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The effect of gait enhancer mechanism on functional balance and endurance of walking in children with Cerebral Palsy

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ABSTRACT

The purpose of this study was to investigate the effectiveness of Gait Enhancer Mechanism on functional balance and walking endurance in children with cerebral palsy. We designed a new gait trainer according to Theo Jansen mechanism. Two separated Jansen linkages were placed on both sides of a frame and were connected to the lower limb at the ankle joint by a plate under foot.

This experimental research organized in a single subject system, A-B-A design for four children with spastic diplegic cerebral palsy from level III of gross motor function classification system. This method includes repetitive measures in three phases, baseline and intervention and then maintenance. All the participants received conventional occupational therapy during the study period. They had 18 gait training sessions, 3 times per week, with *Gait Enhancer Mechanism* for 30 minutes in intervention phase. Pediatric balance scale and 6-Minute walk test were performed to evaluate functional balance and walking endurance, respectively. Results were considered by visual graphs and statistically by measuring Non-overlap indices and Cohen's d. The results indicated significant improvement in both functional balance and covered distance in 6-Minute walk test. Cohen's d which represents the effect size was greater than 0.8 for all subjects. Functional balance and walking endurance were improved in children with cerebral palsy following gait training with Gait Enhancer Mechanism besides conventional occupational therapy.

Keywords: cerebral palsy, gait training, functional balance, walking endurance, walking capacity

1. INTRODUCTION

Cerebral palsy (CP) occurs at approximately 2-2.5 per 1000 live births (Stanley, 2000). It is the most common childhood physical disability, describes a group of non- progressive disorders of the premature developing brain that adversely affect movement and Posture, causing limitations in activities and participation. Children with CP experience various impaired muscle functions, such as reduced selective motor control, spasticity and muscle weakness (Rosenbaum,2007). These impairments often lead to difficulty with walking, such as walking speed, walking endurance or climbing stairs (Styer-Acevedo, 1999). Children with cerebral palsy or complex developmental delays are often less mobile and interactive than their peers (Palisano 2009). This lack of mobility and dependent condition can have a negative impact on overall development, social interaction and social status (Lancioni 2009; Mcewen 1992). For these children and their Family, Improving walking ability to walk or to perform other functional activities are often the primary therapeutic goal (Shepherd, 1995). Because walking plays an important role in activities of daily living, improves bone density and cardiopulmonary endurance (Dodd, 2007)

Studies of motor behavior in children with cerebral palsy have demonstrated characteristic patterns of motor development according to severity of the condition (Scrutton, 1997). Severity of cerebral palsy, classifies with the 5-level Gross Motor Function Classification System (GMFCS). Evidence-based prognostication about gross motor progress in children with cerebral palsy is now possible and it providing parents and clinicians with a means to plan interventions and to judge progress over time (Rosenbaum, 2002; Wood, 2000). Independent walking is difficult for a large number of children with cerebral palsy due to impaired postural control, abnormal muscle tone, and pathological muscular coordination of the legs, especially in children with spastic diplegia (Liao, 1997). According to GMFCS, children in level III are dependent on assistive devices in order to walk (Andersson, 2001). Half of the parents of children with cerebral palsy have reported that modifications have moderate to very large effect on the child's mobility. These findings indicate the essential need to design and use of walking aids in these children (Ostensjø, 2005). In a study on adults with CP, 35% reported decreased walking ability despite using walking aids, and 9% had stopped walking (Andersson, 2001). Reduced endurance is the main factor in the decline in walking ability for individuals with CP (Gorter, 2009).

Gait trainers or supportive walking devices are the most aids for this population to influence different types of outcomes as defined by the International Classification of Functioning, Disability and Health (ICF) (Darrah, 2008). But there is some confusion about the term gait trainers as they are not always used to 'train gait' or develop independent, but as a means to enhance activity and participation like simple walkers (Low, 2011). However, use of a gait trainer to increase ability of children with cerebral palsy to take steps and increase walking distance is supported. But the lack of experimental evidence suggests that further research is needed to explore the broad range of outcomes that may be influenced by gait trainer interventions (Paleg, 2015). So we designed a new gait trainer according to Jansen mechanism (Nansai, 2013) to help children with cerebral palsy to increase their ability to walk independently along with training them for promote their walking parameters gradually during therapy sessions. *Gait Enhancer Mechanism (GEM)* is the name that we chose for this gait trainer.

