CHANGES IN TOTAL AND PERCENT DISTRIBUTION OF JOINT POWER IN DISTANCE RUNNERS OVER A COMPETITIVE SEASON

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The purpose of this study was to identify changes in joint power in distance runners over a competitive season. Thirteen cross-country runners (age, 19.8±2.2 yrs; height, 1.74±0.10 m; mass, 61.9±9.0 kg) from the same university team underwent 3D biomechanical gait analyses at the start and end of a seven-week competitive season. Total negative lower limb power did not change, p=0.641. Total positive power increased by 1.8 W/kg, but it was not significant, p=0.311. While negative joint power contributions shifted proximal to distal, these were not significant for ankle (p=0.404), knee (p=0.930), or hip (p=0.261). Positive joint power contributions shifted distal to proximal, the changes were not significant for the ankle (p=0.652), knee (p=0.776), or hip (p=0.156). Joint power contributions may potentially change over a competitive season and reflect fatigue or influence injury risk.

KEYWORDS: running gait, lower limb power, running biomechanics

INTRODUCTION: Distance running is one of the most popular physical activities and is the activity of competitive university cross-country teams. An understanding of biomechanical function of lower limb kinetics is of interest for achieving high performance and reducing running-related injuries (RRIs) (Schache et al., 2014). Negative joint power is primarily generated by eccentric muscle contractions where potential strain energy is stored. During running, the knee and ankle joints contribute greatly to limb power absorption compared to the hip joint (Hashizume et al., 2018). Hashizume and colleagues (2019) found limb differences in hip, knee, and ankle joint negative power of 7.4-18.9 % in a group of adult males running at 3.0 m/s suggesting symmetry as a variable of interest. The current study focused on overall changes versus interlimb differences. Positive power is primarily generated by concentric muscle contractions and potential strain energy is released. Most of the positive power (>60%) is conducted around the ankle joint during ground contact when the plantarflexors (gastrocnemius and soleus muscles) contract to propel the body forward (Swinnen et al., 2021). Sanno and colleagues (2018) reported that prolonged running near maximal effort shifted the distribution of positive joint work proximally in recreational but not competitive runners. They suggested that the shifting positive joint work from the ankle plantarflexors towards hip extensors could be detrimental to running economy which is an important determinant of distance running performance. This has also been reported to occur in older runners as a sign of declining performance (Kim & Park, 2022). However, joint work was not shifted in well trained rearfoot strikers completing a submaximal run, but peak and absolute negative ankle work were significantly reduced (Melaro, et al., 2020). In a group of soccer players who completed a fatigue run, joint power was not shifted during sprinting (Vial et al., 2023). These studies provide results from a single session. University team distance runners may experience changes in power distribution and/or magnitude from the start to end of a competitive season from cumulative loading. Therefore, the purpose of this study was to examine if a seven-week competitive season leads to changes in magnitude or proximal redistribution of positive or negative lower limb power in university competitive cross-country team runners.

METHODS: Thirteen healthy women (n=8) and men (n=5) cross-country runners (age, 19.8±2.2 yrs; height, 1.74±0.10 m; mass, 61.9±9.0 kg) from the same university team participated in this quasi-experimental pre- post-test study. Data were collected at two time points: (a) the start of the competitive season and (b) seven weeks later at the season's conclusion. Participants were cleared by the sports medicine staff for participation and the study was approved by the university's Institutional Review Board (#2017-187). The competitive season was under the direction of a single coach and is presented in Table 1. Sundays were rest days. Four 5k races also occurred between weeks one and seven.

