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Original Article

Effects of task-specific movement patterns during resistance exercise on the respiratory functions and thickness of abdominal muscles of children with cerebral palsy: randomized placebo-controlled double-blinded clinical trial

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Abstract. [Purpose] This study was conducted to examine the effects of task-specific movement patterns during resistance exercise program, which are applied to children with cerebral palsy, on respiratory functions and thickness of abdominal muscles. [Participants and Methods] This study was conducted with randomized double-blinded controlled research was pursued since it is a clinical trial with minors with disabilities as the participants. Seventeen children with cerebral palsy were randomly allocated to both experimental group and placebo group by means of simple randomized sampling. The experimental group wore weighted vest to which loaded-resistance was applied by means of sand bag while the placebo group wore weighted vest without loaded-resistance. Task-specific movement patterns during resistance exercise were performed for 40 minutes 2 times a week over a period of 12 weeks for the participants in both groups. Differences in respiratory functions and thickness of abdominal muscles measured prior to and after 12 weeks of the experiment were compared. [Results] All the measurement values for the respiratory functions and abdominal muscle thickness displayed statistically significant changes between those prior to and after the exercise in both of the experimental group and the placebo group. There were statistically significant differences in the changes prior to and following the exercise between the two groups. [Conclusion] Therefore, task-specific movement patterns in anatomical plane, diagonal patterns and combined forms during resistance exercise program on for children with cerebral palsy can be considered as an efficient intervention method in improving respiratory capacity.

Key words: Cerebral palsy, Task-specific movement, Respiratory function

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INTRODUCTION

Cerebral palsy is one of the main neurological diseases that induce physical disabilities such as the loss of sensation and motor control, and dysfunction of the respiratory system[1, 2)]. Children with cerebral palsy are characterized with a lower level of fitness in comparison to normally developed children[3, 4)] and display reduction in physical activities along with problems in their mobility[5, 6)]. This is because the lowered level of physical activities induces the vicious cycle of deconditioning in which the fitness is degraded and aggravation of mobility is induced, thereby generating further disabilities[7)]. In addition, motor function disabilities of children with cerebral palsy motor function act as the key factor in interfering with development and recovery from illness since they further aggravate the ability of the children for daily life activities by causing paralysis

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of respiratory muscles or inducing abnormally distorted chest, limitations in physical activities and delay in the development of cardiorespiratory system[8]. Such problems in physical activities can continue into the adolescence and adult stage[9], and it is very important to implement physiotherapy intervention in the initial stage for prevention by the time they reach school age prior to their adolescence in which the activities decrease in the case of children with cerebral palsy.

In the case of children, progressive resistance exercise in which the duration of progress of intensity can be set well and can be used as a method of further promoting muscle strengthening rather than normal development or growth[10]. Important factors in progressive resistance exercise is to sustain the exercise program over sufficient period of time in which improvement of muscular strength can occur by providing low level loaded-resistance appropriate for the limited repetition number (generally, 8–12 times) and gradually increasing the intensity of resistance in order to complete the exercise before fatigue sets in[10]. However, providing loaded-resistance that determines the effectiveness of progressive resistance exercise only by means of body weight[11] is not appropriate for the principle of overloading of muscle strengthening exercise[12]. Moreover, it is difficult for loaded-resistance provided in non-functional tasks such as repetitive leg push to improve motor learning or be metastasized into functional performance[13].

Since the activities of children in their daily lives in general are composed of composite movements of closed kinematic chain and multi-angle joints, it is necessary for them to perform functional task exercises in specific methods that are appropriate for the situations repeated in their home rather than progressive resistance exercise of specific muscle or muscle groups conducted manually or by using mechanical resistance. In particular, it is more effective to fortify muscular strength through task-specific movement patterns in anatomical plane, diagonal patterns and combined forms during resistance exercise rather than selectively fortifying the strength of specific muscular groups in the case of children with cerebral palsy. In addition, since children with cerebral palsy have difficulties in coordination and motor plan, exercise environment for improvement of habitual physical activities or walking abilities must be considered[14]. Accordingly, it has been proposed that task-specific exercise that combined progressive resistance exercises is effective in improving the muscular strength and mobility of children with cerebral palsy in order to improve the functional movements of closed kinematic chain and multi-angle joint[11, 15–17]. According to the recent studies, it is possible for research participants capable of diversity to perform intense activities including ambulation are able to maintain or further advance their respiratory functions related to physiological functions[18, 19]. Therefore, for physiotherapy intervention of children with cerebral palsy, exercise program capable of not only improving fitness level through muscle strengthening[20] and promoting physical activities[21, 22], but also improving respiratory capacity is required clinically. As such, this study was conducted to examine the effects of task-specific movement patterns in anatomical plane, diagonal patterns and combined forms during resistance exercise program, which are applied to children with cerebral palsy, on respiratory functions and thickness of abdominal muscles. In addition, it was carried out to provide effective and reliable basic clinical data at the time of designing intervention program for the improvement of respiratory capacity of children with cerebral palsy by pediatric physiotherapists in the future.

