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Peak Ground and Joint Forces in Step-Exercise Depending on Step-Pattern and Stepping-Rate

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Abstract: The assessment of biomechanical loading is quite important for exercise prescription and injury prevention in the scope of Exercise Biomechanics. The study of ground reaction forces, joint forces and joint moments of force at ankle, knee and hip, allows the understanding of the magnitude of external and internal loading experienced by the lower extremity joints and the pattern of force-absorbing adjustments while performing a dynamic activity. The main purposes of this study were to compare the peak values of those forces, during the ascending and the descending phases of four Step-Exercise patterns (*basic-step*, *knee-lift*, *run-step* and *knee-hop*), performed at varying stepping-rate conditions (125, 130, 135 and 140 beats per minute), in a group of 18 skilled females. The results showed that vertical ground reaction forces and joint forces at ankle varied from: 1.6-1.7 BW (body weight) in *basic-step*, 1.3-1.6 BW in *knee-lift*, 1.7-2.1 BW in *run-step* and, 1.0-1.8 BW in *knee-hop*; vertical joint forces at knee and hip varied from: 1.5-1.7 BW in *basic-step*, 1.2-1.5 BW in *knee-lift*, 1.5-2.0 BW in *run-step* and, 0.8-1.8 BW in *knee-hop*. Significant greater values were found in *run-step* for all parameters. No significant differences were found among conditions of stepping-rate. The anterior-posterior forces varied from 0.2-0.6 BW considering the four movements. Significant greater values were found in the two propulsive movements. Also, these forces increased with faster stepping-rates. The joint moments of force varied from 0.1-1.0 Nm/BW considering the four movements. Significant greater values were found: at ankle, in *basic-step* and *run-step*; at knee, in *run-step* and knee-hop (ascending-phase); and at hip, in run-step. No significant differences were found among conditions of stepping-rate, at ankle and at knee (decending-phase). Joint moments increased with faster stepping-rates at knee (ascending-phase) and at hip. The results suggest that experienced steppers are capable of stepping at different cadences, with generally similar patterns of kinematics and kinetics. We concluded that lower extremity internal loading can be effectively controlled by varying stepping-rate during Step classes.

Key Words: Sports biomechanics, Exercise and health, Ground reaction forces, Joint forces, Moments of force.

INTRODUCTION

Step-Exercise is claimed to be a high intensity low-medium impact aerobic workout carrying a low injury risk, which conditions the lower body. The description of Step-Exercise characteristics is provided in another paper [1]. Two forms of controlling the intensity of the workout are by changing stepping-rate (125 to 150 *beats per minute* –**bpm**) and by choosing the type of movements included in the choreography (*e.g.* propulsive movements). The major concern is how to control the intensity of the session, maintaining safe and effective levels of mechanical load. Regular exposure to moderately high magnitudes of force is desirable within certain levels, because mechanical stress will induce adaptation on biological structures, such as an increase in bone density, an increase of resistance of tendons and ligament tension, and an increase in cartilage resistance and muscle force [2]. However the same forces can produce undesirable effects such as discomfort, pain and injury. This potential increases when forces are too repetitive in a period of time [3]. Biomechanical loading is related to the magnitude of the external and internal forces; to the frequency of forces applied on the body; to the repetition of load application; and to the way musculoskeletal structures deal with the internal forces. A major role played by the musculoskeletal system is energy dissipation. One way of reducing the injurious effects of impact forces on the extremities would be to gain a better understanding of how body transmits and attenuates impact forces through the muscles, bones and joint tissues. Previous studies reported the ground reaction forces in Step-Exercise [4-6], but few references reported its internal loading, namely, the joint forces at ankle, knee and hip [7,8] and moments of force. Abnormal joint forces are thought to play a role in degenerative joint disease, such as osteoarthritis. Thus, understanding the joint forces is important for the areas of exercise prescription and prevention of injury, and also for clinical areas and to design rehabilitation programs. Therefore, the main purposes of this study were to compare the peak values of ground reaction forces (**GRF**); the peak values of joint forces at ankle (**JFA**), knee (**JFK**) and hip (**JFH**) joints; and the peak values of joint moments of force at ankle (**MA**), knee (**MK**) and hip (**MH**); during the ascending and the descending phases of four Step-

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Exercise patterns (*basic-step*, *knee-lift*, *run-step* and *knee-hop*), performed at varying stepping-rate conditions (125, 130, 135 and 140 **bpm**). We hypothesised that differences exist among the four stepping-rate conditions and between the four Step-patterns: propulsive movements and faster cadences should produce higher forces.

METHODS

Subjects and Tasks: Eighteen Step-experienced females (mean±*sd* age 29.1±6.8 years; body mass 58.9±6.4 kg; height 1.66±0.06 m; Caucasian) with no history of foot, ankle or knee musculoskeletal / neuromuscular trauma or disease, who have volunteered to participate in the study, were led through a sequence of stepping tasks, using approved choreography. Body height was measured previous to data collection. Segment lengths (m) were measured using digitized markers placed in joints. Body weight (BW) was measured using the Kistler force platform. Segment weight (N) and moment of inertia (kg/m^2) were calculated using the equations provided by Winter [9]. These women were experienced fitness instructors who were certified and/or graduate in sport sciences and possessed at least 3 years of teaching experience in Step-Exercise. After being informed about the aims and procedures of the investigation all subjects were screened for health status [10] and gave their consent to participate in this study. The study was approved by the review committee of the Faculty. The subjects performed one sequence (choreography) of four Step-patterns using right and left leading legs resulting in a sequence of 8 movements. This procedure was adopted in order to ensure mechanical balance between both lower limbs, and to better represent the real conditions of practice. No arm movements were added. Thus, the following sequence was performed in the laboratory using two force platforms: *right basic-step*, *right knee-lift step*, *left basic-step*, *left knee-lift step*, *right run-step*, *right knee-hop step*, *left run-step*, *left knee-hop step*. None of the subjects felt discomfort during stepping over the two force platforms. The subjects were allowed to familiarise to each speed by performing few steps before data collection. They were allowed as many practice trials as they wished prior to testing. Each participant was given approximately 60-90s of rest between trials so as to reduce the potential effects of fatigue. For each condition of stepping-rate, one successful sequence was collected. Regular music used in real conditions of practice was used to maintain cadence. All experimental trials were conducted in a "crescent cadence" order. This procedure was adopted so the result would reflect typical class conditions. Participants wore similar Reebok™ sport shoes during data collection; in order to reduce error due to the influence of type of shoe on impact, braking and propulsive forces [11,12].

