IMPULSE AND AVERAGE GROUND REACTION FORCES IN STEP EXERCISE

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The purposes of this study were to analyse selected components of ground reaction forces (GRF) during Step Exercise and to investigate the differences that exist between four stepping rate conditions (125, 130, 135 and 140 beats per minute - bpm) and between four Step patterns (basic step, knee lift, run step and knee hop), performed with right and left leading foot in terms of net average GRF, net impulse, and total time of contact, in a group of 18 experienced females. These parameters were explored concerning ascending and descending phases of the movements. The present investigation provides normative data of biomechanical parameters on the external forces of Step movements.

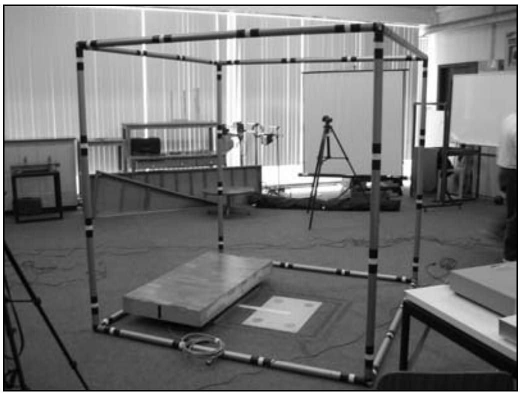
KEY WORDS: ground reaction forces, impulse, step.

INTRODUCTION: When the Step Reebok™ program was presented proponents claimed that ground reaction forces (GRF) were similar to those of walking (Reebok University Press, 1994a,b). Originally introduced as a low impact activity, Step classes now include propulsive movements that have changed the nature of the impact of the activity (Tagen & Zebas, 1996; Machado & Abrantes, 1998). Step Exercise includes performing step on (ascending forward) and step off (descending backward) movements combined with march, dance and jumping exercises, within sequences or choreography, on a bench platform, using right and left leading legs; using single or alternate leading steps, using propulsion or not; and using a stepping rate set by music.
Physical activities such as Step Exercise involve large weight bearing impacts on the feet. The rate and magnitude of skeletal loading, can improve the osteogenic potential of physical activity (reference needed). The foot ground reaction force is affected by the mechanical properties of three bodies: the foot, the footwear, the ground and the sports equipment such as the Step bench. The assessment of biomechanical loading is quite important for exercise prescription and injury prevention in the scope of exercise biomechanics. Therefore, it is important to determine if the differences on the mechanical characteristics of this system have any influence on the mechanical load applied on the musculoskeletal system. The study of ground reaction forces helps to understand the magnitude and pattern of loading experienced by the body while in contact with the ground.
The purpose of this study was to analyze selected components of ground reaction forces in Step Exercise and to investigate the differences that exist between four stepping rate conditions (125, 130, 135 and 140 beats per minute - bpm) and between four Step movements (basic step, knee lift, run step and knee hop), performed with right and left leading legs, in terms of net average ground reaction force (GRF), normalized to bodyweight (BW), net impulse (normalized to BW), and total time of contact (Δt), in a group of 18 experienced females. These parameters were explored concerning ascending and descending phases of the movements.

METHOD:

Data Collection: 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) with no history of foot, ankle or knee musculoskeletal / neuromuscular trauma or disease, that volunteered to participate in the study, were led through a sequence of stepping tasks, using approved choreography. These women were experienced exercise instructors who were certified and/or held a degree in sports sciences and possessed at least 3 years of teaching experience in Step Exercise.