2. MATERIALS AND METHODS

Participants

Four children with spastic diplegic cerebral palsy who are currently receiving conventional occupational therapy sessions as outpatients were enrolled in this study (IR.USWR.REC.1396.286). Inclusion criteria were: Diagnosis of spastic diplegia; aged 6 to 10 years; able to walk independently with an assistive device; able to follow simple verbal instructions according to SPARCLE questionnaire (Colver, 2006); Gross Motor Function Classification System levels III, written consent from their parents; not treated surgically or with botulinum toxin during the last 1-year. Exclusion criteria were: uncontrolled seizure; dislocation or subluxation of hip joints; true shortness of one of the lower limbs more than 2 cm. The average age of the four participants was 7 year and 9 months and they were boys.

Design and Procedure

It was a single subject experimental study with an ABA design. Baseline or Phase (A_1) lasted for 4 weeks, intervention phase (B) and maintenance phase (A_2) each lasted for 6 weeks. Single subject designs represent a powerful decision making tool for clinical research. It is usually easier to incorporate this method into clinical treatment to provide systematic documentation of rehabilitation outcomes (Reboussin, 1996). All the participants received conventional occupational therapy for 3 times per week during the study period. In phase (B) they had 18 gait training sessions with *Gait Enhancer Mechanism* for 30 minutes after conventional therapy.

Outcome measurements

The participants were evaluated by pediatric balance scale (PBS) and 6-Minute walk test (6-MWT) before and after baseline Phase (A_1) and every week during intervention (B) and maintenance (A_2) phases. The PBS, a modification of Berg's balance scale, is used to determine the functional balancing abilities of children with cerebral palsy. It consists of 14 items evaluated on a 5-point scale (0-4). The maximum score is 56. Total test administration and scoring time is 15 minutes. It is useful to monitor progress within a therapeutic program. The inter-rater reliability is 0.99 that demonstrating excellent reliability of this instrument (Franjoine, 2003). The 6-Minute walk test has been widely used for measuring the response to therapeutic interventions. The 6-MWT is easier to administer, better tolerated, and better reflects activities of daily living than other walk tests. It performed on a 20-meter long corridor with poles at each end. The instruction and verbal encouragement of the child applied according to a standardized test protocol (Enright, 2003). The 6-MWT demonstrated good to excellent reliability with narrow 95%CIs for children with cerebral palsy (Thompson, 2008).

Intervention

This new gait trainer has been designed according to Theo Jansen mechanism. A schematic figure of the Jansen linkage mechanism is shown in Fig.1. This mechanism is gaining wide spread popularity among legged robotics researchers due to its scalable design, energy efficiency, bio-inspired locomotion, deterministic foot trajectory among others (Nansai, 2013).