PARTICIPANTS AND METHODS

This study was conducted with quasi-experimental research design with pre-post test between two groups to examine the effects of task-specific movement patterns during resistance exercise on respiratory functions and thickness of abdominal muscles of children with cerebral palsy. In addition, randomized double-blinded controlled research was pursued since it is a clinical trial with minors with disabilities as the participants. Approval of Bioethics Committee of Dong Eui University regarding the responsibilities for the protection of human rights, dignity and safety of the research participants was acquired in advance (IRB No. DIRB-201601-HR-R-005).

Detailed criteria for selection of the research participants included capabilities for task performances according to the instructions of the research and communication by children in the age bracket of 5–12 years with stage II–III spastic cerebral palsy under the Gross Motor Function Classification System. However, children who have unstable seizures, undergone chemoneurolysis or orthopedic surgery for muscle spasticity within the last 6 months were administered with spasmolytic medication or who have other diseases were excluded. Prior to the commencement of the experiments, purposes, methods, procedures, potential risks and inconveniences of the research were explained to the research participants (including legal representative) before collecting their letters of consent that they are participating in the research voluntarily.

Seventeen children with cerebral palsy were randomly allocated to both experimental group and placebo group by means of simple randomized sampling. Firstly, range of joint motion and stretching exercise were performed for the trunk and both legs for 5–10 minutes as warm-up exercise. It was made sure that lumbar extensor muscles, adductor muscles of hip joint, hamstring muscles and ankle plantar flexors were included in the stretching exercise. The experimental group wore weighted vest to which loaded-resistance was applied by means of sand bag while the placebo group wore weighted vest without loaded-resistance. Task-specific movement patterns in anatomical plane, diagonal patterns and combined forms during resistance exercise were performed for 40 minutes 2 times a week over a period of 12 weeks for the participants in both groups. Differences in respiratory functions and thickness of abdominal muscles measured prior to and after 12 weeks of the experiment were compared. However, it was ensured that guardians of the children (legal representative) participated in all the procedures of this experiment including application of resistance exercise or measurement of research results of the research participants.

X-small (chest size of 56–64 cm) and Small (chest size of 66–74 cm) sizes were used for weighted vest (Hongik Trading, HSI3228) applied to the children in the experimental group. Sand bags with weights of 227 g, 318 g and 454 g can be put into the pocket in this weighted vest, thereby enabling the researcher to appropriately adjust the loaded-resistance according to the participant. Low loaded-resistance that allows the participant to repeat the given exercise 8–12 times at the minimum was selected in deciding the sand bag weight to be applied to the weighted vest and it was ensured that loaded-resistance was not increased by more than 5% at a time[23)]. The loaded-resistance began at about 0.5% of the body weight of the research participants and was allowed to be increase to the maximum of approximately 20% of the body weight up until the 12th week of the experiment. Participants were led to learn the functional movements of closed kinematic chain and multi-angle joints in anatomical plane, diagonal patterns and combined forms by increasing the number of repetitions or the overall number of exercises loaded-resistance in the 1st week of task-specific movement patterns exercise. If the participant was able to complete the overall stages and repetitions of task-specific movement patterns during resistance exercise without fatigue, training was continued by increasing the loaded-resistance.

Task-specific movement patterns during resistance exercise was composed as illustrated in Table 1 in accordance with the characteristics of the research participants by making reference to the research by Scholtes et al[24)]. Children in both groups were instructed to perform 8–10 repetitions of each stage of the exercises with 3 minutes of rest between the said stages. All treatments and instructions were rendered by physiotherapist with professional education on neurodevelopmental treatment and more than 5 years of clinical experiences. Moreover, research assistants who received sufficient education on the training program in advance provided supervision and assistance for the safety of the participants.

