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Supervised Walking Exercise Therapy Improves Gait Biomechanics in Patients with Peripheral Artery Disease

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Abstract

Objective—In patients with peripheral artery disease (PAD) supervised exercise therapy is a first line of treatment as it increases maximum walking distances comparable to surgical revascularization therapy. Little is known regarding gait biomechanics following supervised exercise therapy. This study characterized the effects of supervised exercise therapy on gait biomechanics and walking distances in claudicating patients with peripheral artery disease.

Methods—Forty-seven claudicating patients with PAD underwent gait analysis before and immediately following 6 months of supervised exercise therapy. Exercise sessions consisted of a 5 min warmup of mild walking and stretching of upper and lower leg muscles, 50 min of intermittent treadmill walking, and 5 min cooldown (similar to warmup) 3 times per week. Measurements included self-perceived ambulatory limitations measured by questionnaire, ankle-brachial index, walking distance measures, maximal plantarflexor strength measured by isometric dynamometry, and overground gait biomechanics trials performed prior to and after the onset of claudication pain. Paired t-tests were used to test for differences in quality of life, walking distances, ankle-brachial index, and maximal strength. A two factor repeated measures ANOVA determined differences for intervention and condition for gait biomechanics dependent variables.

Results—Following supervised exercise therapy, quality of life, walking distances, and maximal plantar flexor strength improved, while ankle brachial index did not significantly change. Several gait biomechanics parameters improved following intervention including torque and power generation at the ankle and hip. Similar to previous studies the onset of claudication pain led to a worsening gait, or gait that was less like healthy individuals compared with pain free gait.

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Conclusions—Six months of supervised exercise therapy produced increases in walking distances and quality of life that are consistent with concurrent improvements in muscle strength and gait biomechanics. These improvements occurred even though ankle brachial index did not improve. Future work should examine the benefits of supervised exercise therapy used in combination with other available treatments for peripheral artery disease.

Table of Contents Summary

Supervised exercise therapy significantly improved self-perceived ambulatory limitation, walking distances, leg muscle strength, and gait biomechanics in 47 claudicating patients with peripheral artery disease. The authors suggest walking performance and muscle strength can be improved even if blood flow does not change.

Keywords

claudication; walking performance; vascular disease; arterial disease; joint kinetics

I. Introduction

Peripheral artery disease (PAD) is associated with an altered gait profile that is present from the first step, before the onset of claudication pain. The altered gait profile found in patients with PAD presents as decreased muscle power contributions at the ankle, knee, and hip joints with marked weakness of the posterior compartment muscles of the hip and calf [1–7].

Supervised walking exercise therapy (SET) has been shown to significantly increase "pain-free" walking time [8–16], and improve quality of life [9,14,16,17]. SET achieves the best results when the program lasts four months or longer with three sessions per week, lasting 30 minutes or more, at an intensity leading each patient to walk until near maximal pain [8–16]. SET has been found to achieve greater early functional status improvement for claudicating patients with aortoiliac disease compared with surgery and increases in maximum walking distances equal to or better than surgical revascularization, despite the fact that arterial insufficiency remains [17].

Gait impairment at baseline confirms mechanisms other than ischemia contribute to limb dysfunction in PAD. An improved understanding of how muscular strength and gait mechanics contribute to increased walking distances following SET can provide insight into why the SET intervention is effective. We hypothesized that SET for claudicating patients with PAD improves walking distances and quality of life in association with improved plantar flexor strength and gait biomechanics.

II. Methods

The institutional review boards at Nebraska Western Iowa Veteran Affairs Medical Center and University of Nebraska Medical Center approved the study. All patients provided informed consent prior to study participation.

