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IMPACT OF BODY WEIGHT SUPPORT TREADMILL TRAINING ON GAIT RECOVERY OF INDIVIDUALS WITH STROKE

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Abstract

Background: *Restoration of independent gait in stroke patients is an essential part of the rehabilitation process, and is crucial for successful social and vocational reintegration**.** Gait restoration requires different techniques, and often demands considerable assistance from the therapist to help the subject support body weight and control balance**.** Considering that ground level is the most common locomotion surface, and that there is little information about individuals with stroke walking with body weight support treadmill training (BWSTT), it is important to investigate the use of BWSTT on ground level in these individuals to improve gait recovery.*

Methods: *Sixty-nine subjects were assigned to this experiment, of which twenty-six were normal subjects and forty-three were stroke subjects, who were randomly divided into two groups; twenty-one subjects for the control group, and twenty-two subjects for the experimental group. The control group underwent regular rehabilitation care plus conventional gait training, while the experimental group underwent regular rehabilitation care plus BWSTT.*
Measurements were recorded for mean sagittal kinematics values, spatial-temporal values, and FIM™ locomotion

Results: *BWSTT proved superior to conventional gait training in sub-acute stroke subjects, resulting in better locomotor abilities. The use of BWSTT leads to significant improvements for most sagittal kinematics, spatial-temporal and all FIM™ locomotion measurements.*

Conclusion: *The BWSTT system enabled individuals with stroke to walk safely and without physical assistance. The positive results of training by the use of body weight support on a treadmill could be due to a task-oriented type of training.*

Keywords: *Treadmill - Gait training - stroke - body weight support.*

Background:

Stroke is a sudden focal neurological deficit resulting from ischemic or hemorrhagic lesions in the brain[1]. It is the third leading cause of adult disability in the Kingdom of Saudi Arabia, with a crude annual incidence of stroke subjects of 29.8 per 100,000[2]. Thirty percent die during the acute phase, and of the survivors, two thirds will have chronic neurological deficits that persistently impair function[2]. Recovery of walking function following a stroke is variable; between 60% and 95% of stroke subjects will restore their ability to walk. The percentage of subjects who walk will often continue to have limited function due to poor gait pattern[3]. Gait impairment is a significant contributor to long-term disability after stroke[4], making restoration of independent gait an essential part of the rehabilitation process, and crucial to a stroke subject's social reintegration. Gait restoration requires different techniques, often demanding considerable assistance from the therapist to help the subject support their body weight and control balance[5]. Although early rehabilitative intervention in walking training is generally recognized as beneficial in patients with stroke, it is less clear what type of treatment program would produce the best outcome[5]. Conventional gait training alone often leads to low walking speed and poor walking performance in many stroke subjects, which is insufficient to function effectively in the community[6.] BWSTT has been prescribed for subjects with stroke as it decreases postural demands, supports part of the body weight and promotes coordination of the lower extremities. This is accomplished by reducing the requirements for stability, enabling individuals with stroke to practice the gait pattern entirely without the collapse of the affected lower limb[6, 7].

The differences between walking on a treadmill and over ground have been examined in healthy adults and individuals with stroke[8–10]. The different requirements of treadmill and over ground-walking influence gait parameters, such as sagittal kinematic and FIM[11, 12]. Similarly, these differences may also influence the ways the improvements of treadmill-training are transferred to overground-walking[9, 13]. Considering that ground level is the most common locomotion surface, and that there is little information about individuals with stroke walking with BWSTT on ground level, it is important to investigate the use of BWSTT on ground level in these individuals as a possible alternative strategy for gait training. The use of a treadmill may increase the number of steps taken, whereas body weight support (BWS) provides enough assistance to facilitate walking[14.] Step training on a treadmill (TM) with BWS is an example of a neurorehabilitation approach that incorporates recent findings from basic science to promote functional locomotor recovery after stroke. The BWS system enabled individuals with chronic stroke to walk safely, without physical assistance[14].

Although individual studies suggest that treadmill training with BWS may be more effective than treadmill training alone, and that treadmill training plus task-oriented exercise may be more effective than sham exercises, further trials are required to confirm these findings. Therefore, the purpose of this study was to quantify the amount of recovery in temporal-spatial parameters, sagittal kinematic parameters, and locomotion outcome after BWSTT in subjects with stroke in comparison to conventional gait training, and to detect the effects of BWSTT in locomotion outcome in subjects with stroke.

Methods

This was a prospective interventional study that was conducted on 69 individuals. The recruited sample included 43 stroke patients (who were randomly divided into two groups: 21 subjects for the control group and 22 subjects for the experimental group) and 26 age- and sexmatched healthy subjects assigned to the normal group.

All recruited individuals were evaluated by the FIM™ at Riyadh Military Hospital in the gym for physical therapy twice; the first was prior to initiation of the training program, and the second was six weeks later. The locomotion items of the FIM™ walking and stairs-climbing were evaluated as a task-performance. The scoring items have been labeled from 1-7. Therefore, a score of 14 is defined as the highest degree of independence, while a score of two means the subject is dependent on personal assistance.

For gait recoding and analysis, all subjects underwent a 3D gait analysis at Sultan Bin Abdulaziz Humanitarian City in the motion laboratory to obtain temporal-spatial and sagittal kinematics. The control and experimental group gait recording and analysis was obtained 24 hours before the beginning of the training program, and 24 hours after the end of the training program, six weeks apart. The normal group gait analysis was obtained through two walking tests at six-week intervals. The control group underwent regular rehabilitation care plus conventional gait training, while the experimental group underwent regular rehabilitation care plus body weight support treadmill training (BWSTT) (Figure 1).

Gait training of the control group consisted of ambulation over-ground at a self-selected speed for each subject. Subjects were trained to walk using physical assistance as required.

Lower limb orthosis and walking aids were not allowed during training. Verbal cueing and manual guidance were given for gait correction, focusing on straight trunk and limb alignment with proper weight shift and weight bearing onto the paretic limb during the loading phase of gait, as well as stepping to advance the limb forward. A safety belt was also fitted at the waist by the therapist to ensure steady support. If the subject appeared to be at risk during walking, the therapist would hold the loops of the safety belt and provide assistance for propelling forward if needed.

Gait training of the experimental group consisted of ambulation on a motor-driven treadmill; the treadmill speed was constant throughout the study, adjusted at 2.7km/h speed with level treadmill surface. The subjects were assisted in stepping on to the stationary treadmill by the therapist. The pulley system was located directly above the treadmill. Once the subject was on the treadmill, the harness was then adjusted by the therapist snugly, but comfortably, while the subject was in a standing position. The harness consisted of a thoracic and chest belt and two straps around the upper thigh with anterior and posterior attachments to the thoracic belt. The harness was attached to an overhead bar on the body weight support system; the system also has a suspension mechanism with a force transducer that signals the amount of weight being supported, with body weight support adjusted at 30% of the subject's weight. The subject was allowed to accommodate to the change in weight and once the subject felt comfortable with the harness, the treadmill was set and the session was initiated. During the treadmill training, the subject held onto a horizontal bar by his/her front with at least one hand for stability. The therapist stood on the floor beside the subject to provide assistance if needed. No lower limb orthosis was allowed during treadmill training.

All gathered data were analyzed using the Statistical Package for Social Sciences software, version 10 for Windows (SPSS, 1999). Descriptive statistics, including means and standard deviations, were used to show the physical characteristics, temporal-spatial, sagittal kinematics values and FIM™ locomotion measures for the study groups. One-way analysis of variance (ANOVA) was used to compare all measured variables for the control stroke, experimental stroke, and normal groups. Two samples t-test was used to compare the amount of recovery in temporal-spatial, sagittal kinematics value, and FIM™ locomotion measures for the control and experimental groups.

Results

Of the 69 participants recruited to this study, 45 were men. The mean age, height, and weight of all subjects were 63 ± 6 years (range, 50-75 y), 168 ± 6 cm height (range, 150-185 cm), and 78 ± 10 kg weight (range, 55-100 kg), respectively. Thirty-nine stroke subjects had infarction, while 4 subjects had hemorrhage. Twenty stroke subjects had paresis on the right side of the body, while twenty-three subjects had paresis on the left side of the body. Among the 43 stroke patients, 34 had hypertension, 28 had diabetes, 17 had dyslipidemia and 19 had coronary artery disease. The mean time since the onset of the stroke was 71±9 days (range, 54-90 days). Twenty-seven of the male participants were smokers, while the females were non-smokers. ***a) Sagittal kinematic measures***

The sagittal kinematics measures were evaluated before and after intervention, and the prepost recovery score was calculated for pelvis tilt, maximum hip flexion degree, maximum hip extension, maximum knee flexion, maximum knee extension, maximum ankle dorsiflexion and maximum ankle plantar extension degrees.

