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Effects of form-focused training on running biomechanics: A pilot randomized trial in untrained individuals

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Abstract

Objective—To investigate the changes in running biomechanics after training in Form-Focused running using ChiRunning vs. Not-Form focused training and Self-Directed training in untrained individuals.

Design—Pilot study - Randomized controlled trial.

Setting—Research Institution with Tertiary Care Medical Center.

Participants—Seventeen subjects (9 males, 8 females) with pre-hypertension.

Methods—Twenty-two participants were randomized to three study arms but 17 completed the study. The study arms were: 1) group-based Form-Focused running using ChiRunning (enrolled, n =10; completed, n=7); 2) group-based conventional running (enrolled, n=6; completed, n=4); 3) self-directed training with educational materials (enrolled, n =6; completed, n=6). The training schedule was prescribed for 8 weeks with 4 weeks of follow-up. All subjects completed overground running motion analyses before and after training.

Outcomes—Ankle, knee, hip joint peak moments and powers; Average vertical loading rate (AVLR), impact peak, cadence, stride length, strike index, and stride reach. Paired T-tests were used to compare differences with-in groups over-time.

Results—Form-Focused group reduced their Stride Reach (P = .047) after the training but not the other groups. Form-Focused group showed a close to significant reduction in knee adduction

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moment (P = .051) and a reduction in the peak ankle eversion moment (P = .027). Self-Directed group showed an increase in the running speed, (P =.056) and increases in ankle and knee joint powers and moments.

Conclusions—There are differences in the changes in running biomechanics between individuals trained in running form that emphazies mid-foot strike, higher cadence, and shorter stride compared to those not trained in the thise technique. These differences may be associated with reduced lower extremity stress in individuals trained in this running form but future studies are needed to confirm these findings in larger samples.

Keywords

ChiRunning; Knee adduction moment; loading rate; strike index; stride reach; Kinetics

INTRODUCTION

Running is a popular mode of physical activity in the US with a large and growing number of individuals who engage in recreational and competitive running [1]. Of these runners, 19-83 % may sustain a running related injury during their lifetime [2, 3]. Common running related injuries include patellofemoral pain, iliotibial band syndrome, medial tibial stress syndrome, tibial or metatarsal stress fractures, plantar fasciitis and Achilles tendinopathy [4, 5]. Abnormal vertical loading rates [6, 7], external knee adduction moment [8], stride length [9-11], rear-foot strike pattern [12], and low cadence [13] are thought to be related to greater risk of sustaining running injuries. Hence, programs have been proposed that purport to train participants in running form that may result in gait patterns that reduce the risk of these injuries and promote greater amounts of running [14].

ChiRunning is a running training program based in part on mindfulness and body awareness principles of T'ai Chi [15]. It focuses on elements of running form that include a mid-foot strike, shorter stride, and high cadence. Proponents of this training technique claim that it reduces the risk of running related injuries and promote greater amount of running activity [15]. A recent cross-sectional study showed that ChiRunners had lower average vertical loading rates (AVLR), less knee extensor work, higher cadence, and greater ankle plantarflexor work compared to individuals running with a traditional rearfoot strike pattern [16]. However, prospective and randomized studies investigating changes in running biomechanics after training in the ChiRunning technique program are lacking.

We performed a pilot exploratory study to investigate the changes in running biomechanics in individuals without a current running practice during training in a running form using the ChiRunning approach and compared them to those receiving more conventional running training. Participants for this study were recruited for a pilot randomized, controlled trial of the effects of running on elevated blood pressure in individuals with pre-hypertension. The population with pre-hypertension was selected because over 30% of American adults have pre-hypertension [17] and an increasing physical activity is recommended for this population [18]. The aim of this pilot study was to assess feasibility and gathering preliminary data on key outcomes for a larger randomized trial that is currently being planned.

METHODS

Subjects

Entry criteria for the included having a BMI < 35kg/m^2, a mean blood pressure in range (130-150/80-100mmHg) at two separate in-person visits, and an interest in using exercise to lower blood pressure. Exclusion criteria included having a current running practice or a medical condition such as significant osteoarthritis that precluding significant amounts of running. Participants were recruited from the community using flyers and other print and online advertisements. All participants completed an extensive phone screen with the study coordinator including questions from the Physical Activity Readiness Questionnaire (PAR-Q) [19] to assess possible risk associated with starting an exercise program. Callers were ineligible if they answered yes to any of the 7 items on the PAR-Q or provided other information indicating that starting running may not be appropriate for them. All participants signed an informed consent form approved by the Institutional Committee on Human Research.