Four Step patterns were performed using the right leading foot and then the left leading foot resulting in a sequence of 8 Step movements. The following sequence was performed at the cadences of 125, 130, 135 and 140 bpm: *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*. The movements were performed in sequence, in order to better represent the real conditions of practice. No arm movements were added. Regular fitness 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. None of the subjects felt discomfort during stepping on the two force platforms, and did not believe that the laboratory conditions had influenced their stepping style.
The ground reaction forces (GRF) were measured by two force platforms at 1000 Hz and Acknowledge 3.7.3 software (*BIOPAC Systems, Inc., Goleta, CA*) was used to collect GRF data. An AMTI force platform (*Advanced Mechanical Technology, Inc, Watertown, MA*) was used for the ascending phase of movements, substituting a bench, and a Kistler force platform (*Kistler AG, Winterthur, Switzerland*) was used for the descending phase of movements (picture 1).



Picture 1: Image of the AMTI force platform (on the left) and the Kistler force platform (on the right), and also the calibration frame, mounted on the floor of the Laboratory of Biomechanics.

Average values of force (N) and impulse (N.s) were calculated using Acknowledge and normalized to BW in Excel 2003 (*Microsoft Corporation, USA*). Interval time (s) was also collected in Acknowledge. The impulse (in N.s) during the ascending phase was determined by integrating the GRF-time curve from the instant the foot touched the AMTI platform to zero (*impulse* = ∫ *force N. time to peak in sec*); and during the descending phase, from the instant the foot touched the Kistler platform to the instant of peak double support. Net average GRF (in N and in BW) was calculated in Excel (*net GRF* = $\sqrt{Fx^2+Fy^2+Fz^2}$), as well as net impulse.

Data Analysis: The force profiles were analyzed, filtered and processed using Acknowledge software. Descriptive statistics and ANOVA for repeated measures were conducted using SPSS software version 13.0 for Windows (*Statistical Package for the Social Sciences, Chicago, IL*). In all cases, the level of statistical significance was set at $p \leq 0.05$. Anova for repeated measures was used to determine differences among the four conditions of stepping rate and the four movements.

RESULTS: Figure 1 represents the movements studied, concerning the GRF curve profiles.

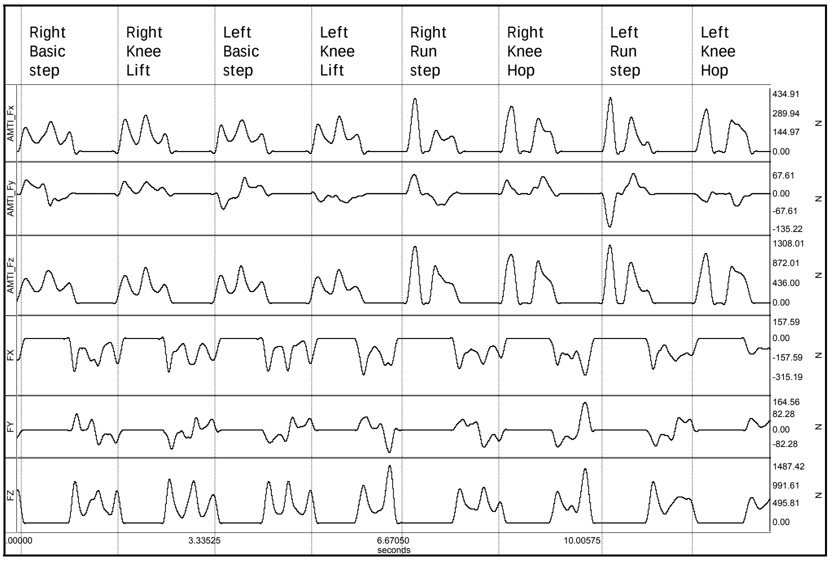


Figure 1: Identification of a sequence of Step movements in the horizontal and vertical components of the GRF, during the ascending (AMTI Fx, Fy & Fz) and descending (Fx, Fy & Fz) phases of the movements performed at 140 bpm (one representative subject).

Tables 1 and 2 show the results of descriptive statistics of net average ground reaction forces normalized to bodyweight (BW) and of net impulse normalized to bodyweight-second (BW.s), during ascending and descending phases of the four Step movements performed at 125, 130, 135 and 140 bpm by 18 skilled subjects.