Equipments and Materials: The movements were performed on a AMTI force platform (*Advanced Mechanical Technology, Inc, Watertown, MA*) of 0.90mx0.60mx0.17m (length, wide, height) for stepping up, and on a KISTLER force platform (*Kistler AG, Winterthur, Switzerland*) of 0.60mx0.40m (length, wide) on ground level for stepping down. A previous study has shown that the GRF obtained by force platforms are representative of those obtained in conditions of practice of Step-Exercise [13]. Spherical reflective markers were placed with double sided adhesive tape on the skin and on the shoe, on the right side of the body. Kinematics data were synchronised with GRF data. One digital video camcorder (JVC GR-DVL 9800) was placed at a distance of 3m perpendicular to the plane of motion capturing the right view of the body. A calibration frame (1.80mx1.80m) was used just before or after each subject' data collection. Digital image of the right side of the whole body was captured at 50Hz using APAS (*Analysis Performance Ariel System, Ariel Dynamics, Inc., San Diego, CA*). Image and force data were synchronised using a *LED*. Video was captured and trimmed for segment analysis (APAS-Trimmer). Initial movement was defined using vertical GRF curve with *right basic-step* when right foot touches AMTI platform with a threshold of 10% of body weight; sequence ends with *left knee-hop step* when right foot descends and joins left foot on the Kistler platform. The automatic function of digitizing process was used (APAS-Digitize and -Transform) and filtered with a low pass digital filter at 5Hz (APAS-Filter), to determine coordinates for: 1) 5th metatarsal head; 2) calcaneus; 3) lateral malleolus; 4) lateral femoral epicondyle; 5) greater trochanter; 6) shoulder; and to obtain kinematics parameters of linear and angular displacement of segments and joints (APAS-Display). The software Acqknowledge 3.7.3 (*BIOPAC Systems, Inc., Goleta, CA*) was used to collect at 1000Hz and process GRF data. Both force platforms were calibrated prior to testing. Data were smoothed with a Hamming low pass digital filter. The optimal cut-off frequencies of 8Hz were determined by the residual error method proposed by Winter [9]. The vertical and horizontal components of GRF were obtained. The force profiles for each recording were analysed using Acqknowledge. As the linear and angular displacement data were obtained at 50Hz and the force curves were obtained at 1000Hz, in order to synchronise them and prevent loss of information, the trajectory curves were interpolated using cubic splines with polynomial interpolants that have the characteristic of preserving the concavity of the interpolated data, as proposed by Caldwell *et al.* [14] and Silva and Ambrósio [15]. Using Matlab-7 (*The MathWorks, Natick, MA*) a resampling routine from 50 to 1000Hz was built in order to transform the linear and angular displacement data, and a derivation routine was built in order to obtain linear and angular acceleration data. JF and moments of force (**M**) were calculated by inverse dynamics, during one leg support of the movements performed at each cadence. All segments were assumed to be rigid and the free-body diagram, the equations and procedures adapted from Nigg and Herzog [2], Enoka [16] and Winter [9] were used in Matlab. Therefore, the kinetics of the three joints was examined. The peak value of each variable analysed was collected during reception of the foot in the force platform (ascending phase) and during the reception of the foot on the ground (descending phase). Our analysis was limited to the single-support phase. The curves were displayed in Acqknowledge, and peak values of JF in Newton (N) and peak values of the M in Newton-meter (Nm) were collected, and then, normalised to body weight (BW or Nm/BW) in Excel.

Biomechanical Parameters and Statistical Analysis: Considering ascending and descending phases of the four Step-patterns performed with right leading leg, at four stepping-rate conditions, the following variables were selected for analysis: Vertical peak ground reaction force (**GRFy**); Anterior-posterior peak ground reaction force (**GRFx**); Vertical peak joint reaction force at ankle (**JFAy**); Anterior-

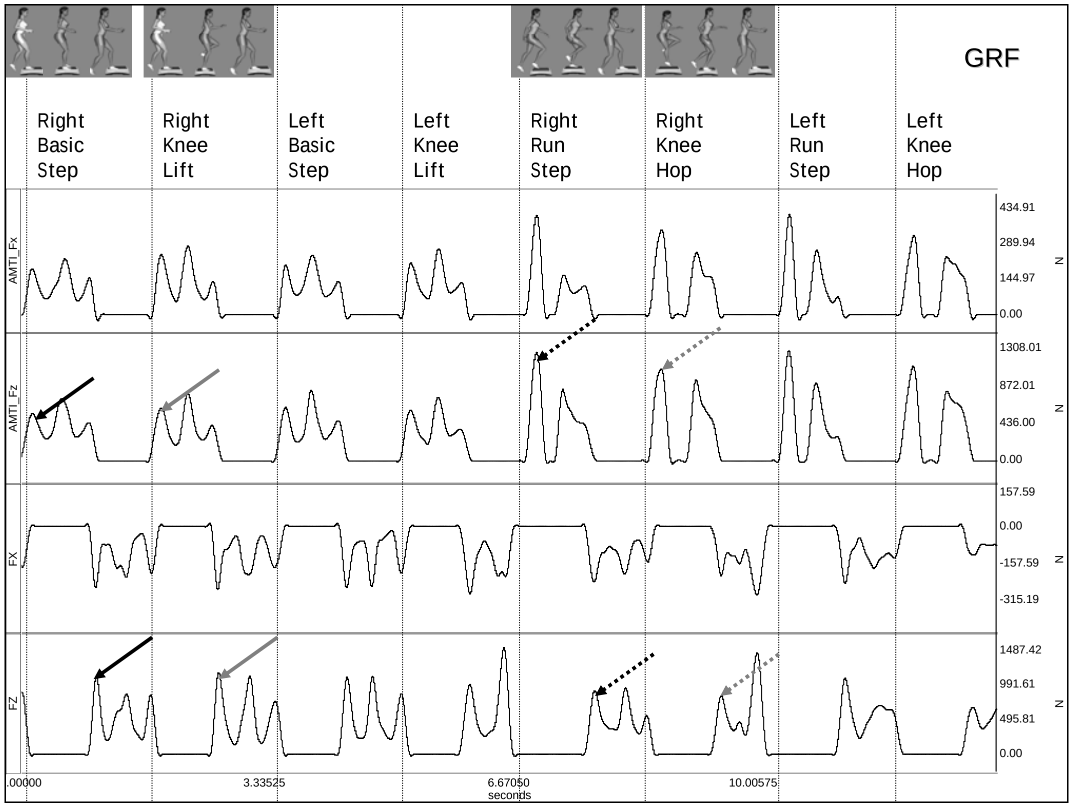

Fig. (1). Anterior-posterior (AMTI_Fx and FX) and vertical (AMTI_Fz and FZ) components of the ground reaction force of one representative subject at 140 beats per minute. The arrows identify the phases during which the peak values were collected within the sequence of the 8 Step movements using the vertical component of the ground reaction force, during the ascending (AMTI Fz) and descending (FZ) phases of the movements: black arrows show basic step; grey arrows show knee lift; black dashed arrows show run step; and grey dashed arrows show knee hop.

posterior peak joint reaction force at ankle (**JFAx**); Vertical peak joint reaction force at knee (**JFKy**); Anterior-posterior peak joint reaction force at knee (**JFKx**); Vertical peak joint reaction force at hip (**JFHy**); and Anterior-posterior peak joint reaction force at hip (**JFHx**), normalised to BW; and Peak moment at ankle (**MA**); Peak moment at knee (**MK**); and Peak moment at hip (**MH**), normalised to Nm/BW. All statistic procedures were conducted using SPSS software version 14.0 for Windows (*Statistical Package for the Social Sciences, Chicago, IL*). All results are reported as mean, standard deviations (±*sd*), maximum, minimum and range. In addition to descriptive statistics, a one-way ANOVA for repeated measures (**RM**) was used to determine whether there where significant differences in force parameters between the four conditions of stepping-rate and the four Step-patterns, resulting in two within-subjects factors. Prior to perform ANOVA RM, Kolmogorov-Smirnov normality test and Mauchly's test of sphericity were conducted. In the cases sphericity was not assumed the Huynh-Feldt correction was used. The pairwise comparisons with the Bonferroni confidence interval adjustments were used to identify where differences could be found. In all cases, the level of statistical significance was set at $p \leq 0.050$ [17].