Table 1: Coach Instructed Training Program.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Week 1	10-13 km easy run; 6 x 100 strides	3.2 km warm-up; form drills; 6-8 x 1km; weight training	15 min. warm-up run; dynamic warm-up drills; speed drills; 50 min. run	8-11 km easy; weight training	15 min. warm-up run; dynamic warm-up drills	60-80 min. steady state
Week 2	11-13 km easy; 8 x 100 strides	3.2 km warm-up; interval runs; weight training	15 min. warm-up run; dynamic warm-up drills; speed drills; 50 min. run	6.5-10 km easy; 8-10 x 100 strides; weight training	Competition	Competition
Week 3	11-13 km easy; 6-8 x 30 sec on: 30 sec off strides	3.2 km warm-up; ladder runs; weight training	15 min. warm-up run; dynamic warm-up drills; speed drills; 50 min. run	6.5-10 km easy; 8-10 x 100 strides; weight training	15 min. warm-up run; dynamic warm-up drills	60-80 min. steady state
Week 4	3.2 km warm-up; dynamic warm-up drills; ladder runs (4 x 400m, 4 x 800 m, 2 x 500 m)	3.2 km warm-up; 6-7 min. base run; weight training	15 min. warm-up run; dynamic warm-up drills; speed drills; 35-60 min. run	8-11 km easy run; weight training	15 min. warm-up run; dynamic warm-up drills	Competition
Week 5	3.2 km warm-up; dynamic warm-up drills; 4-6x 1.6 km at pace with 1 min. rest	10-13 km recovery run; weight training	15 min. warm-up run; dynamic warm-up drills; speed drills; run; 13-16 km steady state run	8-11 km easy run; 8-10 x 100 strides; weight training	Pre-competition short run	Competition
Week 6	85-120 min. steady state run	8-10 km recovery run; weight training	3.2 km warm-up run; intervals 2-3 x 1.6 km, 800 m, 400 m, 400 m.	5-10 km easy run	8-11 km easy; 8-10 x 100 strides; weight training	60-80 min. Steady state
Week 7	3.2 km warm-up; dynamic warm-up drills;; 1 min. on:off x 24-30 min.	3.2 km warm-up; 40-50 min. steady state run; weight training	15 min. Warm-up run; dynamic warm-up drills;	10-13 km easy run	Pre-competition short run	Competition

Running mechanics were captured in a laboratory using a 10 infrared camera (120 Hz) Vicon motion analysis system (Vicon, Centennial, CO, USA) with Vicon Nexus software (version 2.15). Anthropometric measures were measured (i.e., height, weight, pelvis breadth, leg length) and 16 ½" retroreflective markers were placed bilaterally on the participant's pelvis, thighs, knees, lower legs, ankles, and feet according to the specifications of Vicon's Plug-in Gait lower body model. Participants wore sports bra (women), compression shorts, and their own running shoes. They began the testing session with a warm-up consisting of a 6-minute run on an instrumented treadmill sampling at 1000 Hz (Bertec, Columbus, OH, USA) at a self-selected pace (3.33±0.35 m/s). Data were captured for 10 sec beginning at minute 6 and encompassed at least 10 consecutive steps for each limb. Data were post-processed in Vicon Nexus with a low pass Butterworth filter with a cut-off frequency of 40Hz. A custom MATLAB® program (MathWorks, Natlik, MA, USA) to calculate positive power for the ankle, knee, and hip separately and combined. Then, percent contribution of each joint's power to the total power were computed as a new variable in Statistics Package for Social Sciences (SPSS; ver. 28; IBM Corporation, New York NY, USA).

Statistical analyses of the data were performed using SPSS. Data were screened for normality of distribution and homogeneity of variance using a Shapiro-Wilk normality test and a Levene test, respectively. Mean differences in negative and positive power for the ankle, knee, and hip joints combined and the percent contribution of each joint's power to the total from the season start to season end were reduced using Paired *t*-tests, alpha=0.05.

RESULTS: Table 2 presents the pre- and post-test results for the total lower limb power and contribution of the individual joints to the total power for the runners.

Results of the paired *t*-tests showed no significant differences from the pre- to post-test total negative or positive power were found, $t(12) = 0.479$, $p = 0.641$ and $t(12) = -1.058$, $p = 0.311$, respectively. Additionally, there were no significant changes in the percent contributions to total negative power from the ankle ($t(12) = -0.865$, $p = 0.404$), knee ($t(12) = 0.089$, $p = 0.930$), and hip ($t(12) = 1.181$, $p = 0.261$). Finally, there were no significant changes in the percent contributions to total positive power from the ankle ($t(12) = -0.462$, $p = 0.652$), knee ($t(12) = 0.291$, $p = 0.776$), and hip ($t(12) = -1.516$, $p = 0.156$).

Table 2: Means and standard deviation of pre- and post-test individual joint and total lower limb power variables, N=13.

Variable	Pre	Post
Negative total limb power, W/kg	-22.2±4.8	-22.6±4.5
Negative ankle power, W/kg	-10.1±3.8	-10.8±4.5
Negative knee power, W/kg	-8.7±1.6	-8.8±1.3
Negative hip power, W/kg	-3.4±1.2	-3.1±1.3
Positive total limb power, W/kg	29.3±8.0	31.1±9.0
Positive ankle power, W/kg	19.4±5.9	20.3±6.2
Positive knee power, W/kg	5.1±1.4	5.1±1.3
Positive hip power, W/kg	4.8±1.6	5.6±2.3

For the pre- and post-test total of the individual joints, each mean value was added together. Once the total was computed, every lower limb joint was divided by the sum. This calculation configured the specific maximum power percentages of the ankle, knee, and hip joint as presented in Figure 1. The total is out of 100%.

