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Research Article

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Kinematic Comparison Between Walking and Jogging in The Lower Limbs Joints

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Abstract

Background

Walking and jogging are considered two of the most important movements in human daily life. However, no previous studies have been conducted comparing the kinematics between these two movements.

Research questions

Are there any differences in joint kinematics of the lower limbs when walking and jogging?

Methods

Thirteen healthy males participated in this study with a mean age of 31.6 years. A motion capture system was used to collect walking and jogging movements in the lower limbs. The joint angles in hip, knee and ankle were compared between two movements. Statistical method was the repeated measurement of general linear model.

Results

The main finding was a significant difference between walking and jogging in the hip and ankle in sagittal plane in the knee in the transverse plane. During the entire gait cycle, the hip max extension in walking were roughly 9 deg larger than in jogging, but hip max flexion in walking were roughly 4 deg smaller than in jogging; as whole in the sagittal plane, the range of motion in the hip was larger in walking than in jogging by roughly 12%. Knee angles in the transverse plane were significantly greater in jogging than in walking by roughly 6 deg or 26% while similar in the sagittal plane. The ankle had larger range of motion in jogging than in walking by roughly 10 deg or 22% in the sagittal plane.

Significance

The study results demonstrate that jogging has not increased hip range of motion in the sagittal plane, but increased knee rotation in transverse plane largely in compared with walking. Moreover, jogging required greater flexibility at the ankle. The findings indicate that the protection of injury needs to pay more attention to the knee and ankle.

Keywords: Jogging, Walking, Kinematics, Stance phase, Swing phase.

1. Introduction

Walking and jogging are essential skills for human activities. In addition, walking and jogging are considered two of the most popular forms of exercise (Thomas and Londeree, 1989) [1]. Kotera et al. (2021) stated that walking in nature could help improve anxiety [2]. Moreover, a recent study stated that jogging has a positive effect on reducing visceral fat (Abdulsalam et al. 2021) [3]. Therefore, understanding the kinematics of the lower limb joints during walking and jogging is important as the lower limb joints are the main involved joints in both movements and have an important role in weight bearing. Kinematics is the study of the relative motion between two consecutive segments of the human body (Affatato, 2015) [4]. Kinematics focuses on the motion description, regardless of the cause of the motion. However, it is not clear whether lower limb joint kinematics is different between walking and jogging. It is hypothesised that jogging has greater range of motion in kinematic parameters than walking. To the best of our knowledge, no previous studies have compared the lower limb kinematics of walking and jogging. The aim of the study was to identify whether there are differences in the joint kinematics in the lower limbs during walking and jogging. Results from this study could help in rehabilitation science.

2. Methods and materials

The data collection for the project was conducted at University of Dundee. Human experimentation was approved by the School of Medicine Research Ethics Committee (SMED 087/18) and conforms to the Helsinki Declaration. Each participant signed a consent form before data collection commenced.

3. Study Participants

The inclusion criteria were healthy adults invited by recruitment poster to volunteer for the study. Thirteen healthy male volunteers participated. The mean age 32±5.5 (SD) with range from 20 - 40 years old. The mean weight was measured (78.8) kg with range from 53.4 to 102.6 kg and mean height was (171.7) cm with range from 154 to 180 cm.

4. Data Collection

4.1. The Vicon Motion Capture System

The joint movements were collected using a Vicon® motion capture system, 16 high-resolution MX40 cameras (4 Mega-pixel) installed, along with Nexus version 2.7 software, at 200 Hz. The space to be collected by motion capture system was 20 m in length and 4 m in width.

5. Preparation of Subject

The participants were prepared for placement of the 16 reflective markers, and 4 wand markers were placed on the body of each participant (Supplement file). Four reflective markers were placed at the pelvic region for both anterior superior iliac spine and posterior superior iliac spine. In addition, four markers were placed at the knee region on the medial and lateral condyles, two markers on each knee, four markers for both medial and lateral malleolus at the ankle joints, two markers for the heels and finally one marker on the dorsal aspect of each foot.

6. Data Collection

Anthropometric measurements of height, weight, gender, age, and body mass index were collected. Participants were required to perform 10 trials, including 5 trails of walking and 5 trails of jogging at the participants' comfortable speeds. The order of walking or jogging was random. The best three quality trials of the five were selected for analysis. Data were explored to define one gait cycle in each trial. The joint angles in the hip, knee and ankle were calculated using Plug-in-Gait model from Vicon.

7. Statistical Analysis

Data were statistically analysed using Statistical Package of Social Science software (v 22). The study used the statistical method of repeated measurement of general linear model and Bonferroni option was used for post hoc test. The movement way was used as within-subject factor, i.e., main factor and body mass and height as covariate and interactive factors. The data normality was checked using One-Sample Kolmogorov-Smirnov Test. If variables were not normal distribution, a nonparametric test, e.g., Wilcoxson signed rank test, was used to check p value again. The statistically significant level was set at $p < 0.05$.

