OFFICIAL ACCEPTANCE OF MANUSCRIPT:
NOTICE TO AUTHOR

MANUSCRIPT TITLE: "Analysis of Ground Reaction Forces in Step-Exercise Depending on Step-Pattern and Stepping-Rate."

Your manuscript has been officially accepted for publication in the Journal of Strength and Conditioning Research. The exact volume and number are dependent upon editorial page limits for each journal. If you have any questions, please call my office. Your manuscript has been forwarded to the publisher. The editorial staff will make grammatical changes in text where appropriate. You will be receiving page proofs for your inspection 2-3 months prior to publication of the specific journal volume and number. In press time is about 10-12 months. Your manuscript will be published in the order of its acceptance. It is vital that you make a final review of the galley proofs and return them to publisher as instructed.

We truly appreciate the hard work and the time it took to perform the research and to complete the revision process. We congratulate you on a fine professional contribution. On behalf of the National Strength and Conditioning Association, I thank you again for considering this professional journal for the publication of your scientific work. We hope that you may find this journal appropriate for publishing other manuscripts from your laboratory in the future. We look forward to your future contributions. Thank you again for your contribution. Congratulations.

Sincerely,

William J. Kraemer, Ph.D., CSCS
EDITOR-IN-CHIEF

University of Connecticut - Department of Kinesiology - 2095 Hillside Road, Unit 1110 - Storrs, CT 06269-1110
Phone +1 860-486-6892 - Fax: +1 860-486-6888 - William.Kraemer@uconn.edu
ANALYSIS OF GROUND REACTION FORCES IN STEP-EXERCISE DEPENDING ON STEP-PATTERN AND STEPPING-RATE

Rita Santos-Rocha¹,², António Veloso², and Maria Lourdes Machado²

¹Sport Sciences School of Rio Maior, Polytechnic Institute of Santarém, Portugal
²Laboratory of Biomechanics, Faculty of Human Kinetics, Technical University of Lisbon, Portugal

Corresponding author: Rita Santos-Rocha

Affiliation: Sport Sciences School of Rio Maior, Polytechnic Institute of Santarém, Portugal (www.esdrm.pt); Laboratory of Biomechanics, Faculty of Human Kinetics, Technical University of Lisbon, Portugal (www.fmh.utl.pt)

Mailing address: Urb Jardins da Parede, Av das Tilias, 104-1A, 2775-335 Parede, Portugal

E-mail address: rsantos@esdrm.pt

Phone number: +351-966036856

Fax: +351-243999289
ANALYSIS OF GROUND REACTION FORCES IN STEP-EXERCISE DEPENDING ON STEP-PATTERN AND STEPPING-RATE

Abstract

The analysis of ground reaction forces (GRF) helps to understand the magnitude and pattern of loading experienced by the body while in contact with the ground. The GRF reflect a general indicator of mechanical loading of the different forms of Exercise and allows the comparison between different activities. Also, it allows establishing the “biomechanical intensity” of physical activity. Our purposes were to analyze the GRF produced by Step-Exercise such as profile, average GRF, impulse, peak GRF and loading rate, in 18 skilled females; and to investigate the differences that exist between four stepping-rate conditions and between four Step-patterns. Two force platforms were used. The results indicated that lower extremity external loading can be effectively controlled by varying stepping-rate during Step classes. 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. Our results show how experienced subjects deal with the increase of movement cadence in terms of external load.

Key words: force platform, repeated measures, exercise prescription.
ANALYSIS OF GROUND REACTION FORCES IN STEP-EXERCISE DEPENDING ON STEP-PATTERN AND STEPPING-RATE

INTRODUCTION

Step-Exercise was described in a previous study (1). Besides its cardiovascular benefits (2,3,4,5) the structure of exercise sessions, concerning rate and magnitude of skeletal loading, may improve the osteogenic potential of physical activity (6,7). This activity involves a large number of loading cycles during each session (1) but when Step-Reebok™ program was presented its proponents claimed that ground reaction forces (GRF) were similar to those of walking (8,9). Originally introduced as a low impact activity, Step classes now include propulsive movements that have changed the nature of impact of the activity (1,10,11). Step-Exercise is claimed to be a high intensity low-medium impact aerobic workout carrying a low injury risk, which conditions the lower body (10). Two forms of controlling the intensity of the workout are by adjusting stepping-rate (125 to 150 beats-per-minute – bpm); and by selecting the types of movements included in choreography (e.g. propulsive movements).