The study flowchart is shown in Figure 1. We enrolled 22 participants in the overall trial. All but one underwent gait assessment; the remaining participant was the last one enrolled and did not have enough time to schedule and complete the baseline gait assessment prior to the beginning of the trial. The participants were randomized to one of three study arms: 1) group-based form-focused running (intervention) (enrolled, n=10; completed, n = 7); 2) group-based running training with a coach without focus on form, (active control, attention matched) (enrolled, n=6; completed, n = 4); 3) self-directed training with educational materials (self-directed control) (enrolled, n=6; completed, n = 6). Participants were randomized using computer generated random blocks of numbers generated by a statistician who was not a member of the study staff. The statistician provided study staff with the randomized numbers in opaque sealed envelopes. The interventions were delivered over 8 weeks. All subjects were instructed in a run/walk approach to running. The training schedule prescribed walking and running intervals for 12 weeks. However, the post-intervention data were collected between weeks 8-12. The participants were instructed to being each workout with a 5 min walking warm-up, followed by alternating between running and walking breaks throughout the workout. Eventually they were instructed to progress up to running for 30 minutes without any walking breaks. Participants were also instructed to cross-train by devoting one of the 4 rest days to to using other forms of exercise. The training schedule is shown in Table 1. Adherence was calculated as percentage of planned running episodes completed from participant training diaries.

Form-focused running (intervention, n = 10)—The intervention group attended 4 training workshops on Sunday mornings at weeks 0 (baseline), 2, 4 and 8. The first workshop at week 0 was 4 hours long and covered most of the basic content, while the subsequent sessions lasted 2 hours and focused on refinement and more specialized aspects of the technique. The training focused on using body-awareness to help participants engage with and change their running form. Specific biomechanical components of training included – forward lean, mid-foot strike, shorter strides, higher cadence, relaxed legs, and core activation. The training was led by a coach certified in the ChiRunning technique using didactics, practice drills, and video taping to provide individuals with detailed feedback on their running form.

Not form-focused running (active control)—The active control participants attended training sessions in the afternoons on the same Sundays that the intervention group met for an equivalent amount of time. The trainings covered running topics unrelated to form including goal setting, pace, mileage, warm-up/cool down, stretching, core strengthening, cross training, hydration and nutrition, and shoes and gear. A coach certified by the USA Track and Field and the Road Runners Club of America led all of the training sessions using didactics, practice drills and group runs.

Self-directed control—The self-directed control participants were provided with printed educational materials about starting a self-directed run/walk training program. The printed materials provided information on basic running topics other than running form. Examples of the topics included goal setting, pace, mileage, warm-up/cool down, stretching, core strengthening, cross training, hydration and nutrition, and shoes and gear.

Gait analysis

Participants were invited to complete a 3-D motion analysis assessment of running biomechanics at the UCSF Human Performance Center, 1 to 4 weeks before week 0 (baseline) and between weeks 8 and 12 (post intervention). At each session, the same researcher placed 9.5 millimeter spherical retro-reflective markers on the bony landmarks of their bilateral upper and lower extremities to identify joint centers. Participants' upper extremities, lower extremities, trunk and head were tracked using clusters of markers. All participants ran over-ground while 3-D kinematic data was collected at 250 Hz using a passive 10-camera video recording system (VICON, Oxford Metrics, UK). Kinetic data was collected at 1000 Hz from two force platforms embedded in the floor of the lab (AMTI, Watertown, MA, USA). A trial was considered usable when there was a clean foot-strike on any of the force platforms, and the speed was within ± 5% of an initial running pace selected by the participant as "comfortable". We collected four usable trials on each foot.

The marker coordinate data were low-pass filtered using a recursive 2nd order Butterworth filter with a cut-off of 6 Hz. The force platform data were high-pass filtered with a recursive 2nd order Butterworth filter with a cut-off of 20 Hz. Euler angles (X-Y-Z) using a right-handed coordinate system and inverse dynamics were used to calculate kinematic and kinetic data in Visual3D (C-motion, Georgetown, MD, USA). Data from left and right were averaged for each individual. Ankle, knee, hip joint peak external moments, and peak negative and positive joint powers were calculated for all subjects. Average vertical loading rate (AVLR), impact peak, stride length, cadence, and strike index were calculated based on published methods [20]. Stride reach was defined as distance between the center of mass and the center of pressure at initial contact. All net joint moments are expressed as external moments and normalized to each participant's body weight (BW) and height (Ht) (Nm/BW*Ht).