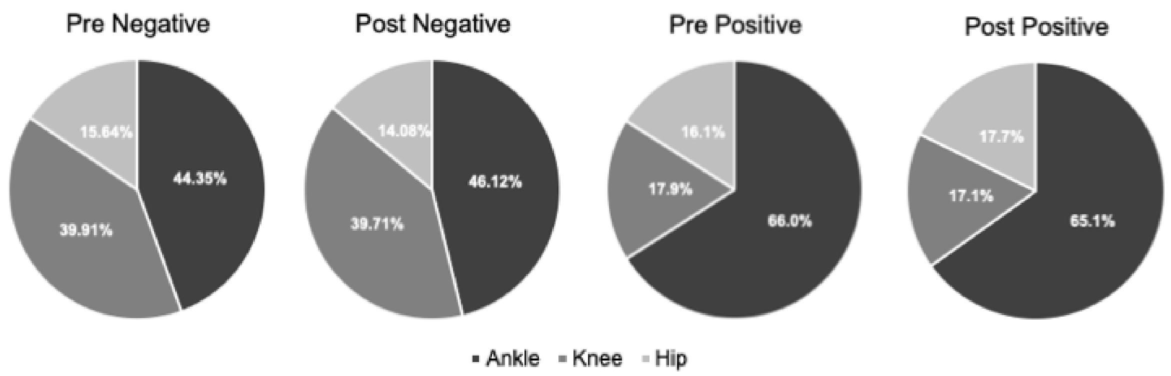

Figure 1: Pre- and post-test percentage contributions of negative and positive ankle, knee, and hip joint to total (total out of 100%).

DISCUSSION: We sought to document changes in the joint power absorbed (negative) and generated (positive) including the percent contributions from each joint to total power that might occur across a competitive season in university runners. Results would be useful for both strength and conditioning and injury prevention programs. Total magnitude of negative power was unchanged indicating general lower limb power absorption was not affected over the course of a competitive season in this group. Total positive power increased by 1.8 W/kg and appears to be due to the increase in positive hip power, but this was not statistically significant. Further, sample size may have affected the power to find significant differences in the contributions of each joint. However, we do believe the findings of a proximal-to-distal shift in negative power and a distal-to-proximal shift in positive power warrant discussion. During prolonged running, joint work and moment tend to decrease at the ankle joint but increase at the hip and knee joints as performance continues (Vial et al., 2023). The current study did not test over the duration of a single run, but at specific instances pre- and post- a seven-week competitive season. Power absorbed and generated from the ankle were still the highest contributors at both instances. However, the contribution of power absorbed at the ankle increased by almost 2%. This finding may influence injury potential since eccentric contractions cause greater damage to recruited muscle fibers than concentric or isometric contractions (Hashizume et al., 2019). Conversely, ankle power generation decreased at the post-test while contribution from the hip increased. This outcome opposed the findings of Vial et al. (2023) and Melaro et al. (2021) who required soccer players and well-trained runners, respectively to undergo prolonged runs. Differences in run duration or distance, running experience or training level, foot strike pattern, and run intensity (Melaro et al., 2021) may influence findings. Participants in the current study ran at a self-selected steady-state pace which may have affected the results. However, using the same pace for both pre- and post-tests allowed for less outside influence on the variables. Symmetry in joint power contribution, especially negative joint power may influence injury risk given the greater damage that can occur with cumulative eccentric loads (Hashizume, et al., 2019). The current study only calculated power for a single limb and is limited in this application. It appears the cumulative effects of a training season may be most detrimental to ankle absorption power, perhaps predisposing the ankle joint musculature to injury as evidenced by the proximal-to-distal shift in negative joint power. Strength and conditioning as well as sports medicine professionals may use this information to construct injury prevention programs.

CONCLUSION: This study identified changes in negative and positive joint power and power distributions among competitive distance runners over the course of their season. Despite the small sample size, we conclude there appears to be a proximal-to-distal shift in negative power and a distal-to-proximal shift in positive power after seven weeks of a competitive season and these finding may warrant continued investigation.

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