Regarding the sagittal kinematics measures, the pelvis tilt was significantly worse among the control group than both experimental and normal subjects for both paretic and non-paretic limbs before and post intervention (table 1 and 2) (figure 2, 3 and 4) ($p<0.05$). After intervention, both control and experimental groups showed a significant improvement of pelvic tilt for the paretic and non-paretic limbs, with a mean improvement degree of -1.20 and -0.07 in the paretic and non-paretic limbs of the control group, respectively, and an improvement of -2.19 and -2.13 in the paretic and non-paretic limbs of the experimental group, respectively. The difference in improvement degree was significant between the control and experimental groups in the non-paretic limb ($p=0.014$) (table 2). Even though, the difference between them in the paretic group was not statistically significant ($p=0.081$) (table 1). The maximum hip flexion degree in the paretic limb was worst among the control stroke patients prior to intervention ($p=0.003$) (table 1). After intervention, the degrees of hip flexion were comparable among the three studied groups ($p=0.0082$). Even though, the degree of improvement among the experimental group (-2.6) was significantly better than the degree of improvement among the control group (-0.62) ($p=0.11$) (table 1). On the other side, the degrees of hip flexion of the non-paretic limbs were not significantly different among the three studied groups neither prior to nor after intervention (p=0.49, 0.33, respectively). There was no significant difference in the degree of improvement of hip flexion of the non-paretic limbs as well ($p=0.218$) (table 2). As regards the hip extension, though the degrees improved significantly among the experimental group patients for both the paretic limb (-3.1, $p<0.0001$) and non-paretic limb (-0.53, $p=0.045$), the difference between the experimental and control groups was not significant in either limb (table 1 and 2).

For the knee, the degrees of knee extension of the paretic limb following intervention were not significantly different among the three studied groups ($p=0.225$). Even though, a significant difference in the degree of improvement was noted among the experimental group (2.74) when compared to the control group (0.52) ($p=0.14$) (table 1). For the non-paretic limb, the degree of extension did not improve significantly among the experimental group ($p=0.75$). In contrast, the degree of improvement in knee flexion of the non-paretic limb was significantly higher among the experimental than the control groups (1.05 versus 0.88, respectively; $p=0.035$) (table 2). The degree in improvement of the knee flexion in the paretic limb was even more significant, 15.9 degrees for the experimental group versus 4.62 degrees for the control group ($p<0.0001$). With regards to the ankle movements, there was a significant improvement in the degree of ankle dorsiflexion and plantar flexion of the paretic limb among the experimental group (3.67 and -5.2, respectively) in comparison to the control group (1.43 and -1.32, respectively) ($p<0.001$) (table 1). The degree of improvement, however, was not significantly different among the studied groups when measured in the non-paretic limb ($p>0.05$) (table 2). ***b) Spatial-temporal measures:***

The spatial temporal measures evaluated were velocity per cycle, stride length, total support time, step length, cadence per cycle, swing phase per cycle, single limb support, and average step width (table 3 and 4) (figure 5 and 6). All the measures were evaluated before and after intervention, and the degree of change was also calculated.

For the velocity per cycle, the experimental group had the lowest velocity in both paretic (22.5 cm/s) and non-paretic (23.05) when compared with the control and normal groups ($p<0.0001$). After intervention, the velocity among the experimental patients became significantly higher than the control patients for both the paretic (28.1 cm/s versus 28.8 cm/s) and non-paretic limbs (35.6 cm/s versus 28.68) ($p<0.001$). The degree of improvement was 15.5 and 4.36 among the experimental group and 5.13 and 4.72 among the control group for the paretic and non-paretic limbs, respectively ($p=0.001$) (table 1 and 2). Closely similar results were noted in the stride length measurements; the experimental group showed a significant increase in the stride length of both the paretic (19.63 cm) and non-paretic limbs (15.6 cm) in comparison to the control group (4.48 and 4.36, respectively) ($p<0.0001$) (table 3 and 4).

Significant positive results were also noticed when the total support time was measured. The total support time decreased from 73.2% to 69.3% in the paretic limb and from 79.5% to 73.9% in the non-paretic limb of the experimental group ($p<0.012$). On the other hand, it increased from 70.96% to 73.12% in the paretic limb and decreased from 78.36 to 76.7% in the nonparetic limb of the control group (table 3 and 4). The difference encountered in the degree of improvement of the total support time was significant among the two groups ($p<0.033$). Step length was also increased significantly among the experimental group for both paretic (6.73 cm) and non-paretic limbs (7.5cm) in comparison to the control group (0.85 and 2.86, respectively) ($p<0.04$) (table 3 and 4).

Reviewing the swing phase per cycle, the experimental group patients showed a significant improvement from 27.1% to 30.9% in the paretic limb ($p=0.031$) and from 20.7 to 25.8 in the non-paretic limb ($p<0.001$), whilst the control group improved only 0.75% and 1.88% in the paretic and non-paretic limbs, respectively ($p<0.04$) (table 3 and 4). Single limb support percentage showed also a significantly higher improvement among the experimental patients (4.78% for the paretic and 5.16 for the non-paretic limbs) than the control group (1.91% for the paretic limb and -1.85 for the non-paretic limb) ($p<0.05$).

As regards the cadence per cycle and average step width, there was no significant increase in the number of steps taken per minute or the average step width among the studied groups neither in the paretic nor in the non-paretic limbs ($p>0.05$) (table 3 and 4).

c) FIM™ locomotion measures:

The FIM™ locomotion measures assessed in this study were walking, stairs, and locomotion. The differences between the control and experimental group regarding these measures before and after intervention are tabulated in table 5. The experimental group had significantly higher improvement rates in the three measured parameters (table 5) (figure 8). The improvement in walking score was 2.3 among the experimental group in comparison to

1.43 Among the control group ($p<0.0001$). The experimental group patients improved from

2.95 on the stairs function to 5.18, whereas the control improved from 5.95 to only 4.38 ($p=0.009$). The degree of improvement of the locomotion score was also significantly higher among the experimental patients (4.55) in comparison to the control patients (2.86) ($p=0.001$) (table 5).

Discussion

Discussion

This study demonstrated significant differences in the outcome of walking ability (kinematics, and FIM™) between stroke patients who had Body Weight Support Treadmill Training (BWSTT), in comparison to those who had walking training on the ground (conventional gait training). In agreement with previous researches[7,8], this study showed that stroke survivors in the early stages of rehabilitation may achieve different significant gains in many of their gait measures. The results of the present study also indicated that treadmill training with BWS was feasible and well tolerated by subjects with paresis. For most gait measures, treadmill training was shown to be more effective than conventional over-ground training. Although one must assume that spontaneous recovery as well as the routine treatment provided by staff therapists contributed to the gains of all participants, other research suggests that the differences in the magnitude of recovery of the two groups could be due to the difference in gait training technique. The results of the present study support and extend findings related to the use of BWSTT to improve walking abilities in individuals with stroke7,14–17.

Results of this study showed that stroke subjects treated BWSTT could train more intensively without getting too tired. The training in both groups (BWSTT and conventional gait training) was intensive with duration of six weeks performance. Richards and his college had previously emphasized that the intensity of training was most important[18]. Treadmill training with BWS after stroke appears beneficial for severely disabled subjects because it provides an opportunity to perform a large amount of practice with many repetitions of complete gait cycles. In addition, one potential advantage of the BWS system calls for a reduction in personal support in order to provide a safer environment for gait training[16].

After the training régime, the BWSTT group had significantly decreased its pelvis tilt by 1.43 degrees more than the conventional gait training group for the non-paretic limb in stroke subjects ($p<0.014$). As for the paretic limb, the corresponding decrease in pelvis tilt was not significant (-0.99 degrees). These findings cleared that BWSTT had positive effects on improving pelvis tilt in subjects with stroke. Stroke subjects must compensate for hemiplegia or hemiparetic limb, either within or between limbs, to achieved a stable and smooth gait. The insufficient hip extension and ankle planter –flexion, associated usually with excessive pelvic tilts, and the significant decrease in pelvic tilt of the experimental group, could be due to the improvements in the hip extension and ankle planter-flexion of this group[19]. BWSTT had significantly ($p<0.011$) improved its paretic maximum hip flexion by 3.22 degrees more than the conventional gait training group, while for the non-paretic side, the between-group, comparison of post- pre-treatment maximum hip flexion (-0.72 degrees) indicates no statistically significant difference between stroke groups. Comparable findings were reported by Patrik et al[20]. They reported that treadmill walking was characterized by greater maximal hip flexion in a comparison to over-ground and treadmill walking of healthy individuals. On the other hand, in a study of Daly et al., there was no significant gain in hip flexion (6.5 degrees) in response to the treatment of BWSTT for the pre- post treatment of the stroke subjects[21].