Respiratory functions of the research participants was measured by using Spirometer Pony FX (Cosmed Ltd., Italy) after having confirmed that the state of health of children with cerebral palsy is good. Firstly, forced vital capacity (FVC) was measured by having the research participants seated on chair with back support in comfortable clothes for movement bite on mouth piece, and inhale as much air as possible and then exhale as quickly and forcibly as possible after having taken normal breath 3 times. Forced expiratory volume at one second (FEV1) and peak expiratory flow (PEF) were deduced through the FVC measured. However, precautions were taken to prevent coughing, leakage of air and errors in the measurement of respiratory functions in accordance with the guidelines of the American Thoracic Society (ATS) (1991). Optimal measurement value was chosen by taking 3 repetitive measurements.

The thickness of abdominal muscles of the research participants was measured by diagnostic ultrasonography equipment (Aloka, SSD-3500X; Aloka Co. Ltd., Tokyo, Japan). Ultrasonography images of rectus abdominis, transverse abdominal muscle, internal oblique muscle and external oblique muscle were taken while the participants were in resting state by means of 10 MHz linear probe used exclusively for muscles by applying high resolution B-mode scan. After having instructed the research participant to lie down on therapeutic bed on supine position, ultrasonography gel was applied to the linear probe and skin of the participant. The center of the linear probe was then situated on the areas of measurement through palpation of the said areas on the basis of ocular examination of ultrasonography images and anatomical knowledge of the researcher. Measurement of rectus abdominis was taken at the midpoint between the lower portion of xiphoid process and belly button of the participant[25)], while the thickness of the rest of abdominal muscles was measured at the trunk section in the dominant leg direction that displays positive reaction more than 2 times in order to maintain balance when standing hopping reaction II was attempted 3 times. Abdominal transverse muscle, internal oblique muscle and external oblique muscle were measured at the position 2.5 cm in front of the midpoint between the 12th rib and iliac crest centered along the armpit line on lateral aspect of the trunk being measured[26, 27)]. The measurement of thickness of abdominal muscles during rest stage was measured at the end of exhalation after having instructed the participant to gently exhale through mouth. Average value was computed after having taken 3 repetitive measurements for all muscles[28)].

Data collected in this study were analyzed by using SPSS 22.0 for Windows programWindows (IBM Corp., USA) with 0.05 as the level of significance, α, for statistical verification. General characteristics of the research participants were ob-

Table 1. Task-specific movement patterns during resistance exercise content

On the floor : attains sit on bench using trunk extension.
Sit on bench to stand and stand to sit without using arms.
Kneeling and half-kneeling to stand without using hand, stand up into left/right foot forward.
Kneeling walks forward/backward, left/right, diagonal side and rotation 10 steps using arms free.
Kneeling to squatted sitting without using arms.
Lower limb up and down in forward/backward, left/right, diagonal side on step box during standing.
Independent gait or walker/assistance gait in forward/backward, left/right, diagonal side and rotation 10 steps using arms free.
Kicking ball with left/right low limb, single leg stance on opposite leg.

First, task-specific movement patterns during resistance exercise participant preferred toys, dolls, blocks, rings, flags, mini cars and cards were used to give motivation and meaningful task in children with cerebral palsy. Second, verbal cue and mirroring feedback was applied during task-specific movement patterns during resistance exercise to maintain good posture and movement.

tained through descriptive statistics and parametric method was performed after having confirmed the normal distribution of measurement variables through Shapiro-Wilk Test. Paired t-test was conducted to analyze the differences in the respiratory functions and thickness of abdominal muscles prior to training and after 12 weeks of training for both groups. In addition, independent t-test was performed to compare the differences in the measurement variable changes prior to and after training between the two groups.

