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Developmentally delayed children with different muscle tone have different muscle activity and acceleration during sit-to-stand

Sun-Young Ha[1], Yun-Hee Sung[2,*]

[1]Institute for Basic Sciences Research, Kyungnam University, Changwon, Korea
[2]Department of Physical Therapy, College of Health Sciences, Kyungnam University, Changwon, Korea

Developmental delays cover a wide range, with different movement characteristics occurring depending on differences in muscle tone. We aimed to investigate muscle activity and acceleration during sit-to-stand in developmentally delayed (DD) children with different muscle tones. Forty participants were divided into three groups: typically developing (TD) children (n=18), DD children with hypertonia (n=12), and DD children with hypotonia (n=10). Electromyography was used to measure muscle activity and BTS G-Walk was used to measure acceleration. As a result, the activities of the rectus abdominal muscle and quadriceps muscle were lower in DD children with hypertonia than in TD children ($P<0.05$). The activity of the tibialis anterior muscle was higher in DD children with hypotonia than in TD children ($P<0.05$). The trunk angle was greater in DD children with hypotonia than in TD children ($P<0.05$), and vertical acceleration was lower in DD children with hypertonia than in TD children ($P<0.05$). Based on these differences, we will be able to provide intervention programs appropriate for the characteristics of DD children with different muscle tone.

Keywords: Hypertonia, Hypotonia, Muscle tone, Sit-to-stand

INTRODUCTION

Sit-to-stand (STS) is a prerequisite for walking and other activities of daily living (Chou et al., 2003; dos Santos et al., 2011). STS is a demanding task that requires forward and upward displacement of the body's center of mass (Hennington et al., 2004). STS performance can be limited by various factors (Bernardi et al., 2004; Janssen et al., 2002), especially knee extensor strength (Yoshioka et al., 2012).

One of the factors that affects movement such as STS is muscle tone. Muscle tone is the resistance to movement when a muscle is at rest and plays a fundamental role in predicting movement as well as maintaining posture (Davidoff, 1992). The common forms of atypical muscle tone are hypertonia or hypotonia (Bodensteiner, 2008; Straathof et al., 2021). Hypertonia is an abnormally high resistance during passive movements (Brogren et al., 1998), and the most common type is spasticity; this is due to hyperexcitability of the stretch reflex, resulting in excessive tendon jerks and a speed-dependent increase in tonic stretch reflex (Smania et al., 2010). Hypotonia is a decrease in resistance within the passive range of motion, and a representative example is central hypotonia; they are associated with normal muscle strength or mild to moderate weakness, and although antigravity movements are present, the response may be weak (Peredo and Hannibal, 2009). Therefore, muscle tone abnormalities such as hypertonia or hypotonia affect movement and postural tasks (Gurfinkel et al., 2006).

Developmentally delayed (DD) children are a group that exhibits atypical muscle tone and reduces motor development (Kaminishi et al., 2021). These include cerebral palsy (CP), intellectual disability, congenital myopathies, chromosomal abnormalities, and congenital malformations, causing problems in gross and fine motor skills, cognition and language, and activities of daily life (Choo

*Corresponding author: Yun-Hee Sung https://orcid.org/0000-0002-4877-9784
Department of Physical Therapy, College of Health Sciences, Kyungnam University, 7 Kyungnamdaehak-ro, Masanhappo-gu, Changwon 51767, Korea
Email: sungpt97@kyungnam.ac.kr
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et al., 2019; Hong et al., 2017).

Although developmental delays encompass a wide range, the majority of STS have focused on typically developing (TD) children and DD children with hypertonia (i.e., spastic CP). Comparing the characteristics of DD children with those of TD children according to muscle tone during STS can provide a detailed understanding of movement differences and can influence decision-making when providing treatment. Thus, we aimed to compare muscle activity and acceleration during STS between TD children and DD children with hypertonia or hypotonia.

MATERIALS AND METHODS

Participants

Participants were DD children aged 5 to 12 who visited the Sky Child Development Center in Yangsan city, and children with typical development of their age. The general characteristics of the participants are shown in Table 1. The inclusion criteria were among children aged 5 to 12; (a) TD children with no problems with motor function, (b) children with hypertonia corresponding to gross motor function measure classification system 2–3, (c) children with hypotonia due to chromosomal abnormalities, intellectual disabilities, genetic problems, etc., who are able to walk independently or walk with an assistive device, (d) Children who can follow simple instructions from the examiner. Exclusion criteria were (a) children with uncontrolled seizures, (b) children with audiovisual problems, (c) children with acute high fever or inflammation, and (d) children who had surgery within 6 months.