8. Results

8.1. Gait Parameters

As expected, the gait parameters showed significant differences between walking and jogging. The cadences, stride lengths, step lengths, step widths and speed were significantly greater when jogging with an exception in step width which was significantly wider during walking than jogging (Table 1 & Figure 1).

Table 1: Comparison of gait parameters between walking and jogging

Dependent Variable	Movement way	Mean	Std. Error	95% Confidence Interval		P value
				Lower Bound	Upper Bound	
Right Cadence (steps/min)	Jogging	166.07	1.36	163.2	168.9	<0.0001
	Walking	117.49	0.53	116.3	118.6	
Left Cadence (steps/min)	Jogging	161.77	1.31	159.04	164.5	<0.0001
	Walking	116.08	0.33	115.38	116.7	
Right Stride Length (m)	Jogging	1.47	0.01	1.45	1.49	<0.0001
	Walking	1.31	0.006	1.3	1.3	
Left Stride Length (m)	Jogging	1.46	0.017	1.42	1.49	<0.0001
	Walking	1.32	0.006	1.31	1.33	
Right Step Length (m)	Jogging	0.75	0.007	0.74	0.77	<0.0001
	Walking	0.66	0.004	0.65	0.67	
Left Step Length (m)	Jogging	0.73	0.008	0.71	0.75	<0.0001
	Walking	0.65	0.004	0.64	0.66	
Right Step Width (m)	Jogging	0.19	0.003	0.19	0.20	0.007
	Walking	0.21	0.003	0.20	0.22	
Left Step Width (m)	Jogging	0.18	0.002	0.17	0.18	0.002
	Walking	0.19	0.003	0.19	0.20	

Right Speed (m/s)	Jogging	2.04	0.024	1.99	2.09	<0.0001
	Walking	1.28	0.008	1.26	1.30	
Left Speed (m/s)	Jogging	1.96	0.029	1.90	2.02	<0.0001
	Walking	1.28	0.008	1.26	1.29	

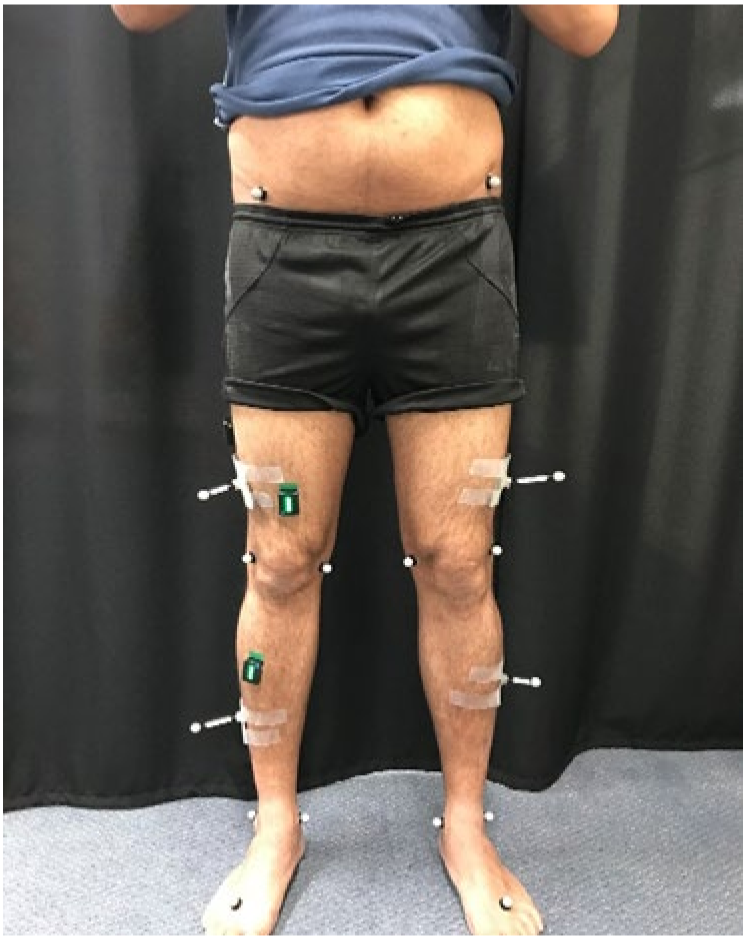

Figure 1: Retro-reflective markers placed according to Vicon Clinical Management System

Highlights

- Comparison of kinematics between walking and jogging
- Jogging has smaller hip extension than walking
- Jogging has larger dorsiflexion than walking
- Jogging has narrower step width than walking

