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A STUDY OF THE INFLUENCE FROM DIFFERENT RUNNING SLOPE ON THE ANGLES OF LIMB JOINTS

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This study focuses on an analysis and comparison of the hip, knee, and ankle joint angle changes and differences during the stance and swing phase of the running gait cycle while running on the same uphill or downhill gradient as well as the lower joint angle changes while running on different uphill or downhill inclines or on level ground. This study should also provide insight into whether or not there is a significant difference between the lower joint angle patterns while running on slopes of different steepness, which in turn can serve as a reference for runners and coaches for uphill or downhill running training or workout exercises. For this study we employed a high-speed camera, which allows us to capture the running motion cycles of the sagittal plane of test subjects while running on different uphill or downhill gradients. Motion analysis software was employed for data compilation, while a comparative analysis was conducted by utilizing statistical software. After extensive discussions and analysis, we reached the following conclusions: 1. Slope gradient changes have a significant impact on hip joint angles during the stance phase. The steeper the incline is, the greater is the difference between the hip joint angles. 2. Slope gradient changes have a significant effect on joint angle changes during the swing phase. The steeper the uphill gradient, the smaller are the hip, knee, and ankle joint angles, while steeper downhill gradients lead to larger hip and knee joint angles. 3. A comparison of the changes of all joint angles during uphill, downhill, and level ground running reveals that angle changes during uphill running are greater than during downhill running. It can be inferred that this phenomenon is caused by the fact that the number of muscle groups involved in uphill running is larger than in downhill running.

KEY WORDS: position, climbing, declining, upgrade, downgrade.

INTRODUCTION: International Marathon events or road running races take place on routes which have been carefully planned by the organizers. Special emphasis is placed on slope gradients and elevation differences to give each section a unique character. Race participants are therefore bound to encounter uphill and downhill slopes of different steepness on certain sections of the routes. Guo-Feng Xu (2011) believes that people change to shorter strides when they run uphill. It is not necessary for runners to consciously lengthen their stride, but they should maintain or accelerate their pace. The faster the pace, the lower is the impact of gravity on the legs. If runners maintain a short stride at a fast pace while running uphill, they need to exert less effort. People also tend to increase their speed when running downhill. They should, however, avoid consciously lengthening their stride and should instead try to accelerate their pace. This is the best way to shift the reaction force to the hands and feet while running downhill. The length of the stride, on the other hand, should be adjusted according to the steepness of the slope (Guo-Feng Xu, 2011). The purpose of this study is to gain a better understanding of the mechanics of the human running gait cycle based on significant differences in lower joint angles while running on level ground or uphill or downhill gradients to provide a reference for future research.

METHODS: We selected 15 male members of the Fu Jen University track and field varsity team who have experience with treadmills as our test subjects. The average age, height, and weight of our test subjects is 20.87 ± 1.19, 173.87 ± 4.85cm, and 67.53 ± 6.40kg. Experimental design and procedures: 1. After performing a pre-experiment speed calibration of the Gaitway treadmill and checking the Mega Speed High-speed camera (MS30K/60Hz), LED lighting device(50W), Customized 2D-coordinate frame(1 meter wide and 2 meters tall), and motion analysis software for proper functioning, we prepared the site for the experiment.

2. After the test subjects who were asked to perform a 10-minute stretching exercise had provided their basic personal data and the length of their limbs had been measured, Transducer Techniques Retro-reflective markers were placed at different spots on their bodies including the 7th cervical vertebra, the hip, knee, and ankle joints, and the 5th metatarsophalangeal joint. 3. After the 3-minute warm-up exercise, the running speed was set to 3m/s. After 5 minutes we started to capture 10-second images of the running sequence from the sagittal plane. Upon completion of the first sequence with the incline set at 0%, if the data collection was successful, the incline of the treadmill was set to 5%. We started to capture another set of 10-second images.If the data collection was successful, the person in charge followed the same procedure to capture 10-second images for another three sequences with inclines of 3%, -3%, and -5%, respectively. 4. Upon completion of all stages of the experiment and the data collection process, the incline and speed were reset to 0. The test subject was asked to step off the mill and take a rest. After the data for all test subjects had been successfully collected, the motion images were fed into the Kwon 3D Motion Analysis Software and digitized to generate a raw data set. The images of the human running gait cycle were encoded and digitized using Kwon 3D motion analysis software. 5. We employed descriptive statistics to calculate the joint angles (mean and standard deviation). The differences between the angles of the same joints during the five different stages of level ground, uphill, and downhill running were analyzed with repeated measures using one-way ANOVA. A comparative analysis was conducted if significant differences were observed.

RESULTS: In this comparative analysis, We employed mean and standard deviation values to describe the joint angles during the stance phase and swing phase (see Table 1).