RESULTS

Fig. (**1**) represents the identification of the movements and phases studied, using the vertical and horizontal components of the GRF curves, during the ascending phase (AMTI_Fx/AMTI_Fz) and during the descending phase (FX/FZ) and shows the phases of reception during which the peak values were collected. Table **1** shows the results of descriptive statistics of the GRFy, of the JFAy, of the JFKy, and of the JFHy normalised to body weight (BW), during ascending and descending phases of the four Step-patterns analysed, performed at 125, 130, 135 and 140 bpm. Table **2** shows the results of descriptive statistics of the peak anterior-posterior component. Table **3** shows the results of descriptive statistics of the MA, MK and MH, normalised in Newton-meters per body weight (Nm/BW). Table **4** shows the summary of the results of the statistical analysis performed with GRFy, JFAy, JFKy, and JFHy parameters, particularly the significantly statistical differences ($p \leq 0.050$) of the Bonferroni pairwise comparisons found between the conditions of stepping-rate and step movement, as well as, the confirmation of the hypothesis that differences exist between stepping-rate conditions and between Step-patterns. Table **5** shows the summary of the results of the statistical analysis performed with GRFx, JFAx, JFKx, and JFHx parameters. Table **6** shows the summary of the results of the statistical analysis performed with the parameters of joint moments.

The test of within-subjects effects has shown no interaction between step-pattern and stepping-rate conditions: in force variables during the descending phase (except JFAx, p=0.018; and JFHx, p=0.013); in joint moments during ascending and descending phases (except MA in ascending phase, p=0.009). There is interaction between conditions during ascending phase, in relation to: GRFx (p=0.005);

Table 1. Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum and Range) of the Peak Vertical Ground Reaction Force (GRFy), of the Peak Vertical Joint Force at Ankle (JFAy), of the Peak Vertical Joint Force at Knee (JFKy), and of Peak Vertical Joint Force at Hip (JFHy), Normalised to Body Weight (BW)

	BASIC STEP				KNEE LIFT				RUN STEP				KNEE HOP			
BPM	**125**	**130**	**135**	**140**	**125**	**130**	**135**	**140**	**125**	**130**	**135**	**140**	**125**	**130**	**135**	**140**
ASCENDING PHASE – PEAK VERTICAL GRF (BW)																
Mean	1.7	1.7	1.7	1.7	1.3	1.3	1.4	1.3	1.9	2.0	2.0	2.1	1.8	1.8	1.8	1.8
sd	0.2	0.2	0.2	0.3	0.1	0.1	0.1	0.1	0.3	0.3	0.4	0.3	0.2	0.2	0.2	0.2
Min	1.2	1.3	1.3	1.4	1.1	1.1	1.2	1.2	1.3	1.6	1.5	1.6	1.5	1.4	1.4	1.4
Max	2.0	2.1	2.1	2.2	1.6	1.5	1.5	1.7	2.5	2.5	2.6	2.5	2.1	2.1	2.0	2.1
Range	0.8	0.8	0.8	0.9	0.5	0.4	0.4	0.5	1.2	1.0	1.2	0.9	0.6	0.7	0.6	0.7
DESSCENDING PHASE – PEAK VERTICAL GRF (BW)																
Mean	1.7	1.7	1.7	1.7	1.5	1.5	1.6	1.5	1.7	1.7	1.7	1.8	1.1	1.1	1.2	1.1
sd	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Min	1.4	1.3	1.3	1.4	0.8	0.8	0.8	0.7	1.3	1.5	1.5	1.4	0.8	0.8	0.8	0.7
Max	2.0	2.1	2.1	2.2	2.0	1.9	2.4	2.2	2.0	2.3	2.2	2.3	1.8	1.7	1.7	1.7
Range	0.6	0.8	0.8	0.9	1.2	1.1	1.6	1.4	0.7	0.8	0.8	0.8	1.1	0.9	0.9	0.9
ASCENDING PHASE – PEAK VERTICAL JFA (BW)																
Mean	1.7	1.7	1.7	1.7	1.3	1.3	1.4	1.4	1.9	2.0	2.0	2.0	1.8	1.8	1.8	1.8
sd	0.2	0.2	0.2	0.3	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.3	0.2	0.2	0.2	0.2
Min	1.2	1.3	1.3	1.2	1.1	1.1	1.2	1.2	1.3	1.5	1.4	1.6	1.5	1.4	1.4	1.4
Max	2.0	2.1	2.1	2.2	1.6	1.5	1.8	1.9	2.4	2.5	2.6	2.5	2.1	2.1	2.0	2.0
Range	0.7	0.8	0.8	1.0	0.5	0.4	0.6	0.8	1.2	1.0	1.2	1.0	0.6	0.7	0.6	0.7
DESCENDING PHASE – PEAK VERTICAL JFA (BW)																
Mean	1.6	1.6	1.7	1.7	1.5	1.4	1.5	1.5	1.7	1.7	1.8	1.8	1.0	1.0	1.1	1.0
sd	0.3	0.3	0.3	0.4	0.3	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Min	0.7	0.9	0.9	0.7	0.8	0.7	0.7	0.7	1.3	1.5	1.5	1.4	0.7	0.7	0.6	0.7
Max	2.0	2.1	2.1	2.2	1.9	1.9	2.4	2.2	2.0	2.3	2.2	2.2	1.8	1.7	1.7	1.7
Range	1.3	1.2	1.2	1.5	1.1	1.2	1.6	1.4	0.7	0.9	0.8	0.8	1.1	1.0	1.1	1.0
ASCENDING PHASE – PEAK VERTICAL JFK (BW)																
Mean	1.7	1.7	1.7	1.7	1.3	1.3	1.3	1.3	1.9	1.9	1.9	2.0	1.8	1.8	1.7	1.7
sd	0.2	0.2	0.2	0.3	0.1	0.1	0.1	0.1	0.3	0.3	0.4	0.3	0.2	0.2	0.2	0.2
Min	1.2	1.2	1.3	1.3	1.0	1.1	1.1	1.1	1.3	1.5	1.3	1.5	1.5	1.3	1.4	1.4
Max	1.9	2.0	2.0	2.1	1.5	1.5	1.5	1.6	2.4	2.4	2.5	2.5	2.0	2.1	2.0	2.0
Range	0.8	0.8	0.7	0.8	0.5	0.4	0.4	0.5	1.1	1.0	1.2	1.0	0.6	0.8	0.6	0.6
DESCENDING PHASE – PEAK VERTICAL JFK (BW)																
Mean	1.7	1.7	1.7	1.7	1.5	1.4	1.5	1.4	1.6	1.7	1.7	1.7	1.0	1.0	1.0	0.9
sd	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Min	1.3	1.2	1.3	1.3	0.8	0.7	0.7	0.7	1.3	1.4	1.4	1.4	0.6	0.7	0.6	0.6
Max	1.9	2.0	2.0	2.1	1.9	1.9	2.3	2.1	2.0	2.2	2.2	2.1	1.7	1.7	1.7	1.6
Range	0.7	0.8	0.7	0.8	1.2	1.2	1.6	1.4	0.7	0.8	0.8	0.8	1.1	1.0	1.1	1.0
ASCENDING PHASE – PEAK VERTICAL JFH (BW)																
Mean	1.5	1.5	1.5	1.6	1.2	1.2	1.2	1.2	1.7	1.8	1.8	1.9	1.7	1.6	1.6	1.6
sd	0.2	0.2	0.2	0.3	0.1	0.1	0.1	0.1	0.3	0.2	0.3	0.2	0.2	0.2	0.2	0.2
Min	1.1	1.1	1.2	1.2	1.0	1.0	1.0	1.1	1.2	1.4	1.3	1.5	1.3	1.3	1.3	1.3
Max	1.8	1.9	2.0	2.0	1.5	1.4	1.4	1.5	2.2	2.2	2.3	2.3	2.0	2.0	1.9	2.0
Range	0.8	0.9	0.8	0.9	0.4	0.4	0.4	0.5	1.0	0.8	1.0	0.8	0.7	0.7	0.6	0.7
DESCENDING PHASE – PEAK VERTICAL JFH (BW)																
Mean	1.6	1.5	1.5	1.6	1.4	1.3	1.4	1.4	1.5	1.5	1.6	1.6	0.8	0.9	1.0	0.9
sd	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2
Min	1.2	1.1	1.2	1.2	0.7	0.7	0.6	0.6	1.2	1.3	1.3	1.3	0.6	0.6	0.7	0.6
Max	1.8	1.9	2.0	2.0	2.0	1.9	2.3	2.1	1.9	2.0	2.0	2.0	1.2	1.5	1.5	1.4
Range	0.7	0.8	0.8	0.9	1.3	1.2	1.7	1.5	0.7	0.7	0.7	0.7	0.6	0.9	0.8	0.8

