Exercise Intensity Based on Heart Rate While Walking in Spastic Cerebral Palsy

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Abstract
We examined the heart rate (HR) of subjects with spastic cerebral palsy (CP) in order to estimate exercise intensity while walking. The subjects were 17 subjects with CP (14.0 ± 3.7 years of age) containing 7 subjects rated as level 1, 4 subjects rated as level 2, and 6 subjects rated as level 3 by the Gross Motor Function Classification System, and 7 normal subjects (12.4 ± 2.8 years of age) were used as a controls. Even in subjects whose gross motor function was excellent (rated as level 1), the HR significantly increased while walking when compared to normal subjects (p < 0.05), although the walking speed between the groups was not different. According to the HR, the exercise intensity while walking was adapted from weakly to moderately and thought to be appropriate for exercise. On the other hand, walking speed was significantly reduced in the subjects rated as level 2 and 3 (p < 0.05), and the HR increased significantly (p < 0.05). Seven of the ten subjects rated as either level 2 or 3 showed a high HR of over 150 beats/min while walking. The HR while walking of the two subjects rated as level 3 continued to increase although the walking speed was kept constant. The walking exercise would be too strong and become detrimental to such subjects.

Physical fitness consists of joint mobility, muscle strength, muscle power, motor coordination, and physical endurance. The individual who has sufficient joint mobility, muscle power and strength, and motor coordination can walk functionally, but is restricted to short distances. In order to walk longer distances, physical endurance is demanded. To enable individuals with spastic paralysis to walk better, walking exercise seems to be a simple choice that may improve their physical endurance. However, there are reports that demonstrate the high-energy expenditure experienced by subjects with spastic cerebral palsy (CP) while walking. Therefore, if the exercise intensity is very strong, this form of exercise cannot be recommended.

This study investigates how exercise intensity affects subjects with CP. In general, when the walking speed is increased, more energy is expended. In order to compare the energy expenditure of different subjects under similar conditions, the walking speed must be the same. In order to regulate walking speed the subjects could be made to walk on a motor driven treadmill. However, only subjects with excellent walking ability can walk on a motor driven treadmill. Regulating walking speed from slow to fast is difficult for CP subjects, adjusting their walking speed to the treadmill speed is difficult. On the other hand, for the disabled subjects, constant walking speed can be achieved by walking at the subjects’ comfortable and self-selected speed instead of walking on a treadmill. Therefore, we measured both walking speeds and the heart rates (HR) of CP subjects while walking at their comfortable, self-selected speed on a flat circular track.

Subjects and Methods
The participants in this study were 17 CP subjects aged from 9.3 to 22.9 years old (average: 14.0 ± 3.7 years) and seven normal subjects ranging in age from 9.3 to
16.3 years old (average: 12.4 ± 2.8 years). All of the subjects gave their informed consent. The CP subjects were classified into three groups, level 1, level 2, and level 3 according to the Gross Motor Function Classification System (Table 1). Seven CP subjects aged from 9.9 to 18.5 years (average: 12.6 ± 2.9 years) were rated as level 1. The level 1 CP subjects consisted of three hemiplegic subjects and four diplegic subjects. Four CP subjects aged from 10.9 to 22.9 years (average: 16.5 ± 4.9 years) were rated as level 2. The level 2 CP subjects were all diplegic. All of the subjects rated as either level 1 or 2 walked in daily life without any assistance. Six CP subjects from 10.2 to 19.8 years of age (average: 16.6 ± 3.9 years) were rated as level 3. The level 3 CP subjects consisted of one paraplegic and five diplegic subjects. One of the level 3 CP subjects walked with crutches in daily life. Another one of the level 3 CP subjects walked with a walker. The other four level 3 CP subjects used wheelchairs in daily life but could walk with crutches.

The HR at rest was first recorded in each CP subject as they lied supine for a period of 20 minutes. The HR was recorded by using a small and light heart rate monitor (model AM01, Nadex Co.). Following the recording of the HR during rest, the HR of the subjects while walking was recorded. The subjects walked at their comfortable speed accompanied by the physiotherapists. The subjects walked on an indoor circular track. The ambient temperature was kept at 24° C by air conditioners. The physiotherapists sent marking signals into the HR recorder via a switch on the AM01 at every 100 m of distance traveled. The distance goal was tentatively set at 800 meters for all subjects. The data on the subjects who could not walk for at least three minutes at a constant speed were excluded. Before recording the HR, rehearsals were performed three times for each subject on different days to avoid any mental influences. After recording of the HR, the AM01 was connected to a personal computer, the mean HR while at rest and HR while walking for every 100 m of distance were analyzed by using an analysis program (AM01-F02A, Nadex Co.). The heart rates were analyzed based on the RR interval (the interval from R wave to R wave on the electrocardiogram).