In the present study, a period of treadmill with BWS training showed little improvement (0.44 and -0.43 degrees) in hip extension in comparison to conventional gait training for the paretic and non- paretic side, which could be due to the motion of the treadmill enforcing an appropriate timing relation between the lower limbs while ensuring the extension of the hips during the stance phase, considered to be critical biomechanical components of walking[14,16,17]. In a previous study, comparison between the experimental (BWSTT) and control (conventional physical therapy) groups was lower in significance with a show of 6.8 degrees in hip extension in favor of the treatment group[22]. Comparable findings were reported in another study which showed that hip extension is increased on the treadmill under BWS conditions in subjects with hemiplegia[16].

Significant improvement of 2.22 degrees for maximum knee extension was observed in the BWSTT group as a result of using such training, more than the conventional gait-training group for the paretic side. It has been reported that kinematics measure (knee hyperextension) was improved significantly by using BWSTT for patients with stroke[23]. As well as after 6 weeks of walking training, the BWSTT group had significantly improved its maximum knee flexion by 11.32 degrees ($p<.0001$) and 1.57 degrees ($p<.044$) more than the conventional gait-training group for the paretic and non-paretic side, respectively. In contrast, it has been reported that treadmill training with BWS had little effect in improving knee flexion during swing[24]. In addition to the post- pretreatment of the stroke subjects, Daly et al. reported that there was no significant gain in knee flexion (1.4 degrees) in response to the treatment of BWSTT[21]. The improvements gained in knee motion in the experimental group can be explained by the findings of Zoblotny and his college that treadmill training has a greater effect on the torque generating capacity of paretic quadriceps and hamstring[23]. Significant improvement was observed in maximum ankle dorsi-flexion after 6 weeks of walking training using BWSTT in comparison to the conventional gait training for the paretic side (2.24 degrees) due to the regular activation pattern of the shank muscles during treadmill walking as compared with floor walking ($p<0.001$)[15,23]. Insignificant improvement was observed for the non- paretic side (0.09 degrees). It has been reported that there was no significant gain in ankle dorsi-flexion (3.3 degrees) in response to the treatment of BWSTT for the pre- post treatment of the stroke subjects[21]. In our study, BWSTT had significantly improved its maximum ankle planter-flexion by -3.88 degrees more than the conventional gait-training group for the paretic side ($p<0.0001$). As for the non-paretic side, insignificant improvement was observed in maximum ankle planter-flexion (-0.04 degrees). Others studies report an advantage gain in kinematics measures produced post treatment with BWSTT following stroke. For chronic cases (>6 months), researchers reported significant gain in maximum knee flexion and maximum ankle movement (dorsi-planter flexion)[13,21]. For subjects in the acute phase, comparative gains with respect to other treatments were reported in response to BWSTT for hip and pelvic kinematics as well as ambulatory status[25,26]. In several studies of subjects in the acute phase after stroke, authors compared BWSTT with TT alone[7,27]. They found a significant advantage for the BWSTT treatment ($p<0.05$ for measures of active joint movement and basic mobility and walking endurance) that give greater support to the explanation of the improvements in gait. This improvement was due to the treadmill effects and the use of body weight support together. Furthermore, a higher gait velocity increased activation (facilitation) of many muscles of the paretic side, in addition it has been founded that all joint kinematics, especially at sagittal plane were characterized predominantly by changes in speed[28]. This could be the case in our experimental group. Velocity altered significantly during the treatment phase of this study. Forward velocity, which improved in both treatment groups (BWSTT and conventional gait training), has been shown to be an important indicator of independence[7,29]. Significant improvements of 10.43 and 7.87 cm/s in velocity/cycle for the paretic and non-paretic side, respectively demonstrate that BWSTT has significant positive effects compared to conventional gait training ($p<0.001$). In a study of subjects with stroke, it has been reported that oxygen uptake was reduced when the subjects walked with 30 % BWS, compared to unsupported walking[30]. Recent research in stroke suggests that training at higher speeds results in even faster over-ground walking speeds. Furthermore, it appears that early (more appropriate) onset and greater amplitude of muscle activity of the legs is facilitated with faster speeds[20]. The clinical implication is that BWS decreases the oxygen demand during treadmill walking and thus energy cost and cardiovascular demands do not limit the use of treadmill training with BWS compared with conventional training. Thus, the older stroke subjects could benefit from using locomotor training with BWS, which can be tolerated by subjects with comorbidities such as cardiovascular problems. Also gait training with BWS is less demanding in terms of energy consumption, which may explain why stroke subjects can begin their locomotor training with BWS on the treadmill very early after their injury, in additio,n giving them the advantage to increase their velocity of walking[22,27]. Another significant point, is that when training locomotion speed replicated normal, or close to normal walking speeds, the motor output enhanced extensor and flexor activity in an appropriately phased manner, accommodating training treadmill speeds of 2.7 km/hr. Consistent improvement in gait velocity has been noted by previous studies[13,16,17,22]. An estimate of .23 m/s was reported for velocity of the supported treadmill training, more than the regular rehabilitation in acute stroke survivors[7,31]. Also, Bayat et al reported that 4-week treadmill and over-ground walking programs (experimental group) significantly increased walking speed by .14 m/s more than the placebo program (control group consisting of a lowintensity, home exercise program and regular telephone contact)[10]. On comparing BWSTT with conventional gait training in stroke subjects, it has been reported that both groups had improvements in walking velocity (treadmill group, .71 m/s vs conventional group, .83 m/s), however treadmill training with body weight support conferred no additional benefit compared with conventional training[32]. This finding may be due to the lack of homogeneousness factor among both treated groups. They also concluded that further research is required to determine whether BWSTT has any additional benefit compared with conventional training in terms of gait characteristics and forward velocity in stroke subjects. On the other hand, Mudge et al. reported that no significant changes were found in gait velocity during the intervention phase using BWSTT in subjects with chronic stroke as it could be the reason of such results[31,33]. Previous studies reported that a subgroup of stroke subjects with major walking deficits showed a significantly greater improvement in over-ground walking speed, endurance, increased motor recovery, and a greater ability to transfer from treadmill to over-ground walking after training with BWS[34]. Other studies showed that a challenging walking speed for two weeks on the treadmill significantly improved over-ground walking speed[35].

After the 6 weeks of walking training, the BWSTT group had significantly increased its stride length by 15.15 cm ($p<.0001$) and 11.33 cm ($p<.004$) more than the conventional gaittraining group for the paretic and non-paretic side, respectively. These results were in agreement to those reported in previous studies which reported that while the control group (floor walking) did not increase its stride length significantly at both pre- and post-test (40 and 47 cm, respectively), a significant increase in stride length was measured in the treadmill training group (36 and 53 cm, respectively)[31,33]. The high improvement in stride length observed in the experimental group in the present study might be related to the fact that this group achieved a greater velocity average (38.1 cm/s). BWSTT had increased its paretic cadence by 6.71 steps/min and its non-paretic cadence by 7.67 steps/min more than the conventional gait-training group. These findings were in agreement with results of the previous study[27,29]. They reported that treadmill training resulted in a greater cadence ($p<0.02$), as compared to over-ground walking in stroke subjects. Also, the use of treadmill training has indicated that cadence was significantly greater ($p<0.005$) after rehabilitation (55.3 steps per minute) than before rehabilitation (49.5) in stroke patients[36]. In contrast, in a study determining the effects of a period of BWSTT on gait in subjects with chronic stroke, it has been reported that no significant changes were found in the number of steps (cadence) during the intervention phase which could be due to the time length of post injury[20]. Improvement in cadence of hemiplegic subjects, have been shown to be related to increases in stride length as well as in velocity[11,37,38] It has been reported that walking velocity is a combination of the distance walked and how many steps are taken[37,38]. In the present study, stride length may not contribute to the increase in the gait velocity of the control group, and one must assume that gait velocity was affected primarily by an increase in cadence. Nakamura et al. reported that the relationship between cadence and speed is linear up to a speed of about 0.33 m/s, with further gains primarily attributable to increases in stride length[39]. In addition, it has been discovered that compared with normal subjects, stroke subjects increased walking speed by increasing cadence35,36.