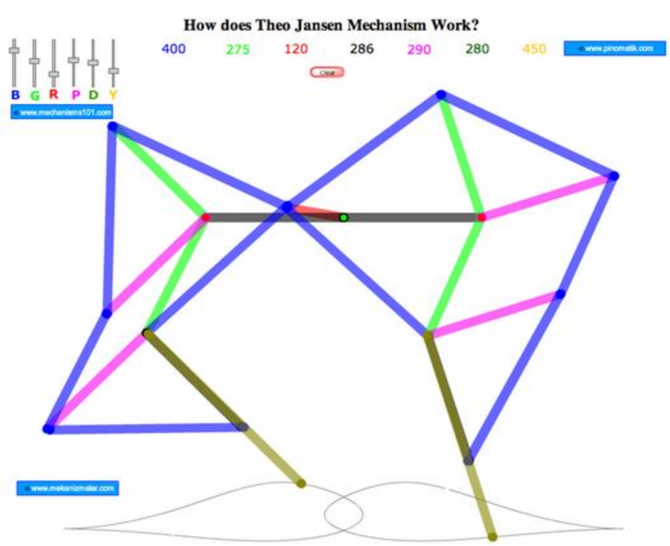


Figure 1 Theo Jansen linkage mechanism

We utilized two separate Jansen linkages on both sides of the frame that are connected to the lower limb at the ankle joint by a plate under foot. Both linkages are adjustable to create desirable step lengths. The mechanism operates only in sagittal plane and guides the lower limb to move in a normal pattern. Limited hip adduction and abduction during gait training with this device are possible but it prevents scissoring gait. Both lower extremities are encouraged to move in the same normal pattern. Pelvic and thigh harnesses help child to stand upright and prevent falling. Cables at the pelvic harness are used for power transmission to the gearbox and from gearbox to the rear wheel (Fig. 2).

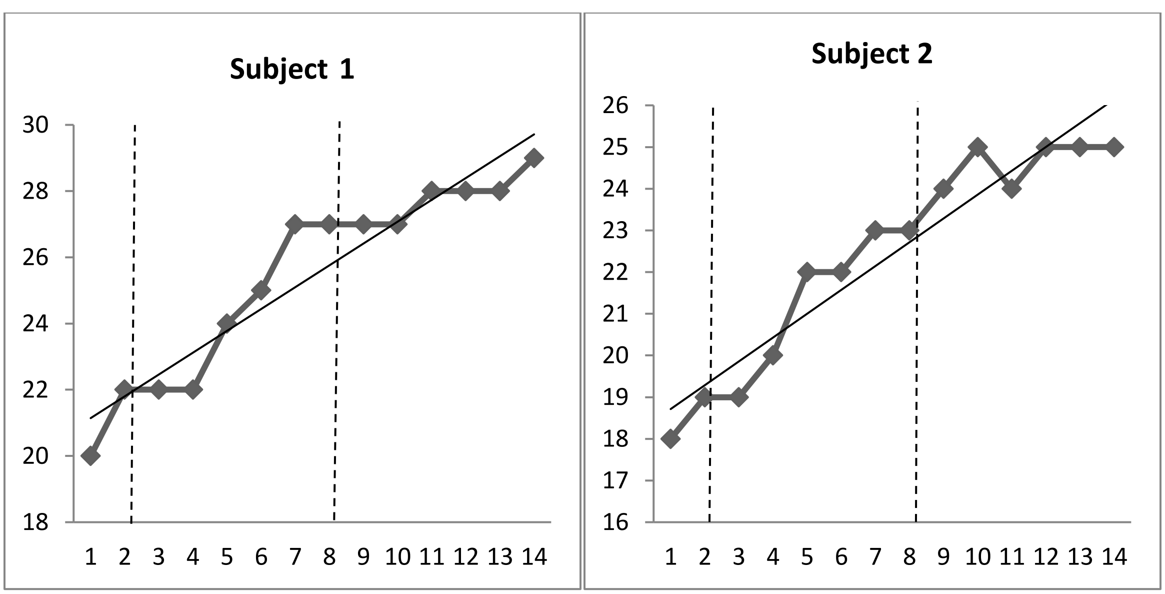
Figure 2 Gait Enhancer Mechanism

3. RESULTS

Traditionally, the interpretation of data from single subject studies is based on graphic presentation and visual analysis (Zhan, 2001).For each variable, visual graph and Nonoverlap indices between phases are presented. After that the effect size is measured by Cohen’s d.

$$\text{Cohen's d} = {}^{(M_2 - M_1)} / {}_{SD_{pooled}}$$

PBS results are presented in visual graphs for all participants in Fig.3. By visually inspecting graphed data for PBS a judgment can be reached about the intervention effectiveness on functional balance. When intervention was compared to baseline, subject 1 demonstrated significantly higher scores in functional balance from 22 to 27. These progresses for subjects two, three and four were 4, 3 and 4 scores respectively. During maintenance phase, no significant alternations were observed in PBS compared with intervention.