Data analysis

Paired t-tests were used in each of the 3 groups to compare the AVLR, Impact Peak, Stride Length, Cadence, Strike Index, Stride Reach, Stride Length, joint powers, and joint moments pre- and post-training. All statistical analyses were done using SPSS (SPSS Inc. Chicago, IL) significance level set at $P \leq 0.05$.

RESULTS

Subjects

Age, BMI, and gender distribution are shown in Table 2. There were no significant differences in these characteristics between the groups. The subjects that were lost to follow-up were not different from the rest of the participants in their demographics. All groups completed over 80% of planned running episodes (Form-Focused = 84%, Active Control − 98 %, Self-Directed − 83 %).

Running gait

There were no significant differences between the groups at baseline for any of the biomechanical parameters studied.

Loading related variables—The results are shown in Figure 2. At baseline, the Form-focused running group had a Strike Index of 9.4±5.2 % (rear-foot strike pattern), the active control group had a Strike Index of 24±26.8 % (rear-foot strike pattern), and the self-directed group had a Strike index of 16.9±20 % (rear-foot strike pattern). Paired t-tests showed that post-training, the Form-Focused group tended to increase their Strike Index, the Active Control group did not change, and the Self-Directed group tended to reduce their Strike Index (Fig 2). However, none of these changes were significant. Post-training, the Form-focused running group reduced their Stride Reach (P = .047). The Active Control group also tended to reduce their Stride Reach but the difference was not significant (P =. 088) whereas the self-directed group did not show a change in their Stride Reach (P = .854). The decrease in Stride Length was not significant for the Form-Focused group (P = .841) and Active Control groups (P =.509). The Self-Directed group showed an increase in the Stride Length post-training (P = .051). The Form-Focused group tended to increase their Cadence (P =.073) whereas the change in Cadence for the other 2 groups was not significant. The decrease in AVLR and Impact Peak for the Form-Focused group and the increase in AVLR and Impact Peak for the other 2 groups were not statistically significant. The Form-focused running group showed a decrease (P = .086) in running speed (pre-training: 3.15±0.57 m/sec, post-training 2.92±0.38 m/sec). The Active Control group (pre-training: 2.99±0.31 m/sec, post-training 3.44±0.64 m/sec, P = .132) and the Self-Directed groups (pre-training: 2.66±0.62 m/sec, post-training 2.93±0.41 m/sec, P = .056) showed an increase in running speed.

Joint powers—Results are shown in Figure 3. Paired t-tests showed that the changes in ankle power after training were not significant for the Form-Focused or the Active Control groups. The Self-Directed group showed an increase in the peak positive ankle power (P =. 028). Similarly the changes in knee power were not significant for the Form-Focused or the

Active Control groups. The Self-Directed group showed an increase in both peak positive (P = .040) and peak negative knee power (P =.054). The changes in hip powers were not significant in any of the 3 groups.

Joint moments—The results for hip, knee, and ankle joint moments are shown Table 3. The changes in hip moments were not significant in any of the groups. At the knee, the peak flexion moment (P =.051) and peak internal rotation moment (P = .055) tended to decrease in the Self-Directed group. The peak knee adduction moment decreased in the Form-Focused group (P =.051). At the ankle, the Form-focused running group showed a significant reduction in the peak eversion moment (P = .027).

DISCUSSION

The goal of this pilot RCT was to gather preliminary data for a larger randomized trial in the future. This included optimizing the study design and evaluating recruitment, retention, delivery of the intervention, and participant compliance, etc. The analyses presented here focus on the exploration of the biomechanical changes with training in Form-Focused running based on ChiRunning compared to a Non-Form Focused training and self-directed training to promote greater activity in individuals with pre-hypertension. Our results demonstrate that it is feasible to train inexperienced individuals in the Form-focused running technique, and there are differences in the changes in running biomechanics between individuals trained in the Form-focused running technique compared to those not trained in the Form-focused running technique.

