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博　士　論　文

Immediate effects of quick trunk exercises performed in a seated position on sit-to-stand movement in children with spastic cerebral palsy

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Contents

I. Summary

Sit-to-stand (STS) movements are a common skill in daily living, as well as being important measures of physical function that require adequate postural control to transfer the center of mass over the feet and to maintain the alignment of both the upper and lower body segments. However, children with cerebral palsy (CP) have difficulty in performing STS movements effectively, as they often have deficits in both movement and postural control. Therefore, improvement of STS performance plays a crucial role in the advancement of the social participation of these children. Previous studies have demonstrated the beneficial effects of interventions aimed at improving STS movements in children with CP. However, the main focus of these interventions was on lower limb impairment, with less consideration for the key role played by trunk control during STS movements and its deficit in children with CP. We are interested in understanding whether quick trunk movements could improve trunk control in children with CP, and therefore allow them to perform STS movements more efficiently. Thus, the aim of this research study was to assess the immediate effects of quick-seated trunk movement exercises (QSTE) on STS movements in children with CP.

In the first study (Research Study 1), the study participants included five children with spastic CP (aged 6–17 years). All participants received five sessions of natural seated trunk exercises (NSTE) at a self-selected speed, as a control intervention. Following a 50-min rest period, five sessions of the QSTE were conducted as an experimental intervention for each child. Assessments were performed before and after each intervention in a single day. To assess STS movements, a motion analysis system with four cameras that were synchronized with a pressure-sensitive trigger device, was used. Both the sagittal and angular movements of the trunk, hip, knee, and ankle were calculated, along with the total STS task duration, the maximum trunk forward tilt, and the ankle dorsiflexion angle.

The results of this research indicated a significant difference in the total duration of STS movements before and after both NSTE (2.40 ± 0.67 s vs. 2.24 ± 0.44 s) and QSTE (2.41 ± 0.54 s vs. 2.06 ± 0.45 s) interventions. However, there was no significant difference in the kinematic parameters after either intervention. The fact that all measurements occurred in a single day, may limit the generalization of the results of this research.

In order to address this limitation, measurements were taken over multiples days during a second research study (Research Study II). A total of seven children with spastic diplegia CP (aged 4–13 years) participated in this study. All subjects participated in both the experimental and control interventions. First, participants were assessed before the start of the experimental intervention (pre-test), followed by a 3–5 day washout period, after which they were reassessed (post-test) immediately after receiving five sessions of QSTE for the experimental intervention. Second, after a 2-4 week interval, all participants were assessed before the start of the control intervention (pre-test). Following a 3–5 day washout period, they were reassessed immediately after the control intervention (post-test), in which all participants sat for 10 minutes on a stool. A conventional video recording camera was used to record STS movements. The sagittal and angular movements of the trunk, hip, knee, and ankle were calculated for each lower limb using Image-J. Subsequently, the total STS task duration was calculated.

The results of Research Study II indicated that both the starting position and STS movement duration of the pre-test data were not significantly different between the experimental and control interventions. A significant difference was observed in the total duration of the STS movements before and after QSTE (2.67 ± 0.34 s vs. 1.69 ± 0.11 s). However, no significant change was found between the total duration of the STS movements before and after the control interventions (2.49 ± 0.25 s vs. 2.41 ± 0.18 s).

The total duration of the STS movements significantly decreased after QSTE in both studies. Although QSTE did not change the abnormal kinematic patterns of the STS movements, QSTE may improve trunk control, which in turn would help children with CP perform STS movements faster. These improvements would facilitate their social participation and lead to better performances during daily activities.

Keys Words: Fast trunk exercise, Sit-to-stand, Cerebral palsy

II. Cerebral palsy

1. Definition

Cerebral palsy (CP), which describes a group of permanent, non-progressive, neurological disorders with varying etiologies and levels of severity, is the most common cause of physical disability in children. Children with CP are recognized by limitations in their movement development and posture [1]. The worldwide incidence of CP is approximately 2 to 2.5/1000 live births [2]. CP is also more prevalent in more adverse socioeconomic populations [3, 4]. The motor disorders associated with CP are frequently accompanied by epilepsy and other secondary disabling conditions, such as musculoskeletal problems. Individuals with CP may also experience disturbances in sensation, perception, cognition, communication, and behavior [1]. This group of disorders results in activity limitations in affected children and interferes with their interactions with their environment.

Although CP is considered a non-progressive disorder, individuals with CP often experience progressive changes in both postural control and functional mobility throughout their lifespan [5]. Therefore, lifelong care and rehabilitation programs are necessary for individuals with CP to reach their maximum independency in performing daily activities and to prevent secondary impairments, both of which would facilitate more effective social participation.

2. Classification

CP is commonly classified based on both anatomic or topographic considerations and movement abnormalities [1]. The typology of the motor disorders includes spasticity, dyskinesia, and ataxia. Spasticity, the most common type of motor dysfunction, refers to a velocity-dependent increase in the muscle tone in resistance to stretching [6]. Dyskinesia refers to irregular, spasmodic, involuntary movements of the limbs or facial muscles. Ataxia refers to a loss of muscle coordination. Anatomical distribution refers to the observed paralytic part of the body, including hemiplegia, diplegia, and quadriplegia [7].

Generally, the severity of CP has been described by the interpretation of mild, moderate, and severe cases. However, the most objective scale to classify CP is based on functional motor abilities [8]. The Gross Motor Function Classification System (GMFCS) was developed to classify the amount of activity limitation seen in children with CP, and describes their activity in relation to walking. According to this classification system, five levels were defined to represent the child's physical activity and mobility in their home, school, and community settings.

- Level I - Walks without limitations
- Level II - Walks with limitations
- Level III - Walks using a handheld mobility device
- Level IV - Self-mobility with limitations; may use powered mobility
- Level V - Transported in a manual wheelchair

The GMFCS has been widely adopted for use in both research and clinical settings [9].

The most common type of CP is the spastic form [10]. The motor disorder most associated with spasticity is abnormal tonic stretch reflex [11, 12], accompanied by an unusual increase in both muscle tone and tendon reflexes, leading to abnormal movements and posture of the body in both the static and dynamic positions. Spasticity during growth would cause to deformities due to muscle contractures, and may cause joint dislocations [11].

Children with spastic CP are characterized by the following:

- Loss of selective muscle control
- Dependence on primitive reflex patterns for ambulation
- Abnormal muscle tone
- Relative imbalance between muscle agonists and antagonists
- Deficient equilibrium reactions [13]

The spastic form of CP could be further subdivided into spastic hemiplegia, diplegia, and quadriplegia types [14, 15]. Spastic hemiplegia is defined as the involvement of the ipsilateral trunk and upper and lower limbs, with the upper limbs more severely affected, and presents as equinovarus of the foot and ankle; flexion of the elbow, wrist, and fingers; and adduction of the thumb [14, 15]. Most of the children with the spastic hemiplegia type of CP can walk independently, but often use assistive devices for everyday locomotion [14].

Spastic diplegia mostly affects the legs, with little or no symptoms in the upper extremities [10, 16]. Contractures are often seen in the following muscle groups:

- Hip flexors
- Hip adductors
- Hamstrings
- Triceps surae (tight Achilles tendon)

This group of muscle contractures results in a crouch gait, which is characterized by excessive movement of the head, neck, trunk, and upper extremities in order to compensate for the lack of mobility in the lower extremities.