A major concern is how to control the intensity of the workout, maintaining safe and effective levels of mechanical load. The GRF of a Step session depend on the type and number of movements performed (1). Regular exposure to moderately high magnitudes of force is desirable within certain levels, because mechanical stress will induce adaptation on biological structures (12). However the same forces might produce undesirable effects such as discomfort, pain and injury, especially when forces are too repetitive in a period of time (13). Clinical evidence suggested that workout intensity plays a major role in the development of overuse injuries of the
musculoskeletal system (14). Several authors referred that Step-Exercise seems to induce greater load compared to impact loading of walking, and at increased stepping-rates its impact loading could be compared to those obtained during comfortable running and high impact aerobics, but with lower risk of injury (10,11,15,16,17,18,19,20).

The assessment of biomechanical loading is quite important for exercise prescription and injury prevention in the scope of Exercise Biomechanics. It has been suggested that there is an optimal amount of loading that healthy individuals should maintain and that loading above a certain limit might be related to the risk of injury (20). High skeletal loading intensity has been defined as peak GRF of greater than 4 times body weight (BW), moderate intensity as 2 to 4-BW, and low intensity as GRF less than 2-BW, and a minimum osteogenic effect was related to GRF of 1 to 2-BW (7,20,21,22). Nevertheless, the result of the loading on the body depends on the magnitude of the force; on the rate at which the force is applied; and on the repetition of load application (23). However, most studies characterize movements concerning only the peak vertical GRF. GRF measurements reflects a general indicator of mechanical loading that allows: establishing the “biomechanical intensity”; the comparison between different activities; establishing comparisons between healthy people and patients; calculating internal forces; calculating osteogenic index; and GRF characteristics were also positively correlated with metabolic energy requirements. Also, the magnitude of GRF has been associated, although never verified, with the high incidence of lower extremities injuries in fitness instructors (24). Most studies that involved Step-Exercise, reported the effects of peak vertical GRF during the descending-phase of basic-step (10,11,12,13,14,15,16,17,18,19,25,26). However,
one may be interested in the magnitude or in how fast the force is increasing or decreasing. The loading-rate describes this behavior. To our knowledge, no studies were performed concerning the loading-rate induced by Step-Exercise. During gait, the vertical and horizontal forces change with cadence and the maximum and minimum peaks increase with cadence (natural, fast and slow walking). Generating horizontal propulsive GRF comprises a substantial (~30%) fraction of the total energetic cost of running \((27,28)\). Few studies reported the peak anterior-posterior and the medio-lateral GRF of Step-Exercise \((15,29)\). Also, to our knowledge, no studies were performed concerning the AGRF and impulse during Step-Exercise.

We hypothesized that the step-patterns with propulsion should present higher load than non propulsive movements, and loading increases with faster stepping-rate. Our purposes were: 1) to analyze the GRF produced by Step-Exercise such as profile, average GRF, impulse, peak GRF and loading rate, concerning its ascending and descending-phases, in 18 skilled females; and 2) to investigate the differences that exist between four stepping-rate conditions (125, 130, 135 and 140 bpm) and between four Step-patterns (basic-step, knee-lift, run-step and knee-hop), performed with right and left leading legs, in relation to: vertical-AGRF \((\text{AGRF}_z)\), anterior-posterior-AGRF \((\text{AGRF}_x)\), medio-lateral-AGRF \((\text{AGRF}_y)\), vertical-impulse \((\text{ImpF}_z)\), anterior-posterior-impulse \((\text{ImpF}_x)\), medio-lateral-impulse \((\text{ImpF}_y)\), total-time-of-contact \((\text{TTC})\), vertical-1\(^{st}\) peak \((\text{F}_z)\), vertical-1\(^{st}\) peak loading-rate \((\text{LR-}_Fz)\), time-to-vertical-1\(^{st}\) peak \((\text{TF}_z)\), anterior-posterior-1\(^{st}\) peak \((\text{F}_x)\), anterior-posterior-1\(^{st}\) peak loading-rate \((\text{LR-}_Fx)\), time-to-anterior-posterior-1\(^{st}\) peak \((\text{TF}_x)\), medio-lateral-1\(^{st}\) peak \((\text{F}_y)\), medio-lateral-1\(^{st}\) peak loading-rate \((\text{LR-}_Fy)\), and time-to-medio-lateral-1\(^{st}\) peak \((\text{TF}_y)\).
METHODS