9. Joint Kinematic Results in the Stance and Swing Phases

9.1. Hip

During the stance phase, the hip joint angle results showed no significant difference in hip flexion, adduction, internal rotation and external rotation. However, the significant differences were seen in some angles, the hip max extension and range of motion were larger in walking than in jogging. Moreover, in the frontal plane, the hip max abduction and RoM angles were significantly greater in walking than in jogging. In general, during the stance phase, there was no significant difference in the hip angles in the transverse plane as in Table 2. [Table 2]. In the swing phase, the results showed that the hip max flexion angle was greater during jogging. In contrast, the hip extension angle was significantly greater during walking as in Table 2. Furthermore, in the frontal plane during the swing phase, the hip adduction angle was greater when jogging than when walking, while the hip abduction angle was greater during walking than when jogging as in Table 2.

Table 2: Comparison of hip angles (deg) between walking and jogging in stance and swing phases

hip joint angles stance phase							hip joint angles swing phase						
Measure		Mean	Std. Error	95% Confidence Interval		P value	Measure		Mean	Std. Error	95% Confidence Interval		P value
				Lower Bound	Upper Bound						Lower Bound	Upper Bound	
hip max flexion	jogging	28.45	0.83	26.79	30.12	0.238	hip max flexion	jogging	34.05	0.88	32.26	35.84	p<.001
	walking	27.72	0.78	26.16	29.29			walking	30.23	0.68	28.85	31.61	
hip max extension	jogging	-2.26	0.98	-4.24	-0.29	p<.001	hip max extension	jogging	-1.20	1.08	-3.40	0.98	p<.001
	walking	-11.21	0.61	-12.45	-9.98			walking	-4.30	0.66	-5.64	-2.96	
hip RoM sagittal plane	jogging	30.72	0.73	29.24	32.20	p<.001	hip ROM sagittal plane	jogging	35.26	1.04	33.16	37.36	0.504
	walking	38.94	0.57	37.78	40.09			walking	34.54	0.61	33.29	35.79	
hip max adduction	jogging	4.45	0.59	3.27	5.64	0.463	hip max adduction	jogging	2.38	0.53	1.32	3.45	p<.001
	walking	4.68	0.53	3.60	5.76			walking	-0.28	0.57	-1.43	0.86	
hip max abduction	jogging	-2.30	0.58	-3.48	-1.13	p<.001	hip max abduction	jogging	-5.63	0.48	-6.60	-4.66	p<.001
	walking	-6.29	0.51	-7.31	-5.26			walking	-7.32	0.47	-8.26	-6.37	
hip RoM frontal plane	jogging	6.76	0.31	6.13	7.39	p<.001	hip RoM frontal plane	jogging	8.02	0.41	7.18	8.85	0.053
	walking	10.97	0.39	10.18	11.76			walking	7.03	0.40	6.23	7.83	
hip max IR	jogging	-7.66	1.11	-9.91	-5.41	0.258	hip max IR	jogging	-3.21	0.81	-4.85	-1.58	0.157
	walking	-8.46	1.17	-10.84	-6.08			walking	-4.07	1.02	-6.12	-2.02	
hip max ER	jogging	-20.78	1.13	-23.07	-18.49	0.498	hip max ER	jogging	-21.66	1.11	-23.91	-19.42	0.029
	walking	-20.38	0.99	-22.40	-18.37			walking	-23.08	1.13	-25.35	-20.80	
hip RoM transverse plane.	jogging	13.12	0.86	11.37	14.86	0.237	hip RoM transverse plane.	jogging	18.44	0.91	16.60	20.28	0.437
	walking	11.92	0.60	10.70	13.13			walking	19.00	0.84	17.30	20.70	

Note: ROM: range of motion, IR: internal rotation, ER: external rotation.

9.2. Knee

During the stance phase in the sagittal plane, the knee RoM were significantly greater during walking. The knee max extension angle was three times greater when jogging compared to walking. In fact, the normal knee extension will be approximately zero degree, but this could be because the marker placement. However, to reduce the marker placement errors we compared the same participant as paired data. In the frontal plane, the knee max adduction angle was significantly greater when walking than when jogging. In contrast, the knee max abduction angle was greater during jogging compared to walking. Furthermore, in the transverse plane, the knee joint results showed that knee max internal rotation, max external rotation, and RoM were significantly greater during jogging than in walking as in Table 3.