In the spastic quadriplegia form, all four limbs are symptomatic, with the upper limbs being the most affected. Therefore, this type of spastic CP presents as a lack of coordination or voluntary movement of the hands and arms [14]. Because of severe upper limb impairment, children with spastic quadriplegia need support from parents or caregivers for daily routine activities, such as feeding and self-care.

3. Motor Development

The clinical diagnosis of CP is based on the presence of permanent developmental impairments of motor function [17]. CP affects both muscle tone and movement coordination, which cause awkward gross and fine motor skills. Children with CP exhibit a delay in the expected age of attainment of motor development milestones compared to their unaffected peers. They have difficulty in controlling their head, neck, trunk, and upper and lower limbs, as well as both immature grasp-release and finger pinch functions. Physical therapists help these children to reach the milestones of gross motor skill development, such as rolling, crawling, standing, and walking depending on their level of GMFCS.

III. Sit-to-stand movements

1. Healthy adults

The ability to rise from a chair is one of the most commonly executed movements and is both a fundamental and essential activity for upright mobility and daily living [18-20]. Rising from a seated position requires both the forward and upward displacement of the body's center of mass (CoM) in order to transfer the body mass over the feet [21, 22]. As the body's support base is narrowed down to the area of the feet, adequate body balance and equilibrium reactions are required to maintain an upright posture [23, 24]. Additionally, the central nervous system is challenged to control both whole-body movements and body equilibrium simultaneously [19].

In sit-to-stand (STS) movements of healthy adults, the trunk has the major responsibility to bring the CoM forward, within the area supported by the feet [20, 25, 26]. The trunk both accelerates and generates the horizontal momentum of the CoM. Additionally, the ankle contributes to the forward displacement of the CoM and also indirectly imparts horizontal momentum to the trunk [27, 28]. In this manner, the interaction of trunk motion with both the stability and mobility of the ankle is an important factor in achieving effective lift-off (LO). This inter-segmental coordination between the trunk and ankle motions is necessary to reach adequate standing balance after LO. Moreover, healthy adults leave the seat effectively with the interaction of the knees and hip, which lock together and extend in the same linear pattern [29, 30].

2. Spastic cerebral palsy

Children with CP show a wide variety of abnormalities of postural control and movement patterns that interfere with the development of functional tasks, such as walking, standing from a seated position, and the ability to participate normally in home, school, and community life [1].

With specific regard to STS tasks in particular, children with spastic CP have difficulty in performing this balance-threatening task [18, 19], since they often show deficits in movement and postural control. Impairments in muscle function including weakness, spasticity, lack of coordination, and reduced selective motor control, result in various abnormal movement patterns during STS tasks in children with spastic CP compared with normally developing children [31]. The patterns of STS transfer in spastic diplegia were characterized by the following:

- Slow speed
- Increased anterior pelvic tilt
- Early abrupt knee extension
- Decreased knee extensor moment
- Decreased extensor power generation of the hip and knee joints [31]

Therefore, improvement of STS performance is important to allow children with CP to independently function in the environment in which they live.

IV. Treatment to facilitate sit-to-sand movements in children with spastic cerebral palsy

1. Literature review

Over the years, CP has been widely discussed, and despite the long history of investigations and scientific research, new interventions and treatments are still required. In fact, the complexity of this neurodevelopmental disorder requires a variety of interventions from multiple rehabilitation resources, such as physical and occupational therapists. Physical therapists play a critical role in the management of movement and posture disorders in children with CP, and in the improvement of functional mobility skills in these children. In general, physical therapists conduct different interventions to enhance a child's ability to perform everyday movements. However, these interventions are mostly targeted at the level of body structure and function, such as range of motion and strength [32]. For this reason, both activity levels and participation rates in activates [33, 34] of children with CP remain lower than their typically developing peers.

Although improvement in activity level is an optimal outcome, in most interventions, the activities are not the main target. Indeed, physical therapists aim to reduce a specific impairment, which is likely to be a limitation for a specific activity. For example, increasing ankle range of motion could promote STS ability in a child with CP, which is generalized to greater functional activity when the child stands up from the chair to reach his/her book on the shelf.

In recent years, a few studies have investigated the effectiveness of STS interventions in children with CP [35-37]. After these children used both ankle and foot orthoses and underwent a botulinum toxin injection in the ankle plantar flexor muscle, increased ankle dorsiflexion was observed during STS movement [35, 36]. Additionally, children with spastic diplegia underwent a neurodevelopmental treatment in which they performed STS movements. Not only was the ankle dorsiflexion increased, but the forward tilt of the trunk also decreased [37]. However, despite having beneficial effects, these interventions mainly focused on lower limb impairment, with less consideration for the key role of trunk control during STS movements [26, 38], and its deficit in children with CP [39]. Moreover, altered trunk movements by children with CP during walking reflect a true underlying trunk deficit, but the compensatory role of trunk movements with respect to lower limb impairments might be quite limited [39]. According to this viewpoint, further interventions that target trunk control deficits in children with CP might facilitate STS movements more effectively.

2. New trunk training method

To improve trunk control in children with CP, focusing on trunk control exercises during conventional therapy is difficult. Some evidence exists that hippotherapy, or simulators, have a positive effect on trunk stability in children with CP [40, 41]. However, the inevitable risk of falling, high cost of equipment, and need for the active involvement of a therapist, limit the wide feasibility of these interventions. Therefore, employing a new, simple, and safe exercise regime is necessary. Exercises that emphasize speed have been shown to be an important predictor of balance and functional mobility [42, 43]. Moreover, several studies indicated that velocity is an essential component of muscle power during functional movements [42, 44]. Gray et *al.* reported that performing an exercise that comprised of fast, functional movements improved muscle activation and postural responses in people suffering from strokes [45, 46]. However, this exercise was not always safe, as the participants performed it in a standing position. To reduce the risk of falling, Iwata et *al.* suggested that a quick exercise should be performed with the patient in a more stable position [47, 48]. They used quick trunk movements to assess the mobility of frail, elderly people while they sat on a chair. These studies found that the quickness of trunk movements is related to functional performance such as gait and STS movement. Based on these studies, we are interested in understanding whether quick trunk movements could be performed safely, and could lead to an improved trunk control in children with CP. Therefore, if their trunk control ability could be improved, STS exercises could also be performed efficiently.

V. Objective

These studies aimed to examine the immediate effects of quick-seated trunk movement exercises (STE) on STS movements in children with spastic CP.

VI. Research Study I

Immediate effects of quick trunk movement exercises on the temporal and kinematic parameters of sit-to-stand movements in children with spastic cerebral palsy

1. Methods

1. 1. Participants

The study participants included five children with spastic CP who received regular physical therapy (Table 1). The inclusion criteria were children with spastic diplegia or hemiplegia CP, age ranging between 4 and 18 years, GMFCS [49] level of I or II (able to perform STS exercises independently), modified Ashworth scale grade 1–2 [50], those without deformities in the lower limbs and who did not undergo any orthopedic procedures within the past 6 months, and those with the ability to understand simple commands.

This study was conducted in accordance with the ethical standards of the Declaration of Helsinki. The purpose of this study was explained to the participants' parents, and written consent was obtained. This research study was conducted with the approval of the ethics committee of Osaka Prefecture University (2015–118).