The walking distance the subjects could walk, HR, and walking speed for every 100 m of distance were analyzed and the walking energy efficiency calculated by the following formula:

\[
\text{WEE (m/beats)} = \frac{\text{walking speed (m/min)}}{HR \text{ while walking - while at rest (beats/min)}}
\]

The walking energy efficiency (WEE) was an inverse number of the energy expenditure index (EEI). Statistical differences between groups were tested using analysis of variance (ANOVA). The significance level was set at 0.05.

**Results**

**Walking Distance**

All of the subjects rated as level 1 and 2 could walk the 800 m distance. Only one subject rated as level 3 could walk 800 m. The other subjects rated as level 3 walked less than 800 m: one subject for 500 m, one subject for 300 m, one subject for 200 m, and one subject for 100 m.

**HR and Walking Speed**

The relationship between HR while walking and walking speed is shown in Figure 1. Although walking speed in subjects rated as level 1 showed no difference in walking speed compared to normal subjects, their HR while walking increased significantly. Walking speed ranged from 51.5 to 79.5 m/min (average: 64.8 ± 10.1 m/min), and the HR while walking ranged from 84.9 to 124.0 beats/min (average: 101.1 ± 14.4 beats/min) in the normal subjects. Walking speed ranged from 51.1 to 70.8 m/min (average: 61.3 ± 9.8 m/min), and the HR while walking ranged from 114.7 to 141.9 beats/min (averaged 125.8 ± 10.6 beats/min) in the subjects rated as level 1. There were four level 1 subjects whose heart rates were

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<tr>
<th>Level</th>
<th>Self-mobility</th>
<th>Notes</th>
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<tr>
<td>Level 1</td>
<td>Walks without restriction; limitations in more advanced gross motor skills.</td>
<td>Children walk indoors and outdoors, and climb stairs without limitation. Children perform gross motor skills including running and jumping.</td>
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<tr>
<td>Level 2</td>
<td>Walks without assistive devices; limitations walking outdoors and in the community.</td>
<td>Children walk indoors and outdoors, and climb stairs holding onto a railing but experience limitations walking on uneven surfaces and inclines, and walking in crowds or confined spaces. Children have at best only minimal ability to perform gross motor skills such as running and jumping.</td>
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<tr>
<td>Level 3</td>
<td>Walks with assistive mobility devices; limitations walking outdoors and in the community.</td>
<td>Children walk indoors or outdoors on a level surface with an assistive mobility device. Children may climb stairs holding onto a railing. Depending on upper limb function, subjects propel a wheelchair manually or are transported when traveling for long distances on uneven terrain.</td>
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<tr>
<td>Level 4</td>
<td>Self-mobility with limitations; children are transported or use power mobility outdoors and in the community.</td>
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<td>Level 5</td>
<td>Self-mobility is severely limited even with the use of assistive technology.</td>
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over 120 beats/min. But, there were no level 1 subjects whose HR while walking was over 150 beats/min.

Walking speed in subjects rated as levels 2 and 3 decreased significantly, but HR while walking increased significantly compared to normal subjects. There were no differences in HR while walking between subjects rated as either level 2 or 3. The walking speed of level 3 subjects decreased significantly compared to level 2 subjects. Walking speed ranged from 34.4 to 65.3 m/min (average: 61.3 ± 9.8 m/min), and HR while walking ranged from 112.1 to 179.8 beats/min (average: 157.1 ± 31.7 beats/min) in the subjects rated as level 2. There were three level 2 subjects whose HR was over 150 beats/min. Walking speed ranged from 11.0 to 57.6 m/min (average: 29.0 ± 17.2 m/min), and HR while walking ranged from 140.7 to 178.6 beats/min (averaged 156.8 ± 14.3 beats/min) in the subjects rated as level 3. There were four level 3 subjects whose HR was over 150 beats/min.