Table 3: Knee angles between walking and jogging in stance and swing phases

knee joint angles stance phase							knee joint angles swing phase						P value
Measure		Mean	Std. Error	95% Confidence Interval		P value	Measure		Mean	Std. Error	95% Confidence Interval		
				Lower Bound	Upper Bound						Lower Bound	Upper Bound	
Knee max flexion	jogging	37.198	1.325	34.543	39.852	0.77	Knee max flexion	Jogging	68.97	1.31	66.33	71.6	p<0.001
	walking	36.94	1.24	34.45	39.44			Walking	61.01	1.16	58.69	63.33	
knee max extension	jogging	13.46	0.75	11.93	14.99	p<0.0001	knee max extension	jogging	10.35	0.68	8.97	11.72	p<0.0001
	walking	4.73	0.39	3.94	5.53			walking	3.64	0.51	2.62	4.67	
knee RoM sagittal plane	jogging	23.99	0.67	22.62	25.36	p<0.0001	knee RoM sagittal plane	jogging	56.52	0.63	55.24	57.81	0.130
	walking	32.61	0.61	31.36	33.87			walking	55.35	0.48	54.39	56.32	
knee max adduction	jogging	-0.21	0.42	-1.06	0.64	p<0.0001	knee max adduction	jogging	0.39	0.53	-0.69	1.47	p<0.0001
	walking	1.24	0.38	0.45	2.03			walking	1.99	0.51	0.96	3.03	

knee max abduction	jogging	-6.61	0.53	-7.70	-5.52	P= 0.001	knee max abduction	jogging	-9.15	0.75	-10.68	-7.62	0.431
	walking	-4.99	0.61	-6.24	-3.74			walking	-8.81	0.66	-10.14	-7.48	
knee RoM frontal plane	jogging	6.40	0.40	5.57	7.22	0.753	knee RoM frontal plane	jogging	9.54	0.42	8.68	10.40	0.023
	walking	6.23	0.65	4.91	7.55			walking	10.81	0.54	9.71	11.90	
knee max IR	jogging	19.85	0.71	18.42	21.28	p<0.0001	knee max IR	jogging	14.30	0.57	13.15	15.46	p<0.0001
	walking	11.17	0.69	9.77	12.58			walking	11.98	0.55	10.88	13.09	
knee max ER	jogging	4.46	0.70	3.05	5.87	p<0.0001	knee max ER	jogging	-2.39	0.78	-3.97	-0.81	0.162
	walking	-0.82	0.69	-2.22	0.57			walking	-3.07	0.64	-4.36	-1.78	
knee RoM transverse plane.	jogging	15.38	0.67	14.04	16.73	p<0.0001	knee RoM transverse plane.	jogging	16.70	0.69	15.31	18.09	0.012
	walking	12.00	0.65	10.69	13.31			walking	15.06	0.59	13.86	16.26	

Note: ROM: range of motion, IR: internal rotation, ER: external rotation.

While in the swing phase, the knee joint results showed that the knee max flexion and max extension angles were greater in jogging than in walking as in Table 3. No significant difference was found in the knee RoM in the sagittal plane. Moreover, the knee joint in the frontal plane showed that the knee max adduction and RoM were greater in walking than in jogging. With regards the knee joint results in the transverse plane, the knee max internal rotation and knee RoM angles were significantly greater when jogging. However, there was no significant difference in knee external rotation angle in the swing phase.

9.3. Ankle

The ankle joint results during stance phase showed a significant difference in the sagittal and frontal planes. Therefore, the max ankle dorsiflexion, plantarflexion, inversion, eversion was significantly larger when jogging as in Table 4. In addition, the ankle RoM was significantly greater while jogging compared to walking in all three planes. However, the max ankle internal rotation and external rotation angles were significantly greater in walking compared to jogging as in Table 4. During the swing phase the ankle joint angles were significantly different. In the sagittal plane the max ankle dorsiflexion, plantarflexion and RoM angles were greater during jogging compared to walking. While, in the frontal plane results showed no significant difference in ankle inversion angle. However, the angles of ankle max eversion and RoM were significantly greater during jogging as in Table 4. Moreover, in the transverse plane, the results showed a significant difference in the ankle external rotation with the angle being double that of walking compared to jogging. However, the ankle RoM angles were significantly greater during jogging compared to walking as in Table 4.

