

# PLANTAR PRESSURE VARIATIONS DURING EXERCISE ON FOUR PIECES OF COMMERCIALLY AVAILABLE CARDIOVASCULAR EQUIPMENT

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## INTRODUCTION

Plantar pressures during exercise are influenced by variations in forces generated at the foot-floor interface and contact area between the foot and supporting surface (Kernozek & Zimmer, 2000; Burnfield et al., 2004). Recent emphasis on the value of exercise for prevention of secondary medical complications combined with an expansion of the availability of commercial fitness equipment into medically-based fitness facilities has resulted in a wide range of cardiovascular exercise options for persons with acute and chronic medical conditions. As prolonged exposure to elevated plantar pressures can lead to pain and tissue injury in persons with orthopaedic and neuropathic foot disorders, a better understanding of the impact of select exercises on foot pressures appears warranted. The purpose of this study was to explore plantar pressure variations during exercise on four commercially available cardiovascular exercise devices which were selected due to the expected variations in foot-contact patterns and weight-bearing loads on the foot while exercising.

## METHODS

Ten subjects (19-35 years old; 5 male, 5 female) with no known musculoskeletal or neurological disorders were recruited. Each participated in four sessions. During the first three sessions, subjects were familiarized

with the cardiovascular equipment (Life Fitness™ Treadmill 97Ti, Elliptical Cross-Trainer 95Xi, Recumbent Bike 95Ri, Stairclimber 95Si) and instructed to exercise on each at a speed that they could maintain for a thirty minute workout. During the fourth session, plantar pressure variables (Pedar by Novel) and support surface kinematics (Motion Analysis) were recorded simultaneously as subjects performed treadmill walking, treadmill running, elliptical training, recumbent biking, and stairclimbing in self-selected footwear. Each was performed for five minutes, and the order was randomized. Data were recorded during the final minute of each exercise. Mean Maximum Peak Pressure (PP) values in the heel, arch, and forefoot were identified, and their respective Mean Maximum Force (MF) and Mean Contact Area (CA) values were recorded for the dominant limb. Separate one-way analyses of variance with repeated measures determined if PP, MF, or CA varied significantly across activities in each region. A Bonferroni adjusted alpha level of  $P < 0.0167$  assessed significance.

## RESULTS AND DISCUSSION (Table 1)

**Heel:** PP under the heel was significantly higher during walking and running compared to elliptical training, stairclimbing, or recumbent biking ( $P \leq 0.005$ ) owing primarily to a significantly higher MF under the heel during walking

and running compared to the other three conditions ( $P \leq 0.002$ ). Compared to all other activities, biking registered the lowest heel MF ( $P \leq 0.001$ ) and CA ( $P \leq 0.002$ ). Heel CA was also diminished during stairclimbing, registering a significantly lower value than during running ( $P = 0.009$ ).

**Arch:** PP under the arch was significantly higher during running compared to all other activities ( $P \leq 0.010$ ), primarily due to the presence of significantly higher MF during running compared to all other conditions ( $P \leq 0.003$ ). Arch PP was also elevated during walking, exceeding those during biking and stairclimbing ( $P < 0.001$ ). PP under the arch was lowest while biking versus all other exercise conditions ( $P < 0.001$ ) owing primarily to a significant reduction in MF under the arch during biking compared to all other activities ( $P < 0.001$ ). Significantly lower PP during biking occurred despite the reduction in arch CA during biking compared to walking, running and stairclimbing ( $P \leq 0.007$ ). PP was significantly higher during elliptical training compared to stairclimbing ( $P = 0.016$ ) despite insignificant MF and CA variations.

**Forefoot:** PP under the forefoot was significantly higher during running, walking and elliptical training compared to biking and stairclimbing ( $P \leq 0.007$ ), resulting primarily from significantly higher MF in the forefoot during the former three activities ( $P \leq 0.002$ ). Forefoot PP was significantly lower while biking compared to all other activities ( $P < 0.001$ ), owing mainly to a significantly reduced MF during

this activity compared to all other tasks ( $P < 0.001$ ). Forefoot MF during elliptical training was notably lower than that recorded during running ( $P = 0.010$ ). Forefoot CA did not vary significantly across exercise conditions.

## SUMMARY/CONCLUSIONS

In healthy young adults, PPs varied greater than seven-fold under the heel, four-fold beneath the arch, and five-fold under the forefoot across exercises due primarily to variations in MF. While further research is required in persons with pathology, rehabilitation from orthopaedic conditions where protection of heel tissues is important should consider use of the recumbent bike, stairclimber, and elliptical trainer due to the associated low heel pressures and forces. Persons with pain or injury in the arch region or at risk for neuropathic forefoot ulcers should consider use of the recumbent bike and stairclimber due to the associated low arch and forefoot pressures and forces.

## REFERENCES

- Burnfield. J.M. et al. (2004). *Clinical Biomechanics*, **19**, 78-84.  
 Kernozek, T.W., Zimmer, K.A. (2000). *Foot & Ankle International*, **21**, 749-752.

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**Table 1.** Mean Maximum Peak Pressure (N/cm<sup>2</sup>), Maximum Force (N), and Contact Area (cm<sup>2</sup>) on heel, arch, and forefoot regions for five activities during the fifth minute of exercise (mean  $\pm$  SD).

Activity	Heel			Arch			Forefoot		
	PP	MF	CA	PP	MF	CA	PP	MF	CA
Walking	22.4 $\pm$ 3.1	414.4 $\pm$ 139.4	27.9 $\pm$ 8.8	12.2 $\pm$ 1.4	165.7 $\pm$ 44.8	27.6 $\pm$ 4.9	24.9 $\pm$ 8.1	217.3 $\pm$ 45.2	14.5 $\pm$ 2.3
Running	19.9 $\pm$ 4.6	376.9 $\pm$ 149.9	28.2 $\pm$ 9.3	15.4 $\pm$ 2.8	294.8 $\pm$ 92.7	27.3 $\pm$ 5.7	25.2 $\pm$ 4.9	251.8 $\pm$ 61.3	14.5 $\pm$ 2.4
Elliptical Training	10.3 $\pm$ 4.0	215.8 $\pm$ 122.5	29.1 $\pm$ 7.4	10.8 $\pm$ 2.3	186.0 $\pm$ 54.8	29.6 $\pm$ 6.8	18.6 $\pm$ 8.0	181.8 $\pm$ 78.3	15.0 $\pm$ 2.0
Recumbent Biking	3.0 $\pm$ 1.0	25.4 $\pm$ 22.8	10.28 $\pm$ 8.9	3.8 $\pm$ 1.0	52.8 $\pm$ 24.1	19.0 $\pm$ 7.5	4.4 $\pm$ 1.5	36.5 $\pm$ 21.0	11.1 $\pm$ 5.2
Stairclimbing	7.6 $\pm$ 1.6	133.3 $\pm$ 68.8	24.5 $\pm$ 8.9	8.6 $\pm$ 2.3	156.3 $\pm$ 34.2	28.6 $\pm$ 4.3	10.8 $\pm$ 2.0	122.9 $\pm$ 30.8	15.9 $\pm$ 2.0