Table 1

Joint angles during the stance and swing phase(unit：degrees)

	stance phase						swing phase					
	Hip joint angle changes		Knee joint angle changes		Ankle joint angle changes		Hip joint angle changes		Knee joint angle changes		Ankle joint angle changes	
Incline	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
0%	173.645	6.752	150.251	4.373	95.929	2.772	179.389	5.200	137.596	6.400	121.069	4.400
-3%	174.811	6.225	150.008	4.417	96.889	2.325	182.369	5.200	137.781	6.300	122.043	4.900
-5%	175.623	6.883	150.49	4.336	97.731	3.308	184.144	5.500	138.4	5.900	121.235	5.500
3%	174.539	6.42	149.911	4.141	95.47	2.839	175.036	5.600	134.711	6.200	119.987	4.700
5%	177.241	6.203	151.517	4.347	95.998	3.319	173.009	5.600	134.006	6.000	118.667	4.600

See Table 2 for a one-way ANOVA of the joint angles during the stance phase and swing phase. It is obvious from the table that the hip joint angle patterns are significantly different for each of the five different incline types during the stance phase($P < .05$). Slope gradient changes therefore have a significant impact on hip joint angle changes during the stance phase. The swing phase shows that the angle change patterns of all joints are significantly different for each of the five different incline types($P < .05$). Slope gradient changes therefore have a significant impact on hip, knee, and ankle joint angle changes during the swing period.

Table 2

Variance analysis of joint angles during the stance and swing phase

	stance phase												swing phase											
	Variance analysis of hip joint angles				Variance analysis of knee joint angles				Variance analysis of ankle joint angles				Variance analysis of hip joint angles				Variance analysis of knee joint angles				Variance analysis of ankle joint angles			
Source of variation	Type III sum of squares	Degree of freedom	Sum of mean squares	F value	Type III sum of squares	Degree of freedom	Sum of mean squares	F value	Type III sum of squares	Degree of freedom	Sum of mean squares	F value	Type III sum of squares	Degree of freedom	Sum of mean squares	F value	Type III sum of squares	Degree of freedom	Sum of mean squares	F value	Type III sum of squares	Degree of freedom	Sum of mean squares	F value
Inter-group	110.197	2.221	49.611	8.502	24.958	1.672	14.929	2.784	48.873	1.805	27.072	2.793	1340.228	4.000	335.057	246.855	238.188	1.875	127.036	17.748	102.255	1.746	58.563	3.644
Intra-group	2778.837	14.000	198.488		1183.020	14.000	84.502		358.514	14.000	25.608		1983.052	14.000	141.647		2467.779	14.000	176.270		1254.894	14.000	89.635	
	$P = .001 < .05$				$P = .09 > .05$				$P = .085 > .05$				$P = .000 < .05$				$P = .000 < .05$				$P = .047 < .05$			

A comparative analysis of hip joint angles during the stance phase shows that while running on uphill and downhill slopes of the same steepness, the hip joint angles during downhill running are significantly different from those on level ground, which in turn indicates that the differences of the hip joint angles during downhill running are greater than during level-ground running. During uphill running the greatest differences are observed at inclines of 5%. In swing phase, there are significant differences between the hip, knee, and ankle joint angle patterns, while running on uphill and downhill slopes of the same steepness. Ankle joint patterns are significantly different at inclines of -3％ and 3％. During uphill running, hip joint and knee joint angle patterns are significantly different for all inclines, while ankle joint patterns show a significant difference only for 5% inclines. During downhill running, hip joint angle changes show significant differences.

Table 3

Comparison of joint angles during the swing and stance phase average variance standard error

