COMPARISON OF TWO ELLIPTICAL MOTION RUNNING MACHINES AND TREADMILL RUNNING

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INTRODUCTION: One of the major problems associated with rehabilitation from impact-related injuries is maintaining cardiovascular fitness. Recently elliptical motion exercise machines have been developed in an attempt to simulate running while maintaining cardiovascular fitness. However, these machines have not been shown to truly simulate the running motion. Therefore, the purpose of this study was to evaluate the lower extremity kinematics, impact shock and muscle patterns during treadmill running and two elliptical-motion machines, the NordicTrak E-Motion and the NordicTrak Ellipse.

METHODOLOGY:

Subjects - Ten young, healthy, college-aged individuals served as subjects in this experiment. The subjects reported that they had no recent history of lower extremity injury over the last several years. They then completed a physical activity questionnaire to establish their participation in the study and an informed consent form in accordance with University policy.

Experimental Set-up - Three types of data were collected in this study: 1) kinematic; 2) accelerometry; and 3) electromyography. Five high-speed 60 Hz cameras were used to collect the kinematic data. The cameras were placed such that reflective markers placed on the subjects were always visible in at least two cameras at all times. Three-dimensional coordinates were generated for the three lower extremity joints using a Direct Linear Transformation technique.

To assess impact forces, a 1.7 g PCB accelerometer was placed on the distal medial aspect of the right tibia. The low mass accelerometer was firmly attached using elastic strapping tightened to the limit of subject tolerance. The accelerometer signal was sampled at 960 Hz using a 12-bit A/D converter interfaced to a microcomputer. During each 5-minute interval, three data trials were collected for a period of 5 s each. Each data collection trial contained information from several running cycles.

Electromyographic (EMG) data were collected using pre-amplified electrodes and a Therapeutics Unlimited amplifier. The EMG signals were sampled concurrently with the accelerometry data. A pulse signal from the cameras was also sampled concurrently with these data signals allowing a precise synchronization of the Video, accelerometry and EMG data.

Protocol - Each subject attended one testing session lasting approximately 1.5 hours. EMG electrodes were placed on seven lower extremity muscles: 1) anterior tibialis (AT); 2) soleus (SOL); 3) gastrocnemius (GA); 4) rectus femoris (RF); 5) vastus lateralis (VL); 6) biceps femoris (BF); and 7) gluteus maximus (GM). Retro-reflective markers were placed on the following anatomical landmarks: 1) iliac crest; 2) greater trochanter; 3) lateral epicondyle of the knee; 4) lateral malleolus; 5) heel; and 6) 5th metatarsal head. Subjects were then asked to complete a 15-minute bout in each of three conditions: C1 - Nordic Track Ellipse; C2 - Nordic

Track E-Motion; and C3 - treadmill running. The order of presentation of the conditions was randomized. The subjects performed each exercise protocol at an intensity level of 65% of their age-predicted heart rate maximum. Data were collected at intervals of 5 minutes (i.e., at 5, 10, 15 minutes).

Data Analysis - In each subject/condition/time interval, there were at least 10 trials (i.e. strides) evaluated. These strides were chosen because concurrent accelerometry and EMG data were available. Calculation of hip, knee and ankle joint angles was then accomplished and relevant parameters were calculated. Peak leg acceleration and the time to peak leg acceleration were evaluated for each stride. The raw EMG data were rectified and smoothed with a digital filter to create a linear envelope. The data for each stride was then analyzed to determine if the muscle was active or not.

Statistical Analysis - Mean values for each parameter in each subject/condition/time interval were entered into a ReANOVA (Cinditions X Time X Subjects) for statistical analysis. Post hoc comparisons were conducted when appropriate.

RESULTS: Mean values and the statistical analyses for the kinematic parameters are presented in Table 1. Of the 24 kinematic parameters evaluated, 14 produced significant results across conditions. In each case, C1 and C2 were not significantly different from each other but both were significantly different from treadmill running ($p < 0.05$).

Mean values and the statistical analyses for the impact parameters are presented in Table 2. Both the peak impact value and the time to peak impact exhibited the same trend. C1 and C2 were not significantly different from each other but both were significantly different from C3 ($p < 0.05$).

The only significant test regarding the peak EMG values was a Condition X Time interaction for the peak EMG value for BF. Only three muscles exhibited significant differences among conditions for the duration of onset: GA, RF and VL. In the case of the GA, C1 and C3 were significantly different from the C2 condition ($p< 0.05$). For RF and the VL, C1 and C2 were significantly different from C3 ($p< 0.05$).

DISCUSSION: The kinematic, accelerometry and EMG data obtained during the treadmill running condition were in agreement with the findings of previously published studies 2, 3, 4.

The major differences in the kinematics of the locomotor stride occurred at the ankle and knee joints. The ankle angle data on C1 and C2 are much different from those during C3. When using C1 or C2, the subject never achieves a plantar flexed ankle position. This is not surprising since the major function of plantar flexion during the late support period of the running stride is to push the body off the ground. The plantar flexion motion is not necessary on either C1 or C2 because there is, in effect no push-off necessary to project the body forward. The level of dorsiflexion achieved on C1 and C2 during the locomotor stride is comparable to treadmill running. In running, there are two peaks reached in the knee flexion angle during the stride. The first is reached at the mid-stance portion of the support period and the second during the recovery of the leg during the swing period. The flexion peak that occurs during mid-stance serves as a shock attenuating motion slowing

Table 1 - Mean values and statistical analyses for kinematic parameters.