Table 1 *General characteristics of the participants*

Participant	Age (year)	Sex	Height (cm)	Weight (kg)	GMFCS	Type
A	6	Male	124	30	I	SH
B	8	Female	120	21	I	SH
C	8	Male	129	25	II	SD
D	8	Male	132	30	I	SH
E	17	Male	169	49	II	SD

GMFCS: Gross Motor Function Classification System, SH: spastic hemiplegia, SD: spastic diplegia

1. 2. Study Design

All participants received five sessions of natural seated trunk exercise (NSTE) at a self-selected speed, as the control intervention. Following a 50-min rest period [35], five sessions of the quick-seated trunk exercise (QSTE) were conducted, as the experimental intervention for each child. Each STE session included 10 repetitions each in the anterior-posterior and lateral directions. The duration of each intervention was 5–10 min. The participants were assessed before and after each intervention. All measurements were performed in a single day (Fig. 1).

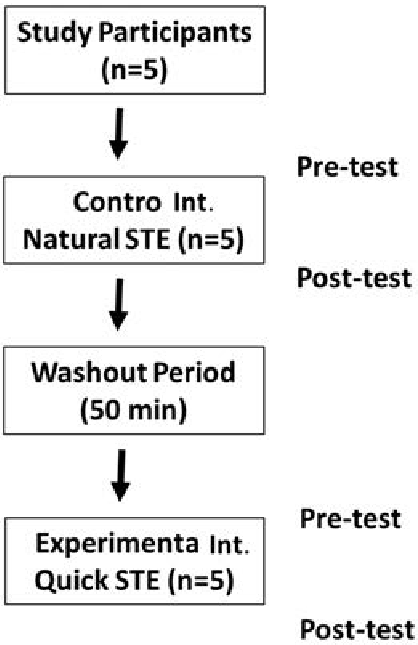

Fig. 1 *Flow chart for the study design*

2. 3. Intervention procedure

The children with CP were required to sit on a stool that was placed in front of a wall, with a gap of approximately 5 cm between the children's backs and the wall. The trunk was upright, and the feet were kept shoulder-width apart. The children raised both of their arms to shoulder height in front and laterally, with the elbows extended as far as they could extend them (Fig. 2). For children with spastic hemiplegia, a wooden cylinder block or a small-sized ball was used to allow them to achieve symmetric, bimanual reach. Targets (physio rolls) were placed at a distance of approximately 10 cm from the tips of their fingers. The children were asked to tap the targets by moving their trunk, and they repeated this movement while looking forward and without changing the position of their feet. The therapist fixed the child's feet on the floor if he or she tried to widen the area supported by the feet during the exercise. Then, the STE was performed at a self-selected speed, and therapists encourage the child to move as quickly as possible [48]. The STE session was performed 10 times in the anterior-posterior and lateral directions each. A 20-sec rest time was set between each session.

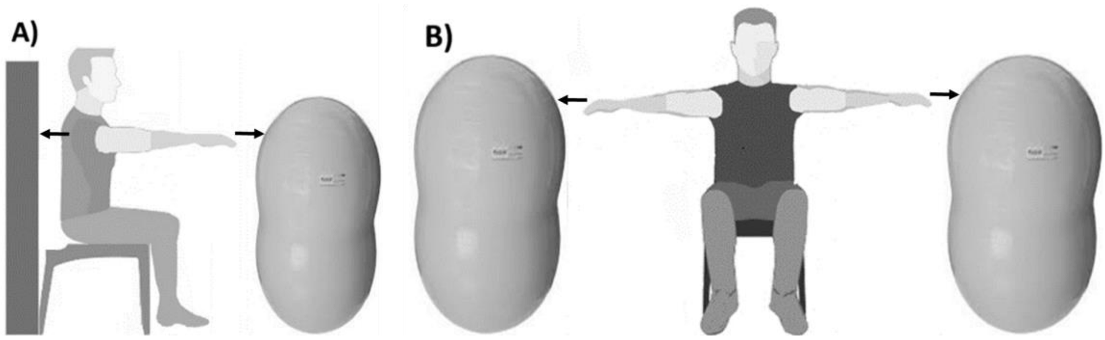

Fig. 2 *Schematic view for intervention procedure*

1. 4. Data analysis

To assess STS movements, a motion analysis system (Kinema Tracer, Kissei Comtec, Matsumoto, Japan), with four cameras (30 Hz) that were synchronized with a pressure-sensitive trigger device (100 Hz), was used. Two cameras were placed on each side of the participant: one perpendicular and one oblique to the sagittal plane of their body (Fig. 3). Ten markers were placed bilaterally at the acromion process, greater trochanter, lateral tibial condyle, lateral malleolus, and lateral aspect of the fifth metatarsal.

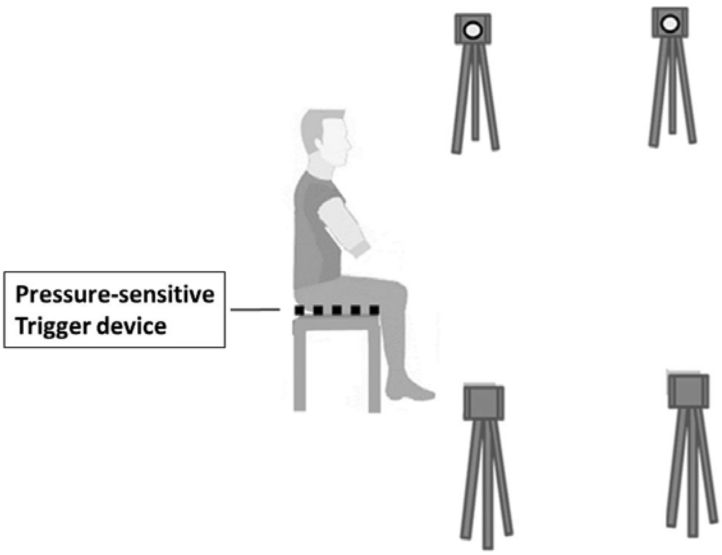

Fig. 3 *Schematic view of the subject's position relative to the cameras and force plate*

The participants sat on a hard-surface stool that was set at the height of their knee joint in the sitting position. Each participant performed the STS tasks at a self-selected speed while barefoot, with the soles of their feet on the floor and their hands placed on their chest. Both feet were kept shoulder-width apart. The task began with the participant's trunk positioned as upright as possible and their knees bent at approximately 90° by the therapist. The participants were asked to look forward and start the task without changing the position of their feet. Then, five trials were recorded for each child. Among the five trials for each participant, three smooth trials were selected for data analysis.

The sagittal and angular movements of the trunk, hip, knee, and ankle were calculated for a total of seven lower limbs, including the affected side, in three children with spastic hemiplegia and two with spastic diplegia. All these data were normalized from the beginning of the STS task (0%) to the end of the STS task (100%). The beginning of the STS task was the time when the magnitude of the horizontal velocity at the midpoint between the acromion markers was >5% of its peak value [27]. The time when the magnitude of the horizontal velocity of the midpoint between the hip markers was $\leq$0.10 m/s, was considered the endpoint of STS task [27]. The time at which the electrical waveform that was derived from the trigger device reached its initial lowest electrical voltage was defined as lift-off (LO). The STS movement was divided into two phases, before and after LO. The total duration of the STS movement and the durations of the two phases were assessed.