Approach to the problem

One particular source of loading on the body is the ground reaction force (GRF). Characteristics such as force profile, impact peak, loading-rate, impulse, average force, and other can be readily quantified and have a functional relationship to the performance (30). AGRFz was referred as an extremely stable indicant (28). Impulse (represented by the area enclosed between the baseline and the force curve) was referred as a variable for assessment of performance that reflects the change in velocity of the centre of mass. Vertical impulse was the only GRF characteristic significantly correlated to aerobic demand (30). The quantification of the initial part of the vertical GRF curve may be effectively characterized by the loading-rate, due to the absence of an impact peak in certain cases. The loading-rate of a force-time signal is the time derivative of the force-time curve. This parameter indicates how fast the force changes in time and can be depicted as the slope of the force-time curve. It is often assumed that the loading-rate is associated with the development of movement-related injuries (31). Four step-patterns were performed at varying cadences on two force platforms. Selected biomechanical parameters were used for input in statistical analysis.

Subjects

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, were led through a sequence of stepping tasks, using approved choreography. These women were experienced
fitness instructors with 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 (32) and gave their consent to participate in this study before performing any exercise trials. The study was approved by the review committee of the Faculty. The subjects performed the sequence of 8 Step movements: right-basic-step, right-knee-lift, left-basic-step, left-knee-lift, right-run-step, right-knee-hop, left-run-step, left-knee-hop. This procedure was adopted in order to ensure mechanical balance between both lower limbs, and in order to better represent the real conditions of practice. No arm movements were added. None of the subjects felt discomfort during stepping over the two force-platforms, and also, they did not manifest that the laboratory conditions had influenced their stepping style. Our previous study showed that metal force-platforms surfaces are suitable to assess mechanical load of stepping, with experienced subjects (33). The subjects were allowed to familiarize 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. Fitness music was used to maintain cadence. All experimental trials were conducted in a “crescent cadence” order. These procedures were adopted so the result would reflect typical class conditions. Verbal instruction was provided during the tests. In order to reduce error participants wore similar Reebok™ shoes, because the type of footwear influence peak pressures, impact, braking and propulsive forces, and alter foot mechanics (34,35).
Procedures

The movements were performed on the AMTI force-platform (*Advanced Mechanical Technology, Inc, Watertown, MA*) of 0.90x0.60x0.17 cm (length/wide/height) for stepping-up (substituting the step-bench) and on the KISTLER force-platform (*Kistler AG, Winterthur, Switzerland*) of 0.60x0.40 cm (length, wide) on ground level for stepping-down. After calibrating force platforms, GRF were measured at 1000-Hz and the software Acqknowledge 3.7.3 (*BIOPAC Systems, Inc., Goleta, CA*) was used to collect and process data. Data were smoothed with a Hamming low pass digital filter. The optimal cut-off frequencies of 8-Hz were determined by the residual error method proposed by Winter (36). The three components of GRF were obtained. The force profiles for each recording were analyzed using Acqknowledge. In each condition of stepping-rate, the trajectories of the components of the GRF of all subjects were normalized in time, and the average curve was calculated, and presented graphically. AGRF (N), Impulse (N.s), time to peak and TTC (s) were read in Acqknowledge. The impulse during ascending-phase was determined by integrating the GRF-time curve from the instant the foot touches the AMTI-platform to zero (impulse= ∫force N.TTC); and during descending-phase, from the instant the foot touches the Kistler-platform to the instant of peak double support. AGRF and impulse were normalized to body weight (BW). Loading-rate (N/s) was calculated (loading-rate=peak-force-N /time-to-peak-s) and normalized to BW/s in Excel (loading-rate=peak-force-BW/time-to-peak-s). Force was normalized to BW in Excel (*Microsoft Corporation, USA*). GRF were measured in three directions vertical (Fz), anterior-posterior (Fx), and medio-lateral (Fy), during a sequence of Step movements performed at varying cadences. **Figure 1** represents the identification of the movements studied, during the ascending-phase and during the descending-phase.
Statistical analyses