After the 6 consecutive weeks of gait training, when compared between BWSTT and conventional gait training, significant deviations in total support time were reduced by -6.03 ($p<0.033$) and -3.99 % ($p<0.003$) for the paretic and non-paretic side, respectively. BWSTT improved the total support time of subjects with stroke significantly. Riley et al., in their study, argued that the sustention lifted the subjects up and minimized the vertical displacement of the center of gravity, thus reducing the ground contact times of both feet[20]. Treadmill walking training with body weight support increased step length in the BWSTT group significantly with 5.88 cm ($p<0.041$) and 4.72 cm ($p<0.047$) more than in the conventional gait training group for the paretic and non-paretic leg, respectively this might be due to increase knee and hip extension in stance which give advantage for the contralateral extremity to advance the limb forward. These findings were supported by literature studies which reported that step length for the both paretic and non-paretic leg had increased significantly more in the experimental group (4-week treadmill and over-ground walking program) than in the control group (placebo program)[13]. Their post and pretest differences of the step length for the experimental and control groups were 0.10 and 0.01 m, respectively. Also, substantial improvements were reported in step length using BWSTT in a subject with spinal cord injury[13,26]. Both post and pretest differences of the swing phase for the BWSTT and conventional gait training groups for the paretic side were 3.84% and 1.75%, respectively. The corresponding differences for the non-paretic side were 1.88% and 5.16%. Significant improvements of 5.59% (0.043) and 3.28% ($p<0.013$) for swing phase were observed in the experimental group resulting from the use of treadmill training.

BWSTT had significantly increased the single limb support by 2.87 % ($p<0.018$) and 5.63 % ($p<.050$) more than the conventional gait training for the paretic and non-paretic side, respectively, Treadmill training with body weight support in hemiparetic subjects allows them to practice a more favorable gait pattern characterized by a greater stimulus for balance training, because of the prolonged single stance period of the paretic and non-paretic limbs which could be an explanation of this improvement in experimental single limb support[15]. Previous studies reported increased single limb support time on the paretic limb during treadmill walking[24,40]. Increased single limb support time may provide a higher training stimulus for impaired equilibrium reflexes[31]. Reduced single limb support time is a prominent characteristic of hemiparetic gait[16]. Also, Zablotny et al· reported that BWSTT was responsible for improving single limb support[16]. After the 6 weeks of walking training, the BWSTT group had insignificantly decreased its average step width by -2.81 cm more than the conventional gait-training group in the present study. These findings cleared that BWSTT had little positive effect on improving average step width in subjects with stroke. These results were in agreement with those reported by Ada et al who found that step width did not improve, suggesting that there was insufficient focus on balance in training[32]. Although the decrease in the step width was not significant statistically, it still shows a decrease in comparison to the conventional type of training. This explains that the position of the hip provides important sensory information for modulation of stepping in humans[41] In addition, hip extension is a precursor for weight transference onto the contra lateral leg both in gait and balance, which is necessary for movement of the center of gravity in response to or in anticipation of changes in balance requirements, which could give an explanation that the improvement of hip extension affects their balance which is reflected by the decrease in step width.

The improvement in temporal measures may be due to an improvement in proximal control of the lower limb therefore having the ability and confidence to step more rhythmically. Another explanation may be due to the treadmill encouraging a more symmetrical stepping pattern and therefore increasing the loading of the paretic limb during the gait cycle[21,22]. A third possible explanation for the improvement gained in the experimental group in the present study may be related to an increase in the muscular activity in the paretic limb, which has been proven to be important for the power generation needed for walking[39].

FIM™ scores are widely used as a clinical outcome measure, and are part of the routine classification, goal setting, evaluation, and discharge criteria for stroke subjects in different rehabilitation settings[6]. After 6 weeks of walking training, the BWSTT group had significantly improved its FIM™ walking, FIM™ stairs, and FIM™ locomotion by 0.89 score ($p<0.0001$), 0.80 score ($p<0.009$) and 1.69 score ($p<0.001$) more than the conventional training group, respectively. Many researchers confirmed these results. In comparing BWSTT with regular rehabilitation groups of stroke subjects, Filho et al. reported that mean FIM™ scores of both groups improved clinically, however no statistical difference was found between them[6]. Their pre- post intervention FIM™ scores were 3.83 vs. 8.50 for the BWSTT, and 2.83 vs. 8.67 for the regular rehabilitation. In the present study, the difference between the mean post treatment FIM™ locomotion score of the conventional group (2.86) and the mean post treatment FIM™ locomotion score of the BWSTT group (4.55) may have clinical significance. It indicates that the group trained by treadmill has a better ability to negotiate stairs and uneven surfaces, which is one of the important determinants of independence.[34] These results are similar to those reported in a comparison between treadmill training with weight support and conventional therapy, also indicating the contribution of treadmill training to functional gait capabilities[42]. On the other hand, upon comparing body weight support treadmill training with conventional gait training in stroke subjects, it has been reported that both groups had improvements in FIM™ measures, but treadmill training with body weight support conferred no additional benefit compared with conventional training[22]. They also showed that the significant difference in mean age between both groups (treadmill group, 69.4 y vs. conventional group, 62.0 y) may be a contributing factor to these results. Nor did the groups (walking training on a treadmill with body weight support and walking training on the ground) differ with respect to the FIM™ [6]. In addition, using BWSTT in subjects with chronic stroke, Mudge et al. reported that the FIM™ showed a small improvement in the motor score after the intervention[33]. The capacity to perform and sustain ambulatory activities after hemiparetic stroke depends not only on the severity of the neurologic gait deficits but also on the individual's exercise capacity and the relative energy demands of the task. The energy demand of hemiparetic ambulation is more than 1.5 to 2 times that of non-stroke subjects, and stroke subjects have poor exercise capacity, particularly in advancing age. Results of other studies proved that treadmill training improved peak exercise capacity and lower energy demands for subjects with stroke[14,22]. This explains the high FIM™ locomotion score for the experimental group trained with treadmill. Another possible explanation as suggested by previous studies is that walking velocity is the most suitable of the temporal variables for measuring gait performance, and velocity is correlated with other gait measures that support our finding of high FIM™ scores in the BWSTT group16,17.

It is important to highlight from a pure clinical point of view, repetitive practice using conventional gait rehabilitation may teach a compensatory mode of ambulation that may not take advantage of the plasticity of the neuromuscular system[43.] For instance, when using walking aids or assistance from the therapist, due to the lower-limb not having adequate strength to load the body weight in an attempt to walk, attaining hip extension may be compromised due to the forward or sideways flexion of the trunk while weight bearing on the arm. This posture likely attenuates hip extension during stance and reduces lower-limb loading, thereby altering the sensory input that facilitates the swing phase, also negatively affecting the joints kinematics of the lower-limbs and decrease velocity[43].

The role of a physical therapist is to help stroke subjects increase their functional ability.

One tool. Which assists therapists in enabling their subjects to reach this goal, is the use of BWSTT. Once subjects' ambulation improves, independence levels increase leading to positively improved interactions within the community resulting in a better quality of life[44,45]. Therefore, the results of the present study support the increasing clinical interest in using treadmills in stroke rehabilitation. As suggested by treadmill retraining, gait might improve functional mobility and these improvements might be enhanced by the provision of bodyweight support.

Conclusion

The six-week treadmill training with body weight support program proved superior to conventional gait training in sub-acute stroke subjects, resulting in better locomotor abilities and improvement of gait efficiency to the degree of close to normal age –matched subjects.

This type of training is well tolerated by subjects with stroke and is a training strategy that is compatible with rehabilitation practice in a clinical setting.

The responses to training are explainable by the plasticity of the nervous system and its capacity to respond to locomotor-specific afferent input to generate stepping.

This training regimen employs a dynamic and integrative approach for the management of gait dysfunction after stroke. It also provides the individual with opportunities to participate in the community and indirectly reduces the burden on caregivers.