Angular movements were defined similarly to those reported in a previous study (Fig. 4) [37]. The angular movement of the trunk (A) was defined as the angle between the imaginary line from the acromion process to the greater trochanter and the vertical line through the greater trochanter. Similarly, the angular movement of the hip (B) was defined as the angle between the line extended from the acromion to the greater trochanter and a line connecting the greater trochanter and the lateral femoral condyle. The angular movement of the knee (C) was defined as the angle between the line extended from the greater trochanter to the lateral femoral condyle and a line connecting the lateral femoral condyle and the lateral malleolus. The angular movement of the ankle (D) was defined as the angle between a vertical line extended from the lateral femoral condyle to the lateral malleolus and a line connecting the lateral malleolus and the lateral aspect of the fifth metatarsal head.

Finally, the total STS task duration and the maximum trunk forward tilt and ankle dorsiflexion angle were calculated.

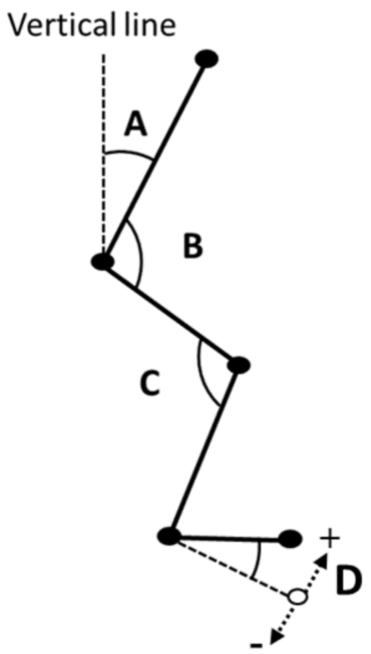

Fig. 4 *The angular movement definition for each joint*

1. 5. Statistical analysis

The data were analyzed using SPSS version 23 (SPSS Inc.). Data are expressed as the mean ± standard deviation. Nonparametric tests were used for all outcomes. The differences of variables within and between the experimental and control interventions were assessed using the Wilcoxon signed-rank test. A p value of < 0.05 was considered to be statistically significant.

2. Results

2. 1. Difference in start position in the pre-test data

No significant difference was observed between the pre-test data for angular movement in the starting position before the NSTE and QSTE (Table 2).

Table 2 *Differences in the start position in the pre-test data (n=5)*

Joint angle (˚)	NSTE	QSTE	p-value
Trunk FT	5.5±2.1	5.6±2.3	n.s
Hip flexion	95.4±8.4	94.1±10.4	n.s
Knee flexion	87.2±8.2	85.2±10.4	n.s
Ankle DF	-1.1±4.5	1.4±4.2	n.s

NSTE: natural seated trunk exercise, QSTE: quick seated trunk exercise, FT: forward tilt, DF: dorsiflexion, n.s: not significant, Data are presented as a mean ± standard deviation.

2. 2. Difference in the temporal and kinematic parameters in the pre-test data

There were no significant differences in the temporal and kinematic parameters for all pre-test data (Table 3).

Table 3 *Differences in the temporal and kinematic parameters in the pre-test data (n=5)*

	NSTE	QSTE	p-value
Temporal			
Duration (s)	2.40±0.67	2.41±0.54	n.s
Before LO (s)	0.85±0.13	0.88±0.17	n.s
After LO (s)	1.61±0.55	1.54±0.49	n.s
LO (%)	35.9±6.5	37.6±6.5	n.s
Kinematic (˚)			
Max trunk FT	47.5±8.9	49.9±6.5	n.s
Max ankle DF	9.3±6.7	8.8±5.7	n.s

NSTE: natural seated trunk exercise, QSTE: quick seated trunk exercise, LO: lift off, FT: forward tilt, DF: dorsiflexion, n.s: not significant, Data are presented as a mean ± standard deviation.

2. 3. Differences in the start position pre-test and post-test data for each intervention

The pre-test and post-test starting position data was not significantly different for each intervention (Table 4).

Table 4 *Differences in the start position in the pre-test and post-test data for each intervention (n=5)*

	NSTE			QSTE		
Joint angle (˚)	Pre	Post	p-value	Pre	Post	p-value
Trunk FT	5.5±2.1	5.6±1.8	n.s	5.6±2.3	5.1±2.4	n.s
Hip flexion	95.4±8.4	94.3±4.6	n.s	94.1±10.4	92.5±6.4	n.s
Knee flexion	87.2±8.2	85.5±9.5	n.s	85.2±10.4	86.3±9.9	n.s
Ankle DF	-1.1±4.5	-2.2±5.1	n.s	1.4±4.2	1.6±5.0	n.s

NSTE: natural seated trunk exercise, QSTE: quick seated trunk exercise, FT: forward tilt, DF: dorsiflexion, n.s: not significant, Data are presented as a mean ± standard deviation.

2. 4. Differences in the temporal and kinematic parameters in the pre-test and post-test data for each intervention

A significant difference was observed in the total duration of the pre and post STS movements for both the NSTE and QSTE interventions ($p<0.05$). However, no significant change was found in angular movements with either of the interventions (Table 5).

Table 5 *Differences in the temporal and kinematic parameters in the pre-test and post-test data for each intervention (n=5)*

	NSTE			QSTE		
	Pre	Post	p-value	Pre	Post	p-value
Temporal						
Duration (s)	2.40±0.67	2.24±0.44	*	2.41±0.54	2.06±0.45	*
Before LO (s)	0.85±0.13	0.83±0.13	n.s	0.88±0.17	0.80±0.13	n.s
After LO (s)	1.61±0.55	1.41±0.36	n.s	1.54±0.49	1.27±0.44	n.s
LO (%)	35.9±6.5	37.7±4.5	n.s	37.6±6.5	39.8±7.9	n.s
Kinematic (˚)						
Max trunk FT	47.5±8.9	49.0±5.3	n.s	49.9±6.5	49.1±7.5	n.s
Max ankle DF	9.3±6.7	4.1±6.4	n.s	8.8±5.7	9.9±6.2	n.s

NSTE: natural seated trunk exercise, QSTE: quick seated trunk exercise, LO: lift-off, max: maximum, FT: forward tilt, DF: dorsiflexion, n.s: not significance, Data are presented as a mean ± standard deviation, *:$p<0.05$

The total duration of STS tasks increased after the NSTE in one subject while they decreased after QSTE in all subjects (Fig. 5).