The following variables were analyzed statistically:

- vertical-AGR (\textit{AGRF}_z), anterior-posterior-AGR (\textit{AGRF}_x), medio-lateral-AGR (\textit{AGRF}_y), vertical-1st peak (\textit{FZ}), anterior-posterior-1st peak (\textit{FX}), and medio-lateral-1st peak (\textit{FY}) (force parameters);
- vertical-impulse (\textit{ImpF}_z), anterior-posterior-impulse (\textit{ImpF}_x), medio-lateral-impulse (\textit{ImpF}_y), vertical-1st peak loading-rate (\textit{LR-FZ}), anterior-posterior-1st peak loading-rate (\textit{LR-FX}), and medio-lateral-1st peak loading-rate (\textit{LR-FY}) (combined parameters);
- total-time-of-contact (\textit{TTC}), time-to-vertical-1st peak (\textit{TFZ}), time-to-anterior-posterior-1st peak (\textit{TFX}), and time-to-medio-lateral-1st peak (\textit{TFY}) (temporal parameters).

All statistic procedures were conducted using SPSS 14.0 for Windows (Statistical Package for the Social Sciences, Chicago, IL). All results are reported as mean, standard deviations (\(\pm sd\)), maximum, minimum, range and coefficient of variation (\textit{CV}). Kolmogorov-Smirnov normality test and Mauchly’s test of sphericity were conducted. A one-way ANOVA for repeated measures with two within-subjects factors (\textit{ANOVA-RM}) was used to determine whether there were significant differences in parameters between conditions of stepping-rate and between Step-patterns. 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 \(p \leq 0.050\) (37).
RESULTS

Figures 2 to 5 represent the mean curves obtained for 18 subjects, for the different cadences. Considering the profile of ground reaction forces curves, the vertical component of GRF dominates the impact force-time history in comparison to the other two components. The magnitude of vertical GRF increased with increasing speed. Similar results were obtained in running, slow jogging and walking (38). During ascending-phase, vertical GRF curve for basic-step and knee-lift exhibited a triple-peak while run-step and knee-hop exhibited a double-peak. In basic-step, the typical time-history GRF curve demonstrated three distinctive maximums (triple-hump) during ascending-phase, with 1st peak related to foot contact on the bench, the 2nd peak related to weight transfer between both feet, and 3rd peak related to the impulsion for descending-phase. In knee-lift, the typical time-history of the curve also demonstrated three distinctive maximums (triple-hump) during ascending-phase, with 1st peak (the greater) related to foot contact on the bench, the 2nd peak related to knee-lift, and 3rd peak related to the impulsion for descending-phase. In run-step and knee-hop, the curve demonstrated two distinctive maximums (double-hump) during ascending-phase, with 1st peak related to foot contact on the bench with propulsion, and the 2nd peak related to the 2nd propulsion and to the impulsion for descending-phase. During descending-phase, all movements exhibited one peak (single-hump) related to 1st foot contact on the floor; a 2nd peak exists if weight transfer occurs between both feet; a 3rd peak corresponds to the beginning of another movement, if the movement is followed by another. These patterns didn’t change at varying cadences. The results showed that during stepping at different cadences the vertical GRF curves were very regular and repetitive among subjects, despite different
interval time among conditions. We observed the absence of impact peaks in the movements analyzed.

