Effects of Head-Centered Gross Motor Training on Balance, Gait and GMFM in the Children with Spastic Diplegia

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Purpose This study was to investigate the effects of head-centered gross motor training on balance, trunk sway, gait and gross motor functions of children with spastic diplegia. **Methods** The experimental group (n=10) participated in head-centered gross motor training program (30 minute per session and 2 sessions per week), while the control group (n=10) received regular physical therapy (30 minute per session and 2 sessions per week). Changes in static balance ability, gait ability, and gross motor functions were measured pre- and post-intervention to determine the effect of the intervention. **Results** The experimental group showed a significant difference in terms of trunk sway during static gait after the intervention. In the gait function test, the experimental group showed a significant difference only in single-support phase, while the control group showed a significant difference only in step width. In the gross motor function measure (GMFM), the experimental group showed significant differences in the mean of C, D, E and total whereas the control group showed significant differences in the mean of D, E and total. In the between-groups comparison, a significant difference in only mean of E was found in the gross motor function measure. **Conclusion** Based on these findings, it was determined that head-centered gross motor training improves static balance, trunk control, and postural stability during gait, and gross motor functions in children with spastic diplegia. Improved postural stability through such head-centered gross motor training could be helpful in improving balance and postural control.

Key words Spastic diplegia, Head-centered Gross motor training, Static balance, Trunk sway, GMFM

Ⅰ. Introduction

Children with spastic diplegia have greater spasticity and dysfunction in the lower limbs than in the upper limbs,[1] which is caused by periventricular leukomalacia (PVL) arising from focal necrosis of the white matter due to surrounding cerebrovascular problems, infection/inflammation and inherent vulnerability of the brain tissue.[2] Children with spastic diplegia have primary damage in the form of reduced muscle activation, decline in selective motor control function, and abnormal muscle tone, along with secondary problems including muscle contracture and musculoskeletal deformities.[3] These primary and secondary problems have significant effects on postural control impair-

ment, walking, and gross motor function.[4] In particular, decline in head control function in children with cerebral palsy (CP) leads to static and dynamic postural instability, resulting in impaired postural control.[5] Healthy children acquire head control and the ability to maintain their head upright at around 3~4 months after birth with the development of head stabilization.[6] Head control at different head position angles is essential for postural control[7] and enhancement of this postural control leads to acquisition of gross motor skills.[8] Children with spastic diplegia, however, have impaired head control that affects three-dimensional spinal alignment and pelvic tilt, causing inaccurate body posture regulation.[4] In addition, they have difficulty maintaining proper posture and achieving balance due to altered trunk movements[6, 9] and express

a characteristic pathological gait pattern and gross motor function problems.[10]

A recent study showed that a decline in head control in children with spastic diplegia affects trunk sway and reduces dynamic stability of the head and trunk compared with the gait of normal children.[9] These results suggest that head/trunk stability is integral to spinal stability and balance maintenance and greatly affect gross motor function.[11, 12] Children with spastic diplegia with mild impairment of gross motor function tend to fix the head and trunk as a single unit and thus show increased lateral bending, while moderately impaired children show high instability due to a greater increase in trunk sway in all three dimensions.[9, 13] Therefore, providing the opportunity for normal development of movement, along with head/trunk stability, is highly critical to resolving postural instability.[11]

In a previous study of children with spastic diplegia, supporting the head for stability during walking induced less trunk sway than supporting the thoracic, which suggests that increasing head stability with head-centric sensory signals enhances trunk control and optimizes gait and is thus highly important for postural control.[14] Such improvement in head control effectively increases trunk stability and improves static and dynamic balance, as well as gross motor function.[15] However, previous studies investigated the effects of proximal exercise intervention for the respective body part but there have been no reports on the effects of head-centered gross motor training on balance and gait. The present study thus aimed to investigate the effects of head-centered gross motor training on balance, gait, and gross motor function in children with spastic diplegia. The study was conducted with the approval of the Institutional Review Board at YongIn University (approval number 2-1040966-AB-N-01-20-1903-HSR-135-2).