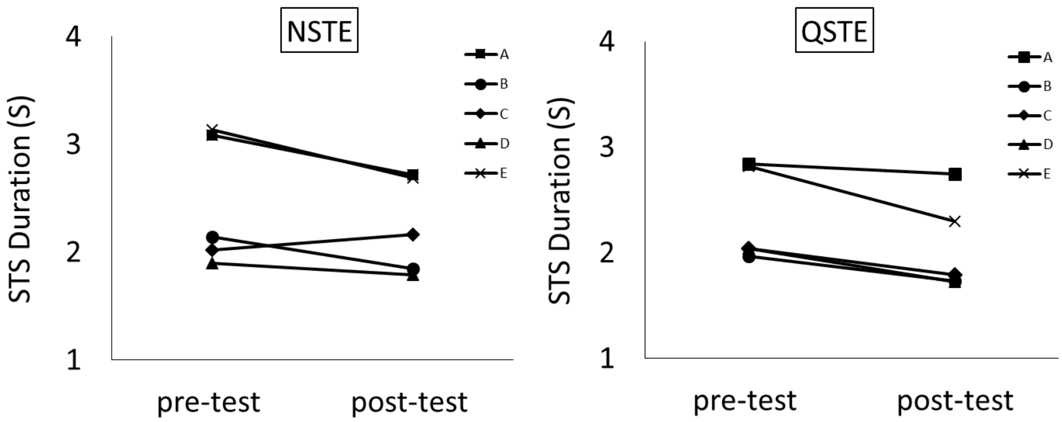

Fig. 5 *Total duration of STS for each participant*

3. Discussion

This study was conducted to examine the immediate effect of QSTE on STS movements in children with spastic CP. The temporal parameters of the STS movement improved immediately after implementing the QSTE. The aim of this study was to alleviate the abnormal kinematic patterns of the upper body during the STS movement, which has not been the focus of previous studies [35, 37]. For this purpose, trunk-targeted exercises with an emphasis on speed [45, 46] were chosen, so that participants with CP could perform them safely in a seated position [47, 48] to improve trunk control. Therefore, QSTE could facilitate the STS movement by improving trunk control. The exercises may decrease the total duration of STS movements, reduce maximum trunk forward tilt, and allow greater ankle dorsiflexion.

3. 1. Validity of assessments

Several studies demonstrated that changing the initial position of the trunk and ankle, affects both the temporal and kinematic parameters of the STS movement [27, 51, 52]. With regard to the present study design, before and after each intervention, the STS movement was performed from the same initial position. The findings of the present study showed that there was a similar angular movement in the starting position before the NSTE and QSTE. Thus, the same STS performance was expected.

Although the design of this study was only applicable to a small population size, the possibility of carryover effects should be considered carefully. For this reason, a 50-min rest time was set between the NSTE and QSTE [35]. As a result, the STS movement had similar temporal and kinematic parameters before both NSTE and QSTE, indicating a lack of carryover effect. These findings demonstrated that the present study design could clarify the immediate effect of QSTE on STS movements in children with CP.

3. 2. Improvement in temporal parameters of STS after quick-seated trunk exercise

The total duration of the STS movements significantly decreased after both interventions, which was similar to the results of previous studies [35, 37]. STE may improve trunk control, which in turn would help children with CP to rise faster. Although the total duration of the STS tasks decreased after both interventions, in one participant, the total duration of the STS movements increased after NSTE while after QSTE they decreased in all participants. Therefore, a greater improvement in STS duration was found after QSTE. As demonstrated previously, fast movements improved muscle activation and postural responses [45, 46]. Thus, QSTE helps children with CP to rise from a seat position faster.

3. 3 Immediate effects of quick trunk movement exercise on the kinematic parameters of the sit-to-stand movement

According to the hypothesis of this study, both temporal and kinematic parameters might improve after QSTE. However, unlike the results of previous interventions to facilitate STS movements in children with CP, in this study, QSTE did not effectively alleviate abnormal movement patterns. Children with CP are known to exhibit various impairments in muscle activity and movement coordination [18]. Therefore, these children have difficulty performing effective STS movements, which requires intersegmental interaction between the upper body and lower limbs [53]. A lack of intersegmental interaction during the QSTE may have led to insufficient changes in the abnormal kinematic patterns of STS. Therefore, further studies are needed to examine the beneficial effects of fast movements that involve the interaction between the upper body and lower limbs, on improving both the temporal and kinematic parameters of the STS movements in children with CP.

3. 4. Limitation of the present study

This study has some limitations. First, the temporal parameters of the STS movements after the control intervention improved similar to experimental intervention. Therefore, it can be said that the lack of rest time after the pre-test assessments before both interventions may increase the possibility of learning effects, which affect the results of post-test assessments after the NSTE and QSTE.

Second, despite the same STS performances before the natural and quick STE, carryover effects are still controversial. Although, the washout period in this study was similar to the pervious study by Park et *al.* [35], unlike their study, this present study consisted of four measurements to compare the pre-test and post-test data for the two different interventions. Thus, because of insufficient washout time [54, 55], the possibility of carryover effects from the control intervention, could affect the results of experimental intervention.

Third, there was a difficulty in defining a natural speed of STE and instructing the children thusly. Therefore, STE using a self-selected speed was set first, to help the children understand the difference between NSTE and QSTE. Thus, improvement in STS duration could not only be considered as a result of the quickness of the trunk exercises.

Finally, the sample size was both small and heterogeneous, with both spastic diplegia and hemiplegia children included. Thus, generalizing the results is difficult. For this reason, a different study design with a larger and homogenous patient population, is suggested to support the results of the improvement in the temporal parameters of STS tasks after QSTE, with less learning effects.

VII. Research Study II

Immediate effects of quick trunk movements exercise to improve the temporal parameters of sit-to-stand movements in children with spastic cerebral palsy (using 2-dimensional video recording)

In our previous study [30], performing a QSTE in a seated position resulted in the immediate improvement of the temporal parameters of STS in children with spastic CP.

In addition, similar results were found after natural STE, the control intervention. It can be said that, the learning effects of the STS tasks might result in similar findings after both the control and experimental interventions in Research Study I.

Therefore, a new study design in which the measurement procedures were conducted over a 3-5 day interval, was chosen to weaken the learning effects. Moreover, the addition of 2-4 week washout could decline the possibility of carryover effects. Additionally, Research Study II had a different control intervention and a larger, homogenous, study population.

The aim of this new study was to clarify the immediate effects of quick trunk movement exercises to improve the temporal parameters of STS tasks in children with spastic diplegia using portable (2-dimensional) video recording.

1. Methods

1. 1. Participants

Seven children with spastic diplegia CP were recruited to participate in this study (Table 6). The inclusion criteria were children with spastic diplegia CP, age ranging between 4 and 18 years, GMFCS [49] level of I or II (able to perform STS exercises independently), modified Ashworth scale grade 1–2 [50], those without deformities in the lower limbs, who did not undergo any orthopedic procedures within the past 6 months, and those with the ability to understand simple commands.

The purpose of this study was explained to the participants' parents, and written consent was obtained. This research study was conducted with the approval of the ethics committee of Osaka Prefecture University (2015–118).

Table 6 *General characteristics of the participants*

Participant	Age (year)	Sex	Height (cm)	Weight (kg)	GMFCS
A	4	Male	100	14	I
B	6	Male	116	18	II
C	6	Female	112	16	I
D	6	Female	110	18	I
E	8	Female	120	20	I
F	13	Female	148	33	I
G	13	Female	160	46	I

GMFCS: Gross Motor Function Classification System

1. 2. Study design

A nonrandomized study design was used, where all subjects performed both the experimental and control interventions.

First, participants were assessed before the experimental intervention (pre-test). Then, after a 3–5 day interval, they were reassessed (post-test) immediately after receiving five sessions of QSTE as the experimental intervention.

Second, after a 2-4 week washout period, all participants were assessed before the control intervention (pre-test). Following a 3–5 day interval, they were reassessed immediately after the control intervention (post-test) (Fig. 6). The participants sat for 10 minutes on a stool for control intervention.