The action of stepping-up from the ground to the bench was expected to produce greater force in the anterior direction. The typical anterior curves of the four patterns were similar to the corresponding vertical curves, however with lower magnitude. Thus, the 1st peak is related to foot contact on the bench, the 2nd peak is related to weight transfer between both feet, and the 3rd peak is related to the impulsion for descending-phase, in basic-step and knee-lift. In run-step and knee-hop, the typical time-history GRF curve also demonstrated a double-hump during ascending-phase, with 1st peak related to foot contact on the bench with propulsion, and the 2nd peak related to the 2nd propulsion and to the impulsion for descending-phase. The action of stepping-back from the bench to the ground was expected to produce greater force in the posterior direction. This might cause eccentric loading in Achilles’ tendon. During descending-phase, all movements exhibited one posterior peak (single-hump) corresponding to the contact with the ground.

The medio-lateral curves of basic-step and the run-step during ascending-phase, were of lower magnitude than the vertical GRF, and represent the right foot contact (positive-hump) followed by the left foot (negative-hump). The medio-lateral curves of knee-lift and knee-hop during ascending-phase were also of lower magnitude than the vertical. These curves exhibited two positive-humps that represent the right foot contact during knee-lift or hop, followed by the propulsion of the right foot for stepping-down. During descending-phase, the four movements exhibited one positive or negative peak depending on the first foot to contact the ground: right foot in basic
and run, and left foot in knee-lift and knee-hop. The patterns of the horizontal curves also didn’t change at varying cadences, showing that during stepping at different cadences these parameters were very regular among subjects. However, although smaller in magnitude, the GRF horizontal components applied to the lower extremity during the loading phases may also influence biomechanical loading. These results indicate that lower extremity external loading can be effectively controlled by varying stepping-rate during Step classes.

Table 1 shows the results of descriptive statistics of the vertical-AGRF (BW). Table 2 shows the results of descriptive statistics of the vertical-impulse (BW.s). Table 3 shows the results of descriptive statistics of FZ, during ascending and descending-phases of four selected Step-patterns performed at varying cadences. Table 4 shows the results of descriptive statistics of FX. Tables 5 and 6 show the results of descriptive statistics of LR-FZ and LR-FX, respectively, during ascending and descending-phases of four selected Step-patterns performed at varying cadences.

Figures 2, 3, 4 and 5 show the average ground reaction force (in Newton) curves during the ascending and descending phases of basic-step, knee-lift, run-step and knee-hop, respectively, performed at 125, 130, 135 and 140 bpm.

Acceptable variability was considered a CV of less than 10% (39). CV of the force, temporal and combined parameters were acceptable and showed that these kinetic variables were more variable at faster conditions, indicating that changes occur as a function of increased stepping velocity. Impulse presented greater variability. CV showed that the medio-lateral parameters were more variable than the other
components. The medio-lateral and the anterior-posterior parameters presented an unacceptable variation. The CV of the force and combined parameters were more variable in descending-phase of the movements.

Tables 7 to 10 show the results of ANOVA-RM and Bonferroni pairwise comparisons of the parameters analyzed.

The test of within-subject effects has shown no interaction between step-pattern and stepping-rate in relation to the AGRF, impulse and temporal variables. The test of within-subjects effects has shown no interaction between step-pattern and stepping-rate in temporal variables, FY, LR-FY, FX (descending-phase) and LR-FZ (descending-phase). There was interaction between conditions in relation to: FZ (ascending-phase, \( p=0.001 \); descending-phase, \( p=0.011 \)); LR-FZ (ascending-phase, \( p=0.002 \)); FX (ascending-phase, \( p=0.000 \)); and LR-FX (ascending-phase, \( p=0.002 \); descending-phase, \( p=0.048 \)).