Table 2. Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum and range) of the Peak Anterior-Posterior Ground Reaction Force (GRFx), of the Peak Anterior-Posterior Joint Force at Ankle (JFAx), of the Peak Anterior-Posterior Joint Force at Knee (JFKx), and of the Peak Anterior-Posterior Joint Force at Hip (JFHx), Normalised to Body Weight (BW)

	BASIC STEP				**KNEE LIFT**				**RUN STEP**				**KNEE HOP**			
BPM	**125**	**130**	**135**	**140**	**125**	**130**	**135**	**140**	**125**	**130**	**135**	**140**	**125**	**130**	**135**	**140**
ASCENDING PHASE – PEAK ANTERIOR-POSTERIOR GRF (BW)																
Mean	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5
sd	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Min	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4
Max	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.7	0.6	0.7	0.7
Range	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.5	0.4	0.5	0.4	0.3	0.3	0.3
DESCENDING PHASE – PEAK ANTERIOR-POSTERIOR GRF (BW)																
Mean	-0.3	-0.4	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3
sd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Min	-0.5	-0.6	-0.6	-0.6	-0.4	-0.4	-0.5	-0.4	-0.5	-0.6	-0.7	-0.6	-0.4	-0.4	-0.4	-0.4
Max	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.2	-0.2	-0.3	-0.3	-0.3	-0.2	-0.2	-0.2	-0.1	-0.2
Range	0.3	0.4	0.4	0.4	0.2	0.2	0.4	0.2	0.2	0.3	0.4	0.4	0.2	0.2	0.3	0.2
ASCENDING PHASE – PEAK ANTERIOR-POSTERIOR JFA (BW)																
Mean	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5
sd	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Min	0.3	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.4
Max	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.3	0.3	0.3	0.3	0.7	0.7
Range	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.5	0.4	0.3	0.3	0.3
DESCENDING PHASE – PEAK ANTERIOR-POSTERIOR JFA (BW)																
Mean	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3
sd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
Min	-0.5	-0.5	-0.6	-0.6	-0.4	-0.4	-0.5	-0.4	-0.5	-0.6	-0.7	-0.6	-0.4	-0.4	-0.4	-0.4
Max	-0.2	-0.2	-0.2	-0.2	-0.2	0.0	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2	-0.1	-0.3
Range	0.3	0.3	0.4	0.4	0.2	0.4	0.3	0.2	0.2	0.3	0.4	0.4	0.2	0.2	0.3	0.2
ASCENDING PHASE – PEAK ANTERIOR-POSTERIOR JFK (BW)																
Mean	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.5	0.5	0.6	0.6
sd	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Min	0.3	0.3	0.2	0.3	0.4	0.3	0.3	0.4	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.4
Max	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7
Range	0.1	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.4	0.5	0.5	0.5	0.4	0.3	0.3	0.3
DESCENDING PHASE – PEAK ANTERIOR-POSTERIOR JFK (BW)																
Mean	-0.4	-0.4	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3	-0.4	-0.4	-0.4	-0.4	-0.2	-0.3	-0.2	-0.3
sd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Min	-0.6	-0.6	-0.6	-0.6	-0.4	-0.4	-0.5	-0.4	-0.5	-0.7	-0.7	-0.6	-0.4	-0.4	-0.4	-0.4
Max	-0.3	-0.3	-0.3	-0.3	-0.2	-0.2	-0.1	-0.1	-0.3	-0.3	-0.3	-0.3	-0.1	0.0	-0.1	-0.1
Range	0.3	0.3	0.4	0.3	0.2	0.2	0.5	0.4	0.2	0.4	0.4	0.3	0.3	0.4	0.3	0.4
ASCENDING PHASE – PEAK ANTERIOR-POSTERIOR JFH (BW)																
Mean	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
sd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1
Min	0.3	0.3	0.2	0.3	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.4	0.4	0.4	0.4
Max	0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.8	0.9	0.9	1.0	0.8	0.8	0.9	0.9
Range	0.2	0.2	0.4	0.3	0.2	0.3	0.2	0.3	0.6	0.6	0.7	0.8	0.4	0.4	0.5	0.4
DESCENDING PHASE – PEAK ANTERIOR-POSTERIOR JFH (BW)																
Mean	-0.4	-0.5	-0.5	-0.5	-0.3	-0.3	-0.4	-0.4	-0.5	-0.5	-0.5	-0.5	-0.2	-0.2	-0.2	-0.2
sd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Min	-0.6	-0.7	-0.7	-0.6	-0.4	-0.5	-0.5	-0.5	-0.6	-0.8	-0.8	-0.7	-0.3	-0.5	-0.5	-0.4
Max	-0.3	-0.3	-0.3	-0.3	-0.2	-0.1	-0.1	-0.1	-0.4	-0.4	-0.4	-0.4	-0.1	-0.1	-0.1	-0.1
Range	0.3	0.4	0.4	0.3	0.3	0.3	0.4	0.4	0.2	0.4	0.5	0.4	0.3	0.4	0.3	0.3