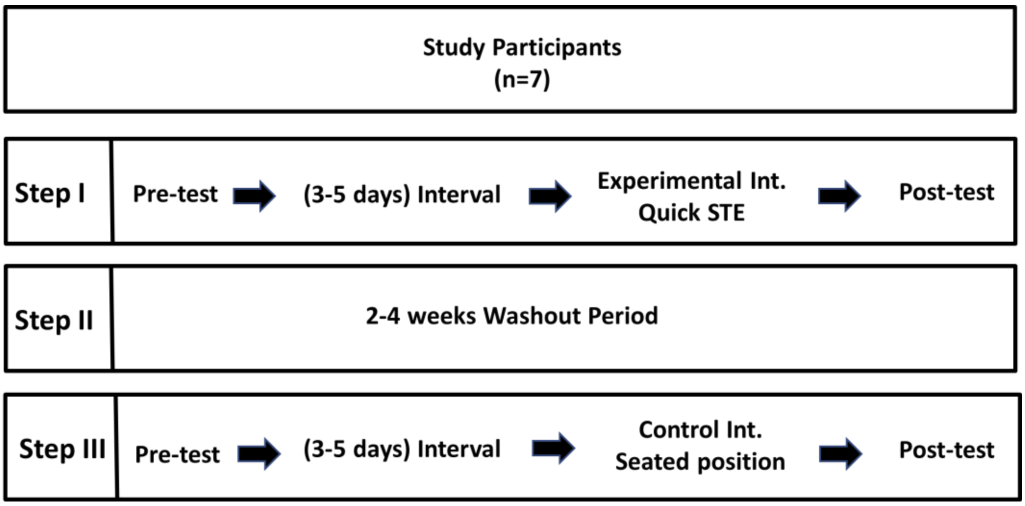

Fig. 6 Flow chart for the design of the study

2. 3. Intervention procedure

The QSTE procedures were the same as described in Research Study 1 (Fig. 2). Each QSTE session included 10 repetitions in the anterior-posterior and lateral directions. The duration of each QSTE was 5–10 minutes.

1. 4. Data analysis

A conventional video recording camera (30 Hz) was used to record STS movements. The camera was placed on the right side of the participants, perpendicular to the hip joint in seated position, and 3m away (Fig. 7) [56].

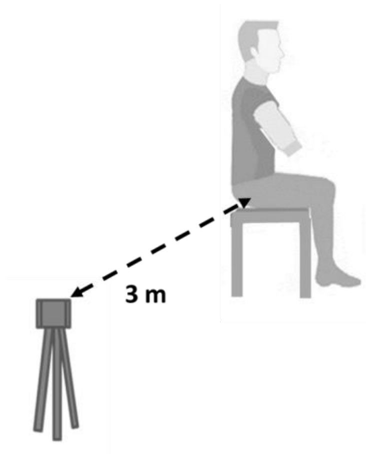

Fig. 7 *Schematic view of camera relative to the subject's position*

All of the measurement procedures for STS movements were similar to those described in Research Study 1. Each participant performed the STS tasks at a self-selected speed. Five trials were recorded for each child. Among the five trials for each participant, the three smoothest trials were selected for data analysis.

The start and end points of the STS tasks were defined by the movie maker software by clicking forward. The beginning of the STS task was the time when the acromion marker first moved forward. The time when the acromion marker reached the last backward point after standing, was considered as the endpoint of the STS task [53]. The sagittal and angular movements of the trunk, hip, knee, and ankle were all calculated for each lower limb using ImageJ. Angular movements were defined similarly to those reported in a previous study [37]. The total STS task duration was calculated, along with the rate of change percentage before and after each intervention.

1. 5. Statistical analysis

The data were analyzed using SPSS version 23 (SPSS Inc.). Data are expressed as the mean ± standard deviation. Nonparametric tests were used for all outcomes. The differences of the variables both within and between the experimental and control interventions were assessed using the Wilcoxon signed-rank test. A paired-t test was used to determine the rate of change percentage before and after each intervention. A p-value of < 0.05 was considered statistically significant.

2. Results

2. 1. Differences in start positions in the pre-test data

No significant differences were observed between the pre-test data for angular movement in the starting position before both the experimental and control interventions (Table 7).

Table 7 *Differences in the start position in the pre-test data (n=8)*

Joint angle (˚)	Experimental Int.	Control Int.	p-value
Trunk FT	0.8±1.7	2.2±2.1	n.s
Hip flexion	90.3±4.1	88.4±4.3	n.s
Knee flexion	86.9±2.3	86.9±3.9	n.s
Ankle DF	3.0±3.4	2.0±2.9	n.s

Int. : intervention, FT: forward tilt, DF: dorsiflexion, n.s: not significance, Data are presented as a mean ± standard deviation.

2. 2. Differences in the starting position in the pre-test and post-test data for each intervention

The starting position between the pre-test and post-test data was not significantly different for the experimental and control interventions (Table 8).

Table 8 *Differences in the start position in the pre-test and post-test data for each intervention (n=8)*

	Experimental Int.			Control Int.		
Joint angle (˚)	Pre	Post	p-value	Pre	Post	p-value
Trunk FT	0.8±1.7	1.8±3.4	n.s	2.2±2.1	2.6±2.1	n.s
Hip flexion	90.3±4.1	89.2±3.5	n.s	88.4±4.3	90.3±3.6	n.s
Knee flexion	86.9±2.3	87.0±3.8	n.s	86.9±3.9	87.3±11.4	n.s
Ankle DF	3.0±3.4	1.8±4.0	n.s	2.0±2.9	1.0±5.1	n.s

Int. : intervention, FT: forward tilt, DF: dorsiflexion, n.s: not significance, Data are presented as a mean ± standard deviation.

2. 3. Difference in STS duration in the pre-test data

There were no significant differences in the total duration of the STS tasks for pre-test data between the experimental (2.67±0.34 s) and control (2.49±0.25 s) interventions.

2. 4. STS duration before and after each intervention

The total duration of the STS movements before and after each intervention for each subject is depicted in Fig. 8.

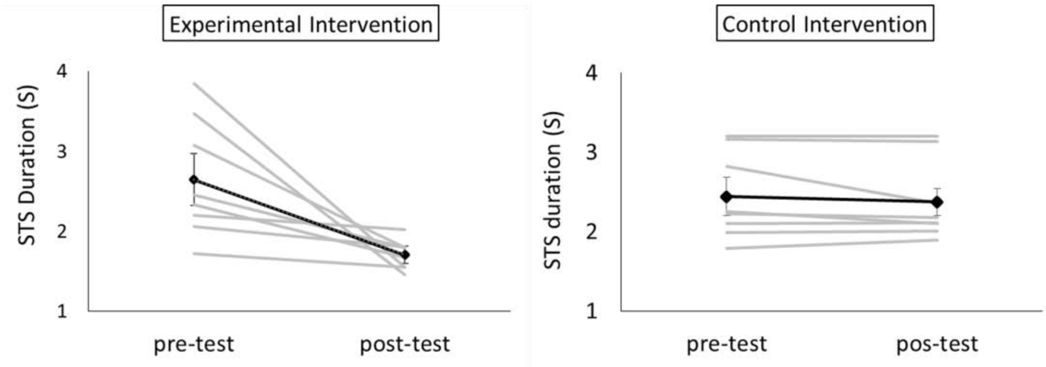

Fig. 8 *Mean and standard deviation of STS duration before (Pre-test) and after (Post-test) the experimental and control interventions (black line) and for each subject (gray line)*

2. 5. Differences in the rate of change percentages before and after each intervention

A significant difference was observed between the rate of change percentages for the STS duration before and after the experimental and control interventions (Fig. 9).