Parameter	C1	C2	C3	Condition	Time	CXT
Ankle						
Touchdown Angle	11.99	22.04	2.26	14.73*	<1	3.87*
Max. Dorsiflexion Angle	19.93	23.64	22.44	<1.0	<1	2.73*
Time to Max. DF Angle	20.03a	6.68	26.96a	22.79*	<1	<1
Max. Plantar Flexion Angle	-1.24a	2.55a	-26.35	22.53*	<1	3.37*
Time to Max. PF Angle	51.52	43.42	52.64	3.11	<1	1.14
Range of Motion	21.17a	21.08a	48.78	33.60*	1.07	6.44*
Knee						
Touchdown Angle	34.92a	33.93a	12.05	24.10*	<1	2.12
Max. Support Flexion	36.47a	34.21a	46.56	6.49*	<1	5.12*
Time to Max. Flexion	4.99a	3.26a	21.72	72.16*	1.58	1.46
Max. Extension	18.53	17.85	11.50	2.76	<1	2.31
Time to Max Extension	32.19	30.56	34.35	<1	<1	<1
Range of Motion	17.94a	16.36a	35.06	52.73*	1.55	<1
Hip						
Touchdown Angle	28.78	29.99	23.78	<1	<1	<1
Max. Flexion Angle	29.29	31.72	27.62	<1	<1	<1
Time to Max. Flexion	2.89a	4.82a	12.86	10.94*	<1	1.18
Max. Extension	9.49	9.35	5.35	<1	1.21	<1
Time to Max. Extension	42.27a	44.07a	52.08	9.83*	1.01	<1
Range of Motion	19.80	22.37	21.69	<1	1.45	1.44

Angle : degrees; time : percent of stride. Means with same subscripts are not significantly different.

Table 2 - Mean values and statistical analyses for accelerometer parameters.

Parameter	C1	C2	C3	Condition	Time	CXT
Peak g	1.74a	2.04a	4.78	41.02*	<1	1.65
Time to peak g	22.45a	18.76a	6.02	147.68*	2.07	1.93
Stride Time	0.92a	0.92a	0.77	10.18*	<1	<1

G : value times 9.81 m/s2; time : milliseconds. Means with same subscripts are not significantly different.

the downward motion of the body's center of mass. This support peak was certainly evident in C3. The level of knee flexion, however, was generally constant throughout the support phase on C1 and C2. These findings indicate that shock attenuation is not of major concern when performing on the elliptical motion machines. The second peak did not show any differences in the three conditions indicating that the recovery motion on the elliptical machines was comparable to that during treadmill running.

The hip angle parameters in each of the three conditions were remarkably similar with only a slight difference in the timing of the peaks. However, the general similarity among the three conditions indicates that hip joint function is not altered on these "running" machines.

The initial impact shock values on the elliptical machines ranged from 36.4% (C1) to 42.7% (C2) of those values seen in C3. The time of occurrence of this impact peak was also much delayed in the elliptical machine conditions. The lack of impact shock during the initial portion of support is manifested in the absence of a knee flexion peak during the mid-stance portion of support. Thus, in terms of rehabilitation, the performance on these machines can be considered "low" impact.

The overall muscle activity patterns were generally the same in each of the three conditions with a few exceptions. GA acts as a plantar flexor of the ankle. For GA, the duration of onset on the C2 was greater than in C3 but not greater than in C1. While there were significant differences in the kinematics of the ankle joint, there appeared to be only subtle differences in the patterns of activity in the muscles than cross this joint. RF and VL are knee extensors while BF is a knee flexor. The knee extensors act eccentrically early in the support phase of running to control the downward vertical velocity of the center of mass. The reduced impact concerns on C1 and C2 resulted less peak activity in the knee flexors. However, since the knee angle did not change significantly during the support phase on C1 and C2, these muscles along with BF probably acted to hold the knee angle constant throughout support.

CONCLUSIONS:

1) It is clear that there are differences in the function of the ankle and knee joints during the locomotor stride between the elliptical machines and treadmill running. These machines do not require the ankle joint to plantarflex during the "push-off" phase of support. There is also a difference in the function of the knee joint between the elliptical-motion conditions and treadmill running during the support portion of the stride, but not in the recovery phase of the locomotor stride. The difference in knee joint function during the support phase can be explained by the relative lack of impact shock on the elliptical machines.

2) The lack of a flight phase when performing on the elliptical motion machines results in a significantly lesser impact shock than in treadmill running. Differences in kinematics and EMG among conditions appeared to be a function of the reduced impact shock.

3) Studies have shown that elliptical machines give a good cardiovascular work-out 1 and the kinematics of the lower extremity are a reasonable facsimile of running. Most importantly, there is significantly less impact shock to the system on these machines than one would receive when running. It would appear that using an elliptical machine would be a good substitute for running without the "wear and tear" of running.

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