Participant inclusion and exclusion criteria

Patients with a positive history of exercise-limiting, chronic claudication were recruited from the vascular surgery clinics of the aforementioned institutions (Table I). The study screened patients for ambulation limiting cardiac, pulmonary, neuromuscular, or musculoskeletal disease to ensure patients whose walking was limited by reasons other than claudication were not included in the study. All patients had no previous history of revascularization and had Fontaine Stage II in the leg used for analysis (37 Bilateral Fontaine Stage II, 10 Unilateral). Patient evaluation included resting ankle-brachial index (ABI; value <0.9), detailed history, physical examination, and direct assessment and observation of the patients walking impairment by a vascular surgeon.

Exercise Protocol

Patients participated in a 6 month, 3 times per week (72 session), SET program that followed the American College of Sports Medicine recommendations in concordance with previous studies that best produced increases in walking distances[10,18]. The program was conducted at the Center of Cardiovascular Disease Prevention and Rehabilitation of Creighton University Medical Center or associated Rehabilitation centers of Nebraska and Western Iowa under a unified protocol. Each session included a 5-minute warm-up of mild walking and static stretching of upper and lower body muscles, 50 minutes of intermittent exercise on a treadmill, and 5 minutes of cool down activities similar to the warm-up. Exercise was initiated at a workload of 2 mph, or lower if desired by the patient, and 0% grade. Subjects walked until claudication pain reached a moderate/severe level and then rested until claudication pain subsided, at which point they would walk again, up to 50 minutes. The SET program progressed after a patient could walk 8–10 continuous minutes at the initial workload (2mph, 0% grade) by increasing the grade 1–2% or the speed by 0.5mph as tolerated.

Experimental Procedure and Data Collection

Patients were evaluated at the Biomechanics Research Building at the University of Nebraska at Omaha. The evaluations were performed before and after participation in SET. The patients completed tests in the following order 1) the walking impairment questionnaire and the timed up and go test, 2) graded treadmill test [19], 3) pain free overground walking trials, 4) six minute walk test [20], 5) pain induced overground walking trials, and 6) maximal isometric strength testing. During the overground walking trials, kinematics and kinetics were recorded as previously described [2,21] using a 12 high-speed infrared camera system (60 Hz, Motion Analysis Corp, Santa Rosa, Calif), and force platforms (600 Hz; AMTI). Each patient walked across a 10 meter pathway containing a force platform set level with the floor. Patients walked at a self-selected pace before (pain free) and after (pain) the onset of claudication pain. A mandatory rest of at least one minute was required between each pain-free walking trial to prevent the onset of claudication. Symptomatic claudication pain was induced by completing the six-minute walk test between pain free and pain induced trials. Once pain was induced patients immediately returned to the 10 meter pathway to perform the additional walking trials for the pain condition, with no rest given between trials. All patients experienced a "moderate to severe level of pain" in the leg used for analysis (more affected in bilateral claudicants; affected in unilateral claudicants) Five separate passes over the force platform per condition were collected for analysis.

Measurements

Questionnaire—The Walking Impairment Questionnaire (WIQ) is a measure of ambulatory limitation, measured by questionnaire that defines and detects changes in claudication symptoms over four sub-scores: pain, distance, speed, and stair climbing. Each question ranges in difficulty from 0 to 100, with 0 representing the most severe symptoms [22,23].

Walking distance measures—Patients performed a standardized graded treadmill test; a protocol speed of 0.89 m/s (2.0mph) that begins at 0% grade, and increases by 2% grade every two minutes [19]. Initial claudication distance was recorded as the first indication of claudication pain from the patient, and the total distance the patients were able to walk before stopping because of pain was recorded as the absolute claudication distance. For the six-minute walk test, two cones were placed 50 feet apart in the gait analysis laboratory. Patients were instructed to cover as much distance as possible during six minutes; initial claudication distance and total distance walked were recorded [20]. The Timed Up and Go test was performed as a measure of function as it has been associated previously with balance and fall risk. Patients began seated in an armed chair and were instructed to stand up, walk until both feet crossed a piece of tape (3m away), turn around, walk back and sit down [24].

Ankle brachial index (ABI)—The highest ABI value obtained during the patient’s clinical evaluation was reported as the pre-SET value for the leg used in analysis. The post-SET ABI values reported are from the same leg as in the baseline evaluation and obtained in the patient’s clinical post-evaluation.