Table 3. Descriptive Statistics (Mean, Standard Deviation, Minimum, Maximum and Range) of the Peak Joint Moments at Ankle (MA), at Knee (MK), and at Hip (MH), Normalised to Nm per Body Weight (Nm/BW)

	BASIC STEP				**KNEE LIFT**				**RUN STEP**				**KNEE HOP**			
BPM	**125**	**130**	**135**	**140**	**125**	**130**	**135**	**140**	**125**	**130**	**135**	**140**	**125**	**130**	**135**	**140**
ASCENDING PHASE – PEAK MA (Nm/BW)																
Mean	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
sd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Min	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Max	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Range	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0
DESCENDING PHASE – PEAK MA (Nm/BW)																
Mean	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0
sd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Min	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
Max	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1
Range	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0
ASCENDING PHASE – PEAK MK (Nm/BW)																
Mean	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.3	-0.3	-0.4	-0.4	-0.3	-0.3	-0.3	-0.3
sd	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Min	-0.2	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.5	-0.5	-0.5	-0.6	-0.4	-0.4	-0.4	-0.4
Max	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.2	-0.1	-0.2	-0.1	-0.2	-0.2	-0.2
Range	0.1	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.3	0.3	0.4	0.4	0.2	0.3	0.3	0.2
DESCENDING PHASE – PEAK MK (Nm/BW)																
Mean	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
sd	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Min	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
Max	-0.1	0.0	0.0	0.0	-0.1	0.0	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Range	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1
ASCENDING PHASE – PEAK MH (Nm/BW)																
Mean	-0.4	-0.5	-0.5	-0.5	-0.6	-0.6	-0.6	-0.6	-0.9	-0.9	-1.0	-1.0	-0.8	-0.8	-0.8	-0.8
sd	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2
Min	-0.6	-0.7	-0.7	-0.7	-0.8	-0.7	-0.8	-0.9	-1.2	-1.3	-1.3	-1.3	-1.0	-1.1	-1.1	-1.1
Max	-0.3	-0.2	-0.2	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.6	-0.4	-0.4	-0.5	-0.5	-0.5	-0.6
Range	0.3	0.5	0.5	0.4	0.5	0.3	0.4	0.5	0.8	0.7	0.9	0.9	0.6	0.6	0.5	0.5
DESCENDING PHASE – PEAK MH (Nm/BW)																
Mean	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.1	0.1	0.1
sd	0.0	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Min	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Max	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.2	0.3	0.2	0.3	0.2	0.1	0.1	0.2	0.2
Range	0.1	0.1	0.2	0.2	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1

Table 4. Summary of the Results of the Statistical Analysis Performed with Vertical Ground Reaction Forces (GRFy) and Joint Forces at Ankle (JFAy), at Knee (JFKy) and at Hip (JFHy). Significantly Statistical Differences ($p \leq 0.050$) were Found Between the Following Conditions of Stepping Rate and Step Movement

	Stepping Rate	Step Movement
GRFy ascending phase	No differences	$F(3,51)=58.757$ ($p=0.000$) All ($p \leq 0.018$); except *basic-hop* Hypothesis confirmed Greater values in *run step*
GRFy descending phase	No differences	$F(2.198,37.359)=38.405$ ($p=0.000$) *basic-hop* ($p=0.000$); knee *lift-hop* ($p=0.000$); *run-hop* ($p=0.000$) Hypothesis confirmed Greater values in *run step*
JFAy ascending phase	No differences	$F(2.341, 39.799)=53.197$ ($p=0.000$) All ($p \leq 0.020$); except *basic-hop* Hypothesis confirmed Greater values in *run step*
JFAy descending phase	No differences	$F(3, 51)=33.858$ ($p=0.000$) All ($p \leq 0.035$); except *basic*-knee *lift*; except *basic-run* Hypothesis confirmed Greater values in *run step*
JFKy ascending phase	No differences	$F(3,51)=55.198$ ($p=0.000$) All ($p \leq 0.021$); except *basic-hop* Hypothesis confirmed, Greater values in *run step*
JFKy descending phase	No differences	$F(2.295, 39.022)=39.737$ ($p=0.000$) All ($p \leq 0.046$); except *basic*-knee *lift*; except *basic-run* Hypothesis confirmed Greater values in *run step*
JFHy Ascending phase	No differences	$F(3, 51)=53.869$ ($p=0.000$) All ($p \leq 0.012$); except *basic-hop* Hypothesis confirmed Greater values in *run step*
JFHy descending phase	No differences	$F(2.160, 36.713)=40.717$ ($p=0.000$) *basic-hop* ($p=0.000$); knee *lift-hop* ($p=0.000$); *run-hop* ($p=0.000$) Hypothesis confirmed Greater values in *run step*

GRFy ($p=0.008$); JFAx ($p=0.005$); JFKx ($p=0.001$); JFKy ($p=0.011$); and JFHy ($p=0.014$).

DISCUSSION

Ground and Joint Forces Profile

The joint forces-time curves through the step cycle were similar to the pattern of the GRF. The vertical components of GRF and JF dominate the impact force-time history in comparison to the anterior-posterior components. The action of stepping up from the ground to the bench was expected to produce higher force in the anterior direction, and the action of stepping back from the bench to the ground was expected to produce higher force in the posterior direction. The analysis of GRF has shown that higher loads occur during the reception on the step-bench (in movements with propulsion) and during the reception on the ground (in movements without propulsion). During ascending phase of *basic-step*, *knee-lift*, *run-step* and *knee-hop*, the horizontal component of the GRF and JF at ankle, knee and hip shows an anterior force about three times smaller than the corresponding vertical component. Negative moments reflect hip flexion and knee

Table 5. Summary of the Results of the Statistical Analysis Performed with Anterior-Posterior Ground Reaction Forces (GRFx) and Joint Forces at ANKLE (JFAx), at Knee (JFKx) and at Hip (JFHx). Significantly Statistical Differences (*p*≤0.050) were Found between the Following Conditions of Stepping Rate and Step Movement

