

A COMPARISON OF LOADING FORCES INCURRED DURING EXERCISE

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INTRODUCTION

Cycle ergometers have been the primary choice for exercise in the home and in clinical rehabilitation settings for the purpose of achieving and maintaining cardiorespiratory fitness. In the home setting, these ergometers are easy to use, can be moved and stored with ease, and are relatively inexpensive. Clinically, patients recovering from lower extremity injuries can safely use cycle ergometers to maintain fitness levels and range of motion without overloading the musculoskeletal system by generating high impact forces. A major disadvantage of the cycle ergometer is the discomfort felt from poorly designed and padded bicycle seats. One could only exercise to the extent that the seat could endure!

The market for exercise equipment has proliferated in the last ten years. Advertisements regularly bombard the public, extolling the virtues of the equipment while lauding the health benefits gained through regular exercise. Some of this equipment has been manufactured to meet the needs of the home exercise market as well as to provide closed kinetic chain exercise in a clinical setting. Providing an aerobic workout which will not exacerbate a preexisting condition for individuals who exercise at home, as well as for patients in a rehabilitation setting, may very well depend on the amount of weight the client/patient can support throughout the exercise bout. The purpose of this study was to quantify the amount of loading force applied by the feet during exercise on five exercise ergometers. In addition, loading symmetries were also investigated.

METHODOLOGY

Six males, mean body mass of $73.3 \text{ kg} \pm 10.8$, and 6 females, mean body mass of $59.6 \text{ kg} \pm 28.7$ were recruited for participation in this study. All subjects signed a consent form and were then required to attend a minimum of three practice sessions to become familiar with each piece of exercise equipment. During the practice sessions, subjects exercised on each machine for five minutes or until their movements assumed a fluid, rhythmical pattern. The five exercise ergometers consisted of the following: curvilinear shuffle skier (CSS), pedal type stair stepper (S), rectilinear shuffle skier (RSS), non-motorized treadmill (T), and motorized treadmill (MT). The subjects stepped or skied at a cadence of 80 bpm for four minutes per exercise bout and were not allowed to use the hands for support. Data were collected in the last minute of exercise. All ergometers, with the exception of the MT, required the subject to provide the propulsive force to maintain the cadence. Vertical force data were collected with in-shoe pressure

sensors (Tekscan, Inc.) operating at 60 Hz for 6 seconds during each condition. Each sensor was calibrated to the subject's body mass and the same model shoe was worn by each subject. Peak vertical forces were obtained from the left (LF) and right feet (RF) simultaneously for three consecutive gait cycles during each condition. A one-way repeated measures analysis of variance was used to determine the significance of differences between trials. A Tukey's post hoc test was used to determine in which trials the significant differences occurred.

RESULTS

The mean values and standard deviations for peak vertical forces for the left and right feet are listed in Table 1 and in Figure 1. The forces are expressed as a percentage of body mass (BM).

Table 1. Mean peak vertical forces expressed as a percentage of body mass..

	CSS	S	RSS	T	MT
LEFT	71.6*	86.8	78.8*	105.9	102.5
st. dev.	10.4	13.0	12.7	9.7	5.4
RIGHT	71.2*	84.7	75.4*	106.4	102.9
st. dev.	12.9	11.5	6.0	5.6	7.2

* $p < 0.05$

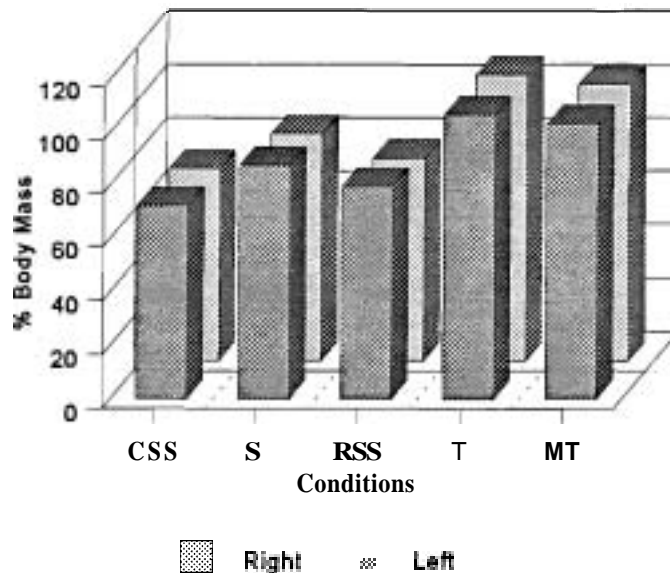


Figure 1. Mean values for left and right foot peak in-shoe pressure.

The peak force values for the curvilinear shuffle skier and rectilinear shuffle skiers were significantly different from the force values obtained from the pedal

type stair stepper, non-motorized treadmill, and motorized treadmill. The curvilinear shuffle skier condition elicited the lowest peak forces (71% of BM) and the non-motorized treadmill elicited the highest peak forces (106% of BM). There were no significant differences found between the two shuffle skiers. In addition, there were no significant bilateral differences found between the five conditions.

DISCUSSION

Shuffle skiers and stair steppers allow the foot to remain loaded throughout the entire gait cycle, whereas walking on treadmills and overground walking result in collision type impacts between the foot and walking surface. Peak vertical ground reaction forces during foot landing have been reported by numerous researchers and are noted as a possible source of soft tissue and bone injury (Newton & Humphries, 1991; Nigg, Denoth, & Neukomm, 1981; Scott & Winter, 1990). The peak in-shoe forces, while the foot was in contact with the ergometer surface, were found to be greater in the treadmill conditions and concentrated at the heel, lateral midfoot, and medial forefoot regions, depending on the phase of the gait cycle. The peak in-shoe forces found in the shuffle skier conditions were relatively constant throughout the cycle, with the forces equally distributed throughout the base of support.

There are numerous exercise ergometers available to use in the home or clinical setting to obtain and/or maintain cardiorespiratory fitness. Several factors contribute to the selection of equipment, however, one factor which should not be ignored is the amount of loading force that is placed on the lower extremities during exercise. The results of this study indicate that curvilinear and rectilinear shuffle skiers significantly reduce the loading forces and allow the exerciser to spread the forces evenly throughout the base of support during the entire gait cycle. The pedal type stair stepper and treadmills used in this study elicited higher peak vertical forces which were not equally distributed throughout the foot. Although no bilateral loading differences were found in this study using healthy subjects, persons with injuries or disabilities might unintentionally overload the uninjured leg, setting up the potential for overuse injuries. There is a need for continued research in this area, with emphasis placed on diverse subject populations.

CONCLUSIONS

The analysis of the in-shoe force data revealed significant differences in peak vertical forces across conditions. Lowest peak forces were recorded on the curvilinear shuffle skier and highest peak forces were recorded during the non-motorized treadmill condition. There were no significant bilateral differences found between conditions.

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