RESULTS

General characteristics and past medical history of the research participants are given in Table 2. Results of analysis of the changes in the average score within the experimental group and placebo group regarding respiratory functions and thickness of abdominal muscles, and differences in the changes prior to and following exercise between the two groups are presented in Table 3. All the measurement values of FVC, FEV1 and PEF for the respiratory functions displayed statistically significant changes between those prior to and after the exercise in both of the experimental group and the placebo group. Moreover, there were statistically significant differences in the changes prior to and following the exercise between the two groups ($p<0.05$). There also were statistically significant changes between the measurement prior to and after the exercise in the thickness of abdominal muscles in both the experimental group and the placebo group as the results of the measurement of rectus abdominis, abdominal transverse muscle, internal oblique muscle and external oblique muscle. There also were statistically significant differences in the changes prior to and following the exercise between the two groups ($p<0.05$).

Table 2. Characteristics of the participants (N=34)

Variables	Experimental group (N=17)	Placebo group (N=17)
Gender (male/female)[a]	9/8	9/8
Age (years)[b]	8.12 (2.33)	7.53 (2.07)
Height (cm) [b]	117.65 (16.88)	116.28 (11.48)
Weight (kg) [b]	24.11 (8.81)	22.14 (6.05)
Gestational age (weeks) [b]	34.76 (3.17)	33.06 (5.20)
Birth weight (g) [b]	2,487.06 (754.25)	2,096.47 (775.78)
Incubator care (weeks) [b]	5.06 (4.07)	6.47 (5.20)

[a] Number (%), [b] Mean (SD).

Table 3. Comparison of respiratory function and abdominal musclesthickness within and between groups (N=34)

Variables	Group	Pre-exercise	Post-exercise	Change values	
Respiratory function					
FVC (l)	Experimental	1.08 (0.44)	2.80 (0.47)*	1.72 (0.49)	*
	Placebo	1.08 (0.43)	2.51 (0.36)*	1.44 (0.20)	
FEV1 (l)	Experimental	0.99 (0.35)	2.68 (0.56)*	1.69 (0.62)	*
	Placebo	0.86 (0.43)	2.01 (0.88)*	1.15 (0.88)	
PEF (l/sec)	Experimental	1.80 (0.77)	3.19 (0.74)*	1.69 (0.66)	*
	Placebo	1.41 (0.69)	2.64 (0.61)*	1.23 (0.63)	
Abdominal muscle thickness (unit: mm)					
External oblique	Experimental	3.58 (0.66)	3.88 (0.69)*	0.30 (0.39)	*
	Placebo	3.16 (1.01)	3.26 (0.99)*	0.10 (0.08)	
Internal oblique	Experimental	4.55 (0.81)	4.91 (0.66)*	0.37 (0.43)	*
	Placebo	4.20 (1.04)	4.34 (1.02)*	0.14 (0.10)	
Transverse abdominis	Experimental	1.59 (0.45)	1.73 (0.46)*	0.14 (0.08)	*
	Placebo	1.65 (0.44)	1.73 (0.52)*	0.08 (0.09)	
Rectus abdominal	Experimental	5.75 (0.67)	5.93 (0.68)*	0.18 (0.12)	*
	Placebo	5.03 (1.05)	5.14 (1.03)*	0.11 (0.09)	

FVC: forced vital capacity; FEV1: forced expiratory volume in one second; PEF: peak expiratory flow.
Values are Mean (SD). *$p<0.05$.

DISCUSSION

Since cerebral palsy induces pulmonary dysfunction due to weakening of the breathing muscles arising from damages to brain, it is a disease that generally requires long-term hospitalization or has high death rate[29, 30]. In particular, pulmonary diseases in children can impart harmful effects on physical development related to sensory-motor functions and can directly damage the cardiorespiratory system[31, 32]. Therefore, improvement of respiratory capacity enables relatively high efficiency of the physiological capacity by improving the functions for physical[33]. On the basis of such clinical importance, this study was conducted to examine the application of task-specific movement patterns during resistance exercise by wearing weighted vest that provides loaded-resistance by means of sand bags on the respiratory functions and thickness of abdominal muscles in order to enhance the functions for physical activities of children with cerebral palsy.