	Stepping Rate	Step Movement
GRFx ascending phase	*F*(2.572, 43.724)=21.503 (*p*=0.000) All (*p*≤0.013); except 125-130 bpm; except 130-135 bpm Hypothesis confirmed Increases as stepping rate increases	*F*(2.661, 45.239)=40.991 (*p*=0.000) All (*p*=0.000); except *run-hop* Hypothesis confirmed Greater values in *run step* and *knee hop*
GRFx descending phase	*F*(3, 51)=9.008 (*p*=0.000) 125-135 bpm (*p*=0.013); 125-140 bpm (*p*=0.000) Hypothesis confirmed Increases as stepping rate increases	*F*(1.991, 33.845)=14.302 (*p*=0.000) All (*p*≤0.035); except *basic-hop*; except knee *lift-hop* Hypothesis confirmed Greater values in *run step*
JFAx ascending phase	*F*(3, 51)=19.338 (*p*=0.000) All (*p*≤0.027); except 125-130 bpm Hypothesis confirmed Increases as stepping rate increases	*F*(2.643, 44.929)=42.702 (*p*=0.000) All (*p*=0.000); except *run-hop* Hypothesis confirmed Greater values in *run step* and *knee hop*
JFAx descending phase	*F*(3, 51)=9.194 (*p*=0.000) 125-135 bpm (*p*=0.007); 125-140 bpm (*p*=0.000) Hypothesis confirmed Increases as stepping rate increases	*F*(1.990, 33.833)=14.039 (*p*=0.000) *basic-run* (*p*=0.006); knee *lift-run* (*p*=0.001); *run-hop* (*p*=0.001) Hypothesis confirmed Greater values in *run step*
JFKx ascending phase	*F*(3, 51)=20.022 (*p*=0.000) All (*p*≤0.046); except 130-135 bpm Hypothesis confirmed Increases as stepping rate increases	*F*(2.657, 45.177)=46.592 (*p*=0.000) All (*p*=0.000); except *run-hop* Hypothesis confirmed Greater values in *run step* and *knee hop*
JFKx descending phase	*F*(3, 51)=4.267 (*p*=0.009) 125-140 bpm (*p*=0.020) Hypothesis confirmed Increases as stepping rate increases	*F*(2.306, 39.209)=19.338 (*p*=0.000) All (*p*≤0.019); except knee *lift-hop* Hypothesis confirmed Greater values in *run step*
JFHx ascending phase	*F*(3, 51)=11.439 (*p*=0.000) 125-135 bpm (*p*=0.026); 125-140 bpm (*p*=0.000) Hypothesis confirmed Increases as stepping rate increases	*F*(1.740, 29.587)=20.569 (*p*=0.000) All (*p*≤0.001); except knee *lift-run*; except *run-hop* Hypothesis confirmed Greater values in *knee hop*
JFHx descending phase	No differences	*F*(1.908, 32.436)=58.392 (*p*=0.000) All (*p*≤0.024) Hypothesis confirmed Greater values in *run step*

flexion, and positive moment reflects ankle dorsiflexion. The results showed that during ascending phase, the GRF and the JF curves were quite regular between subjects stepping at different cadences, particular in what regards to non-propulsion movements. During descending phase of *basic-step*, *knee-lift*, *run-step* and *knee-hop*, the horizontal component of the GRF and JF at ankle, knee and hip shows a posterior force about three times smaller than the corresponding vertical component. Positive moments reflect hip extension and knee extension, and ankle dorsiflexion. In terms of technique, the descending phase is supposed to be similar between the four patterns analysed. The results showed that the GRF and the JF curves were very regular between subjects stepping at different cadences and in different Step-patterns.

The results suggest that experienced steppers are capable of stepping at different cadences, with generally similar patterns of kinematics and kinetics. However, there are some potentially important differences relating to how they use lower limb segments. The study of the different moments of force and force magnitudes obtained allows the analysis of the pattern of force-absorbing adjustments, concerning the external and internal forces. Concerning the four movements analysed, the magnitude of vertical GRF was similar or

Table 6. Summary of the Results of the Statistical Analysis Performed With Joint Moments of Force. Significantly Statistical Differences ($p \leq 0.050$) were Found between the Following Conditions of Stepping Rate and Step Movement

	Stepping Rate	Step Movement
MA ascending phase	No differences	*F*(1.523, 25.886)=169.141 (*p*=0.000) All (*p*≤0.000); except *basic-run* Hypothesis confirmed Greater values in *run step* and *basic step*
MA descending phase	No differences	*F*(2.303, 39.156)=126.037 (*p*=0.000) All (*p*≤0.001); except *basic-run* Hypothesis confirmed Greater values in *run step* and *basic step*
MK ascending phase	*F*(3, 51)=5.422 (*p*=0.003) 125-135 bpm (*p*=0.021); 125-140 bpm (*p*=0.025) Hypothesis confirmed Increases as stepping rate increases	*F*(2.552, 43.389)=97.954 (*p*=0.000) All (*p*≤0.026) Hypothesis confirmed Greater values in *run step* and *knee hop*
MK descending phase	No differences	No differences
MH Ascending phase	*F*(3, 51)=6.727 (*p*=0.001) 125-135 bpm (*p*=0.000); 125-140 bpm (*p*=0.011); 130-140 bpm (*p*=0.049) Hypothesis confirmed Increases as stepping rate increases	*F*(2.239, 38.059)=145.977 (*p*=0.000) All (*p*≤0.007) Hypothesis confirmed Greater values in *run step*
MH descending phase	*F*(3, 51)=2.815 (*p*=0.048) 125-135 bpm (*p*=0.039) Hypothesis confirmed Increases as stepping rate increases	*F*(2.336, 39.710)=20.079 (*p*=0.000) All (*p*≤0.010); except *basic-run*; except knee *lift-hop* Hypothesis confirmed Greater values in *run step*

greater than JF at the ankle joint, and were greater than JF at knee and hip joints. On the contrary, the horizontal GRF was similar or smaller than JF at ankle joint, and were smaller than JF at knee and hip joints.

In relation to the **vertical** component of GRF, JF at the ankle joint decreased **1 to 9%** or increased 1% in the ascending phase of *knee-lift*. The vertical JF at the knee joint decreased **3 to 12%**. The vertical JF at the hip joint decreased **9 to 12%** and decreased 16 to 25% in the descending phase of *knee-hop*. These relationships showed a pattern of force absorbing adjustments from distal to proximal joints. The results of the present investigation showed how experienced instructors deal with dissipation of forces across distal to proximal joints. Concerning vertical JF the lowest magnitudes were found at hip joint, as expected. In relation to the **horizontal** component of GRF, the magnitude of JF at the ankle joint maintained similar to GRF or increased **1 to 6%**, except during the descending phase of the *knee-hop* that decreased 3%. The horizontal JF at the knee joint increased **3 to 9%**, or decreased 18 to 21% during the descending phase of *knee-hop*. The horizontal JF at the hip joint increased **5 to 31%** or decreased 29 to 37% during the descending phase of *knee-hop*. These relationships are in agreement with the results obtained during descending phase of the same Step-patterns performed at 130 bpm [8].

Peak Vertical Ground and Joint Forces

The mean GRFy in ascending phase were about 1.7 BW in *basic-step*, 1.3-1.4 BW in *knee-lift*, 1.9-2.1 BW in *run-step* and 1.8 BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between Step-patterns, except between *basic-step* and *knee-hop*. In descending phase the GRFy were about 1.7 BW in *basic-step*, 1.5-1.6 BW in *knee-lift*, 1.7-1.8 BW in *run-step*, and 1.1-1.2 BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between *knee-hop* and the other Step-patterns. In propulsion steps (*run-step* and *knee-hop*) the magnitude of loading is higher during ascending phase in comparison with descending phase. On the contrary, in non-propulsion steps (*basic-step* and *knee-lift*) the magnitude of loading is higher during descending phase in comparison with ascending phase.