Maximal Strength—A ten second, isometric strength measurement of the ankle plantar flexors was performed in a pain-free condition as previously described [7]. Area under the curve, which is representative of work performed, and peak torque / body weight were obtained from the resultant torque curves.

Biomechanics—Joint kinetics and kinematics were calculated for the sagittal plane during the stance phase of walking (from heel contact to toe off) from the overground walking trials. The stance phase was divided into the weight acceptance, single leg support, and propulsion phases of stance. Ground reaction forces and joint angles, torques, and powers for the ankle, knee and hip were analyzed using custom MATLAB (Mathworks, Inc., Natick, MA) and Visual 3D (C-Motion, Inc., Germantown, MD) software for the pain free and pain conditions of patients with PAD before and after the SET.

The dependent variables for joint angles calculated include the maximum and the minimum of each joint’s flexion and extension angles. Ankle plantarflexion, knee flexion, and hip flexion occur during the weight acceptance phase of stance. Maximum knee extension takes place during single support phase of stance, and ankle dorsiflexion and hip extension occur during the propulsion phase of stance.

Joint torque is the net result of all forces acting around a joint. The peak values for extensor and flexor torques were identified for the ankle, knee, and hip joints. Ankle dorsiflexor torque, knee flexor torque, and hip flexor torque were identified in weight acceptance. Ankle plantarflexor torque, knee extensor torque, and hip extensor torque were identified in the propulsion phase of stance.

A joint power is the product of the angular velocity and the net torque across a joint. It is the rate of work produced by contracting to move or stabilize a joint. Peak values were identified at the ankle, knee, and hip joints. In the weight acceptance phase power absorption at the ankle and knee and generation at the hip were measured. In single support of stance power absorption at the ankle and hip were assessed and power generation at the knee. Power generation at the ankle and hip, and absorption at the knee were measured in propulsion.

A ground reaction force represents the force exerted on the ground by the subject’s weight-bearing limb to which the ground exerts an equal and opposite force. The force is extracted into three orthogonal components (anterior-posterior, medial-lateral, and vertical). The magnitude and direction of the forces were collected using AMTI force platforms sampling at 600 Hz. Peak force values occurring in the weight acceptance phase include the impact of vertical force, braking force, braking impulse, and lateral force. Vertical force at midstance and medial force peaks occur during single support. The propulsion phase of stance includes peak push-off vertical force, propulsive force, and propulsive impulse discrete points.

Statistical Analysis—Data was summarized in group means and standard deviations for all variables. One leg, the more symptomatic for each patient, was used for analysis. Paired t-tests were used to detect the effects of the SET on the questionnaire, walking distances, ABI, and maximal strength dependent variables. A two factor, intervention (pre/post SET) and condition (pain free/pain), repeated measures ANOVA was used for all biomechanics dependent variables ($p<0.05$; SPSS version 22 software, IBM, Armonk, NY).

III. Results

Subjects

In forty-seven patients with PAD, body mass and ABI did not significantly change between pre and post SET evaluations (Table II). While the ABI decreased 7.1%, this was not significant (p=.078).

Questionnaire

Three of the four subcategories of the WIQ (pain (20.3%, p=.008), distance (26.7%, p=.043), and stair climbing (20.5%, p=.045)) showed significant increases after SET. Increased scores on the WIQ correspond to the patient indicating less difficulty walking due to pain, the perception that they walk farther and are able to climb more flights of stairs on average following SET (Table II).

Walking distances

Both initial (175.9%, p<.001) and absolute (110.6%, p<.001) claudication distances on the standardized treadmill test significantly increased following SET (Table II). For the six minute walk test, initial claudication distance (63.1%, p=.046) improved but absolute claudication distance was not significantly improved (−2.1%, p=.700; Table III). No effects were observed for timed up and go (Table II).

