ALTERATIONS IN JOINT KINEMATICS AND KINETICS DURING DOWNHILL RUNNING

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The purpose of this investigation was to find how joint kinematics and kinetics during downhill running change compared to level running. Fifteen recreational runners ran on a force plate imbedded treadmill with three different slopes (0 º, -6º, and -9º) at a controlled speed of 3.2 m/s. Ten steps on each slope were selected for analysis. Increased knee flexion with decreased ankle plantar-flexion and hip flexion was found during downhill running compared to level running. Decreased peak propulsive ground reaction force and posterior impulse were found during downhill running compared to level running. Additionally, increased extension moment with increased negative joint power at the knee and decreased plantar-flexion moment with decreased negative joint power at the ankle were found during downhill running compared to level running.

KEY WORDS: ground reaction forces, impulse, joint moment, joint power

INTRODUCTION: Distance runners may alter gait mechanism as an adaptive strategy when they encounter various surface conditions. Running downhill requires an increase in eccentric activation of extensor muscles (e.g. the anti-gravity muscles) of the lower extremity to support the weight of body against gravity (Eston, Mickleborough & Baltzopoulos, 1995). This indicates that increased eccentric muscle activity of the lower extremity is essential to decelerate or lower the center of mass during the stance phase of downhill running (Mizrahi, Verbitsky & Isakov, 2000). Previous studies have suggested that downhill running requires less metabolic energy cost (Cavanagh & Williams, 1982) but creates more muscle soreness (Dick & Cavanagh, 1987) which may be related to future joint injuries. In addition, biomechanics studies on downhill running have found a slight increase in stance time (Yokozawa, Fujii & Ae, 2005) and increased vertical impact peak and horizontal breaking impulse (Dick & Cavanagh, 1987) with negative work of the ankle and knee joints (Buczek & Cavanagh, 1990). Particularly, whether this higher vertical impact force during downhill running compared to the level running is related to the probability of joint injuries is controversial (Hreljac, Marshall & Hume, 2000). Therefore, the understanding of the relationship between high impact force and joint injury during downhill running is still limited. More importantly, how a runner changes joint kinematics and kinetics during downhill running as a strategy to compensate for higher demand on the lower extremity has not been fully understood. The purpose of this study was to quantify the changes in kinematics and kinetics characteristics of downhill running compared to level running.

METHODS: Fifteen male recreational runners (mean age: 25.6±4.27yrs; mean mass: 75.38±5.02kg; mean height: 177.0±5.0cm) with no history of lower extremity symptoms or injuries were recruited for this study. The subjects agreed to and completed a written consent form approved by the university ethics committee. An instrumented treadmill (Bertec Corp., Columbus, USA) with an adjustable function of slope and speed was prepared for the test. Sixteen reflective markers were attached to the following anatomical positions; left and right posterior superior iliac spines, left and right iliac crests, sacrum, left and right greater trochanters, medial and lateral femoral epicondyles, medial and lateral malleoli, calcaneus, first metatarsal head, fifth metatarsal, styloid process, second metatarsal base, and calcaneus. An additional two sets of four cluster markers were placed on the right thigh and shank. The subject was asked to stand still in the middle of the treadmill in a position with feet pointing anteriorly and approximately hip width apart and a standing trial was collected for one second. Nine anatomical markers for the definition of joint centers were removed after the standing trial as they were assumed to be the same during running. Each subject was given a five minute adaptation period of running on a treadmill before the test started. The order of running conditions (0º, -6º, and -9º) was randomized and ten successful steps of the right leg during thirty seconds of running were selected for analysis. Subjects wore their own running shoes and their running speed was controlled at 3.2 m/s. Figure 1 shows the experimental setup used in this study. The three-dimensional spatial positions of the markers were collected using a system of seven high-speed video cameras (ProReflex MCU 240, Qualysis, Sweden) at a sampling of 100 Hz and synchronized with ground reaction force data at a sampling of 1000 Hz. The kinematic and kinetic data were filtered using low-pass Butterworth filters with a cutoff frequency of 9Hz and 100Hz, respectively. Both the kinematic and kinetic data were imported into software (Visual 3D, C-Motion, USA) for the further analysis. Three-dimensional joint angular motions, moment, and power were calculated for the stance phase of running using the Newton-Euler inverse dynamics approach. Significant differences between running conditions (0º, -6º, and -9º) were determined using a repeated measures analysis of variance design (ANOVA) with a Bonferroni adjustment at a significant level of 0.05. The statistical analyses were performed using SPSS software (version 15, SPSS Inc., USA).

Figure 1: Experimental setup (Left: level running vs. Right: downhill running).