Table 4: Ankle angles between walking and jogging in stance and swing phases

ankle joint angles stance phase							ankle joint angles swing phase						
Measure		Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	P value	Measure		Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	P value
ankle max DF	jogging	24.08	0.69	22.67	25.49	p<0.0001	ankle max DF	jogging	12.01	0.70	10.58	13.44	p<0.0001
	walking	16.75	0.45	15.83	17.67			walking	5.30	0.39	4.49	6.10	
ankle max PF	jogging	-19.93	0.97	-21.89	-17.97	p<0.0001	ankle max PF	jogging	-20.00	0.93	-21.88	-18.11	0.006
	walking	-13.45	0.86	-15.19	-11.71			walking	-17.06	0.85	-18.80	-15.32	
ankle RoM sagittal plane	jogging	44.02	0.84	42.32	45.72	p<0.0001	ankle ROM sagittal plane	jogging	32.01	1.00	29.97	34.04	p<0.0001
	walking	30.20	0.87	28.44	31.97			walking	22.36	0.84	20.65	24.08	
anke max inversion	jogging	7.79	0.50	6.76	8.82	p<0.0001	anke max inversion	jogging	7.74	0.51	6.68	8.81	0.223
	walking	5.94	0.43	5.05	6.83			walking	8.21	0.56	7.04	9.37	
ankle Mx eversion	jogging	-6.77	0.49	-7.77	-5.77	0.004	ankle max eversion	jogging	-4.84	0.41	-5.70	-3.98	p<0.0001
	walking	-5.50	0.42	-6.37	-4.62			walking	-2.44	0.33	-3.13	-1.74	
ankle RoM frontal plane	jogging	14.56	0.72	13.08	16.05	p<0.0001	ankle RoM frontal plane	jogging	12.59	0.75	11.04	14.14	p<0.0001
	walking	11.44	0.49	10.43	12.45			walking	10.65	0.63	9.33	11.96	
ankle max IR	jogging	22.06	0.97	20.03	24.09	0.045	ankle max IR	jogging	21.83	1.04	19.69	23.96	0.263
	walking	23.59	1.22	21.04	26.14			walking	22.41	1.19	19.99	24.84	

ankle max ER	jogging	1.66	0.78	0.03	3.29	p<0.0001	ankle max ER	jogging	3.36	1.10	1.12	5.61	p<0.0001
	walking	7.42	1.42	4.47	10.37			walking	6.14	1.14	3.81	8.48	
ankle RoM transverse plane	jogging	20.39	0.77	18.79	22.00	p<0.0001	ankle RoM transverse plane	jogging	18.46	0.67	17.08	19.83	0.006
	walking	16.16	0.52	15.07	17.26			walking	16.26	0.68	14.88	17.65	

Note: DF: dorsiflexion, PF: plantarflexion, ROM: range of motion, IR: internal rotation, ER: external rotation.

10. Joint Angles in the Whole Gait Cycle

10.1. Hip

With regards to the gait cycle, the hip joint results showed significant difference in hip flexion, extension and RoM in the sagittal plane. The hip flexion angle was significantly greater during jogging. While the hip extension and the RoM angles were significantly greater when walking, see Table 5 and Figure 2. A, i. In the frontal plane, there was significant difference found in the angles of hip abduction and RoM and were significantly greater during walking. (Table 5) (Figure 2, A, ii). Finally, the results in the transverse plane showed no significant difference in the hip external rotation and RoM angles except for the internal rotation angle which was significantly greater during walking compared to jogging, see Table 5 and Figure 2, A, iii.

Table 5: Hip, knee and ankle joints results (deg) for the whole gait cycle.

Joint angle name in the whole gait cycle		Mean (degree)	Std. Error	95% Confidence Interval		P Value
				Lower Bound	Upper Bound	
Hip Max Flexion	jogging	34.61	0.80	33.003	36.22	p<0.0001
	walking	30.48	0.66	29.14	31.82	
Hip Max Extension	jogging	-1.39	0.94	-3.28	0.49	p<0.0001
	walking	-10.75	0.62	-12.00	-9.50	
Hip RoM in sagittal plane	jogging	36.00	0.76	34.47	37.54	
	walking	41.23	0.48	40.25	42.20	p<0.0001
Hip Max Adduction	jogging	4.93	0.50	3.90	5.95	0.853
	walking	4.99	0.53	3.92	6.06	
Hip Max Abduction	jogging	-5.47	0.48	-6.45	-4.50	p<0.0001
	walking	-7.15	0.47	-8.11	-6.20	
Hip RoM in frontal plane	jogging	10.41	0.31	9.78	11.03	p<0.0001
	walking	12.14	0.43	11.28	13.01	
Hip Max Internal rotation	jogging	-1.89	.83	-3.57	-0.20	0.006
	walking	-3.55	1.06	-5.69	-1.40	
Max External rotation	jogging	-23.03	1.13	-25.31	-20.75	0.280
	walking	-23.66	1.09	-25.87	-21.45	
Hip RoM in transvers plane	jogging	21.14	0.95	19.23	23.05	0.216
	walking	20.11	0.72	18.67	21.56	
Knee Max Flexion	jogging	66.82	0.61	65.58	68.05	p<0.0001
	walking	58.91	0.57	57.75	60.06	
Knee Max Extension	jogging	10.13	0.61	8.89	11.38	p<0.0001
	walking	2.60	0.47	1.65	3.54	