The increases in the initial claudication time results were consistent for the treadmill and the six minute walk test. However because of the differences between the two walking tests, including the ability to rest and select speed in the six minute test, the total distance walked (six minute walk test) and the absolute claudication time (graded treadmill test) were not consistent. To investigate why the total distance achieved during the six minute walk test did not improve, we calculated the number of patients who stopped, the duration of each stop, and the average speed walked during the six minutes (Table III). Average speed during the six minute walk test was an estimate of overall speed as it did not account for the turn distance. Distance achieved was divided by the time each patient walked less time spent for a stop. The duration of average stop time increased and so did the number of subjects who stopped (non-significant) post SET. Only forty patients were included in this analysis because six subjects completed their 6MWT and reported that they did not experience claudication pain following SET.

Maximal isometric strength

Area under the curve (12.5%, p=.012) and peak torque/body weight (10.5%, p=.007) significantly increased following SET. This indicated SET increased the capability of the ankle plantarflexors to produce work and generate maximal force during an isometric contraction (Table II).

Biomechanics, Intervention Factor

Weight acceptance—Patients significantly increased hip extensor torque (17.6%, p=.012) and peak lateral force generation (11.4%, p=.021) during the weight acceptance phase of stance following SET (Table IV).

Single-limb support—The increase in peak lateral force during weight acceptance resulted in a significant increase in ankle power absorption (7.5%, p=.023) during single-limb support following SET. There were no other changes after SET for the single limb support (Table V).

Propulsion—Patients significantly increased power generation at the ankle (14.5%, p=.003) and hip (14.3%, p=.003) during the propulsion phase of gait (Table VI) and these improvements translated to a significant increase in peak propulsive force (12.1%, p=.006). Therefore, following SET, patients were better able to propel themselves forward during terminal stance.

Biomechanics, Condition Factor

Early Stance—A significant effect of condition was found for ankle angle (−8.3%, p<.001) and torque (−7.8%, p-.023), knee angle (−27.0%, p=.030), and hip angle (−25.0%, p>.001). At the ankle, the dorsiflexion angle increased and torque decreased in magnitude during pain conditions. Both knee and hip extension angles decreased in magnitude during pain. Main effects were also observed for peak forces in the braking impulse (−3.2%, p=.041) and lateral force (−8.8%, p<.001), which decreased and increased in magnitude during pain, respectively.

Mid-stance—A main effect was found for ankle power absorption (−7.5%, p<.001), where absorption at the ankle increased when patients were in the pain condition.

Late Stance—Main effects at the ankle included plantarflexion angle (−10.5%, p<.001), plantarflexor torque (−6.3%, p<.001), and power generation (−12.2%, p<.001), knee power absorption (−9.1%, p=.017), hip extensor torque (−4.4%, p=.046) and power generation (−5.2%, p=.039), and peak push-off vertical force (−2.4%, p<.001) and propulsive force (−5.6%, p=.002). Ankle plantar flexion angle increased during pain conditions while all other effects decreased in magnitude during pain.

IV. Discussion

This study characterized and provided an in depth look at limb function in patients with intermittent claudication before and six months following participation in SET as a first line of treatment, before and after the onset of claudication. This study also evaluated whether gait parameters improved in conjunction with questionnaire results, walking distances, ABI, and ankle strength following the intervention. Other studies have utilized either joint kinematics alone [25], or kinematics and partial peak forces [26]. The current study provided a more comprehensive functional evaluation of the effects of a standardized SET to increase walking distances in patients with PAD. It also included evaluation of the primary deficits previously identified as key factors underlying the gait adaptions in claudicating patients with PAD [2–7,27].

Effect of intervention

Our hypothesis was partially supported; weakness in the posterior calf muscles was a consistent and key factor underlying the gait abnormalities patients with PAD experienced prior to pain onset. Improvements in isometric plantarflexion strength and ankle power during the single support and propulsion phases of gait before and after the onset of claudication pain reflected important improvements. Our data also demonstrated significant improvements in absolute walking distances, pain-free walking time, and questionnaire-based assessment of claudication symptoms which are in agreement and consistent with preexisting literature in terms of percentage improvements [8–12,14,16,17,28–30].