Hong[34] asserted that children with cerebral palsy display immature diaphragmatic breathing due to unstable breathing support due to stiff abdominal muscles, and immobility and asymmetric thrust of spine and thoracic rib cage[34]. That is, movement is restricted since the head becomes asymmetrically hyperextended due to hypertonus and the thoracic rib cage is pulled up and asymmetrically distorted. In addition, mouth becomes opened due to jaw retraction and distortion, thereby making deep breathing difficult[35]. In the case of severely affected children, xiphoid process section is excessively pulled rather than the thoracic rib cage being expanded at the time of inspiration, thereby resulting in the occurrence of retracting reverse breathing patterns. This is because the most flexible xiphoid process section is excessively pulled due to failure to move at the time of inspiration if the spine and ribs are stiffened, given the structure of diaphragm that begins from the xiphoid process, 7–12th ribs and L1–L3 lumbar vertebrae, and attached to core tendon[34]. Therefore, in order to improve the breathing of children with cerebral palsy, it is essential to lower the lifted thoracic rib cage by generating flexible movement of spine and thoracic rib cage, and assist the child to breathe deeply through nose with closed mouth by bending the head forward.

In this study, when task-specific movement patterns during resistance exercise composed to promote the functional movement patterns of closed chain and multi-angle joints are applied to children with cerebral palsy FVC, FEV1 and PEF after exercise increased more in the experimental group in comparison to the placebo group. This is because the stiffness was reduced and mobility of thoracic rib cage was increased by promoting the movement of rib-spine joints while executing task-specific movements in anatomical plane, diagonal patterns and combined forms by children with cerebral palsy, thereby inducing the normal diaphragm movement by correcting abnormal breathing pattern. Since the thoracic rib cage capacity is expanded in each of the front-back, left-right and top-bottom directions due to the increase in the mobility of the area between the stiffened thoracic rib cage and spine, it was possible to improve FVC and FEV1 by increasing the flow of air into the lung through deep breathing.

In the case of children with cerebral palsy, muscles of head, neck, shoulder girdle and tongue are abnormally or insufficiently developed due to abnormal retraction of tongue, hyperextension of head and neck, movement pattern of humerus such as extension and adduction, etc., along with restrictions in the development of harmonious muscular activities necessary in stabilizing thoracic rib cage for the pulling of diaphragm at the time of inspiration[35]. Wearing weighted vest with insertion of sand bag, as illustrated in this study, promotes relaxation by lowering the thoracic rib cage that has been lifted up due to pulling back of the head arising from hypertonicity and can apply gentle manual resistance to the thoracic rib cage area. That is, weighted vest using sand bag induces co-activation of the trunk muscles by providing joint approximation. Moreover, it is thought that execution of low intensity and high frequency antigravity activities with task-specific movement patterns while wearing weighted vest can impart influence on PEF that improves breathing and cleanses lung by further developing intercostal muscles and abdominal muscles, and enhancing the movement and stability of thoracic rib cage and trunk. Accordingly, execution of progressive resistance exercise with task-specific movement patterns while breathing in and out naturally can improve breathing efficiencies including respiratory muscle strength, endurance and coordination, and increase metabolic capability and oxygen demand that promote delivery and use of oxygen to and by muscles, thereby improving the respiratory functions of children with cerebral palsy in overall.

Cerebral palsy causes insufficient trunk stability due to failure to achieve co-activation of proximal muscles arising from lack of experience and delayed development in the womb[36, 37]. This causes difficulties in the voluntary movements of all limbs and, in particular, weakening of the abdominal muscles induces not only functional difficulties in normal development but also problems in respiratory functions[38]. It is asserted that execution of trunk muscle strengthening exercise by children with cerebral palsy can help with the improvement of respiratory functions by not only improving the trunk stability, and functions and balancing ability of upper arms but also imparting influence on pulmonary functions[39, 40]. In addition, Vera-Garcia et al.[41] also reported that the level of activation of abdominal muscles including rectus abdominis and oblique muscles of abdomen, etc. that are involved in the stability of trunk increased as the result of having applied trunk muscle strengthening exercise to children with cerebral palsy[41]. In this study, children with cerebral palsy were instructed to perform task-specific movement patterns including transfer of body weight and rotational movement in each direction on anatomical plane or diagonal plane, etc. in a diverse range of postures in which functional restrictions occur in daily life. As the results, there were greater increase in all of rectus abdominis, abdominal transverse muscle, internal oblique muscle and external oblique muscle in the experimental group in comparison to the placebo group. It can be deemed as the result of increase in static stability of joints by inducing activation of agonistic and antagonistic muscles in the areas around joints by wearing weighted vest with application of gradual resistance, and improvement of erectness of spine and dynamic stability of trunk muscles while executing functional activities of arms and legs focused on specific tasks.