II. Materials and Methods

1. Subjects

Twenty patients with spastic diplegia aged 3-15 years or below who visited clinic B in Gyeonggi Province as an inpatient from January to March 2019, capable of independent walking corresponding to Gross Motor Function Classification System (GMFCS) level 1-3, and consented to participate were included in this study. For each GMFCS level, we randomly assigned participants using Microsoft Excel. Participants were children without any cognitive problem, capable of following instructions, and who had not undergone botulinum toxin injection or received surgical treatment within the last 6 months.

2. Procedure

In this study, the experimental group received the head-centered gross motor training program, while the control group received standard physical therapy twice a week, 30 minutes per session, for 8 weeks.

1) Head-centered gross motor training program

This experimental program was conducted by a physical therapist who had expert knowledge in neurodevelopmental treatment. We developed a head-centered gross motor training program, consisting of five domains for a total of six program types, by applying gross motor functions such as supine to sitting, side-lying to sitting, prone to kneeling, sit to standing, and walking. The programs were administered for 5 minutes each, for a total of 30 minutes (Figure 1).[16, 17]

2) Standard physical therapy

Standard physical therapy was conducted by a physical therapist who had expert knowledge in neurodevelopmental treatment. The program for standard physical therapy included exercises for joint mobilization and stretching, muscle strengthening, weight bearing, postural control, and walking.

3. Measurements

1) Static balance ability

To assess the static balance of children with spastic diplegia, we used Biorescue (RM Ingenieri, France). Participants were asked to stand barefoot on the platform and maintain a standing posture for 5 seconds without moving, while looking at a visual marking

Facilitation of Supine to Sit movement	
Facilitation of Side-lying to Side-sit movement	
Facilitation of Prone to Kneeling movement	
Facilitation of Sit to stand & Stand to sit movement	
Facilitation of Gait	

Figure 1. Intervention of Head-centered gross motor training program

placed in front of them at eye-level. We obtained a total of three measurements in the standing position and measured the center of mass (COM) and center of pressure (COP) during left and right weight-bearing to compare the ratio of left/right weight-bearing area and pressure.

2) Comparison of changes in trunk sway displacement
To measure the magnitude of trunk sway from the gait parameters, we used Balance Gear (ALDA, Taiwan), which measures the forward/backward (pitch), in-ward/outward (roll), and upward/downward (yaw) dis-placements of trunk movement.[18] Participants stood barefoot on the floor throughout measurement and si-multaneously underwent functional gait assessment. We

placed the middle portion of the device on the partic-ipant's xiphoid process using an elastic band and en-sured that the sensor was aligned with the midline be-fore the participant started walking. Each participant walked a total of 4 m three times, while the trunk an-gular sway was measured.

We extracted the roll data (angular displacement from the trunk midline to the left (-) or right (+) side in the frontal plane). The extracted data were then converted to radians to compute the trunk sway dis-tance to the left and right using the sine trigonometric function. For each of the three calculations of sway distance, we included data up to the tenth stride, ex-cluding first stride data.

3) Gait analysis

To measure the spatiotemporal gait parameters, we used the two-dimensional Optogait system (Microgate, Italy) as the gait analyzer. Two-dimensional analysis is enabled by positioning all transmission/reception bars within 1 m horizontally and 4 m vertically, allowing for correction of errors due to overlapping motion during measurement and accurate analysis of the measured gait parameters. Participants waited standing barefoot on the floor within the transmission/reception area and started walking following the researcher's "Go" signal towards the opposite end at their desired speed. The measurement was performed a total of three times and the collected gait parameter data were processed using software (Microgate, Italy).

4) Korean Gross Motor Function Measure 88 (K–GMFM88)

To assess the gross motor function, we used the K-GMFM88. Evaluation criteria were divided into a total of five domains: A lying and rolling; B sitting; C crawling and kneeling; D standing; and E walking, running, and jumping. Of the five domains, we used the scores for domains C, D, E, and the total score to compare results.