The Form-Focused training utilized in this study was delivered using ChiRunning principles. This training, and other similar running techniques, is primarily aimed at promoting a mid-foot strike pattern, increasing cadence, and reducing stride length. These changes are thought to reduce the risk of running related injuries by reducing the magnitude of loading applied to the lower extremities. As can be seen in Figure 2, the changes for the Form-Focused group for all of these variables was in the expected direction with a decrease in AVLR, decrease in Impact Peak, an increase in the Strike Index, decrease in Stride Reach and Stride Length, and an increase in cadence. These findings support the utility and feasibility of this training to promote a running gait pattern that may reduce injury risk. However, a number of these changes were not statistically significant likely due to the small sample size. Considering the feasibility nature of this work, these data support further evaluation of this training in a larger cohort over a longer duration.

We observed a significant reduction in the Stride Reach (distance between the center of mass and the center of pressure at initial contact) in the Form-focused running group with the training. Shorter stride reach (or less over-striding) has been shown to be related to lower loads and potentially a lower risk of tibial stress fractures [10, 13]. In the recent cross-sectional study on experienced ChiRunners, the authors did not report Stride Reach but speculated that the rear-foot strikers had a more anterior foot position at initial contact compared to the experienced ChiRunners. However, we did not see significant reductions in the AVLR and the Impact peak for the Form-focused running group. This could be in part due to the small sample size, which limited our ability to detect statistically significant changes in these measures. After training, the mean AVLR for the ChiRunning group was approximately 72 BW/sec. Gross et al. reported an average AVLR of 43 BW/sec in their cohort of experienced ChiRunners. In their study, the average experience with the ChiRunning form was approximately 30 months. Furthermore, they recruited individuals who were running at least 12 miles/week. In our study we enrolled individuals without a current running practice. The observed difference in AVLR between the studies could be related to these differences in the cohorts.

Although the Form-focused runners in our study showed a more anterior Strike Index post-training (14% of foot length) compared to pre-training (9% of foot length), as might be expected since it encourages a mid-foot strike, the difference was not statistically significant. Less over-striding by the ChiRunners as observed in our study could be associated with a more anterior foot-strike pattern or with modifications in the stride length and cadence. Further studies in larger samples are needed to confirm these findings.

As can be seen in Figure 3, the changes in joint powers in the Form-Focused group were in the direction of a decrease except for negative hip power. Further work is needed to evaluate if these changes are significant in larger cohorts and also to evaluate if these changes are independent of the changes in running speed. Specifically, we observed an increase in positive knee and ankle powers in the Self-Directed group after the training. The increase in positive knee power (extensor during late stance) and positive ankle power (plantarflexor during late stance) could be related to the increase in running speed in the Self-Directed group [21]. Gross et al. reported lower negative dorsiflexor work in early stance, higher negative plantarflexor work during early stance, and lower negative knee extensor work in early stance in ChiRunners compared to rearfoot strikers [22]. Similarly, another study reported higher negative plantarflexor work and lower negative knee extensor work in POSE runners with a forefoot strike pattern compared to runners with a rearfoot or midfoot strike pattern [23]. In our study, the Form-Focused group showed a decrease in positive and knee and ankle joint powers but the differences were not statistically significant. It may be possible that these differences become greater with an increase in experience.

There was a close to significant reduction in the knee adduction moment after training in the ChiRunning techniques. High knee adduction moment could lead to greater risk of patellofemoral joint pain, and is known to be related to greater loading over the medial compartment. Hence, a potential reduction in knee adduction moment could be important for individuals who have tibiofemoral or patellofemoral pain.

In summary, training in a running form that emphasizes mid-foot strike, higher cadence, shorter stride length along with other characteristics could lead to changes in running gait in untrained individuals. In this small sample, we observed potential improvements in strike index, and knee adduction moment that need further investigation in larger samples. Since this was a pilot study to assess feasibility and gather preliminary data for a larger trial, future studies are needed to assess the differences in various running form techniques, injury rates, and long-term compliance.

There are limitations to this work which need to be considered while interpreting the results. The cohort included a small number of individuals and hence the results need to be confirmed in larger samples. The small sample in this study could have limited our ability to observe significant changes with the Form-Focused training. We did not account for multiple comparisons with the small sample size considering the preliminary nature of the work. Furthermore, the study included untrained individuals with elevated blood pressure. Hence, the findings may not be generalized to active runners.

CONCLUSION

In conclusion, results from the pilot study demonstrate that there are differences in the changes in running biomechanics between individuals trained in the Form-Focused training that emphasizes mid-foot strike, higher cadence, and shorter stride length compared to those not trained in the the running technique. These differences may be associated with reduced lower extremity stress in individuals who are trained in these running techniques but future studies are needed to confirm these findings in larger samples.

