

A greater PCI was associated with a longer RT in the “go play with the toy” task \( (r = 0.52, P < 0.05) \) for all children.

Discussion

In the present study, we examined the physiological costs of walking and RTs for the initiation of goal-directed movement in children with DD and children with TD. The task that was used to evaluate the physiological demands of walking (8 minutes of continuous walking) required high levels of physiological effort and low levels of cognitive output from the children because the children were guided by continuous prompting during the task. In contrast, the task that was used to evaluate the initiation of movement (the “go play with the toy” task) required high levels of cognitive output and low levels of physiological effort from the children because of the short distance between the children and the toy. We found that long-distance walking did not require more physiological effort for children with DD but that these children walked at a lower speed than children with TD. Importantly, we found that children with DD appeared to have longer RTs for the initiation of goal-directed movement.

In traditional physical therapy for children with DD, therapists have attributed poor walking function to a lack of physical conditioning. This attribution was based on evidence from studies that determined peak physiological parameters, such as peak HR and oxygen consumption. However, peak cardiovascular fitness does not always reflect the fitness of an individual during a task at a submaximal workload; indeed, there has been no evidence that 3- to 5-year-old children with DD show greater energy expenditure than children with TD during activities at submaximal intensities. In the present study, we chose walking, the most common activity in daily living, to examine the energy expenditure.
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Table 2.

Comparisons of Children With Developmental Delay (DD) and Typical Development (TD)α

<table>
<thead>
<tr>
<th>Variable</th>
<th>Children With DD (n=12)</th>
<th>Children With TD (n=12)</th>
<th>t</th>
<th>P*</th>
<th>95% CI</th>
<th>Cohen d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locomotor efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resting HR, bpm</td>
<td>113.8 (11.5)</td>
<td>110.7 (10.9)</td>
<td>0.68</td>
<td>.51</td>
<td>−6.38, 12.58</td>
<td>0.28</td>
</tr>
<tr>
<td>Walking HR, bpm</td>
<td>143.8 (18.3)</td>
<td>138.8 (17.1)</td>
<td>−2.68</td>
<td>.01</td>
<td>−91.63, −11.72</td>
<td>−1.09</td>
</tr>
<tr>
<td>Distance, m</td>
<td>366.1 (32.1)</td>
<td>417.7 (58.5)</td>
<td>−2.73</td>
<td>.01</td>
<td>−0.19, −0.03</td>
<td>−1.12</td>
</tr>
<tr>
<td>Speed, m/s</td>
<td>0.76 (0.07)</td>
<td>0.87 (0.12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PCI, beats/meter</td>
<td>0.65 (0.37)</td>
<td>0.54 (0.18)</td>
<td>0.99</td>
<td>.33</td>
<td>−0.13, 0.36</td>
<td>0.38</td>
</tr>
<tr>
<td>FT, s</td>
<td>100.4 (66.4)</td>
<td>42.0 (33.3)</td>
<td>−2.23</td>
<td>.04</td>
<td>−114.78, −2.11</td>
<td>1.11</td>
</tr>
<tr>
<td>FT, s</td>
<td>76.2 (48.0)</td>
<td>33.2 (20.9)</td>
<td>−2.32</td>
<td>.04</td>
<td>−82.65, −3.28</td>
<td>1.16</td>
</tr>
<tr>
<td>FT/RT, %</td>
<td>0.83 (0.25)</td>
<td>0.81 (0.19)</td>
<td>−0.18</td>
<td>.86</td>
<td>−0.26, 0.22</td>
<td>0.09</td>
</tr>
<tr>
<td>MT, s</td>
<td>4.0 (0.9)</td>
<td>3.3 (0.5)</td>
<td>−2.05</td>
<td>.06</td>
<td>−1.53, 0.03</td>
<td>0.96</td>
</tr>
</tbody>
</table>

α HR=heart rate, PCI=Physiological Cost Index, RT=time between the toy being revealed and movement by the child, FT=time the child spent focusing on the target toy while sitting in the chair, FT/RT=percentage of time the child spent focusing on the target toy while sitting, MT=time between the child standing and reaching the table with the toy.

β Data are reported as mean (standard deviation).