Knee RoM in sagittal plane	jogging	56.68	0.64	55.39	57.97	0.616
	walking	56.31	0.43	55.42	57.19	
Knee Max Adduction	jogging	.59	0.58	-.57	1.76	0.006
	walking	1.65	0.53	.57	2.72	
Knee Max Abduction	jogging	-10.40	0.81	-12.05	-8.75	0 .003
	walking	-8.92	0.71	-10.37	-7.46	
Knee RoM in frontal plane	jogging	10.99	0.50	9.96	12.01	0.497
	walking	10.57	0.57	9.40	11.74	
Knee Max Internal rotation	jogging	20.93	0.68	19.55	22.32	p<0.0001
	walking	14.05	0.61	12.82	15.28	
Knee Max External rotation	jogging	-2.52	0.76	-4.05	-0.99	0.034
	walking	-3.53	0.669	-4.886	-2.191	
Knee RoM in transvers plane	jogging	23.46	0.96	21.52	25.40	p<0.0001
	walking	17.59	0.55	16.47	18.71	
Ankle Max Dorsi flexion	jogging	24.42	0.69	23.02	25.82	p<0.0001
	walking	16.73	0.48	15.75	17.71	
Ankle Max Planter flexion	jogging	-20.34	0.92	-22.20	-18.48	0.007
	walking	-17.78	0.81	-19.42	-16.14	
Ankle RoM in sagittal plane	jogging	44.77	0.85	43.03	46.50	p<0.0001
	walking	34.52	0.87	32.75	36.28	
Ankle Max Inversion	jogging	7.69	0.55	6.57	8.82	0.174
	walking	7.27	0.40	6.43	8.10	
Ankle Max Eversion	jogging	-5.52	0.45	-6.45	-4.60	0.047
	walking	-5.08	0.45	-6.02	-4.15	
Ankle RoM in frontal plane	jogging	13.25	0.79	11.58	14.86	0.039
	walking	12.35	0.73	10.84	13.86	
Ankle Max Internal rotation	jogging	22.10	0.99	20.08	24.13	0.077
	walking	23.03	1.0	20.90	25.16	
Ankle Max External rotation	jogging	-.52	0.80	-2.15	1.11	p<0.0001
	walking	4.26	1.0	2.13	6.38	
Ankle RoM in transvers plane	jogging	22.62	0.59	21.42	23.83	p<0.0001
	walking	18.77	0.54	17.65	19.88	

10.2. Knee

Knee joint results during the whole gait cycle in the sagittal plane showed significant difference in the knee flexion and extension angles. The angles were significantly greater during jogging. (see Table 5 and Figure 2, B, i). The results of the knee joint in the frontal plane during the gait cycle showed significant difference in the knee adduction angle. The angle was three times greater during walking. However, the knee abduction angle was significantly greater during jogging. There was no significant difference in the knee RoM in the frontal plane in the gait cycle (see Table 5 and Figure 2, B, ii). With regards the knee joint result in the transverse plane during the gait cycle, the results showed significant difference in the knee internal rotation and the RoM. The angles were significantly larger when jogging. However, the knee external rotation angle during the gait cycle was significantly larger when walking (see Table 5 and Figure 2, B, iii).

10.3. Ankle

The results of the ankle joint in the gait cycle showed a significant difference in the ankle dorsiflexion, plantarflexion and RoM in the sagittal plane. The angles were significantly larger during jogging (see Table 5 and Figure 2, C, i). Furthermore, in the frontal plane, the results showed a significant difference in the ankle eversion and RoM where the angles were significantly greater when jogging (see Table 5 and Figure 2, C, ii).

In addition, in the transverse plane during the gait cycle, results showed no significant difference in ankle internal rotation, nevertheless, significantly the ankle external rotation angle was larger during walking and the ankle RoM angle was larger when jogging (see Table 5 and Figure 2, C, iii).