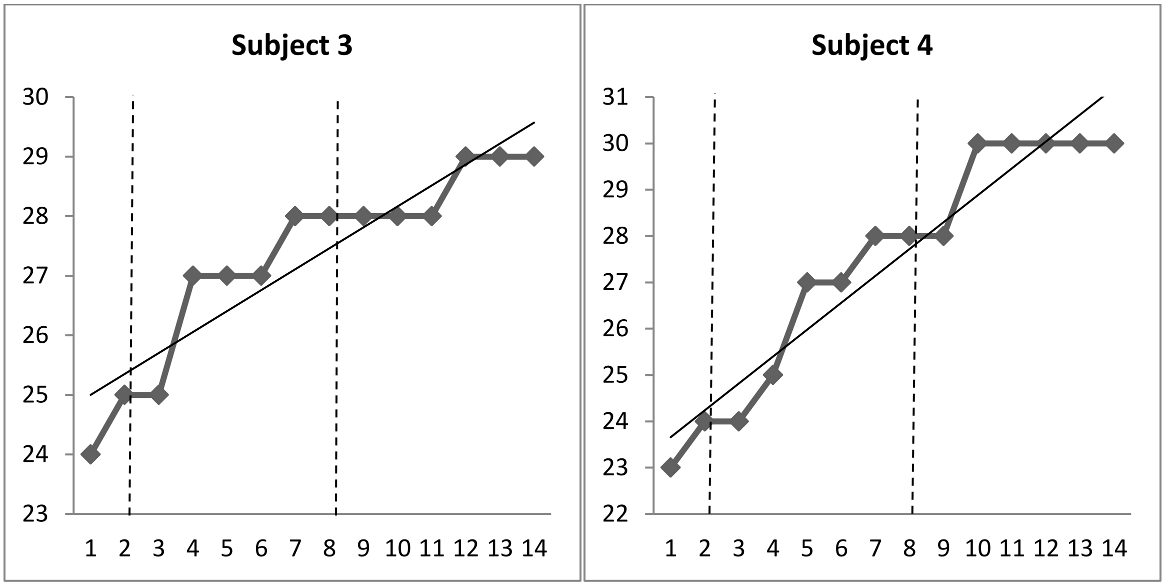


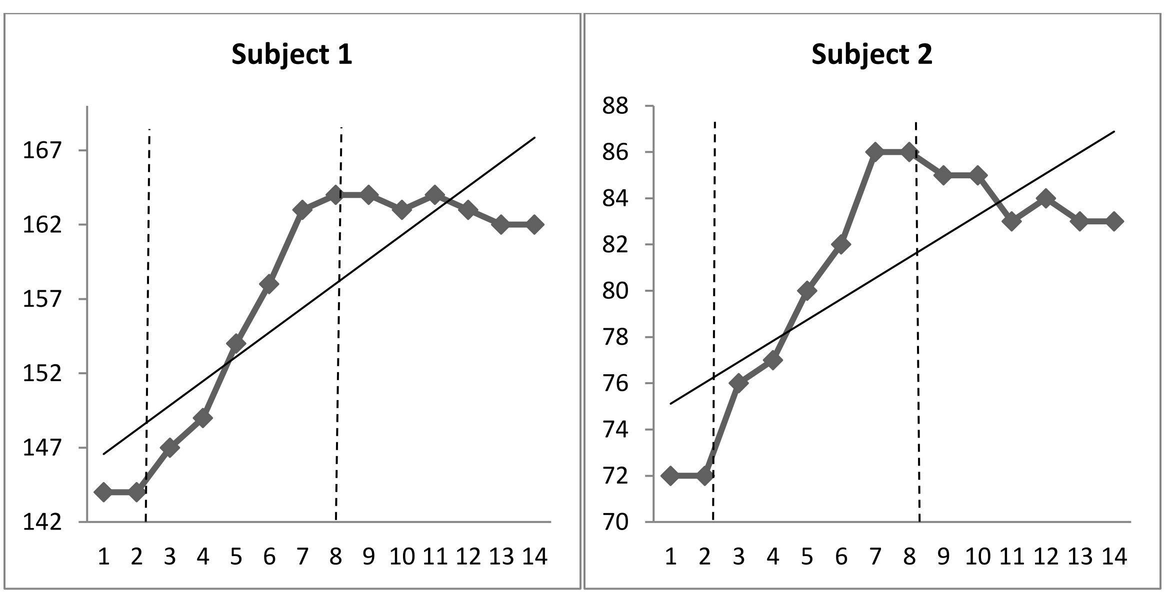
Figure 3 Pediatric balance scale graph of participants.