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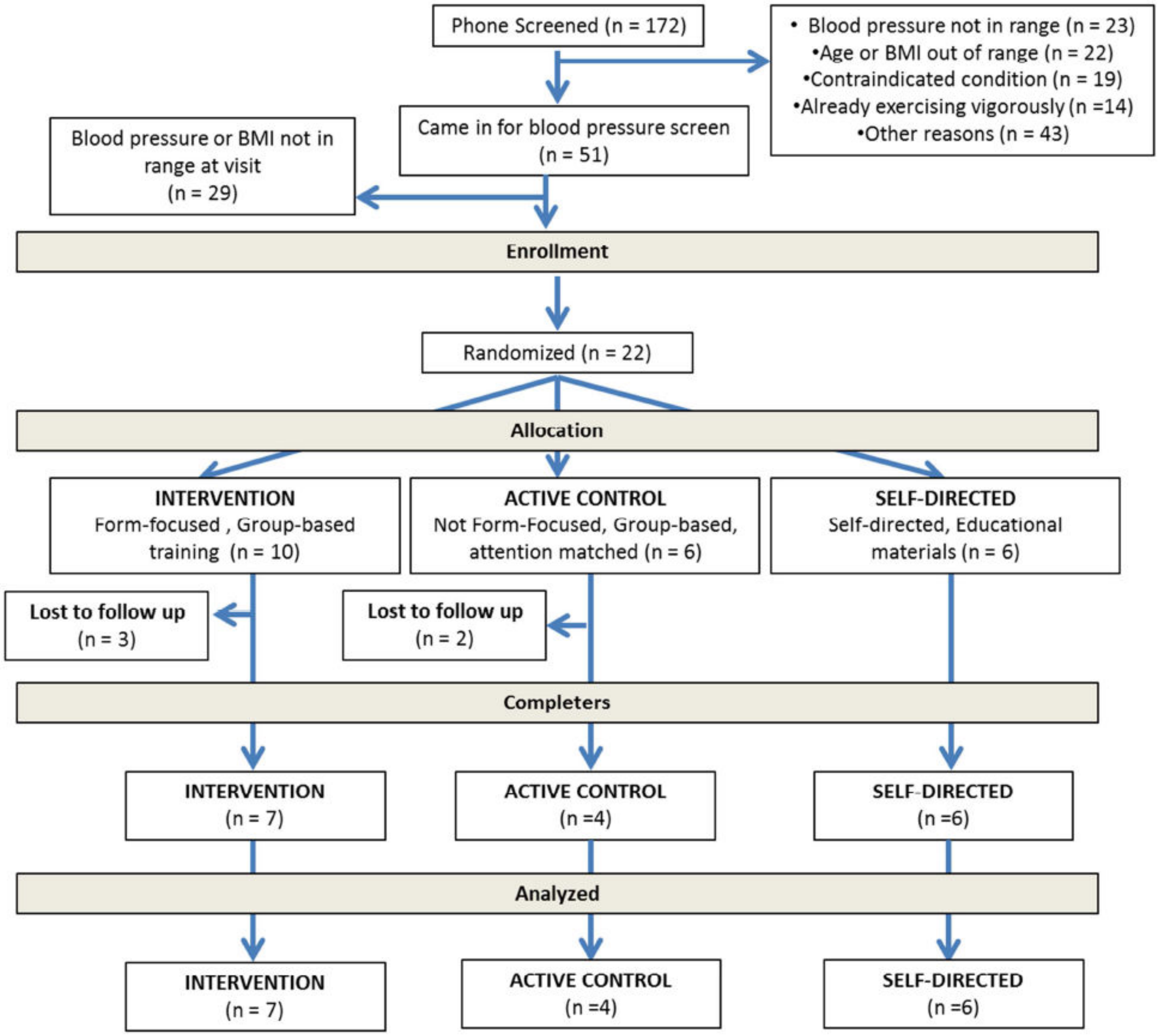

Figure 1.