**DISCUSSION**

Step-Exercise is performed using music that sets movement cadence which involves the repetition of exercises that induce peak GRF of low magnitude (1 to 2.5 BW) but of high frequency (3750 to 4050 loading cycles during a 30 min session, using music speed at 125 to 135 bpm) (1). The FZ component dominates the force-time history in comparison to the horizontal components. However these components also contribute to the magnitude of loading. Our results showed that during stepping at different cadences the GRF curves were very regular and repetitive among subjects, despite different interval time among conditions. Further research is required to see
how these three components can be modified with specific training. The profile of the GRF are similar among propulsion and among non-propulsion movements, especially during ascending-phase, however it appears to be relatively stable and immune to stepping-rate.

The AGRFz ranged from 0.7 to 0.8 BW and decreased as stepping-rate increased. Greater values were registered in run and in descending-phase. These results were lower than the 1.4 BW obtained for running speed at 3 m/s (28). To our knowledge, no other studies were performed concerning the magnitude of the AGRFz in Step-Exercise. The horizontal components exhibited a characteristic shape similar among movements with propulsion and among the non-propulsion movements, differing in magnitude according to the stepping-rate conditions. AGRFx were about 0.2 BW in ascending phase, and -0.2 BW in descending phase. AGRFy ranged from -0.002 to 0.005 BW in ascending phase, and from -0.006 to 0.003 BW in descending phase.

The TTC significantly decreased as stepping-rate increased. TTC ranged from 1.14 to 1.24 s in ascending phase, and from 0.48 to 0.67 s in descending phase.

Impulse increased as stepping-rate decreased. The ImpFz ranged from 0.8 to 1 BW.s, and it decreased significantly among conditions of stepping-rate. In descending-phase, the impulse was lower than in ascending-phase, ranging from 0.4 to 0.6 BW.s. Significant differences were found among step-patterns, except basic/run and knee-lift/knee-hop. The ImpFx were about 0.2 BW.s and -0.1 BW.s in ascending and descending phases respectively. CV values showed that the medio-lateral parameters of GRF were more variable than the other components. The
**ImpFy** were about 0.001-0.006 BW.s and -0.005 to 0.002 BW.s in ascending and descending phases respectively. To our knowledge, no studies were performed concerning the magnitude of the impulse in Step-Exercise, except Maybury and Waterfield (14) that reported (in absolute values) a range of 0.5-0.9 BW.s and mean values of 0.7±0.1 BW.s during the descending-phase of *basic-step* at 120 bpm. Our results reflected that experienced participants become more economical as the stepping-rate increases, such in running (28).

The results indicated that lower extremity external loading can be effectively controlled by varying stepping-rate during Step classes, and by choosing movements mechanically similar to those analyzed in the present study. As an example, the *run-step* clearly induced greater forces, which might be more related to injury.

**Table 7** shows the results of the statistical analysis performed with AGRF, Imp and TTC parameters, as well as the summary of the confirmation of the hypothesis that differences exist among stepping-rate conditions and among step-patterns.

The GRF may provide a surrogate measure for the strain experienced by bone on a variety of loading activities such as Step movements. But most studies focus only the vertical component since it is of much greater magnitude than the other components, and since the major interest in landings has been the effect of vertical loads or impacts on the human body.

In *basic-step* the **FZ** had a mean value of up to 1.4 BW and maximum of 1.5 BW (ascending-phase), and a mean value of up to 1.7 BW and maximum of 2.2 BW
(descending-phase). These results for descending-phase were greater than those reported by other authors that used slower cadences (120 bpm) (14,15,17). The results for descending-phase are in line with those obtained by Teriet and Finch (12) and with those obtained in our previous studies (19). In knee-lift FZ had a mean of up to 1.3 BW and maximum of 1.6 BW (ascending-phase), and a mean of up to 1.8 BW and maximum of 2.3 BW (descending-phase). The results for descending-phase were greater than those reported by Farrington and Dyson (15) that used slower cadences (120 bpm). The results in both phases are in line with those obtained by Panda (40). In run-step the FZ had a mean value of up to 2.3 BW and maximum of 2.7 BW (ascending-phase), and a mean of up to 1.8 BW and maximum value of 2.4 BW (descending-phase). Tagen and Zebas (10) reported 2.5 BW during ascending-phase of run at 126 bpm. In knee-hop the FZ had a mean of up to 1.8 BW and maximum of 2.2 BW (ascending-phase), and a mean of up to 1.6 BW and maximum of 2.2 BW (descending-phase). The results for ascending-phase are in line with those reported by Machado and Abrantes (11) but the authors also used slower cadences (120 bpm). The results for ascending and descending-phases of all movements performed at 130 and 140 bpm were around 0.1 to 0.2 smaller than those obtained in our previous studies using pressure insoles (33). In walking the vertical component had a maximum value of 1 to 1.2 BW, and in running, the maximum value can achieve 3 to 5 BW (28). Therefore, Step-Exercise seems to produce greater load compared to impact loading of walking and at increased stepping-rates its impact loading could be compared to those obtained during comfortable running.