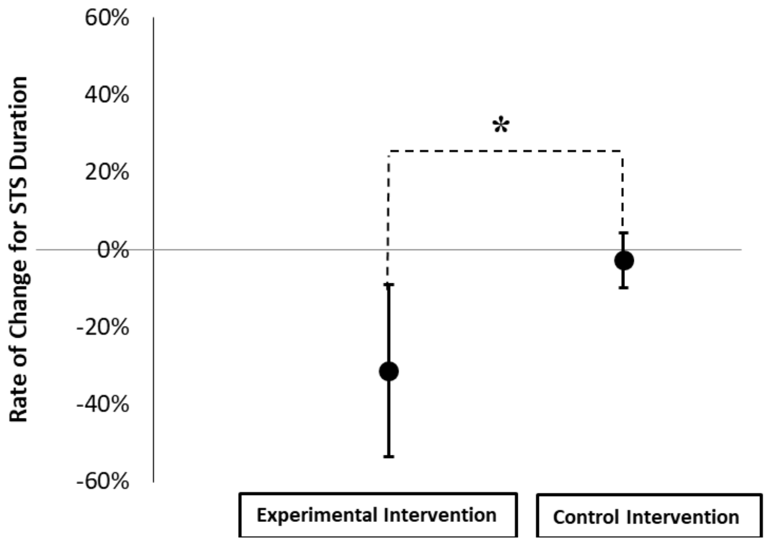

Fig. 9 *Mean and standard deviation of the rate of change percentages before and after each intervention. *p-value<0.05*

3. Discussion

The purpose of this research was to clarify the immediate effects of quick trunk movement exercises on improving the temporal parameters of STS movements in children with spastic CP, using conventional video recording. The findings of the previous study [30] (Research Study I) showed improvements in the STS durations after QSTE. However, the decreasing STS durations of some of the participants after the control intervention, were considered as a possible learning effects. Thus, to resolve the possibility of learning effects and reduce other limitations, such as small sample size and short washout time, a new study design, with measurement procedures over multiple days was suggested.

In the new study design, there was a 3-5 day interval period before the experimental and control interventions and a 2-5 week washout period between the two interventions. In addition, the different method was chosen for the control intervention. Therefore, in this study, the effect of QSTE and a seated position, on STS duration was investigated.

The results of this study indicated that the total duration of STS in children with CP immediately decreased after QSTE but did not changed after the seated position control.

3. 1. Validity of assessments

Similar to the results of Research Study I, the findings of the present study indicated that no significant difference was observed between the angular movements in the starting position before both the QSTE and control interventions. Moreover, the long washout period in this study declined the possibility of carryover effects, a possible issue with Research Study I. This is supported by the findings that there were no significant differences in the total duration of the STS movements prior to the experimental and control interventions. Thus, the assessment procedures in the present study may have some validity in determining the improvements of the temporal parameters of STS movements after QSTE.

3. 2. Improvement in the temporal parameters of STS movements after quick-seated trunk exercise

The total duration of the STS movements improved after QSTE, while there was no significant change after the control interventions. Because of the 3-5 day interval after the pre-test assessment, the improvement in temporal parameters of STS after QSTE likely occurred without the learning effects of the STS movements.

QSTE had a beneficial effect on improving the STS duration in both research studies.. As reported in a previous study, trunk control in children with spastic CP was impaired, which caused abnormal trunk movements during gait and other functional mobility activities, such as STS tasks [39]. Therefore, trunk exercises emphasizing quick movements might improve trunk control in these children and help them to rise from a seated position faster.

3. 3. Limitation for Research Study II

Despite the fact that the new study design of Research Study II rectified the limitations of Research Study I, this current study also has some limitations.

One limitation could be the lack of randomization in the study design.

Another limitation could be the affects of natural development and/or some learning effects. In this new study design, the same group of children with CP participated in both the experimental and control interventions. After completing Step I (pre-test and post-test of the experimental intervention), a 2-4 week washout period was set between the experimental and control interventions. Although there was no significant difference in the duration of the STS movements before both the experimental and control interventions, after this longer interval, natural developments may have affected the STS movements of the participants. Finally, the small increase in the sample size leads to difficulty in generalizing the results of this study.

VIII. Conclusion

Although QSTE did not change the abnormal kinematic patterns of the STS movements, it improved the temporal parameters of the STS movements in children with CP. QSTE is simple and can be performed without specific equipment. Moreover, this trunk exercise is safe because it can be performed in a seated position, and does not require supervision from a therapist to conduct it properly. Thus, QSTE could be implemented by parents or caregivers at home, to facilitate the STS movements of children with CP. These developed interventions could help these children to lead to better performance during daily activities, thus facilitating their social participation.

IX. REFERENCES

1) Rosenbaum P, Paneth N, Leviton A et al (2007) Definition and Classification Document. Supplement 2; A report: the definition and classification of cerebral palsy-April 2006, Dev Med Child Neuro 49: 8-14.

2) Rosenbaum PL, King SM, Cadman DT (1992) Measuring processes of caregiving to physically disabled children and their families. I: Identifying relevant components of care. Dev Med Child Neurol 34: 103-114.

3) Okan N, Okan M, Eralp O, Aytekin AH (1995) The prevalence of neurological disorders among children in Gemlik (Turkey). Dev Med Child Neurol 37: 597-603.

4) Liu JM, Li S, Lin Q, Li Z (1999) Prevalence of cerebral palsy in China. Int J Epidemiol 28: 949-954.

5) Damiano DL (2006) Activity, Activity, Activity: Rethinking Our Physical Therapy Approach to Cerebral Palsy. Physical Therapy 86: 11.

6) Scholtes VA, Becher JG, Beelen A, et al (2006) Clinical assessment of spasticity in children with cerebral palsy: a critical review of available instruments. Dev Med Child Neurol 48: 64-73.

7) Mutch L, Alberman E, Hagberg B, et al (1992) Cerebral palsy epidemiology: where are we now and where are we going? Dev Med Child Neurol 34: 547-551.

8) Palisano R, Rosenbaum P, Walter S, et al (1997) Development and reliability of a system to classify gross motor function in children with cerebral palsy. Dev Med Child Neurol 39: 214-223.

9) Morris C, Bartlett D (2004) Gross Motor Function Classification System: impact and utility. Dev Med Child Neurol 46: 60-65.

10) Tecklin JS (2008) Pediatric Physical Therapy. Baltimore: Lippincott Williams & Wilkins.

11) Gage JR, et al (2009) The Identification and Treatment of Gait Problems in Cerebral Palsy. London: Mac Keith Press.

12) Brashear, Elovic PE (2011) Spasticity- Diagnosis and Management. New York, NY: Demos Medical Publishing.

13) Gage JR (1991) A commitment to excellence and a willingness to change. Dev Med Child Neurol 33: 753-754.

14) Campbell S, Palisano J (2007) Physical Therapy for Children. Philadelphia : Butterworth, Heinemann- Elsevier.

15) Morrisey RT, Weinstein SL (2006) Lovell and Winter's Pediatric Orthopeadics. Philadelphia : Lippincott, Williams & Wilkin's.

16) Panteliadis CP, Strassburg HM (2004) Cerebral Palsy- principles and management. New York: Thieme.

17) Rosenbaum P, Paneth N, Leviton A, et al. (2006) A report: the definition and classification of cerebral palsy April. Dev Med Child Neurol 109: 8-14.

