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Referent body weight values in over ground walking, over ground jogging, treadmill jogging, and elliptical exercise

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ABSTRACT

Objectives: I. To evaluate average percentage body weight (APBW) values and weight-bearing distribution percentages (WBDP) between four common sports activities in a referent adult population. II. To suggest clinical implications.
Design: Original research study.
Setting: Lerner Sports Center, Hebrew University, Mount Scopus, Jerusalem, Israel.
Participants: Seventy-five asymptomatic volunteers, mean age = 33.5 (19–72) years SD = 15.1, mean weight (kg) = 70.7 (43–113) SD = 14.1.
Interventions: Four tests were conducted: 1. Overground walking (OGW) over a 20 m distance, 2. Overground jogging (OGJ) over a 20 m distance, 3. Treadmill jogging (TJ) at a constant speed of 8.5 km/h for a 15-second interval and 4. Elliptical exercise (EE) for a 20 second period at a resistance and incline level of 10, and a steady pace within the range of 70–95 steps/min.
Main outcome measure: The Smartstep™ weight-bearing gait analysis system.
Results: The APBW value on the entire foot in OGW was 112% (SD = 15.57), in OGJ, 201% (SD = 31.24, in TJ, 175% (SD = 25.48) and in EE, 73% (SD = 13.8). Regarding WBDP, the swing phase in OGJ and TJ was significantly longer than the stance phase ($p < 0.05$). OGW resulted in significantly less swing phase compared to OGJ and TJ ($p < 0.05$).
Conclusions: EE significantly reduces weight-bearing as compared to other common functional and sporting activities. These findings may assist the rehabilitation team when considering returning individuals back to early activity following certain bony or soft tissue pathologies or lower-limb surgical procedures. This information is also useful from a repetitive loading standpoint (to prevent overuse injury) or for exercise recommendations for those at greater risk for exacerbating chronic joint pathology.

Specific weight-bearing instructions are given to lower-extremity orthopaedic patients following certain bony or soft tissue pathologies and certain lower-limb surgical procedures (e.g. micro-fracture, cartilage transplantation). Although this continues to be a part of routine orthopaedic clinical practice [1], the patient's ability to comply with these instructions is questioned in the medical literature.

Studies supporting weight-bearing restriction are based on several histopathology principles related to the bone-healing processes after fracture or surgery, as well as the fear that excessive weight on an injured or operative site will lead to implant failure, and therefore affect fracture stability and alignment [2]. Conversely, the rationale for advancing weight-bearing is that repetitive loads can stimulate osteoblastic activity in fracture patterns and fixation constructs in load-bearing extremities [3]. Therefore, the difficulty in ambulating an orthopaedic patient with an affected lower extremity includes both the dual desire to protect the surgical construct by limiting weight-bearing, while simultaneously stimulating bone growth by increasing weight-bearing [4]. This may be regarded as a clinical balancing act between protecting the injury site or surgical construct and increasing bone growth at the fracture site.

Abbreviations: APWB, average weight-bearing values; WBDP, weight-bearing distribution percentages; OGW, overground walking; OGJ, overground jogging; TJ, treadmill jogging; EE, elliptical exercise.

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Table 1
Study group characteristics ($n = 75$).

Test	N	Ave. age (years)	Ave. weight (kg)
Walking	21	35.4 (19–72) SD = 16.2	76.8 (46–113) SD = 16.9
Ground jogging	8	31.0 (20–69) SD = 15.7	55.9 (43–70) SD = 9.4
Treadmill	22	37.4 (21–70) SD = 15.8	74.3 (50–86) SD = 9.5
Elliptical	24	28.8 (21–69) SD = 12.4	66.7 (44–103) SD = 11.7

In order to make reliable clinical decisions in relation to when injured or surgically operated athletes may return to daily functional and weight-bearing sporting activities, there is a need to establish referent average weight-bearing (APWB) and weight-bearing distribution percentages (WBDP) in different sporting activities. Improved understanding of post-operative weight-bearing and standardization in outcome studies could greatly impact both patient and surgeon satisfaction in post-operative partial weight-bearing care [5]. This may be predictive of important rehabilitation outcomes [6].

The authors found four other studies that compared elliptical exercise, stationary cycling, treadmill walking and ground walking. They included electromyographic patterns, biomechanics and kinematics [7,8]. This present study is the first known study that evaluated and compared the APBW and WBDP in overground walking (OGW), overground jogging (OGJ), treadmill jogging (TJ), and elliptical exercise (EE) in one study. APBW may be defined as the average value of the measured body weight of the study participants, expressed as a percentage of the total body weight. The APBW values were evaluated and not their peak values. WBDP refers to the percentage time that the participants spent weight-bearing in the stance phase as compared to the time spent in the swing phase.