The mean JFAy in ascending phase were about 1.7 BW in *basic-step*, 1.3-1.4 BW in *knee-lift*, 1.9-2.0 BW in *run-step* and 1.8 BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between Step-patterns, except between *basic-step* and *knee-hop*. In descending phase the JFAy were about 1.6-1.7 BW in *basic-step*, 1.4-1.5 BW in *knee-lift*, 1.7-1.8 BW in *run-step*, and 1.0 BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between Step-patterns except between *basic-step* and *knee-lift* and between *basic-step* and *run-step*. In propulsion steps (*run-step* and *knee-hop*) and *basic-step* the magnitude of loading is higher during ascending phase in comparison with descending phase. In *knee-lift* the magnitude of loading is higher during descending phase in comparison with ascending phase. The results for descending phase of *basic-step* are in agreement with those reported by Bezner *et al.* [7] despite these authors used slower cadences (100-120 bpm).

The mean JFKy in ascending phase were about 1.7 BW in *basic-step*, 1.3 BW in *knee-lift*, 1.9-2.0 BW in *run-step*, and 1.7-1.8 BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between Step-patterns ($p \leq 0.021$), except between *basic-step* and *knee-hop*. In descending phase the mean JFKy were about 1.7 BW in *basic-step*, 1.4-1.5 BW in *knee-lift*, 1.6-1.7 BW in *run-step*, and 0.9-1.0 BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between Step-patterns except between *basic-step* and *run-step*. In propulsion steps the magnitude of loading is higher during ascending phase in comparison with descending phase. In non-propulsion steps the magnitude of loading at the knee joint is similar or higher during descending phase in comparison with ascending phase. The results for descending phase of *basic-step* are greater than those reported by Bezner *et al.* [7] however the authors used slower cadences (100-120 bpm).

The mean JFHy in ascending phase were about 1.5-1.6 BW in *basic-step*, 1.2 BW in *knee-lift*, 1.7-1.9 BW in *run-step*, and 1.6-1.7 BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between Step-patterns, except between *basic-step* and *knee-hop*. In descending phase the mean JFHy were about 1.5-1.6 BW in *basic-step*, 1.3-1.4 BW in *knee-lift*, 1.5-1.6 BW in *run-step*, and 0.8-1.0 BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between *knee-hop* and the other Step-patterns. In propulsion steps the magnitude of loading is higher during ascending phase in comparison with descending phase. In non-propulsion steps the magnitude of loading at the hip joint is similar or higher during descending phase in comparison with ascending phase. These results for descending phase of *basic-step* are not in agreement with (smaller than) those reported by Bezner *et al.* [7] and have shown an increase in the magnitude of JF, from ankle to hip. None of the results for descending phase are in line with those obtained in our previous study with one subject [8].

Bezner *et al.* [7] reported similar magnitudes of the JF across the joints at each of the three bench-step heights they have studied. These authors referred that this indicated a lack of dissipation of forces across the joints, distal to proximal, which may be a risk factor for injury in this activity. Those authors reported in 9 experienced female subjects, during the descending phase of *basic-step*, at 100-120 bpm, JFAy of 1.6-1.7 BW; JFKy of 1.5-1.6 BW; JFHy of 1.7 BW; on a 15.2cm bench; JFAy of 1.8 BW; JFKy of 1.7 BW; JFHy of 1.8 BW; on a 20.3cm bench; and also, JFAy of 1.9 BW; JFKy of 1.8/2 BW; JFHy of 1.9/2 BW; on a 25.4cm bench. Santos-Rocha and Veloso [8] analyzed four Step-patterns (descending phase) in one experienced female subject, using a 15cm bench at 130 bpm: considering JFAy, JFKy and JFHy, we obtained respectively; 1.5/1.5/1.3 BW for *basic-step*; 2.1/2.0/1.8 BW for *run-step*; 1.5/1.5/1.3 BW for *knee-lift*; and 1.7/1.6/1.5 BW for *knee-hop*. GRFy were similar to JFAy. JFKy and JFHy were smaller than GRFy, and JFHy were smaller than JFKy. This tendency was observed in the four movements analysed. However, the study was conducted with only one experienced subject, and our results are not in agreement with those obtained by Bezner *et al.* [7].

Peak Anterior-Posterior Ground and Joint Forces

The mean anterior GRFx in ascending phase were about 0.3-0.4 BW in *basic-step*, 0.4 BW in *knee-lift*, 0.5-0.6 BW in *run-step*, and 0.5 BW in *knee-hop*. GRFx increased with stepping-rate. There were significant differences between conditions of stepping-rate, except between 125-130 bpm and 130-135 bpm, and showed significant differences between Step-patterns, except between *run-step* and *knee-hop*. In descending phase the mean peak posterior GRFx were about -0.3 and -0.4 BW in *basic-step*, -0.3 BW in *knee-lift*, -0.4 BW in *run-step*, and -0.3 BW in *knee-hop*. GRFx increased with stepping-rate, however, there were significant differences between conditions 125-140 bpm and 125-135 bpm. There were significant differences between Step-patterns, except between *basic-step* and *knee-hop* and between *knee-lift* and *knee-hop*. In propulsion steps (*run-step* and *knee-hop*) the magnitude of loading is higher during ascending phase in comparison with descending phase. On the contrary, in non-propulsion steps (*basic-step* and *knee-lift*) the magnitude of loading is higher during descending phase in comparison with ascending phase.

The mean peak anterior JFAx in ascending phase were about 0.3-0.4 BW in *basic-step*, 0.4 BW in *knee-lift*, 0.5-0.6 BW in *run-step* and 0.5 BW in *knee-hop*. Peak anterior JFAx increased with stepping-rate. There were significant differences between conditions of stepping-rate, except between 125-130 bpm. There were significant differences between Step-patterns, except between *run-step* and *knee-hop*. In descending phase the mean peak posterior JFAx were about -0.4 BW in *basic-step* and *run-step*, and -0.3 BW in *knee-lift* and *knee-hop*. Peak posterior JFAx increased with stepping-rate, however, there were significant differences between conditions 125-140 bpm and 125-135 bpm. There were significant differences between *run-step* and the other Step-patterns. In all movements the magnitude of loading is similar or higher during ascending phase in comparison with descending phase.

The mean peak anterior JFKx in ascending phase were about 0.3-0.4 BW in *basic-step*, 0.4 BW in *knee-lift*, 0.5-0.6 BW in *run-step* and *knee-hop*. Peak anterior JFKx increased with stepping-rate. There were significant differences between conditions of stepping-rate, except between 130-135 bpm. There were significant differences between Step-patterns, except between *run-step* and *knee-hop*. In descending phase the mean peak posterior JFKx were about -0.4 BW in *basic-step* and *run-step*, -0.3 BW in *knee-lift*, and -0.2 to -0.3 BW in *knee-hop*. Peak posterior JFKx increased with stepping-rate, however, there were significant differences between conditions 125-140 bpm. There were significant differences between Step-patterns except between *knee-lift* and *knee-hop*. In propulsion steps (*run-step* and *knee-hop*) and *knee-lift* the magnitude of loading was higher during ascending phase in comparison with descending phase. In *basic-step* the magnitude of loading was higher during descending phase in comparison with ascending phase.