The results obtained for peak vertical forces suggests that Step-Exercise is a low to moderate activity, depending on the inclusion of non-propulsion or propulsion, but not
on stepping-rate (with experienced participants). However the results of the present study are referred to the superimposed GRF which profile represents a summation of bilateral force profiles during the double support phase of the movements. Teriet and Finch (12) suggested that the faster loading and unloading-rates of the musculature due to the faster stepping-rates (122 to 130 bpm) caused less control of the movement, resulting in a 4% increase in the FZ and therefore, the use of faster tempos in a beginning level class could be a source of elevated risk for potential injury. Our results support the conclusion of Scharff-Olson et al. (13) that experience with Step-Exercise may afford an ability to make uniform and force-absorbing adjustments in FZ at increased speeds.

The FX component exhibits a characteristic shape similar to FZ, but of lower magnitude. It reaches 0.15 BW in walking; and 0.25-0.30 BW in running at 3m/s, for both braking and propulsion (28). Concerning to Step-Exercise, Farrington and Dyson (15) found FX of 0.06-0.30 BW in basic-step (120 bpm/15.2 cm/descending-phase). Panda (40) reported 0.06 BW for knee-lift; 0.07 BW for basic-step; 0.10 BW for run (126 bpm/15 cm/ascending-phase); 0.29 BW for knee-lift; 0.26 BW for basic-step; 0.38 BW for run (126 bpm/15 cm/descending-phase). Wieczorek et al. (29) reported 0.10-0.13 BW for basic-step (120 bpm/30 cm/descending-phase); and 0.12-0.15 BW (120 bpm/20 cm/ascending-phase). In the present study the mean FX ranged from 0.3 to 0.6 BW (propulsive) in ascending-phase and from -0.4 to -0.3 BW (braking) in descending-phase. These results are in line with those obtained by Panda (40) and Miller (28) for running (3m/s). No further studies were found concerning the magnitude of FX with similar conditions tested.
The FY component also exhibited a characteristic shape similar in the two movements with propulsion and in the two non-propulsion movements, differing in magnitude according to the stepping-rate conditions. FY ranges from 0.01 BW in walking to 0.10-0.20 BW in running (23,28). Concerning Step-Exercise, Wieczorek et al. (29) reported FY of 0.2-0.3 BW (132 bpm/20 cm/descending-phase). No further studies were found concerning the magnitude of FY with similar conditions tested. In the present study, the mean FY ranged from -0.02 to 0.02 BW (ascending-phase) and from -0.03 to 0.01 BW (descending-phase). In both phases, there were no significant differences among stepping-rates and among step-patterns. These results are in line with those obtained for walking by Wieczorek et al. (29) and by Hamill and Knutzen (23).