CONSORT flow diagram of participants

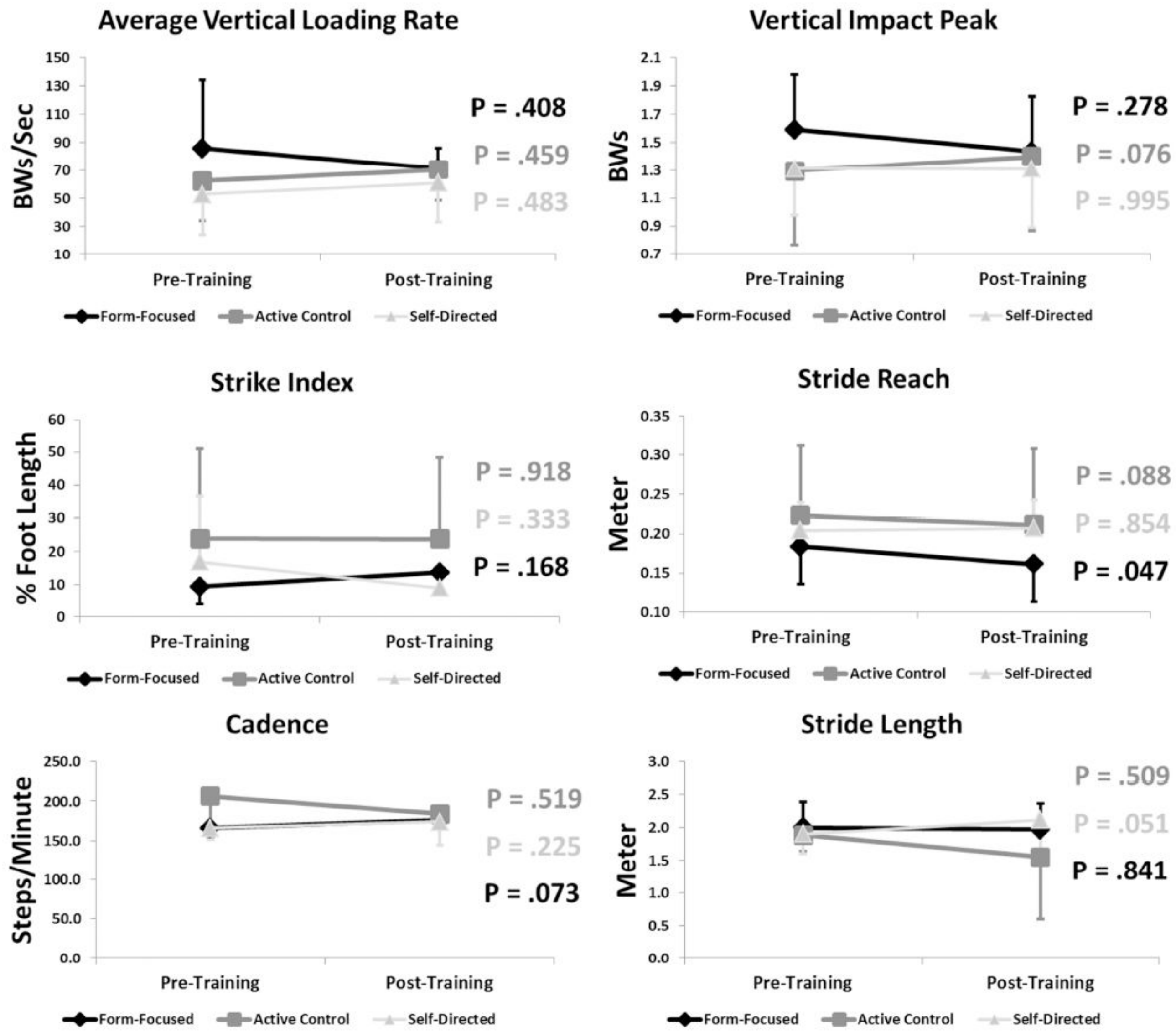

Figure 2.
Loading Related variables for the 3 groups before and after training.