Trunk stability is the ability of the musculoskeletal system for maintenance of balance in the event of occurrence of interference in movement or when executing minor exercise[42] and is achieved through co-activation of diaphragm, intercostal muscles, medial/lateral internal oblique muscle and rectus abdominis, which are the breathing muscles in charge of inhalation and exhalation[43]. McGill et al.[44] stated that stability needs to be achieved through harmonious activities and cooperative contraction of muscles at the front, rear and lateral aspects of the trunk for the spontaneous changes in posture, diversified movement speed and changes imparted on the spine in order to improve trunk stability[44]. Similar to such preceding researches, the muscle thickness also increased in this study through the promotion of activation not only of trunk muscles but also abdominal muscles including rectus abdominis, internal/external oblique muscle, etc. involved in breathing because movements for conversion of postures including transfer of body weight in various directions including front-back, left-right and diagonal direction as well as natural rotation, etc. were performed repetitively by executing task-specific movement patterns at a diverse range of exercise speed while wearing weighted vest that applies gradual weight load onto the spine.

As the results of execution of resistance exercise while wearing weighted vest in task-specific movement pattern at low intensity and high frequency by children with cerebral palsy, strengths of respiratory and trunk muscles increase along with the increase in the angle and gradient between the ribs and spine with the ribs becoming more inclined downwardly from the rear to the front in resistance of gravity by ribs. Moreover, the ability to further expand the size of thoracic rib cage front and back, and left and right improved further. That is, thoracic rib cage capacity for inspiration increased, and the increase in lung capacity can be further promoted since the diaphragm can be contracted even better through the improvement of the actions of external intercostal muscles and internal/external oblique muscle capable of fixating the thoracic rib cage. In addition, it is thought that the strength of abdominal muscles necessary in stabilization of thoracic rib cage has improved since the mechanical advantages of front-back and left-right expansion of thoracic rib cage are increased when inhaling if the active balance between flexor and extensor of trunk increases while executing task-specific movement patterns. In particular, in the case of rectus abdominis, there is positive correlation between the strength of trunk muscle and PEF since it is involved in inhalation aspect of breathing[45]. In this study, as the result of having had children with cerebral palsy perform task-specific movement patterns during resistance exercise, both the muscle thickness of rectus abdominis and PEF also increased in comparison to those prior to training. Therefore, it is deemed that the increase in the strength of rectus abdominis, which is a muscle used in exhaling, can prevent pneumonia or complications of respiratory system by harmoniously discharging foreign matters or secretions in the respiratory tract since it can also impart influence in the improvement of coughing ability of children with cerebral palsy.

This study has several limitations. A limitation of this study was that only a small number of outcomes that focused on respiratory function and abdominal muscle thickness were measured. There may also have been other potentially important benefits to task-specific movement patterns during resistance exercise program that were not measured, such as changes to the child's quality of activities of daily living and self-esteem, as well as changes to physiologic outcomes such as gross motor function and performance, balance. Another limitation of this study is that only 5–12 years children classified as GMFCS II–III spastic diplegia, were included in this study and so the results cannot be generalized to other GMFCS groups. This trial was also limited by a relatively small sample size. Further study is needed to identify the most effects of task-specific movement patterns during resistance exercise of various children of cerebral palsy classified as GMFCS.

Treatment of children with cerebral palsy or development disability, who are the participants of this study, can achieve the maximum effects when performed continuously and repetitively throughout the overall aspects of their daily lives through cooperation among not only specialized treatment center but also patents and therapist. If it is difficult for disabled child to undergo regular treatment as an outpatient of medical institution, then, home-treatment program with the use of weighted vest as complementary intervention by physiotherapist in the local society through activities that link not only the child's parents but also medical and health institutions can be applied as an attractive alternative, temporally and economically. Therefore, task-specific movement patterns in anatomical plane, diagonal patterns and combined forms during resistance exercise program on for children with cerebral palsy can be considered as an efficient intervention method in improving respiratory capacity. Moreover, it is hoped that a diverse range of researches for the development of systematic intervention programs in which weighted vests can be applied to children with cerebral palsy and developmental disabilities, including training with task-specific movement patterns, will be carried out in the future.

Conflict of interest

None.

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