RESULTS: Table 1 shows the changes in joint kinematics and kinetics in a sagittal plane for each of the sloped conditions. There was a tendency to show a decreased range of motion (ROM) at the ankle (0º: 35.44±5.10°, -6°: 24.84±5.10°, and -9°: 20.85±4.89°, *P* < 0.001) and at the hip (0º: 28.91±4.42°, -6°: 24.34±4.88°, and -9°: 21.12±5.92°, *P* < 0.001) as the downhill slope increased while ROM of the knee is increased (0º: 25.33±4.42°, -6°: 29.66±4.42°, and -9°: 32.55±4.15°, *P* < 0.001) with a greater maximum knee flexion (0º: -39.52±5.19°, -6°: -42.04±5.09°, and -9°: -44.85±6.63°, *P* = 0.004). In addition, maximum knee extension moment increased as the slope of downhill running increased (0º: 185.66±.50Nm, -6°: 198.35±60.08Nm, and -9°: 228.93±74.65Nm, *P* = 0.017). In joint energetic, there was a tendency to show decreased maximum positive power at the ankle, knee, and hip joints as the slope of downhill running increased. Finally, the maximum negative power of the ankle decreased (0º: 574.49 ±103.06watts, -6°: 325.43 ±99.18watts, and -9°: 230.16±77.60watts, *P* < 0.001) but the maximum negative power of the knee (0º: -523.06±132.10watts, -6°: -793.32±301.66watts, and -9°: -1068.33±380.97watts, *P* < 0.001) (Figure 2). No significant differences were found in any of the gait parameters (e.g. contact time, swing time, stride length, and stride frequency) among the conditions. However, there was a difference in posterior impulse (-6°: 11.62±4.33Ns, -9°: 9.99±4.45Ns, *P* = 0.002) and maximum posterior force (-6°: 132.83±42.31N, -9°: 117.40±51.51N, *P* < 0.012) between -6° and -9° downhill indicating decreased posterior components of the force with a steeper condition.

DISCUSSION: There were no differences in gait parameters such as contact time, swing time, stride length, and stride frequency with a steeper slope. A previous study investigating the effect of downhill angle on running kinematics at a similar speed of running also found no changes in these variables (Gattschall & Kram, 2005). This finding indicates that downhill running has a minimum effect on these gait parameters in moderately sloped conditions. In joint kinematics, the runners decreased the range of motion in ankle and hip joints but increased the range of the knee during downhill running. Dick and Cavanagh (1987) also found that runners show increased motion of the knee in downhill running compared to level running.