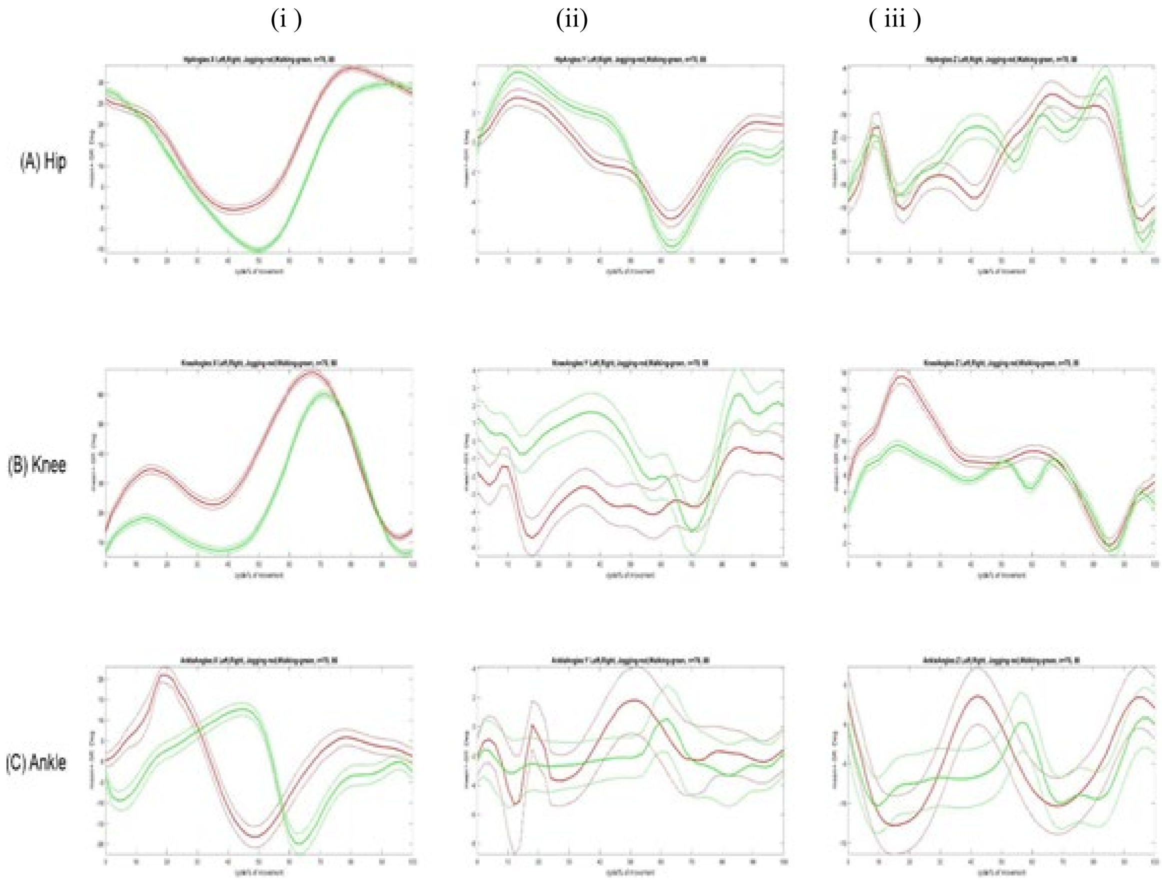

Figure 2: Hip, knee and ankle angles during the whole gait cycle. Red (jogging), green (walking), i (sagittal), ii (frontal), iii (transverse). The solid lines are mean and doted ones standard errors.

11. Discussion

The present study revealed the differences in the joint angles of the hip, knee, ankle between walking and jogging in the sagittal, frontal and transverse planes. The study results rejected the original hypothesis.

12. Joint Angles in the Sagittal Plane

In the sagittal plane, the hip extension angle was greater in walking during the stance phase, swing phase and the gait cycle. Kerrigan et al.(2003) stated that reduction of peak hip extension during gait resulting in static hip flexion contraction [5]. Therefore, hip flexor muscles contracture could occur more while jogging. Kerrigan et al. (2001) noted reduction of hip extension in walking could increase the risk of fall in the elderly population [6] . Therefore, the study results indicate that falling risk could be greater when jogging due to less hip extension angle compared to walking in additon to the narrowing of step width during jogging. Pink et al. (1994)stated that hip extension increased in the early swing phase as speed increased [7]. However, Kerrigan et al. (2001) noted that increasing the walking speed did not increase the hip extension in the elderly [6]. The present study findings support this finding as the significant speed difference between walking and jogging does not appear to influnce hip extnsion as the hip extension angle was greater during walking.

The study found that hip flexion angle was significantly greater when jogging during the swing phase and the gait cycle. This finding increases the risk of hamstring muscle strain (Guex et al. 2012) due to the direct relationship between the hip flexion angle and the hamstring torque [8].

The movments of the knee joint through the sagittal plane is essintial for normal gait. Therefore, the most common cause of abnormal gait is due to abnormal knee kinematics (Whittle 2014) [9]. Our study suggested that lowering the knee flexon angle in swing phase of walking comapred to jogging could be due to higher eccentric contraction of the rectus femoris. Hence ,walking has greater hip extension angle. This suggestion is supported by Piazza et al. (1996) rectus femoris acitvity could reduce the knee flexion during the swing phase [10]. Moreover, speed could influence the knee flexion angle to mantian body balance. Mann and Hagy (1980) stated the body intend to flex the hip and knee joint when the body speed risen to lower its center of gravity [11]. Our study results support this because the hip and knee flexion angles were greater when jogging during the gait cycle and jogging has singinficantlly higher speeds than walking.