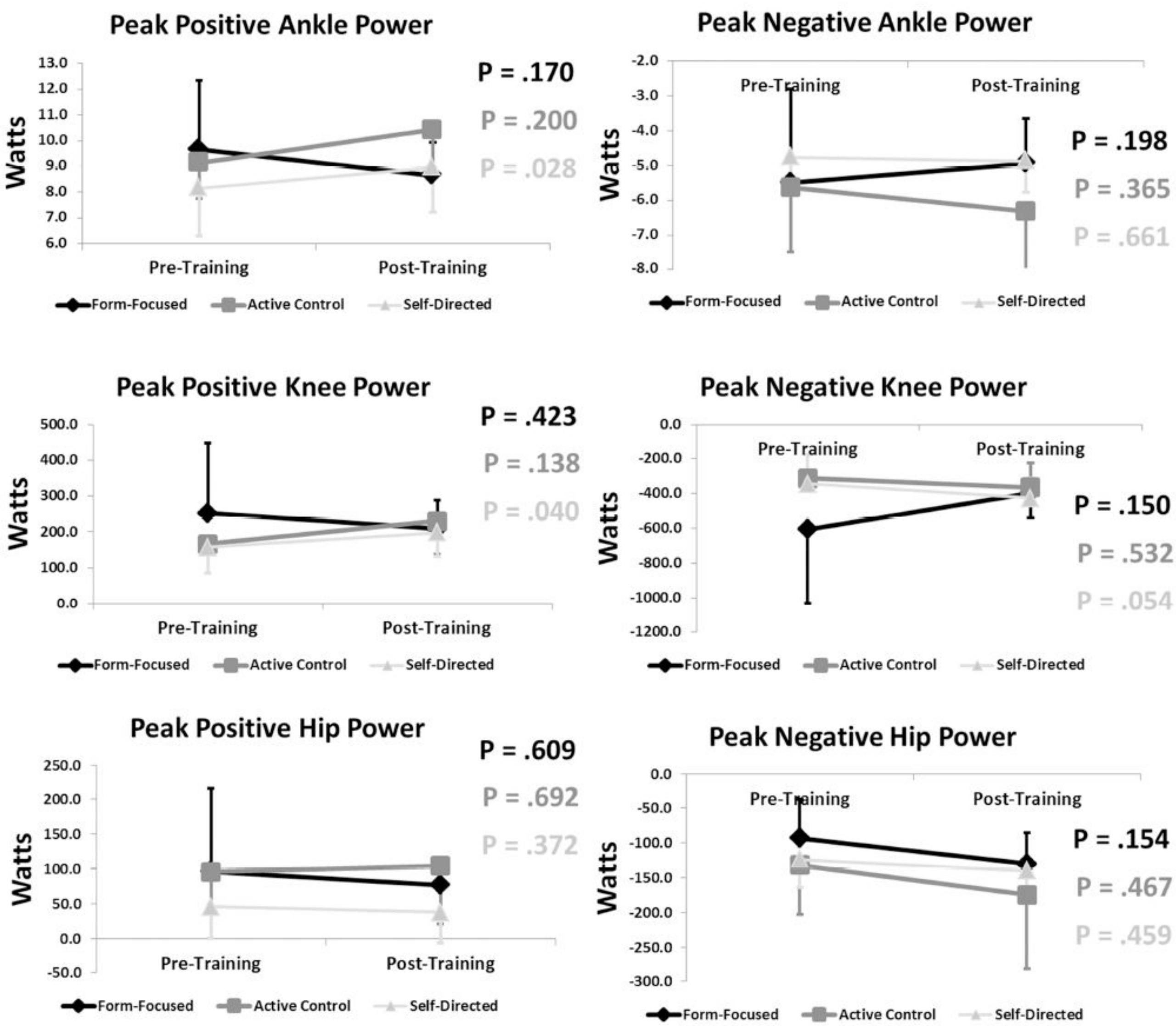

Figure 3.

Peak positive and negative joint powers at the hip (top row), knee (middle row) and ankle (bottom row) for the 3 groups before and after training.

Table 1

The 12 weeks run/walk training schedule.

Week	Day 1	Day 2	Day 3	Day 4
1	Run 1/Walk 3 × 5 Total 20	Run 1/Walk 2 × 6 Total 18	Run 1/Walk 2 × 5 Total 20	Rest
2	Run 2/Walk 2 × 5 Total 20	Run 2/Walk 2 × 5 Total 20	Run 2/Walk 2 × 5 Total 20	Rest
3	Run 2/Walk 2 × 5 Total 25	Run 3/Walk 2 × 5 Total 25	Run 3/Walk 2 × 5 Total 25	Rest
4	Run 4/Walk 2 × 4 Total 24	Run 4/Walk 1 × 5 Total: 25	Run 4/Walk 1 × 5 Total 25	Rest
5	Run 5/Walk 2 × 4 Total 28	Run 5/Walk 1 × 5 Total 30	Run 5/Walk 1 ×5 Total 30	Cross Train 30
6	Run 6/Walk 2 × 4 Total 32	Run 6/Walk 1 × 5 Total 35	Run 7/Walk 2 × 4 Total 36	Cross Train 30
7	Run 7/Walk 1 × 5 Total 40	Run 8/Walk 2 × 4 Total 40	Run 8/Walk 1 ×4 Total 36	Cross Train 30
8	Run 9/Walk 2 × 4 Total 44	Run 9/Walk 1 ×4 Total 40	Run 10/Walk 2 × 3 Total 36	Cross Train 30
9	Run 10/Walk 2 × 3 Total 36	Run 10/Walk 2 × 3 Total 36	Run 10/Walk 1 × 3 Total 33	Cross Train 30
10	Run 15/Walk 2 × 2 Total 34	Run 10/Walk 2 × 3 Total 34	Run 15/Walk 1 × 2 Total 32	Cross Train 30
11	Run 20/ Walk 2/ Run 15 Total 37	Run 20/ Walk 2/ Run 15 Total 37	Run 20/ Walk 1/ Run 15 Total 36	Cross Train 30
12	Run 25/ Walk 2/ Run 10 Total 37	Run 25/ Walk 1/ Run 10 Total 37	Run 30	Cross Train 30