* Determined with an independent t test. P values of less than .05 indicate significant differences.

in children with DD and TD at a submaximal workload. We found that the physiological costs during long-distance walking in children with DD and children with TD were not significantly different. This finding suggests that children with DD have the physical capacity to perform submaximal physical activities as well as children with TD.

Recent intervention trends have incorporated mental processes, such as cognitive processes and motivation, to enhance context-appropriate and efficient goal-directed motor functions. Cognitive information processing is a critical component of motor planning. Several tests, such as RT and MT tests, have been developed to determine children’s cognitive information processing. However, there are some limitations of such tests. First, these tests are mainly for school children with intact cognitive function. Second, although there is a measurement tool for children with disability, it was designed for children more than 5 years old. Third, most of the tasks in these measures do not include activities in which young children participate on a daily basis. Fourth, some tests incorporate subjective ratings of children’s cognitive information processing rather than determining it objectively. To overcome the limitations of the available measures, we designed the “go play with the toy” task, which allows 3- to 5-year-old children to respond actively in a natural context, is compatible with children’s daily activities, and yields results that are evaluated quantitatively. We used a video analysis system to determine RT, FT, and MT; these quantitative data provided objective information to strengthen the previously obtained qualitative data.

We found that children with DD took more time to initiate goal-directed behavior than children with TD. Although previous findings directly linked to the present study of young children with DD and children with TD and matched for age are not available, there are studies that have reported improvements in motor responses with age up until young adulthood. This finding suggests that the motor response is associated with cognitive ability because cognitive ability improves during development. Collectively, our findings and those of previous studies suggest that children with lower developmental levels, such as children with DD, may need more time for cognitive information processing than children with TD and matched for age.

We found that a cognitive component (ie, RT), rather than a physical component (ie, energy cost of walking), may be the individual constraint for performing a well-learned movement (such as walking) in young children with DD. This finding suggests that when facilitating movement and physical activity in children with DD, physical therapists could modify the task and environmental constraints from a cognitive viewpoint (Fig. 1). For example, physical therapists could make tasks simpler and less cognitively challenging by designing a goal-directed task.
with clear instructions and giving continuous prompting during the task.\textsuperscript{36,37}

Another finding of the present study was the positive correlation between the PCI and the time children spent initiating goal-directed movement. This finding suggests that physical abilities may influence the time taken by young children to initiate a movement because a higher PCI value indicates greater energy expenditure. The relationship between physical abilities and RTs for a voluntary movement may be associated with the dependence on cognition to execute a voluntary movement. Cognitive information processing consists of stimulus identification, response selection, and response programming.\textsuperscript{9} Thus, children who have lower physical abilities may spend more time processing cognitive information. In the present study, 5 children with DD did not move until the prompt was given, whereas all children with TD moved toward the toy before the prompt was given. Nevertheless, the components of cognitive processing that play a major role in determining RTs in young children warrant further study. In addition to challenges in cognitive processing, physical difficulties may decrease children’s motivation to initiate goal-directed movement.

The present study had some limitations. First, the nature of the study design limited causal inference from the results. Second, the lower walking speed of children with DD in the walking test may have been influenced by the motivation and cognitive status of the children, although continuous prompting was given during the task. Third, in addition to the cognitive information processing of children, other factors, such as the motivation to move, may have influenced the results in the “go play with the toy” task.

In conclusion, 3- to 5-year-old children with DD spent more time in a stationary position before initiating goal-directed behavior, such as walking, than children with TD. However, the energy expenditures during the walking task were not significantly different in the 2 groups, although children with DD tended to walk at a lower speed. We suggest that greater consideration of the initiation of goal-directed movement is important for clinical and research programs that aim to improve movement in 3- to 5-year-old children with DD.

Dr Chen and Dr Hwang provided concept/idea/research design, project management, and facilities/equipment. Dr. Chen, Dr Hwang, and S-Y. Lin provided writing. Dr Hwang, S-Y. Lin, and Y-C. Lin provided data collection and analysis. Dr Chen provided fund procurement. Dr Hwang provided study participants. The authors thank all of the children and parents for their participation in the study.

This study was approved by the Ethics Committee of Chang Gung Memorial Hospital.

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References