Weight acceptance—Prior to therapy, patients with PAD demonstrated a decreased ability of the hip and knee extensors to perform during weight acceptance and to control forward momentum compared to healthy controls. Our findings in patients with PAD following SET demonstrated increased torque development by the hip extensors. These changes represented an improvement in gait following SET, or gait pattern in PAD more similar to gait of healthy subjects [2,4,27].At the ankle during weight acceptance, the dorsiflexors eccentrically control the movement of the foot until it makes complete contact with the ground. Immediately after heel strike and during the downward movement of the foot is when a brief (2–8%) lateral ground reaction force is produced, and is thought to be directed by the gluteus maximus, adductors of the thigh, and vasti muscles [31]. Patients with PAD demonstrate a foot-drop, or impaired control of the downward motion of the foot following heel strike [3]. Although no improvements were found at the level of the ankle dorsiflexors in this study, an increased lateral ground reaction force following SET was found. This reflected improved synchronization of the ipsilateral adductors at heel strike to accept weight transfer from the contralateral leg, and to permit greater control in the upcoming phases of stance. Previously we found this force to be decreased as a pre-compensatory step to increased medial force (greater than healthy controls), to allow for a wider step and decreased single limb support time [4]. Although the change in lateral ground reaction force is minimal it appears SET may have promoted better coordination and reduced a common compensatory action in patients with PAD.

Single-leg Support—Our data demonstrated an increase in ankle power absorption, which indicated improved energy delivery to the leg and trunk by the plantarflexors during this phase of stance. We have not previously identified this variable to be different from healthy controls at baseline. This adaptation following SET could be the result of increased muscle capacity and ability to utilize the energy generated during this phase.

Propulsion—Our data demonstrated significant improvements in ankle and hip power generation that translated to increased propulsive ground reaction force. More specifically, the plantarflexors improved their contribution to forward progression and support as did the hip flexors in their assistive role in forward trunk acceleration.

Effect of condition: The onset of claudication affected biomechanics throughout stance prior to and following SET. These differences corresponded to a worsening gait, or gait pattern that moved further from healthy individuals compared with pain free gait [2,4,5]. In single-leg support, ankle power absorption increased in magnitude during claudication. In propulsion, ankle plantarflexor angle increased, while torque and power decreased. Knee flexor power decreased, and hip flexor moment and power decreased. The peak propulsive and vertical push-off forces also decreased. Overall, the propulsion phase continued to be the most affected by the onset of claudication, which could be due to purposeful adjustments by the patient to minimize use of and pain felt in the more symptomatic limb.

Improvements in walking distances but not hemodynamics: Significant improvements in initial and absolute claudication distances were observed on the graded treadmill protocol following SET. Parallel improvements were not observed in maximum overground walking distances, measured by the six minute walk test, or in resting ABI measurements. The improvements in treadmill distances and lack thereof in resting ABI are in agreement with previous literature[32]. Average ABI values decreased numerically from 0.56 to 0.52 following

SET, which was not significant. Many previous SET studies do not report post SET ABI[33]. One systematic review of randomized controlled trials evaluating the evidence for the effect of exercise on lower limb hemodynamic measures report no significant change in the resting ABI after SET in 28 of 29 trials. Our study was not designed or powered to explore a potential change in the resting ABI but other studies evaluating the natural progression of ABIs amongst patients with PAD report a decrease of .004 to .02/year as the expected average change[35–37]. In these studies, degree of progressive decrease in ABI is found to be associated with current smoking status, requirement for an intervention, older age, diabetes, and severity of presenting symptoms. The SET protocol was similar to the maximal treadmill test performed and may help explain why improvements in six minute walk distance did not occur. Significant discussion exists in the literature regarding the pros and cons of each type of maximum walking test, and this study further illustrates the points that each test assesses slightly different outcomes (peak versus daily living walking performance).