The aims of this research study were to: (I) evaluate and compare referent APWB values and WBDP in OGW, OGJ, TJ, and EE. In addition (II) to extrapolate clinical implications from the study findings.

1. Methods

Seventy-five healthy adults participated in the study. Participants were randomly selected and each test was conducted on a different day. Exclusion criteria included pain in the hip, knee, ankle and foot during testing or surgery in these anatomical locations less than two years previously. Different subjects participated in each of the four conditions. There was no statistically significant difference between the cohort groups with respect to age or body weight. Twenty-one participated in the over ground walking condition, eight in the over ground jogging condition, twenty-two in the treadmill jogging condition, and twenty-four in the elliptical condition. Their demographic data are displayed in Table 1. The study was conducted in the Lerner Sports Center, Hebrew University of Jerusalem, over a period of four months. All subjects were voluntarily recruited from within the center. The study was approved by the Helsinki ethics committee of the Meir Hospital, Kfar Saba, Israel. Written, informed consent was obtained from all individuals prior to participation in the investigation.

For the purposes of measuring weight-bearing parameters, the SmartStep™[1] system was used. The SmartStep™ pneumatic insole system measures key gait parameters during ambulation. The data are received and then analyzed by the miniature portable microprocessor, which is worn around the ankle. This is subsequently transmitted to a computer system running the SmartStep™ software, which also maintains patient's medical records. The software additionally functions as an assessment of gait analysis, which includes weight-bearing distribution, stance/swing phase and cadence values. The device further contains a biofeedback training application for rehabilitation.

Numerous reliability and accuracy tests have been carried out comparing the SmartStep™ to the AMTI™ force platform, with a statistically high body weight measurement correlation when compared to force plate measurements ($R^2 = 0.9067$, $p = 0.004$) [9]. When using regression analysis to compare measured time in the stance phase between the SmartStep™ with the Gait Mat™, there was a high correlation for the stance/swing/cycle phases between the two systems ($R^2 = 0.996/0.995/0.997$ respectively) [9]. In various randomized control studies, the SmartStep™ has proven to be an effective, accurate gait training and evaluation tool that encourages body weight on the affected limb and improves patient's gait pattern [9–11]. The main advantage of this system over other laboratory measuring devices, lies in its ability to measure weight-bearing parameters in various functional settings, for example, walking, running and stair negotiation. These above mentioned devices are expensive, with measurement apparatuses that are not commonly portable. Additionally, they are not readily available in clinical and rehabilitation settings and cannot be adapted for usage in popular sporting activities, such as ground jogging, treadmill jogging and elliptical exercise.

Prior to the tests, one SmartStep™[1] portable microprocessor control unit was fitted around one lower leg. The tests consisted of:

1. OGW for a 15 second interval at a normative, comfortable pace on a solid floor surface.
2. OGJ for a 15 second interval at their normative, comfortable pace on a solid floor surface (For both OGJ and OGW, the first and last five steps were not included in the analysis).
3. TJ (Technogym™ "run excite 700") at a constant speed set of 8.5 km/h for a 15 second interval (The readings were only taken when the treadmill speed had reached 8.5 km/h and did not include the time period needed to return to zero km/h. The specific speed of 8.5 km/h, was selected, as it reflected the most common speed used in other treadmill studies.) [12].
4. EE (Precor USA 576i EFX) training over a 15 second interval at both a resistance and incline level of ten and a steady pace within the range of 70–95 steps/min. (The participants were not permitted to hold the side handles for support in TJ and EE. The readings were only taken when the participants reached a cadence level within the range of 70–95 steps/min.) The speed and resistance levels were chosen as they represent the mid-range settings of the elliptical trainer. During elliptical training, the fore foot remains planted on the pedal (stance phase) continuously throughout the elliptical motion, whilst the hind foot has a distinct stance and lift (swing) phase.

All participants were free to choose the running shoes of their own preference. The laboratory testing environment was identical for all subjects tested.

1.1. Statistical analysis

In order to compare the APBW values for the heel, fore and entire foot, the WBDP (the percentage time spent in the swing and stance phases), age, weight, as well as cadence differences between the four activities, the one-way ANOVA test with the Dunnett T3 correction for multiple pair wise comparisons was carried out. A Statistical analysis was conducted using the SPSS® predictive

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