Nonoverlap indices presented in Table 1 indicate significant effect of Gait training on balance score between baseline and intervention phases.

Table 1 Nonoverlap indices of PBS between baseline and intervention phases

Subjects	PND	PAND	NAP	PEM	IRD	Phi	Tau	Tau-u	SMD
1	0.67	0.87	0.92	100%	0.67	0.43	0.83	0.75	1.41
2	0.83	0.87	0.96	100%	0.67	0.67	0.92	0.83	2.42
3	0.83	0.87	0.96	100%	0.67	0.67	0.92	0.83	2.02
4	0.83	0.87	0.96	100%	0.67	0.67	0.92	0.83	2.42

Cohen's d values for subject 1, 2, 3 and 4 were 1.63, 1.97, 2.4 and 1.97 respectively. Cohen's d, for measuring the effect size, was greater than 0.8 which shows meaningful changes following intervention. Regarding 6-MWT, outcome values are illustrated in Fig. 4. Visual analyses of these graphs indicate the effect of intervention. When intervention phase was compared to baseline, all subjects show significant changes in 6-MWT. The covered distance for participant 1improved from 144m to 164m, representing a 13.8% increase. For subjects 2, 3 and 4 the covered distance in 6-MWT increased by 19.4%, 9.3% and 9.6% separately. The changes in 6-MWT stopped after removal intervention in maintenance phase.



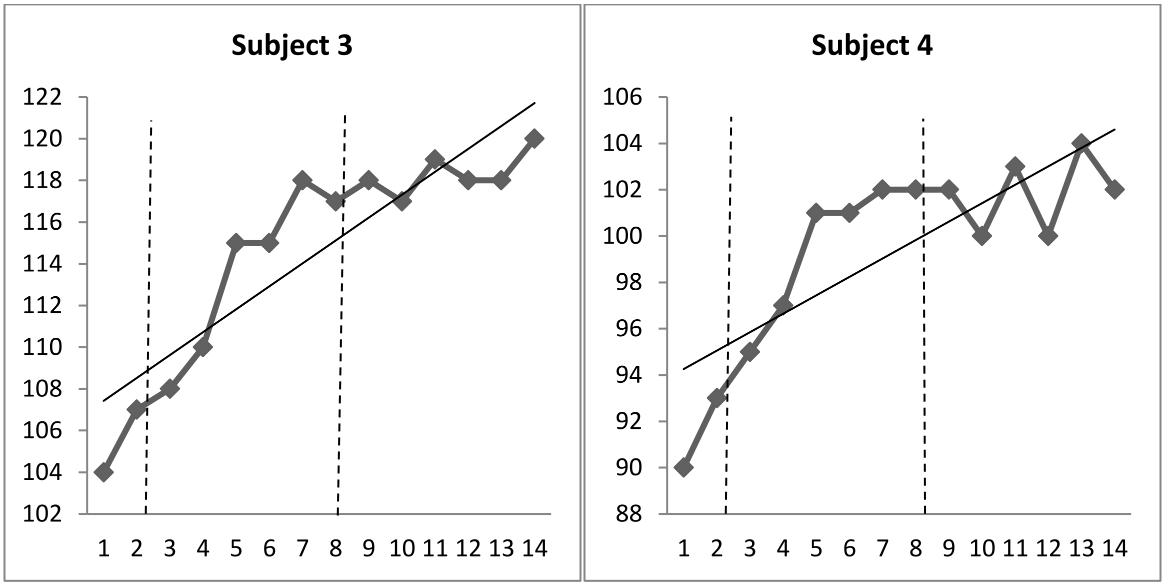


Figure 4 6-Minute walk test graph of participants.