Our analysis of the findings of the six minute walk test and graded treadmill test suggested that SET improved pain tolerance and walking endurance but it did not improve self-selected average walking speed. The increased pain tolerance was seen in increased claudication onset time during both six minute walk (self-paced) and the graded treadmill test (controlled-intensity) and the higher score for the Pain category of the WIQ. Improvement in endurance was demonstrated by increased peak walking time during the graded treadmill test, improved ankle and hip power generation during propulsion, improved peak torque and total work during maximum plantarflexion strength testing, and the higher scores for WIQ distance. Our analysis of average walking speed during the six minute walk test demonstrated that SET did not produce a change in the self-selected speed of our patients. It is possible that if the instructions on the six minute walk test asked patients to maintain speed and not to stop (similar to inherent demands of the graded treadmill test, which controls the intensity), total walking distance would increase in a way that is parallel to that see with the graded treadmill test. Instead, the patients seemed to adapt by slowing down and/or resting, which was likely an attempt to avoid or decrease pain.

A limitation of this study is the modest sample size and additional subjects could strengthen our findings. Our data, however show that SET produces partial restoration of the impaired limb function of patients with PAD despite fixed arterial occlusive disease. The biological pathways by which exercise improves walking performance, were not evaluated by the present work, and their examination has been proposed as a top priority in a recent scientific statement from the American Heart Association under the discussion on the future of investigations of exercise intervention in patients with PAD[38].

Overall, the biomechanical improvements found during weight acceptance and propulsion were in line with the increased walking distances. Specifically, increased activation of the hip extensors helped maintain momentum and walking speed after heel strike. In particular, greater activation of the ankle during propulsion, led to a more efficient gait post SET. Overall these improvements translated to an increased capacity on the graded treadmill test. These increases were not seen on the six minute walk (self-paced) test, which means that subjects may have had a greater maximal capacity due to SET, but lingering impairments in blood flow delivery and the structure and function of leg muscles led subjects to choose to walk slower and/or rest during the self-paced test.

V. Conclusion

Six months of SET produced significant increases in the treadmill walking distances of patients with claudication. These increases were consistent with concurrent improvements in gait biomechanics at the level of the ankle and the hip. SET produced strengthening of the hip extensor and the ankle plantarflexor muscles and this strengthening appears to be the main mechanism producing the improvements of the walking ability of patients with claudication.

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ARTICLE HIGHLIGHTS

Type of Research

Single-site, prospective non-randomized cohort.

Key Findings

Six months of supervised exercise therapy significantly improved self-perceived ambulatory limitation, walking distances, leg muscle strength, and gait biomechanics in 47 patients with peripheral artery disease.

Take home Message

Supervised exercise therapy concurrently increased walking performance and muscle strength even though blood flow did not change. Supervised exercise therapy may be beneficial if used in combination with therapies that increase blood flow.

Table I.

Sample demographics.

Clinical Characteristic	
Gender (Male)	97.8
Race	
Caucasian	78.72
African American	19.15
Hispanic	2.13
Age	64.68(6.74)
Ankle-brachial index Range	0.16–0.89
Disease duration, months	55.7(51.6)
Level of disease (%)	
Aortoiliac	14.9
Femooropopliteal	29.8
Multi-level	55.3
Smoking	
Current	61.70
Former	36.17
Never	2.13
Coronary Artery Disease	36.17
Obesity	21.28
Diabetes	25.53
Dyslipidemia	80.85
Hypertension	87.23

Continuous variables are presented as mean (standard deviation). Categorical variables are presented as %.

Table II.

Ankle-brachial index, walking distances, Walking Impairment Questionnaire, and plantarflexor strength before and after supervised exercise therapy. Higher values for each of these categories suggest improvement.