We divided 40 participants into three groups: TD children (n = 18), DD children with hypertonia (n = 12), and DD children with hypotonia (n = 10). The procedures and purpose of this study were explained to the participants and their guardians, and informed consent was obtained from them. This study was approved by the Research Ethics Committee of Kyungnam University (No. 1040460-A-2022-011).

Table 1. General characteristics of participants (N = 40)

Characteristic	TD children (n = 18)	DD children with hypertonia (n = 12)	DD children with hypotonia (n = 10)	*P*-value
Sex, male:female	13:5	5:7	4:6	
Age (yr)	8.94 ± 1.98	8.00 ± 2.66	8.90 ± 3.07	0.563
Weight (kg)	32.33 ± 11.70	22.83 ± 7.50	31.20 ± 15.41	0.091
Height (cm)	128.94 ± 13.54	116.91 ± 13.97	126.30 ± 21.19	0.132
GMFCS (II/III)		10/2	-	-
Walk independently/ walk with an assistive device	-	-	9/1	-

Values are presented as mean ± standard deviation.
TD, typically developing; DD, developmentally delayed; GMFCS, gross motor function classification system.

Muscle activity

Surface electromyography (sEMG) (Trigo Wireless EMG, Delsys Inc., Natick, MA, USA) was used to measure muscle activity. The sampling of the EMG signal was 1,000 Hz, the frequency bandwidth was 20 to 1,000 Hz, and a 50 Hz notch filter was used. EMG data for muscle activity were processed using root mean square (RMS) and the values were normalized to referenced voluntary contraction (RVC) (Ju, 2020).

Before measurement, the dominant foot was determined by kicking a soccer ball (Schneiders et al., 2010). The participants were asked to sit barefoot on a chair adjusted to knee height, with their ankles bent at 90°, and stand up at a speed of their choosing with arms crossed in front of the chest, according to the examiner's instructions (Fujimoto and Chou, 2012). The activity of the dominant leg was measured from the time the buttocks were lifted off the chair until the knees were straightened (Lee and Yoo, 2017). RVC measured the activity of the rectus abdominal muscle (RA), quadriceps, and tibialis anterior on the dominant side when maintaining a quiet standing position for 5 sec (Ju, 2020), and was measured for 3 sec excluding the first and last 1 sec. Each measurement was performed 3 times, and the average value was used. To minimize the resistance generated on the skin, the electrodes were attached after removing foreign substances with an alcohol swab. The RMS of each muscle was converted into a percentage (% RVC) and used for result analysis. The electrodes were placed as follows; The RA; 2 cm next to the navel, the quadriceps (rectus femoris) muscle; the midpoint between the knee and the superior anterior iliac bone, and the tibialis anterior; at 1/3 on the line between the tip of the fibula and the tip of the medial malleolus (Hermens et al., 2000).

Acceleration

BTS G-Walk (BTS Bioengineering, Garbagnate Milanese, Italy) was used to measure acceleration during STS. The G-walk sensor was placed on the participant's lower back (2nd lumbar vertebra) along with an elastic band. Data on STS were collected during the "timed up and go" set on the equipment. The participant flexed the hip and knee joints 90° while sitting on a chair, stood up, and walked forward according to the examiner's instructions. At this time, the trunk angle and acceleration were measured during STS.

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We measured twice and used the average value.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics version 21.0 (IBM Co., Armonk, NY, USA). The Shapiro–Wilk test was used to test normality. Because the variables were not normally distributed, all analyzes used nonparametric statistics. Muscle activity and acceleration were compared between the three groups using the Kruskal–Wallis test and Dunn *post hoc* test. All data were reported as mean±standard deviation, and the significance level in statistical analysis was set at $P<0.05$.

RESULTS

Muscle activity

The activities of RA and quadriceps were lower in DD children with hypertonia than in TD children ($P<0.05$). The activity of the tibialis anterior was higher in DD children with hypotonia than in TD children ($P<0.05$) (Table 2).

Acceleration

The trunk angle was greater in DD children with hypotonia than in TD children ($P<0.05$). Vertical acceleration was lower in DD children with hypertonia than in TD children ($P<0.05$) (Table 3).

Table 2. Muscle activity during sit-to-stand (%)

Variable	TD children	DD children with hypertonia	DD children with hypotonia	*P*-value
RA	127.88±66.30[a,c]	73.27±39.39[b]	93.53±27.76[a,b,c]	0.017*
Rectus femoris	200.67±74.69[a,c]	123.36±77.25[b]	165.76±65.81[a,b,c]	0.013*
TA	123.54±19.81[a,b]	145.80±31.38[a,b,c]	206.99±91.73[c]	0.004*

Values are presented as mean±standard deviation.
Same superscript alphabet means not statistically difference between groups based on nonparametric statistics Kruskal–Wallis and Dunn *post hoc* test.
TD, typically developing; DD, developmentally delayed; RA, rectus abdominal muscle; TA, tibialis anterior.
*$P<0.05$.