4. Data analysis

In this study, SPSS 22.0 program for Windows was used. Difference between pre- and post-test were analyzed by The general characteristics of the subjects were calculated by using descriptive statistics to mean and standard deviation, and the Shapiro-Wilk test was performed to verify the normality of the measured data. Difference between pre- and post-test were ana-lyzed by Wilcoxon rank sum test and Mann-Whitney U test was performed to compare differences between the groups. Statistically significant levels were = to 0.05.

III. Results

1. Static balance ability

We analyzed the ratio of left/right weight-bearing areas in standing posture and found that the area significantly decreased by 7.94%, from 13.23% to 5.29%, in the experimental group following intervention ($p<.05$), whereas in the control group, the area increased by 0.04%, from 10.96% to 11.00%, which was not statistically significant ($p>.05$). We analyzed the ratio of left/right weight-bearing pressure and found that the pressure significantly decreased by 14.71%, from 19.99% to 5.28%, in the experimental group following intervention ($p<.05$), whereas in the control group, the area had decreased by 2.49%, from 20.43% to 17.94% ($p>.05$). No significant between-group differences were found in these two analyses ($p>.05$) (Table 1).

2. Comparison of changes in trunk sway distance

We analyzed the changes in trunk sway during the 4-m walk and found that sway distance significantly decreased by 1.55 cm, from 9.67 cm to 8.12 cm, in the experimental group following intervention ($p<.05$), whereas in the control group, the distance changed from 10.57 cm to 10.87 cm, which was not statistically significant ($p>.05$) Between-group comparison revealed

Table 1. Comparison of static symmetry, trunk sway within and between groups.

Variable	Experimental group (n=10)			Control group (n=10)			z	p
	pre	post	Change (post-pre)	pre	post	Change (post-pre)		
Foot print area	13.23 ± 7.95	5.29 ± 3.08	8.53 ± 6.65[*]	10.96 ± 5.96	11.00 ± 5.80	6.23 ± 5.74	-0.983	0.326
Foot print pressure	19.99 ± 10.64	5.28 ± 4.67	15.00 ± 10.91[*]	20.43 ± 11.26	17.94 ± 9.77	8.33 ± 5.60	-1.361	0.174
Trunk sway	9.67 ± 3.53	8.12 ± 3.86	1.85 ± 1.32[*]	10.57 ± 4.58	10.87 ± 4.45	1.11 ± 0.62	-1.739	0.082

M±SD : mean±standard deviation, p<0.05 *

Table 2. Comparison of gait analysis variables within and between groups.

Variable	Experimental group (n=10)			Control group (n=10)			z	p
	pre	post	Change (post-pre)	pre	post	Change (post-pre)		
Speed, cm/min	0.69 ± 0.23	0.60 ± 0.18	0.17 ± 0.10	0.61 ± 0.29	0.59 ± 0.24	0.19 ± 0.17	-0.41	0.67
Cadence, steps/min	118.23 ± 26.74	110.60 ± 18.59	16.17 ± 9.90	102.44 ± 40.42	106.47 ± 43.40	20.30 ± 21.15	-0.60	0.54
Step length, cm	34.90 ± 6.85	32.27 ± 5.88	3.97 ± 2.51	37.12 ± 8.54	34.28 ± 8.54	7.10 ± 5.38	-1.09	0.27
Stride length, cm	69.76 ± 13.33	64.93 ± 11.08	7.60 ± 5.57	74.02 ± 17.71	68.79 ± 16.69	14.08 ± 10.69	-1.28	0.19
Step width, cm	14.66 ± 3.45	15.29 ± 3.47	14.66 ± 3.45	16.57 ± 7.35	14.41 ± 6.37	16.57 ± 7.35*	-0.60	0.54
Single support, %	35.29 ± 8.14	31.35 ± 3.60	5.19 ± 8.41*	41.38 ± 22.67	37.31 ± 10.51	8.55 ± 11.70	-1.66	0.09
Double support, %	33.29 ± 11.64	40.03 ± 7.65	8.29 ± 11.94	27.38 ± 27.36	31.03 ± 17.90	9.11 ± 9.97	-0.90	0.36
Stance phase, %	68.27 ± 3.94	70.73 ± 3.64	3.30 ± 3.34	68.18 ± 5.76	66.94 ± 7.78	3.39 ± 2.85	-0.15	0.88
Swing phase, %	31.54 ± 3.79	29.04 ± 3.58	3.47 ± 3.03	32.71 ± 5.76	33.07 ± 7.62	2.87 ± 2.33	-0.03	0.97