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Tables

Table 1: Measures of the pre-post intervention sagittal kinematics measures of the normal subjects, paretic lower limbs of the control and experimental stroke subjects

Sagittal Kinematics Measures (degree)	Groups	N	Pre Means ± SD	Post Means ± SD	Post-Pre recovery Means ± SD	P value
Pelvis Tilt	Normal	26	10.96b ± 1.73	10.92b ± 1.70		
	Control	21	14.60a ± 3.81	13.40a ± 3.21	-1.20 ± 1.26	0.000****
	Experimental	22	13.57a ± 3.56	11.38b ± 2.25	-2.19 ± 2.22	0.000****
	p-value		0.000****	0.002**	0.081 NS	
Maximum Hip Flexion	Normal	26	33.64a ± 2.46	33.62a ± 2.46		
	Control	21	35.77a ± 6.67	35.15a ± 4.77	-0.62 ± 2.57	0.289 NS
	Experimental	22	30.12b ± 5.91	32.72a ± 3.26	2.60 ± 4.89	0.021*
	p-value		0.003**	0.082 NS	0.011*	
Maximum Hip Extension	Normal	26	-9.90a ± 1.23	-9.91a ± 1.34		
	Control	21	-1.03c ± 6.87	-3.69c ± 5.74	-2.66 ± 3.65	0.003**
	Experimental	22	-4.49b ± 3.90	-7.59b ± 2.22	-3.10 ± 2.25	0.000****
	p-value		0.000****	0.000****	0.633 NS	
Maximum Knee Extension	Normal	26	3.18a ± 1.49	3.17a ± 1.50		
	Control	21	2.82a ± 5.30	3.34a ± 3.29	0.52 ± 2.87	0.418 NS
	Experimental	22	-0.53b ± 4.02	2.21a ± 1.60	2.74 ± 2.81	0.000****
	p-value		0.003**	0.225 NS	0.014*	
Maximum Knee Flexion	Normal	26	60.31a ± 2.21	60.32a ± 2.21		
	Control	21	41.67b ± 11.40	46.29b ± 9.41	4.62 ± 4.22	0.000****
	Experimental	22	32.89c ± 11.62	48.83b ± 9.66	15.94 ± 7.03	0.000****
	p-value		0.000****	0.000****	0.000****	
Maximum Ankle Dorsiflexion	Normal	26	9.62a ± 0.75	9.61a ± 0.76		
	Control	21	4.46b ± 3.46	5.89b ± 2.93	1.43 ± 1.65	0.001***
	Experimental	22	2.73b ± 3.97	6.40b ± 2.45	3.67 ± 2.54	0.000****
	p-value		0.000****	0.000****	0.001***	
Maximum Ankle Plantar flexion	Normal	26	-19.16a ± 1.15	-19.19a ± 1.14		
	Control	21	-9.09b ± 5.87	-10.41b ± 6.42	-1.32 ± 2.43	0.022*
	Experimental	22	-6.93b ± 4.38	-12.13b ± 3.55	-5.20 ± 3.40	0.000****
	p-value		0.000****	0.000****	0.000****	

** p<0.01, **** p<0.0001, (a, b, c) Means have no common letter are significantly different

Table 2 Measures of the pre-post intervention sagittal kinematics measures of the normal subjects, nonparetic lower limbs of the control and experimental stroke subjects

Sagittal Kinematics Measures(degree)	Groups	N	Pre Means ± SD	Post Means ± SD	Post-Prerecovery Means ± SD	P value
Pelvis Tilt	Normal	26	10.96b ± 1.70	10.96b ± 1.71		
	Control	21	13.02a ± 3.36	12.32a ± 2.70	-0.70 ± 1.08	0.008**
	Experimental	22	12.96a ± 3.31	10.83b ± 1.81	-2.13 ± 2.32	0.000****
	p-value		0.022**	0.043*	0.014*	
Maximum Hip Flexion	Normal	26	33.64a ± 2.43	33.62a ± 2.49		
	Control	21	34.57a ± 2.69	34.10a ± 2.32	-0.47 ± 1.33	0.119 NS
	Experimental	22	34.29a ± 2.84	33.10a ± 1.64	-1.19 ± 2.30	0.024*
	p-value		0.493 NS	0.338 NS	0.218 NS	
Maximum Hip Extension	Normal	26	-9.90a ± 1.35	-9.90a ± 1.36		
	Control	21	-9.08a ± 1.98	-9.18a ± 1.99	-0.10 ± 0.34	0.215 NS
	Experimental	22	-9.05a ± 1.35	-9.58a ± 0.81	-0.53 ± 1.16	0.045*
	p-value		0.112 NS	0.262 NS	0.109 NS	
Maximum Knee Extension	Normal	26	3.18b ± 1.33	3.17b ± 1.32		
	Control	21	4.14a ± 1.07	3.97a ± 1.03	-0.17 ± 0.46	0.110 NS
	Experimental	22	3.07b ± 0.76	2.94b ± 0.63	-0.13 ± 0.45	0.201 NS
	p-value		0.005**	0.008**	0.759 NS	

Maximum Knee Flexion	Normal	26	60.31a ± 2.72	60.32a ± 2.75		
	Control	21	58.66a ± 4.23	59.54a ± 3.41	0.88 ± 1.50	0.014*
	Experimental	22	59.26a ± 3.11	60.31a ± 1.66	1.05 ± 3.11	0.016*
	p-value		0.300 NS	0.074NS	0.035*	
Maximum Ankle Dorsi-flexion	Normal	26	9.43a ± 0.70	9.61a ± 0.71		
	Control	21	10.40a ± 1.74	10.15a ± 1.27	-0.25 ± 0.73	0.141 NS
	Experimental	22	9.74a ± 1.47	9.58a ± 1.20	-0.16 ± 0.60	0.210 NS
	p-value		0.052 NS	0.069 NS	0.702 NS	
Maximum Ankle Planter-flexion	Normal	26	-19.16a ± 0.85	-19.19a ± 0.85		
	Control	21	-16.52b ± 3.56	-16.98b ± 3.65	-0.46 ± 1.09	0.069 NS
	Experimental	22	-17.79b ± 2.10	-18.29ab ± 1.47	-0.50 ± 1.31	0.088 NS
	p-value		0.001***	0.004**	0.912 NS	

NS = Not Significant, ** p<0.01, **** p<0.0001, (a, b) Means have no common letter are significantly different

Table 3 Spatial-temporal measures at pre and post intervention of the normal subjects, paretic lower limbs of the control and experimental stroke subjects

Spatial Temporal Measures	Groups	N	Pre Means & (± SD)	Post Means & (± SD)	Post-Prerecovery Means & (± SD)	P value
Velocity/Cycle (cm/s)	Normal	26	69.37a ± 19.37	69.35a ± 19.31		
	Control	21	23.67b ± 9.09	28.80b ± 10.53	5.13 ± 4.03	0.000****
	Experimental	22	22.54b ± 10.26	38.10b ± 17.78	15.56 ± 12.36	0.000****
	p-value		0.000****	0.000****	0.001***	
Stride Length (cm)	Normal	26	99.1a ± 18.22	97.5a ± 18.48		
	Control	21	43.80b ± 12.00	48.28c ± 14.54	4.48 ± 8.00	0.019*
	Experimental	22	42.80b ± 13.82	62.43b ± 14.58	19.63 ± 11.69	0.000****
	p-value		0.000****	0.000****	0.000****	
Total Support Time (%)	Normal	26	64.23b ± 5.15	64.10c ± 5.15		
	Control	21	70.96a ± 11.27	73.12a ± 6.21	2.16 ± 10.85	0.372 NS
	Experimental	22	73.20a ± 7.28	69.33b ± 6.81	-3.87 ± 6.64	0.012*
	p-value		0.001***	0.000****	0.033*	
Step Length (cm)	Normal	26	49.90a ± 8.79	49.80a ± 8.76		
	Control	21	24.45b ± 9.88	25.30c ± 11.19	0.85 ± 7.32	0.602 NS
	Experimental	22	26.49b ± 9.26	33.22b ± 9.17	6.73 ± 12.64	0.021*
	p-value		0.000****	0.000****	0.041*	
Cadence/cycle (steps/min)	Normal	26	83.62a ± 13.63	83.70a ± 13.79		
	Control	21	64.45b ± 16.90	69.61b ± 14.05	5.16 ± 6.78	0.002**
	Experimental	22	60.50b ± 18.21	72.37ab ± 29.66	11.87 ± 24.37	0.033*
	p-value		0.000****	0.048*	0.230 NS	
Swing Phase/cycle (%)	Normal	26	35.74a ± 5.16	36.00a ± 5.49		
	Control	21	29.70b ± 11.27	30.05b ± 6.35	0.75 ± 11.00	0.473 NS
	Experimental	22	27.14b ± 7.55	30.98b ± 7.07	3.84 ± 7.78	0.031*
	p-value		0.001***	0.000****	0.043*	
Single Limb Support (%)	Normal	26	35.70a ± 5.27	36.10a ± 5.69		
	Control	21	21.32b ± 5.85	23.23b ± 6.48	1.91 ± 2.50	0.002**
	Experimental	22	20.73b ± 6.73	25.51b ± 7.04	4.78 ± 4.75	0.000****
	p-value		0.000****	0.000****	0.018*	
Average Step Width (cm)	Normal	26	14.97a ± 4.12	14.96a ± 4.24		
	Control	21	16.16a ± 6.42	17.66a ± 6.67	1.50 ± 4.79	0.165 NS
	Experimental	22	16.93a ± 4.13	15.62a ± 4.28	-1.31 ± 4.36	0.174 NS
	p-value		0.38 NS	0.190 NS	0.051 NS	