18) Levitt S (2010) Treatment of cerebral palsy and motor delay. New Jersey: Wiley-Blackwell, 125-259.

19) Shepherd RB, Gentile AM (1994) Sit-to-stand: functional relationship between upper body and lower limb segments. Hum Mov Sci 13: 817-840.

20) Lomaglio MJ, Eng JJ (2005) Muscle strength and weight-bearing symmetry relate to sit-to-stand performance in individuals with stroke. Gait Posture 22: 126-131.

21) Schenkman M, Berger RA, Riley PO, et al (1990) Whole-body movements during rising to standing from sitting. Phys Ther 70: 638-648.

22) Roebroeck ME, Doorenbosch CA, Harlaar J, et al (1994) Biomechanics and muscular activity during sit-to-stand transfer. Clin Biomech 9: 235-244.

23) Schultz AB, Alexander NB, Ashton-Miller JA (1992) Biomechanical analyses of rising from a chair. J Biomech 25: 1383-1391.

24) Riley PO, Schneckman ML, Mann RW, et al (1991) Mechanics of a constrained chair-rise. J Biomech 24: 77-85.

25) Schultz AB, Alexander NB, Ashton-Miller JA (1992) Biomechanical analyses of rising from a chair. J Biomech 25: 1383-1391.

26) Pai YC, Rogers MW (1991) Speed variation and resultant joint torques during sit-to-stand. Arch Phys Med Rehabil 72: 881-885.

27) Khemlani MM, Carr JH, Crosbie WJ (1999) Muscle synergies and joint link ages

in sit-to-stand under two initial foot positions. Clin Biomech 14: 236-246.
28) Doorenbosch C, Harlaar J, Roebroeck M, et al (1994) Two strategies of transferring from sit-to-stand: the activation of monoarticular and bi-articular muscles. J Biomech 27: 1299-1307.
29) Tully EA, Fotoohabadi MR, Galea MP (2005) Sagittal spine and lower limb movement during sit-to-stand in healthy young subjects. Gait Posture 19: 338-345.
30) Abdolrahmani A, Sakita H, Yonetsu R, et al (2017) Immediate effects of quick trunk movement exercise on sit-to-stand movement in children with spastic cerebral palsy: a pilot study. J Phys Ther Sci 29: 905-909
31) Park ES, Park CI, Lee HJ, et al (2003) The characteristics of sit-to-stand transfer in young children with spastic cerebral palsy based on kinematic and kinetic data. Gait Posture 17: 43-49.
32) Voorman JM, Dallmeijer AJ, Knol DL, et al (2007) Prospective longitudinal study of gross motor function in children with cerebral palsy. Arch Phys Med Rehabil 88: 871-876.
33) Dillon ER, Bjornson KF, Jaffe KM, et al (2009) Ambulatory activity in youth with arthrogryposis: a cohort study. J Pediatr Orthop 29: 214-217.
34) Bjornson KF, Belza B, Kartin D, et al (2007) Ambulatory physical activity performance in youth with cerebral palsy and youth who are developing typically. Phys Ther 87: 248-257.
35) Park ES, Park CI, Chang HJ, et al (2004) The effect of hinged ankle-foot orthoses on sit-to-stand transfer in children with spastic cerebral palsy. Arch Phys Med Rehabil 85: 2053-2057.
36) Park ES, Park CI, Chang HC, et al (2006) The effect of botulinum toxin type A injection into the gastrocnemius muscle on sit-to-stand transfer in children with spastic diplegic cerebral palsy. Clin Rehabil 20: 668-674.
37) Yonetsu R, Iwata A, Surya J, et al (2015) Sit-to-stand movement changes in preschool-aged children with spastic diplegia following one neurodevelopmental treatment session - a pilot study. Disabil Rehabil 37: 1643-1650.
38) Yu B, Holly-Crichlow N, Brichta P, et al (2000) The effects of the lower

extremity joint motions on the total body motion in sit-to-stand movement. Clin Biomech 15: 449-455.
39) Heyrman L, Desloovere K, Molenaers G, et al (2013) Characteristics of impaired trunk control in children with spastic cerebral palsy. Dev Disabil 34: 327-334.
40) Hamill D, Washington KA, White OR (2007) The effect of hippotherapy on postural control in sitting for children with cerebral palsy. Phys Occup Ther Pediatr 27: 23-42.
41) Shurtleff TL, Engsberg JR (2010) Changes in trunk and head stability in children with cerebral palsy after hippotherapy: a pilot study. Phys Occup Ther Pediatr 30: 150-163.
42) Fielding RA, LeBrasseur NK, Cuoco A, et al (2002) High-velocity resistance training increases skeletal muscle peak power in older women. J Am Geriatr Soc 50: 655-662.
43) Bean JF, Herman S, Kiely DK, et al (2004) Increased Velocity Exercise Specific to Task (InVEST) training: a pilot study exploring effects on leg power, balance, and mobility in community-dwelling older women. J Am Geriatr Soc 52: 799-804.
44) Marigold DS, Eng JJ, Dawson AS, et al (2005) Exercise leads to faster postural reflexes, improved balance and mobility, and fewer falls in older persons with chronic stroke. J Am Geriatr Soc 53: 416-423.
45) Gray VL, Juren LM, Ivanova TD, et al (2012) Retraining postural responses with exercises emphasizing speed post stroke. Phys Ther 92: 924-934.
46) Gray VL, Ivanova TD, Garland SJ (2012) Effects of fast functional exercise on muscle activity after stroke. Neurorehabil Neural Repair 26: 968-975.
47) Iwata A, Higuchi Y, Kimura D, et al (2013) Quick lateral movements of the trunk in a seated position reflect mobility and activities of daily living (ADL) function in frail elderly individuals. Arch Gerontol Geriatr 56: 482-486.
48) Iwata A, Higuchi Y, Sano Y, et al (2014) Quickness of trunk movements in a seated position, regardless of the direction, is more important to determine the mobility in the elderly than the range of the trunk movement. Arch Gerontol Geriatr 59: 107-112.

49) Palisano RJ, Rosenbaum P, Bartlett D, et al (2008) Content validity of the expanded and revised Gross Motor Function Classification System. Dev Med Child Neurol 50: 744-750.
50) Bohannon RW, Smith MB (1987) Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther 67: 206-207.
51) Shepherd RB1, Koh HP (1996) Some biomechanical consequences of varying foot placement in sit-to-stand in young women. Scand J Rehabil Med 28: 79-88.
52) Kawagoe S, Tajima N, Chosa E (2000) Biomechanical analysis of effects of foot placement with varying chair height on the motion of standing up. J Orthop Sci 5: 124-133.
53) Riley PO, Schneckman ML, Mann RW, et al (1991) Mechanics of a constrained chair-rise. J Biomech 24: 77-85.
54) Kuo HC, Gordon AM, Henrionnet A, et al (2016) The effects of intensive bimanual training with and without tactile training on tactile function in children with unilateral spastic cerebral palsy: A pilot study. Res Dev Disabil 50:129-139.
55) Unger M, Jelsma J, Stark C (2013) Effect of a trunk-targeted intervention using vibration on posture and gait in children with spastic type cerebral palsy: a randomized control trial. Dev Neurorehabil 16:79-88.
56) Churchill AJ, Halligan PW, Wade DT (2002) RIVCAM: a simple video-based kinematic analysis for clinical disorders of gait. Comput Methods Programs Biomed 69: 197-209.