M±SD : mean±standard deviation, p<0.05 *

no significant difference (p>.05) (Table 1).

3. Gait analysis

We analyzed the spatiotemporal parameters identified through gait analysis in the experimental and control groups and obtained the following results. In the experimental group, the single support time significantly decreased by 3.94%, from 35.29% to 31.35%, following intervention (p<.05), while in the control group it decreased by 4.07%, from 41.38% to 37.31% (p>.05). In the control group, the step width significantly decreased by 2.16 cm, from 16.57 cm to 14.41 cm (p<.05) (Table 2).

4. Korean Gross Motor Function Measure 88 (K-GMFM88)

Analysis of the K-GMFM88 results revealed that in the experimental group, C crawling & kneeling increased by 2.16%, from 94.97% to 97.13%; D standing increased by 5.87%, from 78.96% to 84.83%; and E walking, running and jumping increased by 9.85%, from 63.59% to 73.44%, which were all significant changes (p<.05). In addition, the mean total score increased by 5.96%, from 79.17% to 85.13%, which was also a significant change (p<.05).

The before-after comparison in the control group revealed that D standing significantly increased by 2.32%, from 70.45% to 72.77% and E walking, running and jumping changed by 2.48%, from 53.30% to 55.78% (p<.05). On the other hand, C crawling & kneeling increased by 0.95%, from 91.62% to 92.57%, which was not significant (p>.05). Moreover, the mean total score showed a significant change from 71.79% to 73.70% (p<.05).

Between-group comparison of the rate of change in gross motor function revealed no significant difference, with C crawling & kneeling at 2.16% and 0.95%, and D standing at 5.84% and 2.32% (p>.05). E walk-

Table 3. Comparison of gross motor function within and between groups.

Variable	Experimental group (n=10)			Control group (n=10)			z	p
	pre	post	Change (post-pre)	pre	post	Change (post-pre)		
C. Crawling and kneeling (range)	94.97 ± 6.31	97.13 ± 5.25	2.16 ±2.38[*]	91.62 ± 4.80	92.57 ± 4.42	0.85 ± 1.65	-1.33	0.18
D. Standing (range)	78.96 ± 9.73	84.83 ± 6.90	5.87 ±4.68[*]	70.45 ± 10.20	72.77 ± 9.82	2.32 ± 2.83[*]	-1.70	0.09
E. Walking, running and jumping (range)	63.59 ± 16.97	73.44 ± 16.44	9.85 ±6.86[**]	53.30 ± 15.17	55.78 ± 15.89	2.48 ± 1.82[*]	-2.77	0.01[**]
Average score (range)	79.17 ± 9.82	85.13 ± 8.01	5.96 ±2.97[**]	71.79 ± 8.74	73.70 ± 9.04	1.91 ± 1.52[*]	-3.03	0.01[**]

M±SD : mean±standard deviation, $p < 0.05$ *, $p < 0.01$ * *

ing, running and jumping, however, showed a significant difference between the two groups, 9.85% and 2.48% ($p<.05$). The mean total scores were 5.96% and 1.91%, which was also a significant difference ($p<.05$) (Table 3).