DISCUSSION

STS is a basic activity for upright movement such as walking, running, and jumping (Ploutz-Snyder et al., 2002). Efficient STS tasks require an appropriate amount of energy to accelerate the center of mass from sitting to standing (Cameron et al., 2003) and coordinated contraction of lower extremity muscles and trunk muscles (Lee et al., 2015).

DD children with hypertonia exhibit atypical movements due to abnormal muscle recruitment and excessive coactivation of antagonist muscles (Brogren et al., 1998). Adjenti et al. (2017) reported that in children with CP, the activity of the lateral abdominal muscles decreased during activity compared to rest in the supine position, but there was no difference in the activity of RA. They said that RA was least affected by spasticity. In this study, DD children with hypertonia during STS had lower RA activity than TD children, showing different results from Adjenti et al. (2017). These results are thought to be due to differences in the posture in which the movement is performed. In this study, it is thought that DD children with hypertonia made movements through compensation because the base of support was narrow during STS, making it difficult to control RA effectively. DD children with hypotonia and TD children show similar abdominal muscle contraction (Ha and Sung, 2022). Peredo and Hannibal (2009) reported that DD children with hypotonia exhibit mild muscle weakness. In this study, there was no difference in RA activity between groups in DD children with hypotonia and TD children. This result is thought to be because the supraspinal control system mechanisms are not damaged in children with hypotonia.

Weakness of the knee extensors increases trunk flexion before standing (Van der Heijden et al., 2009). Children with hypotonia have overall muscle weakness that affects their balance (Malak et

Table 3. Acceleration and trunk angle during sit-to-stand

Variable	TD children	DD children with hypertonia	DD children with hypotonia	*P*-value
Flexion angle (°)	32.28±4.75[a,b]	37.51±6.87[a,b]	41.60±13.08[c]	0.032*
AP acceleration (m/sec^2)	5.50±2.22[a]	3.75±1.45[a]	3.97±1.08[a]	0.068
ML acceleration (m/sec^2)	5.05±2.47[a]	3.83±2.72[a]	3.92±1.40[a]	0.117
Vertical acceleration (m/sec^2)	7.43±2.43[a,c]	4.75±2.04[b]	5.35±1.77[a,c]	0.009*

Values are presented as mean±standard deviation.
Same superscript alphabet means not statistically difference between groups based on nonparametric statistics Kruskal–Wallis and Dunn *post hoc* test.
TD, typically developing; DD, developmentally delayed; AP, anterior-posterior; ML, medial-lateral.
*$P<0.05$.

al., 2015). Muscles with spasticity activate muscles other than the prime mover or cause cocontraction during movement (Tedroff et al., 2006). Therefore, muscle tone problems or muscle weakness affect STS performance. In this study, quadriceps activity was lower in DD children with hypertonia than in TD children, but trunk flexion angle was greater in DD children with hypotonia than in TD children. We believe that in DD children with hypertonia, spasticity activates muscles other than the intended agonist, resulting in reduced quadriceps activity. It was thought that in DD children with hypotonia, activation of the tibialis anterior muscle was increased to compensate for decreased balance, and the trunk flexion angle was further increased to compensate for this.

Acceleration is the rate of change of speed over time. During routine walking, the body's center of mass changes velocity in all three directions of movement (anterior-posterior, medial-lateral, and vertical), generating regular and repeatable distinct accelerations from step to step (Lowry et al., 2013). During STS, trunk flexion generates forward momentum that accelerates the body's center of mass forward, while the knee extensors are used to accelerate the body upward with the assistance of the hip extensors (Murray et al., 1967; Roebroeck et al., 1994). In this study, DD children with hypertonia had significantly lower vertical acceleration than TD children. It is thought that the low quadriceps activity of DD children with hypertonia contributed to the decrease in vertical acceleration.

In summary, DD children with hypertonia had lower activities of the RA and quadriceps and lower vertical acceleration during STS than TD children. DD children with hypotonia showed larger trunk flexion angles and higher tibialis anterior activity than TD children. Therefore, it is necessary to consider the differences in movement during STS and apply an intervention program appropriate for their characteristics. Limitations of this study include the small number of study subjects, making it difficult to generalize its contents, and the need to measure the activity of various muscles that affect sit-to-stand. Future research should supplement these limitations.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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