Dependent Variable	**Pre**	**Post**	**P**
Body Mass (kg)	89.38(18.7)	88.99(18.9)	.460
Ankle-brachial index	0.56(0.17)	0.52(0.22)	.078
Timed Up and Go (s)	11.14(1.45)	10.84(1.96)	.300
Distances (m)			
Initial claudication	99.20(74.5)	272.73(249.3)	<.001
Absolute claudication	317.23(230.8)	668.22(566.4)	<.001
Six Minute Walk Distance	340.42(117.3)	333.11(123.3)	.700
Walking Impairment Questionnaire			
Pain	54.55 (21.99)	65.63 (22.63)	.008
Distance	29.80 (25.49)	39.75 (29.84)	.043
Walking speed	39.60 (24.91)	46.34 (26.19)	.127
Stair climbing	44.70 (29.04)	53.88 (27.54)	.045
Isometric plantar flexor strength (N)			
Area	697.77(264.03)	784.84(234.25)	.012
Peak torque / BW	0.95(0.34)	1.05(0.35)	.007

Mean(standard deviation)

Table III.

Walking performance characteristics from the 6 minute walk test (6MWT).

Dependent Variable	Pre	Post	P
Initial claudication distance, 6MWT (m)	108.07 (68.8) *	176.21 (83.1) *	.046
Total number of stops	15	14	ns
Subjects who stopped (num)	9 (n=9)	12 (n=5)	
Average stop time per six minutes	91.56 (47.4)	111.58 (53.9)	
Overground speed	2.21 (0.8)	2.2 (0.7)	
TM preferred speed	1.65 (0.6)	1.65 (0.6)	

Mean(standard deviation)

[*] Forty patients experienced pain during 6MWT and are included in the analysis. Six patients were excluded because they completed their 6MWT without any claudication pain

Table IV.

Dependent variables from the weight acceptance phase of stance. To support the trunk at heel strike, the hip extensors, primarily gluteus maximum and the hamstrings [32], concentrically contract to extend the hip, while the extensors at the knee eccentrically contract to permit slight flexion at the knee. The hip extensors stabilize posture of the trunk by preventing it from flexing forward under the influence of a large posterior reaction force at the hip, which helps the knee extensors to eccentrically contract and prevent collapse at the knee [33]. A positive torque value represents a flexor response while a negative torque value indicates an extensor response. Positive power represents energy generation and is associated with concentric muscle contraction whereas negative power indicates energy absorption and is associated with eccentric muscular contraction.

Joint and/or Variable		Pain-free		Pain		
	Pre	Post	Pre	Post	Pi	Pc
Ankle						
Dorsiflexion angle	12.89(4.7)	13.28(4.7)	14.15(4.7)	14.21(4.9)	.677	**<.001**
Dorsiflexor torque	−0.25(0.1)	−0.26(0.1)	−0.24(0.1)	−0.23(0.1)	.885	**.023**
Power absorption	−0.48(0.2)	−0.51(0.3)	−0.48(0.3)	−0.49(0.3)	.514	.554
Knee						
Flexion angle	2.89(5.0)	2.41(5.1)	2.35(5.1)	1.52(5.5)	.265	**.003**
Extensor torque	0.53(0.3)	0.56 (0.3)	0.56(0.3)	0.56(0.3)	.695	.404
Power absorption	−0.66(0.5)	−0.74(0.5)	−0.81(0.8)	−0.75(0.5)	.861	.089
Hip						
Flexion angle	−2.86(4.9)	−3.90(5.8)	−2.00(5.2)	−3.07(6.0)	.281	**<.001**
Extensor torque	0.67(0.3)	0.81(0.2)	0.69(0.4)	0.79(0.3)	**.012**	.963
Power generation	0.4(0.4)	0.44(0.4)	0.42(0.4)	0.43(0.4)	.682	.988
Peak forces						
Vertical impact	1.09(0.1)	1.12(0.15)	1.09(0.12)	1.1(0.12)	.253	.529
Braking force	−0.15(0.04)	−0.16(0.05)	−0.16(0.05)	−0.16(0.05)	.393	.219
Braking impulse	−0.032 (0.01)	−0.030 (0.01)	−0.031 (0.01)	−0.029 (0.01)	.559	**.041**
Lateral force	−0.038 (0.02)	−0.042 (0.02)	−0.041 (0.02)	−0.046 (0.02)	**.021**	**<.001**

Means(standard deviation); Pi: Intervention (pre/post Supervised Exercise Therapy); Pc: Condition (pain free/pain)

Note: Angle (degrees), Torque (N*m), Power (Watts), Peak Forces (Body Weights), Impulse (N*s/kg)

Table V.