		swing phase									stance phase		
		Paired comparison of hip joint angle patterns			Paired comparison of knee joint angle patterns			Paired comparison of ankle joint angle patterns			Paired comparison of hip joint angle patterns		
Incline	Incline changes	Average variance	Standard error	Significance	Average variance	Standard error	Significance	Average variance	Standard error	Significance	Average variance	Standard error	Significance
0%	-3%	-2.980*	0.395	0.000	-0.186	0.833	0.827	-0.975	0.764	0.223	-1.166*	0.473	0.027
	-5%	-4.756*	0.424	0.000	-0.803	0.920	0.397	-0.165	1.125	0.886	-1.977*	0.778	0.024
	3%	4.353*	0.467	0.000	2.886*	0.809	0.003	1.083	0.799	0.197	-0.895	0.684	0.212
	5%	6.380*	0.439	0.000	3.590*	0.452	0.000	2.401*	0.491	0.000	-3.596*	0.748	0.000
-3%	0%	2.980*	0.395	0.000	0.186	0.833	0.827	0.975	0.764	0.223	1.166*	0.473	0.027
	-5%	-1.776*	0.340	0.000	-0.617	0.368	0.116	0.81	1.225	0.519	-0.811	0.437	0.084
	3%	7.333*	0.430	0.000	3.072*	0.482	0.000	2.058*	0.500	0.001	0.271	0.593	0.655
	5%	9.360*	0.465	0.000	3.776*	0.731	0.000	3.376*	0.658	0.000	-2.430*	0.606	0.001
-5%	0%	4.756*	0.424	0.000	0.803	0.920	0.397	0.165	1.125	0.886	1.977*	0.778	0.024
	-3%	1.776*	0.340	0.000	0.617	0.368	0.116	-0.81	1.225	0.519	0.811	0.437	0.084
	3%	9.108*	0.504	0.000	3.690*	0.456	0.000	1.247	1.496	0.418	1.082	0.849	0.223
	5%	11.135*	0.499	0.000	4.394*	0.771	0.000	2.566	1.369	0.082	-1.619	0.847	0.077
3%	0%	-4.353*	0.467	0.000	-2.886*	0.809	0.003	-1.083	0.799	0.197	0.895	0.684	0.212
	-3%	-7.333*	0.430	0.000	-3.072*	0.482	0.000	-2.058*	0.500	0.001	-0.271	0.593	0.655
	-5%	-9.108*	0.504	0.000	-3.690*	0.456	0.000	-1.247	1.496	0.418	-1.082	0.849	0.223
	5%	2.027*	0.209	0.000	0.704	0.609	0.267	1.319*	0.574	0.038	-2.701*	0.339	0.000
5%	0%	-6.380*	0.439	0.000	-3.590*	0.452	0.000	-2.401*	0.491	0.000	3.596*	0.748	0.000
	-3%	-9.360*	0.465	0.000	-3.776*	0.731	0.000	-3.376*	0.658	0.000	2.430*	0.606	0.001
	-5%	-11.135*	0.499	0.000	-4.394*	0.771	0.000	-2.566	1.369	0.082	1.619	0.847	0.077
	3%	-2.027*	0.209	0.000	-0.704	0.609	0.267	-1.319*	0.574	0.038	2.701*	0.339	0.000

*P < .05

Discussion: 1. A comparison of the joint angle patterns during the stance phase shows that the steepness of inclines has a significant impact on hip joint angles during the stance phase. The hip joint angles while running on level ground were significantly smaller compared to the 4 different uphill and downhill inclines. We were able to observe larger hip joint angles for steeper inclines compared to 0% inclines. We also noticed that the hip joint angles for 5% inclines were significantly larger compared to the other four uphill and downhill gradients. These results indicate that an adjustment of the incline angle mainly affects the hip joint angles during the stance phase. 2. On the other hand, reveals that the steepness of the incline has a significant effect on the hip, knee, and ankle joint angles during the swing phase. The steeper the uphill slope, the smaller are the hip, knee, and ankle joint angles, while steeper downhill gradients lead to increasing hip and knee joint angles. However, the knee and ankle joint angle changes are significantly greater during uphill running than during downhill running. The pattern for these two joints is not significantly different from the level ground pattern. The fact that knee and ankle joint changes are greater during uphill running may be the main reason why uphill running is more energy-consuming than downhill running. 3. While running on different uphill and downhill inclines, runners have to adjust their joint angles accordingly to soften the impact of the reaction force on the muscles and joints. While downhill running is less energy-consuming, it has to be pointed out that the angles of the lower joints during the swing phase and the angles of the ankle joints during the stance phase are significantly larger on descending inclines, which may cause an excessive strain on the lower limbs, which in turn can lead to injuries. 4. Data reveals that the maximum angle changes occur on uphill inclines of 5%. The greater joint angle changes at this steepness require the involvement of more muscles in the lower limbs, which is the main reason why uphill running is more energy-consuming.

CONCLUSION: After an analysis and discussion of the data, we reached the following conclusions: 1. Slope gradient changes have a significant impact on the hip joint angles during the stance phase. The steeper the uphill or downhill inclines, the greater is the difference between the hip joint angles. The maximum angle changes for all joints occur on uphill inclines of 5%. 2. Slope gradient changes also have a significant impact on the angle change patterns of all joints during the swing phase. The steeper the uphill slope, the smaller are the hip, knee, and ankle joint angles, while steeper downhill gradients lead to increasing hip and knee joint angles. 3. A comparison of the joint angles change for the running gait cycle on level ground, uphill and downhill gradients reveals that, compared to downhill running, the joint angle changes are greater when running uphill, which indicates that a larger number of muscles are involved in uphill running than downhill running. This also implies that uphill running consumes more energy and trains the muscles more efficiently than downhill running.

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