Table 1: Descriptive statistics of Net Average Ground Reaction Force

ASCENDING PHASE – NET AVERAGE GRF (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
Mean	0.762	0.744	0.723	0.715	0.727	0.707	0.694	0.689	0.817	0.799	0.773	0.752	0.772	0.748	0.723	0.701
sd	0.042	0.034	0.040	0.041	0.031	0.029	0.027	0.028	0.038	0.030	0.035	0.104	0.039	0.034	0.036	0.086
Median	0.763	0.744	0.727	0.718	0.728	0.701	0.696	0.688	0.818	0.804	0.771	0.770	0.778	0.753	0.714	0.710
Variance	0.002	0.001	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.011	0.002	0.001	0.001	0.007
Minimum	0.669	0.676	0.609	0.635	0.657	0.655	0.629	0.628	0.729	0.736	0.703	0.181	0.698	0.668	0.664	0.271
Maximum	0.884	0.811	0.800	0.799	0.807	0.767	0.743	0.744	0.899	0.883	0.845	0.851	0.854	0.809	0.818	0.779
Range	0.215	0.135	0.191	0.164	0.149	0.112	0.114	0.116	0.170	0.147	0.142	0.669	0.156	0.141	0.154	0.508
cv	0.056	0.045	0.056	0.057	0.042	0.041	0.039	0.041	0.047	0.038	0.045	0.138	0.051	0.046	0.050	0.118
DESCENDING PHASE – NET AVERAGE GRF (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
Mean	0.953	0.965	0.960	0.943	0.897	0.902	0.901	0.907	0.940	0.965	0.944	0.945	0.843	0.875	0.862	0.863
sd	0.125	0.139	0.078	0.063	0.073	0.077	0.094	0.069	0.155	0.049	0.067	0.052	0.091	0.068	0.061	0.061
Median	0.940	0.943	0.951	0.949	0.910	0.893	0.903	0.914	0.944	0.958	0.939	0.946	0.857	0.865	0.860	0.868
Variance	0.016	0.019	0.006	0.004	0.005	0.006	0.009	0.005	0.024	0.002	0.004	0.003	0.008	0.005	0.004	0.004
Minimum	0.746	0.797	0.841	0.737	0.672	0.758	0.469	0.661	0.622	0.865	0.791	0.826	0.470	0.678	0.720	0.744
Maximum	1.589	1.724	1.320	1.078	1.037	1.075	1.034	1.038	1.649	1.057	1.140	1.053	0.940	1.026	0.980	0.964
Range	0.844	0.927	0.479	0.341	0.365	0.317	0.566	0.377	1.026	0.192	0.349	0.226	0.470	0.348	0.260	0.220
cv	0.131	0.144	0.081	0.067	0.082	0.086	0.104	0.076	0.164	0.051	0.071	0.055	0.108	0.078	0.071	0.071