The mean peak anterior JFHx in ascending phase were about 0.4 BW in *basic-step*, 0.5 BW in *knee-lift*, 0.5-0.6 BW in *run-step* and 0.6 BW in *knee-hop*. Peak anterior JFHx increased with stepping-rate, however, there were significant differences between conditions 125-130 bpm and between 125-140 bpm. Also, there were significant differences between Step-patterns, except between *run-step* and *knee-hop* and between *run-step* and *knee-lift*. In descending phase the mean peak posterior JFHx were about -0.4 to -0.5 BW in *basic-step*, -0.3 to -0.4 BW in *knee-lift*, -0.5 BW in *run-step* and -0.2 BW in *knee-hop*. No significant differences were found in peak posterior JFHx between conditions of stepping-rate. There were significant differences between all Step-patterns. In propulsion steps (*run-step* and *knee-hop*) and *knee-lift* the magnitude of loading was higher during ascending phase in comparison with descending phase. In *basic-step* the magnitude of loading was higher during descending phase in comparison with ascending phase.

Peak Moment of Force at Ankle, Knee and Hip Joints

Positive moment at ankle reflects ankle dorsiflexion during ascending and descending phases. The mean peak MA in ascending phase were about 0.1 Nm/BW in *basic-step* and *run-step*, 0.04-0.05 Nm/BW in *knee-lift*, and 0.05-0.06 Nm/BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between Step-patterns, except between *basic-step* and *run-step*. In descending phase the mean MA were about 0.1 Nm/BW in *basic-step*, *knee-lift* and *run-step*, and 0.04-0.05 Nm/BW in *knee-hop*. No significant differences were found between conditions of stepping-rate. There were significant differences between Step-patterns, except between *basic-step* and *run-step*. In *basic-step*, *run-step* and *knee-hop* the magnitude of loading was similar in ascending and descending phases. In *knee-lift* the magnitude of loading was higher during descending phase in comparison with ascending phase.

Negative moment at knee reflects knee flexion during ascending and descending phases. The mean MK in ascending phase was about -0.1 to -0.2 Nm/BW in *basic-step*, -0.2 Nm/BW in *knee-lift*, -0.3 to -0.4 Nm/BW in *run-step*, and -0.3 Nm/BW in *knee-hop*. There were significant differences between conditions 125-135 bpm and 125-140 bpm. There were significant differences between all Step-patterns. In descending phase the mean MK was about -0.1 Nm/BW in *basic-step*, *knee-lift*, *run-step*, and *knee-hop*. No significant differences were found between conditions of stepping-rate and between Step-patterns. In all Step-patterns the magnitude of loading was higher during ascending phase in comparison with descending phase.

Negative moment at hip reflects hip flexion during ascending phase. Positive moment reflects hip extension during descending phase. The mean MH in ascending phase was about -0.4 to -0.5 Nm/BW in *basic-step*, -0.6 Nm/BW in *knee-lift*, -0.9 to -1 Nm/BW in *run-step*, and -0.8 Nm/BW in *knee-hop*. There were significant differences between conditions of stepping-rate except between 125-130, 130-135 and 135-140 bpm. There were significant differences between all Step-patterns. In descending phase the mean MH were about 0.1-0.2 Nm/BW in *basic-step* and *run-step*, and 0.1 Nm/BW in *knee-lift* and *knee-hop*. There were significant differences between 125-135 bpm. There were significant differences between Step-patterns except between *basic-step* and *run-step* and between *knee-lift* and *knee-hop*. In all Step-patterns the magnitude of loading was higher during ascending phase in comparison with descending phase.

None of the results obtained for peak joint moments in the three joints during the descending phase are in agreement with those obtained in our previous study with one subject [8]. Winter *et al.* [18] referred that the mean MA, MK and MH, change their profile with cadence (natural, fast and slow walking). The same was observed in the hip and the knee joints (ascending phase). Santos-Rocha and Veloso [8] calculated peak MA, MK and MH of 0.2, -0.2 and 0.2 Nm/BW, respectively, in *basic-step*; 0.2, -0.2 and 0.2 Nm/BW, respectively, in *run-step*; 0.2, 0.1 and 0.2 Nm/BW, respectively, in *knee-lift*; 0.2, -0.2 and 0.2 Nm/BW, respectively, in *knee-hop*. These values are lower than those obtained in the present study.

In propulsion steps (*run-step* and *knee-hop*) the magnitude of loading was greater during ascending phase in comparison with descending phase. On the contrary, in non-propulsion steps (*basic-step* and *knee-lift*) the magnitude of loading was greater during descending phase in comparison with ascending phase.

The horizontal component of the JF is much smaller than the vertical but it increased as stepping-rate increased. It also increased from distal to proximal joints. Anterior-posterior internal forces, although much smaller than the vertical component, were more affected by stepping-rate. Both components differ between propulsion and non-propulsion step-patterns. The vertical component of force, on the contrary, decreased from distal to proximal joints. It increased with stepping-rate but there was no statistical significance. The results indicate that lower extremity joint loading can be effectively controlled by varying stepping-rate and Step-patterns during Step classes. The maintenance of similar peak forces, particularly the vertical component, for different conditions of stepping-rate was explained by observed kinematic adjustments; especially at knee joint [19]. Also, the peak values of MK were affected by stepping-rate, which might be related to the occurrence of overuse injuries.

There were several limitations in the methodology of this study that should be noticed in future research. We only investigated sagittal plane biomechanics of the tasks. The development of a three dimensional model in the future would bring more information. We do not know from JF and M how loading is shared between the various structures. The calculations were made during the one leg support period. Those periods were identified manually by visioning the limited resolution video images. In future research, four force platforms should be used in order to calculate GRF in both feet. The present results are based on a sample of 18 instructors, physically active and with a long experience in this activity. Both the kinematics and force characteristics of the tasks may be different if participants with less experience in Step are used. The present investigation is limited in that it cannot denote a specific time-interval at which step-exercise experience begins to elicit a change in the characteristics of the landing curve. The instructors had an experience that ranged from 4 to 15 years.

The present investigation provides data of kinetics parameters of Step movements, that may be used as a basis of comparison with elder and novice Step participant's in future biomechanical research. Further research is needed focusing other Step-patterns in order to select those that are more appropriate to be included in Exercise and Rehabilitation programmes. Also, these results are related to the mechanical characteristics of this physical activity and might be analysed under the ergonomic perspective, since the group of subjects was constituted by experienced Step instructors.

CONCLUSIONS

Understanding the biomechanics of the lower limb during Step-Exercise is very important for instructors to prescribe Exercise correctly and for therapists to design Rehabilitation programs. The analysis of the GRF, JF and joint moments helps to understand how musculoskeletal structures transmit and attenuate the impact forces. This study investigated the external forces and the internal loading experienced by the ankle, knee and hip joints during four common Step movements performed at various cadences of stepping-rate. The results indicated that lower extremity joint loading can be effectively controlled by varying stepping-rate and Step-patterns during Step classes. The results contribute to increase the knowledge about Exercise prescription and injury prevention of this physical activity and help to understand how skilled participants deal with the increase of the external load. The results are also relevant to determine which movements and cadences can be recommended to be included in rehabilitation programs where walking and running are prescribed. Assuming that walking or running are "safe" activities to be included in Exercise and Rehabilitation programs, controlled stepping exercise appear relatively safe with respect to the magnitude of loading. However, further research is required in order to select other Step-patterns that are appropriate or not to be included in Exercise and/or Rehabilitation programs.

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