NS = Not Significant, * p<0.05, *** p<0.001, **** p<0.0001, (a, b) Means have no common letter are Significantly different

Table 4: Pre-post intervention spatial temporal measures of the normal subjects, non-paretic lower limbs of the control and experimental stroke subjects

Spatial Temporal Measures	*a) Groups*	N	Pre Means & (± SD)	Post Means & (± SD)	Post-Pre-recovery Means & (± SD)	P value
Velocity/Cycle (cm/s)	Normal	26	69.37a ± 20.64	69.35a ± 20.63		
	Control	21	23.96b ± 8.69	28.68b ± 10.93	4.72 ± 4.36	0.000****
	Experimental	22	23.05b ± 10.82	35.64b ± 15.10	12.59± 9.52	0.000****
	p-value		0.000****	0.000****	0.001***	
Stride Length (cm)	Normal	26	99.10a ± 18.00	97.50a ± 18.01		
	Control	21	46.01b ± 12.59	50.37c ± 14.97	4.36± 6.52	0.006**
	Experimental	22	46.26b ± 12.58	61.95b ± 16.12	15.69 ± 15.65	0.000****
	p-value		0.000****	0.000****	0.004**	
Total Support Time (%)	Normal	26	64.20b ± 5.26	64.10b ± 5.34		
	Control	21	78.36a ± 6.11	76.76a ± 6.48	-1.60 ± 3.08	0.027*
	Experimental	22	79.53a ± 6.75	73.94a ± 6.70	-5.59 ± 5.03	0.000****
	p-value		0.000****	0.000****	0.003**	
Step Length (cm)	Normal	26	49.90a ± 10.51	49.80a ± 10.75		
	Control	21	21.43b ± 8.88	24.29b ± 7.51	2.86 ± 8.16	0.124 NS
	Experimental	22	21.85b ± 8.19	29.43b ± 8.23	7.58 ± 6.91	0.000****
	p-value		0.000****	0.000****	0.047*	
Cadence/cycle (steps/min)	Normal	26	83.62a ± 12.90	83.70a ± 13.33		
	Control	21	63.37b ± 14.21	68.05b ± 10.02	4.68 ± 7.76	0.012*
	Experimental	22	59.53b ± 18.26	71.88ab ± 31.65	12.35 ± 26.28	0.039*
	p-value		0.000****	0.031*	0.206 NS	
Swing Phase/cycle (%)	Normal	26	35.74a ± 5.27	36.00a ± 5.69		
	Control	21	21.35b ± 5.86	23.23b ± 6.48	1.88 ± 2.49	0.002**
	Experimental	22	20.73b ± 6.73	25.89b ± 6.59	5.16 ± 5.23	0.000****
	p-value		0.000****	0.000****	0.013*	
Single Limb Support (%)	Normal	26	35.70a ± 5.16	36.10a ± 5.49		
	Control	21	29.03b ± 11.27	27.18c ± 6.17	-1.85 ± 10.89	0.445 NS
	Experimental	22	27.17b ± 7.53	30.95b ± 7.07	3.78 ± 7.72	0.032*
	p-value		0.001***	0.000****	0.050*	
Average Step Width (cm)	Normal	26	14.97a ± 4.12	14.96a ± 4.24		
	Control	21	16.16a ± 6.42	17.66a ± 6.67	1.50 ± 4.79	0.165 NS
	Experimental	22	16.93a ± 4.13	15.62a ± 4.28	-1.31 ± 4.36	0.174 NS
	p-value		0.0380 NS	0.190 NS	0.051 NS	

NS = Not Significant, *** p<0.001, **** p<0.0001, (a, b) Means have no common letter are significantly different

Table 5: Pre and post intervention FIM™ locomotion measures of the control and experimental groups along with a significant test

FIM™ Locomotion Measures (Score)	Group	N	Pre Means & (± SD)	Post Means & (± SD)	Post-Pre change Means & (± SD)	P value
FIM™ Walking	Control	21	3.52 ± 0.60	4.95 ± 1.02	1.43 ± 0.68	0.000****
	Experimental	22	3.45 ± 0.59	5.77 ± .75	2.32 ± 0.77	0.000****
	p-value		0.706 NS	0.005**	0.000****	
FIM™ Stairs	Control	21	2.95 ± 0.92	4.38 ± 1.32	1.43 ± 0.74	0.000****
	Experimental	22	2.95 ± 0.89	5.18 ± 0.90	2.23 ± 1.10	0.000****
	p-value		0.994 NS	0.025*	0.009**	
FIM™ locomotion	Control	21	6.47 ± 1.47	9.33 ± 2.28	2.86 ± 1.31	0.000****
	Experimental	22	6.40 ± 1.43	10.95 ± 1.58	4.55 ± 1.73	0.000****
	p-value		0.880 NS	0.010**	0.001***	

NS = Not Significant, * p<0.05, ** p<0.01

Figures and figure legends

Figure 1: The body weight support treadmill training (BWSTT) used in this study

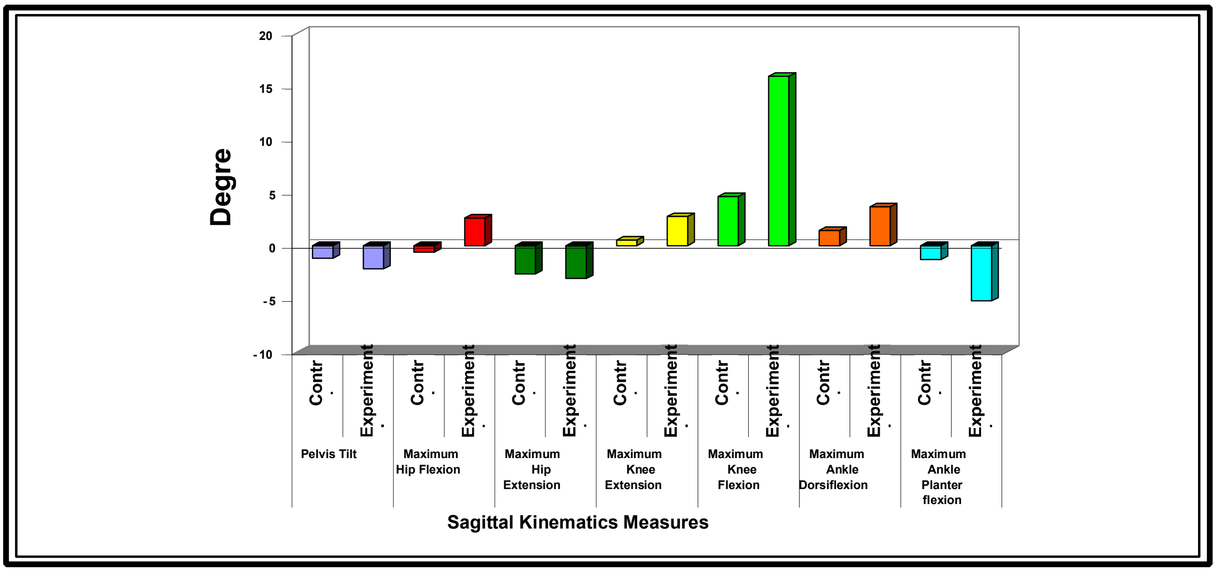
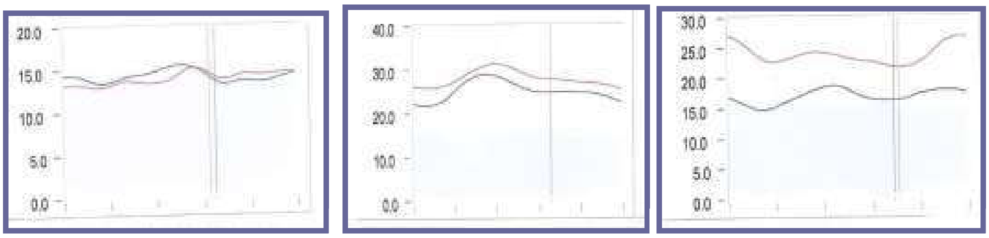
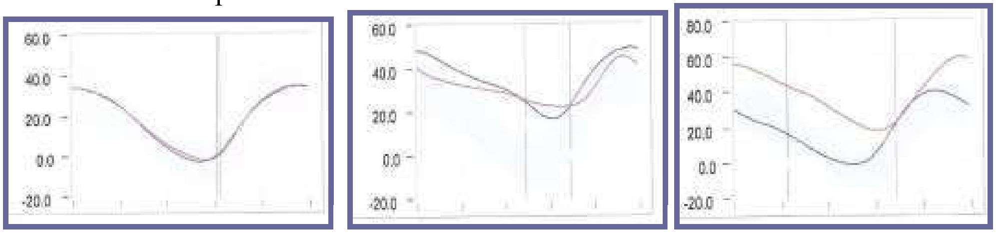