Table 2: Descriptive statistics of Net Impulse

ASCENDING PHASE – NET IMPULSE (BW.s)																
	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
Mean	0.905	0.873	0.843	0.815	0.886	0.836	0.810	0.786	0.996	0.941	0.915	0.885	0.955	0.904	0.876	0.852
sd	0.049	0.037	0.038	0.035	0.037	0.035	0.052	0.042	0.039	0.035	0.045	0.030	0.042	0.048	0.051	0.048
Median	0.911	0.866	0.845	0.811	0.882	0.836	0.817	0.787	0.994	0.945	0.922	0.882	0.954	0.900	0.871	0.842
Variance	0.002	0.001	0.001	0.001	0.001	0.001	0.003	0.002	0.002	0.001	0.002	0.001	0.002	0.002	0.003	0.002
Minimum	0.721	0.786	0.743	0.746	0.816	0.772	0.621	0.712	0.917	0.829	0.745	0.814	0.879	0.769	0.735	0.761
Maximum	0.979	0.951	0.930	0.916	0.952	0.920	0.894	0.888	1.061	0.995	0.969	0.984	1.064	1.014	0.962	0.958
Range	0.258	0.166	0.186	0.170	0.136	0.148	0.274	0.176	0.144	0.166	0.224	0.169	0.185	0.245	0.228	0.197
cv	0.054	0.042	0.045	0.043	0.042	0.042	0.064	0.053	0.039	0.037	0.049	0.034	0.044	0.053	0.058	0.056
DESCENDING PHASE – NET IMPULSE (BW.s)																
	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
Mean	0.620	0.615	0.595	0.559	0.536	0.515	0.495	0.461	0.620	0.608	0.575	0.551	0.461	0.443	0.439	0.416
sd	0.062	0.076	0.071	0.053	0.116	0.106	0.123	0.108	0.101	0.061	0.081	0.068	0.090	0.066	0.114	0.071
Median	0.629	0.613	0.589	0.563	0.509	0.492	0.490	0.453	0.634	0.619	0.593	0.557	0.459	0.434	0.429	0.423
Variance	0.004	0.006	0.005	0.003	0.014	0.011	0.015	0.012	0.010	0.004	0.006	0.005	0.008	0.004	0.013	0.005
Minimum	0.480	0.498	0.476	0.432	0.281	0.323	0.317	0.256	0.399	0.375	0.368	0.360	0.234	0.335	0.292	0.269
Maximum	0.740	0.946	0.917	0.681	0.738	0.676	0.843	0.636	0.941	0.710	0.714	0.643	0.639	0.554	0.980	0.550
Range	0.260	0.447	0.441	0.249	0.457	0.353	0.526	0.380	0.541	0.334	0.346	0.283	0.405	0.219	0.689	0.281
cv	0.100	0.124	0.120	0.094	0.218	0.206	0.248	0.235	0.162	0.100	0.140	0.124	0.196	0.149	0.259	0.170

DISCUSSION: The net average GRF ranged from 0.69 BW in the ascending phase of *knee lift* at 140 bpm, to 0.97 BW in descending phase of *basic step* and *run step* at 130 bpm. Miller (1990) reported that the average vertical GRF exerted throughout the entire stance phase of running is an extremely stable indicant, and this parameter can be used to monitor treatment or training programs that result in changes in the vertical acceleration of the total body centre of gravity. ANOVA repeated measures (RM) showed a significant decrease between conditions, from 125 to 140 bpm in net average GRF, during ascending phase. As expected, during descending phase, average GRF is quite similar between conditions and Step patterns.
The net impulse ranged from 1 BW in the ascending phase of *run step* at 125 bpm, to 0.42 BW in descending phase of *knee hop* at 140 bpm. Impulses reflect the change in velocity of the centre of mass. The impulse momentum relationship becomes useful when there is an interest of knowing the influence of a force that varies over its duration of application. The impulse-momentum relationship can be used to evaluate the effectiveness of a force in altering the momentum or velocity of a body. ANOVA RM showed a significant decrease between conditions, from 125 to 140 bpm in net impulse during both phases. These results reflect that experienced participants become more economical as the stepping rate increases.
Total time of contact ranged from 1.24 s at 125 bpm to 1.41 s at 140 bpm during ascending phase of the tasks analyzed, and from 0.48 at 140 bpm to 0.67 s at 125 bpm during descending phase. As expected, ANOVA RM showed a significant decrease between conditions, from 125 to 140 bpm in total time of contact during both phases.
These results indicate that lower extremity external loading can be effectively controlled by varying stepping rate during Step classes.

CONCLUSION: 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 are relevant to determine which patterns 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, stepping exercise appears relatively safe with respect to the magnitude of loading. The present investigation provides normative data of biomechanical parameters on the external forces of Step patterns. It is the intention that results of this study may be used as a basis of comparison with elder and novice Step participants in future biomechanical research.

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