With regards the ankle joint, most movements of the ankle joint are in the sagittal plane (Brockett and Chapman, 2016) [12]. The ankle dorsiflexion, plantarflexion and RoM were significantlly greater in jogging during the stance and swing phase. Rabin et al. (2016) stated that participants with low dorsiflexion angle exhibited lower knee flexion, which may 'explain why the knee flexion angle was lower when walking compared to jogging [13]. Drewes et al. (2009) stated that joggers with chronic ankle instability show a limitation in dorsiflexion movement, which may be the cause of recurrent ankle sprains in chronic ankle injury [14] . The study suggested that restoring full normal dorsiflexion RoM in patients with ankle sprain is essential before recommencing jogging.

13. Joint Angles in the Frontal Plane

The hip abduction angle was greater when walking during the stance phase, swing phase, and the whole gait cycle. Therefore, gluteus medius activation could be greater during walking. Liu et al. (2006) [15] suggested that gluteus medius play in imprtant role in walking dynamics, and the findings from the present study support this and suggest that the muscles in the frontal plane work more when walking than when jogging [15].

In the swing phase, the hip adduction angle was significanttly greater when jogging. The study suggested that jogging has greater injury risk due to the greater hip adduction angle during the swing phase. A large number of lower limb injuries during running are linked with excessive hip adduction (Baggaley et al., 2015) [16]. Interstinglly, results for the knee in the frontal plane show adduction angles were significantly greater during walking in the stance phase, swing phase, and whole gait cycle. Hsu et al. (1990) noted approximately 75% of knee load is passed through the medial compartment. Therefore, during normal walking, excessive knee adduction angle may increase the risk of knee osteoarthritis [17]. This analysis, supported by Barrios et al. (2010) , in that knee varus aligment is a risk factor for medial knee osteoarthritis due to the knee adduction moment [18].

Injuries occuring due to high-impact exercises mostly affect the knee joint in females when running and highlights a greater knee abduction angle than in males (Sakaguchi et al., 2014) [19]. Hewett et al. (2005) noted females with greater knee abduction are more exposed to anterior cruciate ligament injury[20]. In fact, our study did not compare genders. However, the study results suggested that increasing knee abduction angle could explain injuries seen in high-impact exercises. Ivins (2006) noted the most common musculoskeletal injury is acute ankle sprain. Our study finding suggested that jogging has a greater risk of injury on the ankle joint due to the greaterankle joint angles in both sagittal and frontal planes [21].

14. Joint Angles in the Transverse Plane

The joint rotation movements mainly occur in the transverse plane. The hip results showed significant difference in hip external rotation in the swing phase and was greater during walking. The hip postion in the swing phase while walking may enhance sacroiliac joint mobility. Bussey et al. (2009) noted that sacroilic joint pain is linked with a reduction in hip abduction and external rotation [22]. The study suggested that patients with sacroiliac pain could partake in normal walking to enahance sacroilic joint mobility. While the knee internal rotation and RoM were greater when jogging in the stance phase, swing phase and the whole gait cycle. Therefore, the combination of greater knee abduction and internal rotation when jogging could increase the risk of anterior cruciate ligament injury (Navacchia et al. ,2019) [23]. The ankle external rotation was significantly greater during walking in both phases and the whole gait cycle. The study suggests that hip position and angles during walking could be the key point for the greater ankle external rotation. Interstingly, the ankle RoM was significantlly greater when jogging in all three planes. However, Brockett and Chapman (2016)stated that age and gender could influnence ankle RoM. As age increased the ankle RoM decreased, while females have a larger RoM than males [12].

15. Conclusion

Walking has larger hip extension, abduction, external rotation, and knee adduction angels than jogging. While jogging has larger hip adduction angle. However, walking has wider step width than jogging so the base of support is larger in walking, which may indicate more stability in walking. Jogging has greater ankle angles on the sagittal and frontal planes. The study concludes that there is no direct relationship between speed and hip extension angle. The study results demonstrate that jogging has not increased hip range of motion in the sagittal plane, but increased knee rotation in transverse plane largely in compared with walking. Moreover, jogging required greater flexibility at the ankle. The findings indicates that the protection of injury needs to pay more attention to the knee and ankle. Farther study needed to investigate whether the knee adduction angle in walking has any relation with medial knee osteoarthritis, and weather the hip adduction angle in jogging during the swing phase would increase the risk of injures.

Limitations

the present study the data were collected from a small group of people and the participants were only male. Participant selection was done amongst a mixed group of sportsperson and non-ortsperson. We recommend further study to compare the relation of gender and age in the kinematics of walking and jogging. In the future study, ctromyogr aphs for muscles in the lower limbs should also be considered.

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