Figure 2: Post- pre-recovery of sagittal kinematics measures of the paretic control and experimental lower limbs

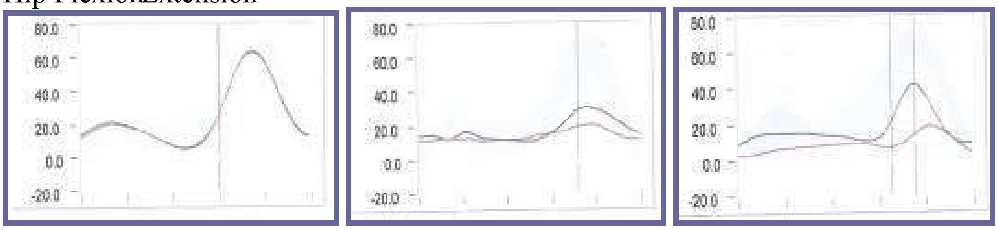
<u>A</u> <u>B</u> <u>C</u>



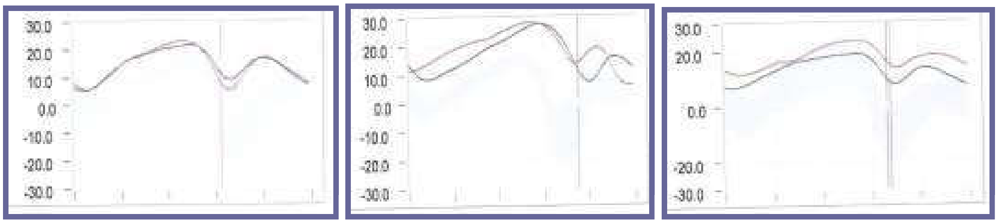
Anterior-Posterior pelvic Tilt



Hip Flexion-Extension



Knee Flexion-Extension



Ankle Dorsiflexion-PlantarFlexion

———— Pre-intervention assessment ———— Post intervention assessment

Figure 3 Sagittal Kinematics motion (degree) of the A. 1st and 2nd walking test for the normal subject, B. Pre-post intervention assessment for the paretic lower limb of control stroke subject and, C. Pre-post intervention assessment for the paretic lower limb of experimental stroke subject.

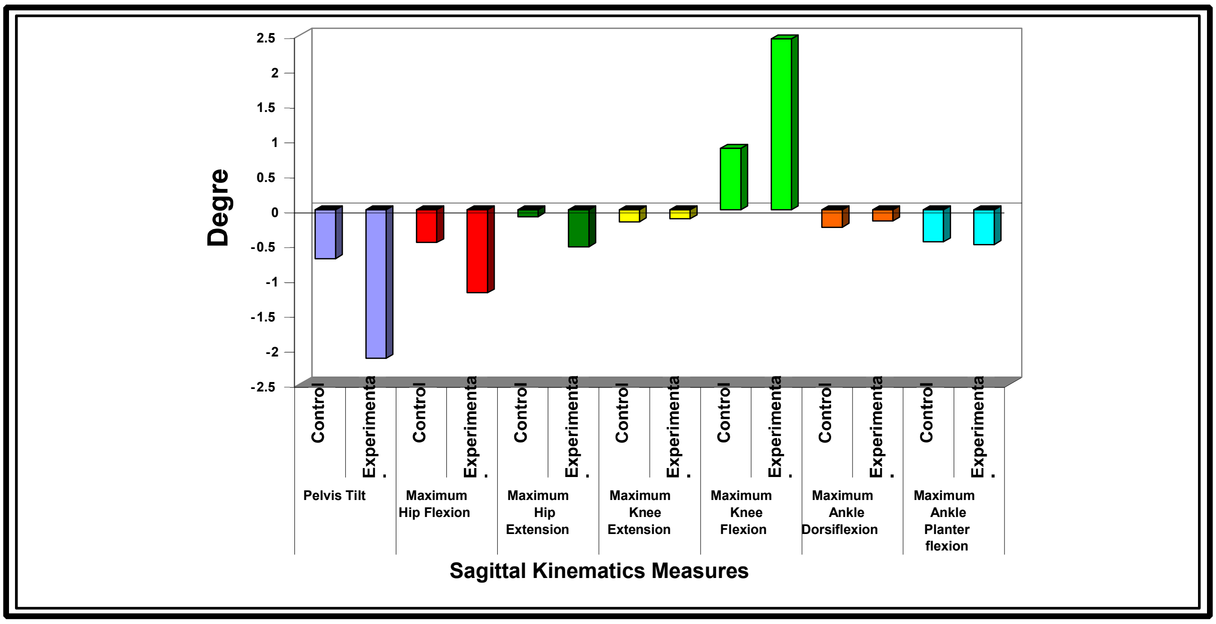
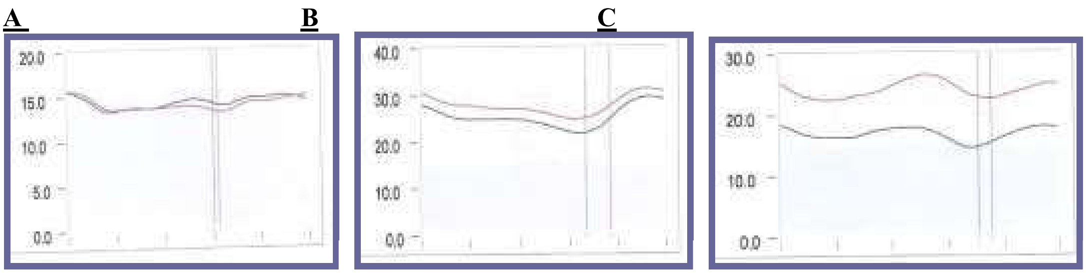
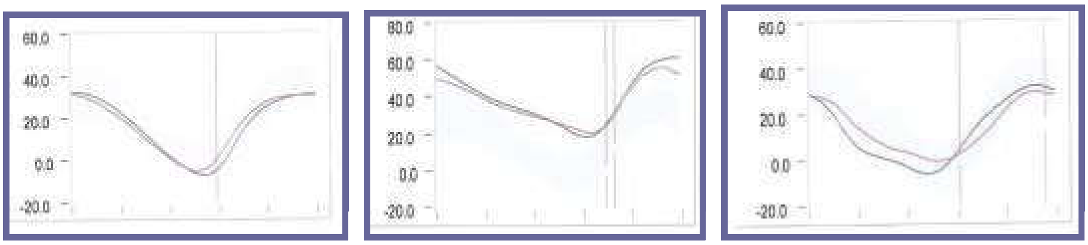


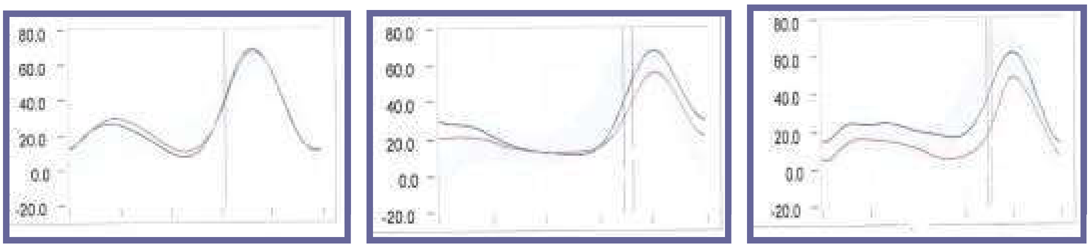
Figure 4: Post- pre-recovery of sagittal kinematics measures of the non-paretic control and experimental lower limbs