Dependent variables from the single leg support phase of stance. During single-leg support, the plantarflexors contract isometrically and produce a net effect of reaction forces to the leg and trunk which provide support and enable subsequent transfer of body mass in forward progression.

Joint and/or Variables	**Pain Free**		**Pain**			
	Pre	Post	Pre	Post	Pi	Pc
Power						
Ankle absorption	−0.83(0.3)	−0.9(0.3)	−0.9(0.3)	−0.96(0.3)	**.023**	**<.001**
Knee generation	0.32(0.3)	0.37(0.4)	0.4(0.3)	0.35(0.2)	.937	.332
Hip absorption	−0.59(0.3)	−0.61(0.3)	−0.61(0.4)	−0.61(0.3)	.804	.485
Peak forces	−0.59(0.3)	−0.61(0.3)	−0.61(0.4)	−0.61(0.3)	.804	.485
Vertical midstance	0.77(0.07)	0.79(0.11)	0.79(0.09)	0.79(0.11)	.516	.118
Medial	0.062(0.002)	0.066(0.002)	0.061(0.002)	0.063(0.002)	.128	.292

Means(standard deviation); Pi: Intervention; Pc: Condition

Note: Angle (degrees), Torque (N*m), Power (Watts), Peak Forces (Body Weights)

Table VI.

Dependent variables from the propulsion phase of stance. The primary muscles contributing to propulsion are the plantarflexors, where the gastrocnemius delivers energy to the leg and the soleus to the trunk for support and forward progression [34]. The hip pattern during propulsion includes contribution by the flexors and hamstrings to achieve a greater energy level of the thigh leading into the swing phase of gait.

Joint and/or Variable	**Pain Free**		**Pain**			
	Pre	**Post**	**Pre**	**Post**	**Pi**	**Pc**
Ankle						
Plantarflexion angle	−7.34(4.6)	−7.38(4.7)	−7.95(4.5)	−8.31(4.4)	.735	**<.001**
Plantarflexor torque	1.32(0.2)	1.37(0.3)	1.24(0.2)	1.28(0.2)	.148	**<.001**
Power generation	2.15(0.5)	2.43(0.6)	1.86(0.7)	2.16(0.7)	**.003**	**<.001**
Knee						
Flexion angle	14.38(5.7)	14.14(6.5)	14.29(5.6)	13.81(6.8)	.573	.476
Flexor torque	−0.18(0.2)	−0.2(0.2)	−0.18(0.2)	−0.2(0.2)	.656	.921
Power absorption	−0.8(0.3)	−0.85(0.4)	−0.75(0.4)	−0.75(0.3)	.705	**.017**
Hip						
Extension angle	34.04(6.2)	34.12(7.0)	34.54(6.9)	34.55(7.5)	.950	.055
Extensor torque	−0.79(0.2)	−0.8(0.3)	−0.76(0.3)	−0.76(0.3)	.946	**.046**
Power generation	0.71(0.2)	0.83(0.2)	0.69(0.2)	0.77(0.2)	**.003**	**.039**
Peak forces						
Vertical push-off	1.03(0.07)	1.07(0.14)	1.01(0.07)	1.04(0.13)	.130	**<.001**
Propulsive	0.17(0.03)	0.19(0.05)	0.16(0.04)	0.18(0.04)	**.006**	**.002**
Propulsive impulse	0.031(0.01)	0.033(0.02)	0.031(0.01)	0.033(0.01)	.412	.944

Means(standard deviation); Pi: Intervention; Pc: Condition

Note: Angle (degrees), Torque (N*m), Power (Watts), Peak Forces (Body Weights), Impulse (N*s/kg)