Ⅳ. Discussion

This study was conducted to investigate the effects of the head-centered gross motor training program on balance, gait, and gross motor function in spastic diplegia. Until about the age of 6 years, coordinated movements using head control are highly crucial for maintaining balance and at approximately the age of 7–8 years, more information comes from the balance control centers than from head position, which suggests that the development of head control is critically implicated in the development of balance.[16, 19] In addition, standing posture, an example of static balance, requires anti-gravity posture orientation for maintaining body alignment against gravity and postural stability in base of support (BOS).[20] Trunk muscles must be activated via anticipatory postural control to provide proximal stability and minimize body sway, thus enabling smooth distal movements.[21] The present

study thus aimed to evaluate the left/right symmetry during static balance by exploring differences in the ratio of left/right weight-bearing area and pressure in the base of support in the standing posture.

The results of the static balance ability measurement showed that in the experimental group, the symmetry increased as the difference in the ratio of left/right weight-bearing area and pressure decreased following the intervention. Such results of static balance assessment are consistent with previous findings that improvement in head control leads to enhanced head-trunk connectivity, balance, and proprioception.[22, 23]

Head control is also known to play an integral role in gait development,[24] but there is almost no literature on differences between the head and trunk during walking in spastic diplegia and research is focused mainly on the effects of lower limb damage, rather than the movements of the head and trunk.[25] Nevertheless, a previous study by Wallard[13] analyzed the range of head and trunk sway during walking in CP children and found a significant change in the rotational angle of the head roll in the frontal plane. Therefore, CP children use the "en bloc" strategy when it is difficult or impossible to make separate rotational movements of the head and trunk, in which the head and trunk move together as a single unit,

thereby limiting the degrees of freedom, and display a gait pattern with increased trunk sway.

Accordingly, the present study also found a significant decrease in the trunk sway distance during the 4-m walk; following intervention, trunk sway decreased by 1.55 cm, from 9.67±3.53 to 8.12±3.86 cm, only in the experimental group ($p<.05$). Another previous study by Schulleri[14] demonstrated a decrease in sway with interpersonal touch (IPT) at the apex and occiput area and not with thoracic support in CP children, but this change was not significant. These findings support the results of the present study based on head stabilization.

In the functional gait assessment, we could not confirm that the head-centered gross motor training program significantly affected gait, contrary to our experimental hypothesis. The gait assessment results showed that only single support significantly decreased by 3.94%, from 35.29±8.14% to 31.35±3.60% in the experimental group ($p<.05$). This suggests the presence of several other underlying reasons for CP-related difficulties with achieving or controlling proper posture and unstable gait pattern.[26] Factors influencing gait in CP include ankle stability[27] and hip movement[9, 28, 29]; thus, it is difficult to change gait using head control alone. However, in the present study, we confirmed a significant change in single support in the experimental group, as well as a 6.74% increase in double support from 33.29±11.64% to 40.03±7.65%, a non-significant 2.46% increase in stance phase, from 68.27±3.94 to 70.73±3.64, and an increase in mean support stability, through which we can conclude that dynamic instability affects gait.

Finally, the K-GMFM results revealed a significant within-group change following intervention in the experimental group ($p<.05$). In the control group, however, there was a significant change in standing; walking, running, and jumping; and the total score ($p<.05$), but there was no significant change in crawling and kneeling ($p<.05$). These results are consistent with previous findings that improvements in head stabilization affects the increase of range of motion and motor function.[15, 22] Such findings support the results of the present study.

In conclusion, we believe that the head-centered gross motor training program positively affected static balance, trunk sway, gait stability, and gross motor function in diplegic CP children. We have provided the therapeutic evidence and rationale for using the head-centered gross motor training program to enhance postural control. Furthermore, the proposed program can be delivered not only by physical therapists but also through parental education so that the child can independently perform the functional movements and apply them to daily activities. We expect it to be used as the basis for the development of home training programs, therapy, and research in the future. Nevertheless, this study has limitations in its small sample size, short intervention period, and wide range of subject ages. A follow-up study to reinforce the evidence of this intervention program is required.

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