**Walking Energy Efficiency (WEE) and Walking Speed**

The relationship between WEE and walking speed is shown in Figure 2. Both the walking speed and WEE were significantly different among the groups. The WEE was significantly different between level 2 and 3, although the HR while walking was not different (Fig. 1). Those rated as level 3 exhibited the worst walking energy efficiency. The WEE of the level 1 subjects was relatively good but significantly lower than the normal subjects. The WEE of the level 2 subjects was significantly lower than the level 1 subjects. The WEE ranged from 0.98 to 1.65 m/beats (average: 1.23 ± 0.27 m/beats) in the level 1 subjects, from 0.47 to 0.89 m/beats (average: 0.63 ± 0.19 m/beats) in the level 2 subjects, from 0.12 to 0.64 m/beats (average: 0.35 ± 0.18 m/beats) in the level 3 subjects, and from 1.35 to 2.74 m/beats (averaged 2.22 ± 0.46 m/beats) in the normal subjects.

The mean and standard deviation (SD) of the HR while walking, walking speed, and WEE related to walking distance in normal subjects is shown in Figure 3. The walking speed was kept constant. The HR increased in the short period of the initiation of gait and then was kept constant. The pattern of HR change while walking for most of the CP subjects was the same as the normal subjects (Fig. 3).

However, an extraordinary pattern of HR change was
observed in two subjects that were classified with a level 3 disability. The HR was not constant in these two subjects even though the walking speed was constant. The HR kept increasing in these subjects (Fig. 4). One was a subject who used crutches the other used a walker in their regular activities of daily living.

Discussion

Subjects classified with a level 1 disability have good gross motor functions (see Table 1). However, the physical endurance of CP subjects with a level 1 disability can be considered to be lower than normal subjects because the HR while walking showed a significant increase although the walking speeds were similar. In other words, WEE of CP subjects rated as level 1 decreased due to their unfavorable physical endurance. The decrease of physical endurance of the level 1 CP subjects may come from the lower physical activity in their daily lives. Appropriate exercise may make their physical endurance and WEE more favorable.

From another point of view, since the heart rates were over 120 beats/min in four of the subjects but not over 150 beats/min in any of these subjects, the exercise intensity of free walking in these subjects corresponds to mild or moderate intensity exercise. Therefore, free walking is a suitable exercise for CP subjects rated as level 1 and could help increase their physical endurance.

The heart rates were significantly increased while walking in level 2 and 3 CP subjects in spite of their slower walking speed. There were 9 level 2 and level 3 subjects whose HR while walking was over 150 beats/min. Although the walking speed of the CP subjects rated as level 2 and 3 was very slow, the intensity of walking for them might be equal to that of running for normal subjects. Walking must be hard exercise for level 2 and 3 CP subjects. Attention should be paid to the data for the level 2 CP subjects; their gross motor function is relatively good and we would think that walking would incur minimal risks if we did not see their HR data.

Our prior study showed a correlation between lower limb contractures and oxygen uptake while walking in CP subjects. In this present study, the HR between the level 2 subjects and the level 3 subjects is not different. And the walking speed was significantly slower in the level 3 CP subjects compared to the level 2 subjects. Therefore, the decrease of WEE in the level 3 CP subjects is thought to come from the slower walking speed. The slower walking speed is a result of the functional impairment of gross motor function, including lower limb joint contractures. On the other hand, our other study showed that the anaerobic threshold of CP subjects with lower physical activities decreased. Therefore, the deconditioning effect that the decreased physical activities of daily life have on cardiopulmonary fitness may contribute to their high HR while walking. As the results of WEE were clearly separated among the groups, WEE could be a good indicator of total physical endurance.

Further, it was a very important observation that the HR while walking continued to increase and did not reach the constant level under constantly slow walking speed in two level 3 CP subjects. This observation indicates that the exercise intensity of free walking in these subjects was already higher than the anaerobic threshold level in spite of the very slow walking speed. These subjects could not regulate their walking speed in order to decrease energy expenditure. Additionally, these subjects could only walk for short distances, indicating that walking is not practical as transportation or as a simple exercise. Although walking, as an exercise, may be a way to increase endurance, it is risky to use or recommend walking as an exercise for these CP subjects with level 3 disability. If walking is to be used for level 3 CP subjects, it is advisable to reduce exercise intensity by means of hydrotherapy walking or a harness to support body weight.
For exercise to improve physical endurance, the exercise intensity of free walking is appropriate for the CP subjects with a level 1 disability. Walking is, however, harder for level 2 CP subjects than one might expect and rather risky for the level 3 CP subjects. When walking is considered as an exercise for CP patients with disabilities above level 1, ways to reduce exercise intensity should be considered.

References