* Understanding the chart: Run 1/Walk 3 x5 Total 20 = Run for 1 minute then walk for 3 minutes for 4 minutes total. Repeat the 4 minute run/walk interval 5 times. The total workout lasts 20 minutes

Table 2

Mean and standard deviation for age and BMI, and the gender distribution for ChiRunning and control groups.

	Form-Focused Training	**Active Control**	**Self-directed Control**	***P* Value**
Age (years)	54.3 (7.9)	56.8 (3.9)	52.3 (4.3)	.542
BMI (kg/m^2)	27.2 (2.7)	26.2 (4.1)	26.8 (3.3)	.140
Men: Women	4:3	2:2	3:3	$\chi 2 = 0.084$, $P = .959$

Table 3

Joint moments (Mean and standard deviation) before and after the intervention for the 3 groups.

			Pre-Training		Post-Training		P value
			Mean	SD	Mean	SD	
Hip	**Extension moment (BW*Ht)**	**Form-Focused**	-0.098	0.04	-0.097	0.03	.935
		Active Control	-0.092	0.01	-0.103	0.02	.464
		Self-Directed	-0.079	0.04	-0.083	0.03	.572
	Flexion moment (BW*Ht)	**Form-Focused**	0.043	0.01	0.038	0.01	.306
		Active Control	0.052	0.01	0.061	0.01	.142
		Self-Directed	0.047	0.01	0.051	0.01	.209
	Adduction moment (BW*Ht)	**Form-Focused**	0.106	0.02	0.106	0.02	.911
		Active Control	0.104	0.01	0.101	0.02	.670
		Self-Directed	0.102	0.01	0.105	0.01	.482
	Internal Rotation Moment (BW*Ht)	**Form-Focused**	0.027	0.01	0.028	0.00	.725
		Active Control	0.022	0.01	0.019	0.01	.665
		Self-Directed	0.019	0.01	0.020	0.01	.866
Knee	**Flexion Moment (BW*Ht)**	**Form-Focused**	-0.154	0.02	-0.154	0.03	.943
		Active Control	-0.138	0.03	-0.150	0.02	.528
		Self-Directed	-0.128	0.03	-0.152	0.02	**.051**
	Adduction Moment (BW*Ht)	**Form-Focused**	0.048	0.01	0.044	0.01	**.051**
		Active Control	0.039	0.01	0.042	0.02	.667
		Self-Directed	0.043	0.02	0.041	0.02	.335
	Internal Rotation Moment (BW*Ht)	**Form-Focused**	-0.029	0.01	-0.028	0.01	.665
		Active Control	-0.025	0.00	-0.026	0.00	.712
		Self-Directed	-0.026	0.01	-0.031	0.01	**.055**
Ankle	**Dorsiflexion Moment (BW*Ht)**	**Form-Focused**	0.131	0.01	0.127	0.01	.273
		Active Control	0.139	0.02	0.138	0.01	.854
		Self-Directed	0.125	0.01	0.124	0.01	.726
	Eversion Moment (BW*Ht)	**Form-Focused**	-0.014	0.01	-0.011	0.00	**.027**
		Active Control	-0.013	0.01	-0.015	0.01	.310

			Pre-Training		Post-Training		P value
			Mean	**SD**	**Mean**	**SD**	
		Self-Directed	-0.016	0.01	-0.013	0.00	.272
	Internal Rotation moment (BW*Ht)	**Form-Focused**	0.023	0.02	0.021	0.01	.613
		Active Control	0.025	0.00	0.021	0.01	.532
		Self-Directed	0.018	0.01	0.019	0.01	.798