Nonoverlap indices presented in Table 2 indicate significant effect of Gait training on covered distance between baseline and intervention phases.

Table 2 Nonoverlap indices of 6-MWT between baseline and intervention phases

Subjects	PND	PAND	NAP	PEM	IRD	Phi	Tau	Tau-u	SMD
1	100%	1	1	100%	100%	1	1	1	0
2	100%	1	1	100%	100%	1	1	1	0
3	100%	1	1	100%	100%	1	1	0.92	2.24
4	100%	1	1	100%	100%	1	1	0.92	2.20

The effect size, measured by Cohen's d, were 1.83, 2.34, 2.23 and 2.90 for subjects 1, 2, 3and 4 respectively. Cohen's d, for calculating the effect size, was greater than 0.8 which means meaningful changes after intervention.

4. DISCUSSION

Functional gait training consists of a range of diverse interventions with the same treatment goal. It can be defined as active walking tasks to improve walking ability. There are two categories of gait training in children with cerebral palsy (Booth, 2018). These interventions involve overground gait training (OGT) and treadmill-based gait training. Both methods of gait training are useful and safe to target improvement of outcomes relating to walking ability (Gorter, 2009; Kurz, 2012).

Recently, gait rehabilitation methods in patients with neurological impairments have relied on technological devices like driven gait orthosis or Lokomat (Hesse, 2001). Although robot-assisted gait training has become an established treatment option to address gait impairments, evidence for its effectiveness is vague (Ammann-Reiffer, 2017). Some studies have shown that both over ground and partial body weight supported treadmill training provide comparable functional improvements in mild to moderately disabled children with cerebral palsy (Ammann-Reiffer, 2017; Swe, 2015). But other researches have indicated active gait training has a trend towards increased distance of walking (Willoughby, 2010). Active gait training led to successful encoding accompanied by characteristic changes in corticomotor excitability, while passive training did not (Kaelin-Lang, 2005), because there are some biomechanical differences between over ground and treadmill walking (Jung, 2016). Furthermore, better interaction between patient and therapist occurs in overground gait training and the opportunity for direct carryover of skills to overground walking environment is provided (Patton, 2008).

This study has shown that overground gait training with *Gait Enhancer Mechanism* provide significant improvements in functional balance and walking endurance in children with cerebral palsy. Our findings are similar to other recent studies (Paleg, 2015; Booth, 2018; Swe, 2015). Children with cerebral palsy have weaker muscles than healthy children (Wiley, 1998). Muscle strength is related to gait and motor function (Damiano 1998). Applying a controlled swing resistance force to the leg during taking steps in *Gait Enhancer Mechanism* induces significant improvements in walking function of child. Repeated exposure to resistance during walking may induce a prolonged retention of increased stride length and more covered distance in walking (Wu, 2017).

5. CONCLUSION

The findings of this study suggest that Gait Enhancer Mechanism can be useful for children with cerebral palsy. Children using the gait trainer and conventional therapy showed a significantly greater improvement in the investigated parameters compared with just conventional occupational therapy. It was only a single subject study after designing a new gait trainer. Further studies like RCTs are needed in order to investigate the impact of this new gait trainer in children with CP.

Authors Contribution Statement

Fatorehchy S. and Hosseini S.A. conceived and designed the study and collected the data. Fatorehchy S. and Haghgoo H.A. performed the experiments. Fatorehchy S. wrote the paper. Hosseinzadeh S. performed the analysis.

Founding

This study was performed as a part of Ph.D. thesis by the corresponding author in the University of Social Welfare and Rehabilitation Sciences.

Ethics approval

Ethical approval for this research has been obtained from Ethics Committee of the University of Social Welfare and Rehabilitation Sciences, reference number IR.USWR.REC.1396.286. http://ethics.research.ac.ir

All participants were provided with verbal and written information about the study and written informed consent obtained prior to enrolment into the study.

Conflict of Interest

The authors declare no conflict of interest.

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