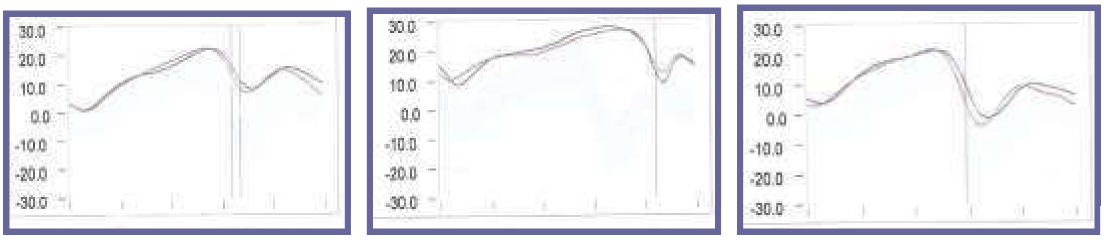
Anterior-Posterior pelvic Tilt



Hip Flexion-Extension



Knee Flexion-Extension



Ankle Dorsiflexion-Plantar flexion ———— Pre-intervention assessment ———— Post intervention assessment

Figure 5 Sagittal Kinematics motion (degree) of the A. 1st and 2nd walking test for the normal subject, B. pre-post Intervention assessment for the non- paretic lower limb of control stroke subject and C. pre-post intervention assessment for the non-paretic lower limb of
Experimental stroke subject

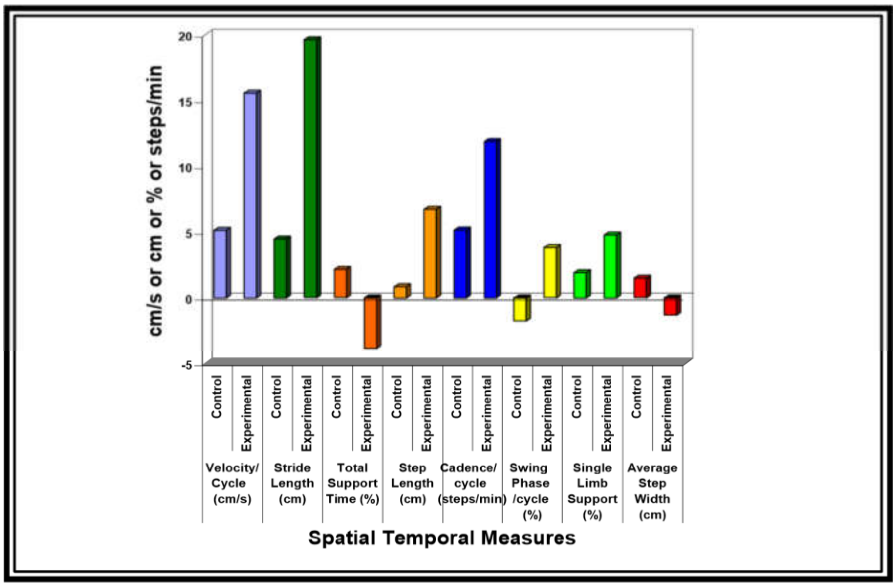


Figure 6: Post- pre-intervention recoveries of spatial temporal measures of the paretic lower limbs of the control and experimental stroke subjects

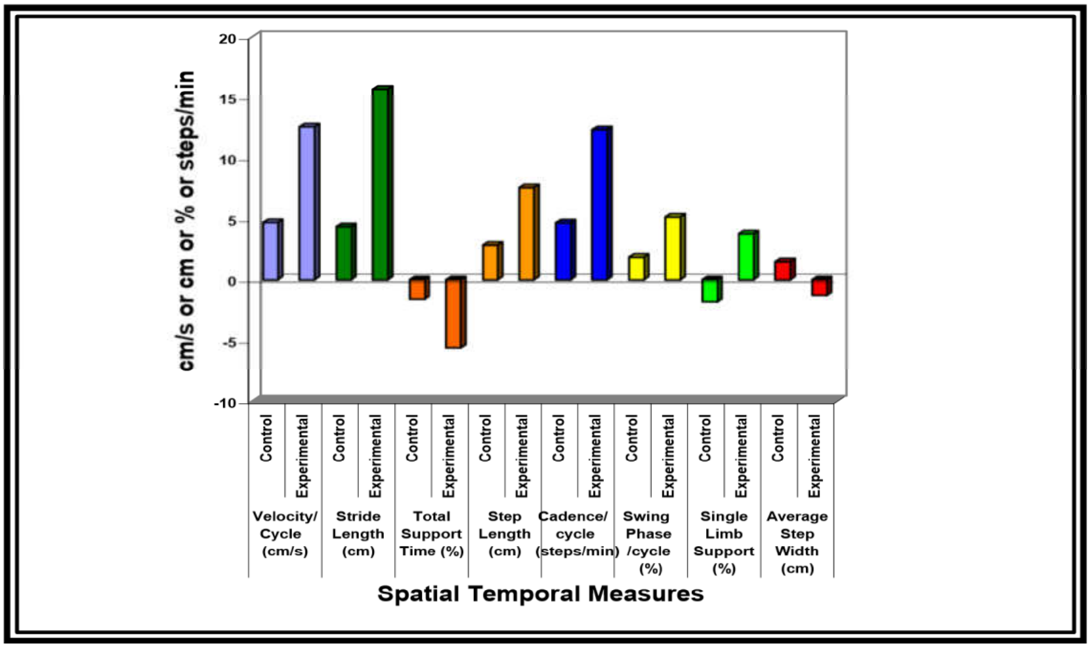


Figure 7: Post- pre-intervention recoveries of spatial temporal measures of the non-paretic lower limb for control and experimental groups

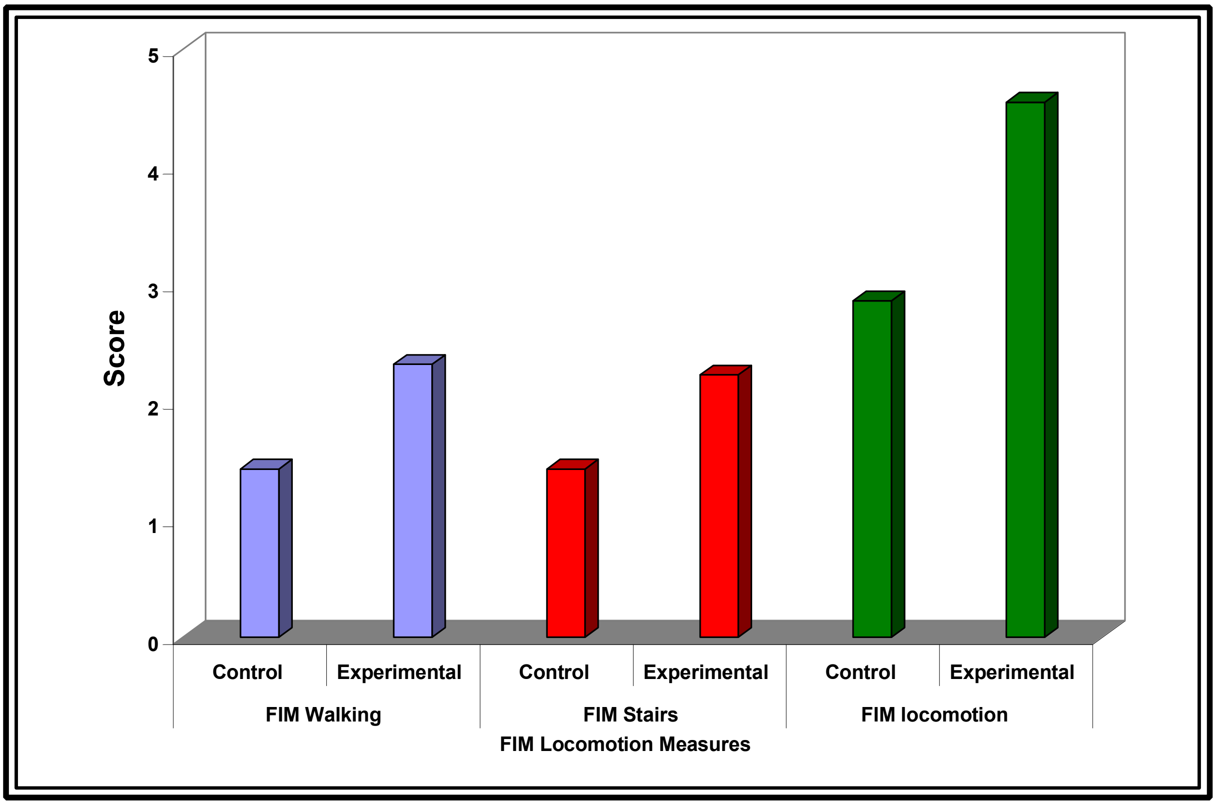


Figure 8: Post- pre-intervention recovery of FIM™ locomotion measures for the control and experimental groups