Table 1 Comparisons of joint kinematics and kinetics between sloped conditions

Joint	Variables	0° M(SD)	-6 Down M(SD)	-9 Down M(SD)	F(df)[p]	p-value 0° vs. -6°	p-value -6° vs. -9°	p-value 0° vs. -9°
Ankle	Max. dorsi-flexion (°)	22.60 (3.37)	18.27 (3.92)	15.73 (3.71)	119.411(1,14) [.000]	**.000**	**.000**	**.000**
	Max. plantar flexion (°)	-12.84 (5.36)	-6.57 (5.41)	-5.12 (5.58)	33.852(1,14) [.000]	**.000**	.475	**.000**
	ROM (°)	35.44 (5.10)	24.84 (5.34)	20.85 (4.89)	203.915(1,14) [.000]	**.000**	**.001**	**.000**
	Max. dorsi-flexion moment (Nm)	9.47 (7.68)	17.40 (15.05)	26.08 (18.50)	13.349(1,14) [.003]	.138	**.006**	**.009**
	Max. plantar flexion moment (Nm)	-169.20 (21.97)	-142.06 (22.76)	-121.64 (25.08)	66.169(1,14) [.000]	**.002**	**.000**	**.000**
	Max. positive joint power (W)	574.49 (103.06)	325.43 (99.18)	230.16 (77.60)	378.431(1,14) [.000]	**.000**	**.000**	**.000**
	Max. negative joint power (W)	-264.05 (72.93)	-245.09 (75.71)	-216.22 (60.02)	15.092(1,14) [.002]	.914	.233	**.006**
	Dorsi-flexion at HC (°)	12.03 (4.38)	10.38 (5.00)	9.85 (5.60)	3.690(1,14) [.077]	.313	.977	.231
Knee	Max. flexion (°)	-39.52 (5.19)	-42.04 (5.09)	-44.85 (6.63)	12.192(1,14) [.004]	**.000**	.191	**.012**
	Min. flexion (°)	-14.19 (5.50)	-12.38 (5.82)	-12.30 (6.30)	6.134(1,14) [.028]	.057	1	.083
	ROM (°)	25.33 (4.42)	29.66 (4.42)	32.55 (4.15)	24.311(1,14) [.000]	**.000**	**.035**	**.001**
	Max. extension moment (Nm)	185.66 (36.50)	198.35 (60.08)	228.93 (74.65)	7.433(1,14) [.017]	.832	**.012**	.052
	Max. flexion moment (Nm)	-17.99 (7.61)	-7.63 (18.63)	-0.97 (24.10)	7.976(1,14) [.014]	.115	**.037**	**.043**
	Max. positive joint power (W)	208.47 (78.73)	187.38 (106.73)	139.19 (84.96)	9.998(1,14) [.007]	.997	**.034**	**.022**
	Max. negative joint power (W)	-523.06 (132.10)	-793.32 (301.66)	-1068.33 (380.97)	40.173(1,14) [.000]	**.001**	**.000**	**.000**
	Flexion at HC (°)	-14.26 (5.48)	-12.23 (5.84)	-12.22 (6.32)	7.034(1,14) [.020]	**.032**	1.000	.060
Hip	Max. flexion (°)	34.05 (8.91)	32.19 (7.67)	31.62 (8.17)	11.250(1,14) [.005]	**.009**	.972	**.016**
	Min. flexion (°)	5.14 (8.20)	7.84 (8.28)	10.50 (9.67)	51.714(1,14) [.000]	**.001**	**.004**	**.000**
	ROM (°)	28.91 (4.42)	24.34 (4.88)	21.12 (5.92)	64.677(1,13) [.000]	**.000**	**.003**	**.000**
	Max. flexion moment (Nm)	36.40 (14.00)	43.52 (38.01)	60.43 (62.43)	2.005(1,13) [.180]	1	.289	.541
	Max. extension moment (Nm)	-70.40 (11.58)	-60.37 (34.45)	-52.14 (50.46)	2.037(1,13) [.177]	.717	.744	.531
	Max. positive joint power (W)	89.02 (40.91)	55.91 (30.36)	69.56 (84.72)	0.714(1,13) [.413]	**.000**	1	1
	Max. negative joint power (W)	-44.55 (50.69)	-108.67 (106.20)	-150.78 (178.33)	5.645(1,13) [.034]	.079	.347	.101
	Flexion at HC (°)	34.00 (8.88)	31.61 (8.27)	30.47 (8.28)	26.967(1,13) [.000]	**.000**	.215	**.001**

Note: Bolded numbers indicate the differences. Max.: maximum, Min.: minimum, HC: heel contact

Furthermore, previous studies have found changed kinetic variables, such as ground reaction forces, joint moments, and joint powers of the lower extremity during downhill running (Buczek & Cavanagh, 1990; Gattschall & Kram, 2005; Yokozawa, Fujii & Ae, 2005). It is expected that the runners on a downhill slope would decrease the propulsive impulse and increase the breaking impulse compared to level running. The current study also found a trend showing decreased propulsive impulse during the stance phase of downhill running.

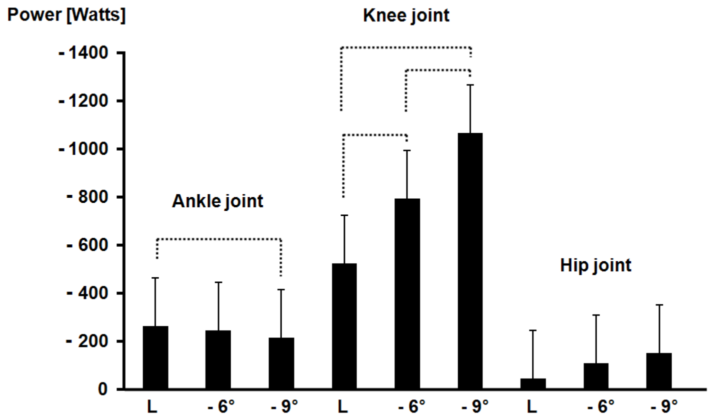

Figure 2: The differences in negative peak joint power at the ankle, knee, and hip joints.

However, the results showed no changes in impact and breaking forces from level to downhill running. These findings contradict the results of the previous studies on the effects of downhill running on ground reaction forces (Gattschall & Kram, 2005). It is assumed that the types of foot contact (e.g. heel or forefoot contact at an initial contact of the foot) of the runners may have different effects on those ground reaction forces during downhill running. For example, most runners who have initial contact with the heel while running on a level surface would switch to initial forefoot contact while running downhill, but some may still initiate each step with contact with the heel.

CONCLUSION: In this study, the runners changed the kinematics and kinetic strategy as they decreased the range of motion at the ankle but the range of motion decreased with increased negative joint power at knee joint during downhill running compared to level running. The findings suggest that runners alter gait strategy as they rely more on the function of the knee on a steep slope when running downhill.

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