Concerning the TFZ, it ranged from 0.20 to 0.28 s (ascending phase) and from 0.21 to 0.22 s (descending phase). The TFX ranged from 0.18 to 0.26 s (ascending phase) and from 0.20 to 0.22 s (descending phase), and the TFY ranged from 0.18 to 0.24 s (ascending phase) and from 0.18 to 0.21 s (descending phase). The interval time decreased with stepping-rate, meaning that the same movement has to be performed in the same form but with less time. This is reflected by the increase in loading-rate. No previous studies were found concerning the behavior of loading-rate in Step-Exercise. Loading-rate was positively related to running speed at 3m/s, associated to an average of 77 BW/s (28). In the present study, the mean LR-FZ in ascending phase ranged from 4.9 BW/s in knee-lift (125 bpm) to 10.2 BW/s in run (140-bpm). It increased with stepping-rate, and the greatest value was found in ascending-phase of run. In descending-phase ranged from 7.4 BW/s in knee-hop (125-bpm) to 8.5 BW/s in run (140-bpm). It increased significantly with stepping-rate.
The mean LR-FX in ascending-phase ranged from 1.7 to 3 BW/s and in descending ranged from -1.96 to -1.5 BW/s. The mean LR-FY in ascending-phase ranged from -0.08 to 0.16 BW/s and in descending-phase it ranged from -0.15 to 0.05 BW/s. In both phases there were no significant differences among stepping-rate conditions and among step-patterns. The larger peaks and loading-rates indicate a loss of shock absorbing capacity. This may increase their susceptibility to lower extremity overuse injuries.

Tables 8, 9 and 10 show the results of the statistical analysis performed with FZ, FX and FY parameters, respectively, as well as the summary of the confirmation of the hypothesis that differences exist among stepping-rate conditions and among step-patterns.

The results indicate that lower extremity external loading can be effectively controlled by varying stepping-rate during Step classes, and by choosing movements mechanically similar to those analyzed in the present study. As an example, the run-step clearly induced greater forces and loading-rate, which might be more related to injury.

These findings indicate the relative contributions of stepping-rate and different choreographic movements to the external forces experienced during Step-Exercise. Further research is needed focusing other Step-patterns in order to select those that are more appropriate to be included in Exercise and Rehabilitation programs. The results of our previous studies with elder people suggested that these programs might have a positive impact on the ageing delay in spite of the improvement of the
well-being and quality of life, and might reduce the risk of making them prone to falling or to other accident related injuries (19). The present investigation provides data that may be used as a basis of comparison with patients, elderly people and beginners that participate in Step programs, in future biomechanical research. However, the present results are based on a sample of 18 experienced and physically active instructors, thus, the force characteristics of the tasks may be different if participants with less experience in Step are used, and establishing norms for other populations requires understanding other factors that affect GRF. Also, these results are related to the mechanical characteristics of this physical activity and might be analyzed under the ergonomic perspective, since the group of subjects was constituted by experienced Step instructors.

**PRACTICAL APPLICATIONS**

This study presents the analysis of the GRF parameters, during Step-Exercise at varying cadences. This study investigated the external loading experienced by the lower extremity during four common Step movements performed at various cadences of stepping-rate. The results contribute to understand how skilled participants deal with the increase of the external load. 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. Our results indicate that lower extremity external loading can be effectively controlled by varying stepping-rate during Step classes and selecting step-patterns. Assuming that walking or running are “safe” activities to be included in Exercise and rehabilitation programs, oriented stepping exercise appear relatively safe with respect to the magnitude of loading. Despite being created as an Exercise program the origins of this physical activity are
in a bench used in rehabilitation programs. For this reason it is acceptable that the actual form of performing some of the Step patterns might be included in rehabilitation programs. However our search has lead to few studies using Step Exercise as a form of rehabilitation exercise. Our results are relevant to determine which patterns and cadences can be recommended to be included in rehabilitation programs where walking and running are prescribed. 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.

References


**Acknowledgements**

**FCT POCI 2010 POCI/DES/61761/2004**

The authors wish to thank to all participants of this study; to Carlos Ferreira, PhD (Faculty of Human Kinetics); to Helô Isa André, MSc (Faculty of Human Kinetics); to Maria Fátima Ramalho, MSc (Sport Sciences School of Rio Maior); to Maria João Valamatos, MSc (Faculty of Human Kinetics) for their contributions to this manuscript; to Pedro Aguiar, MSc (National School of Public Health) and to Isabel Carita, PhD (Faculty of Human Kinetics) for their advice in statistical procedures.

There are no competing interests.