

Ground reaction forces in step aerobics

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Step is a common physical activity which can have positive or negative influence on human movement system. The aim of this study was to test the influence of step height and music tempo on the loads affecting human movement during step exercise. Loads were compared with these typical of human locomotion. Sixteen healthy female students took part in the experiment. Loading forces were measured on a force plate under different step height and music tempo conditions. Generally, loads applied during an exercise to step were significantly lower than in human gait, mainly because of special dumping properties of a step bench.

1. Introduction

Step is a common physical activity which can have positive or negative influence on human movement system. Exercises based on natural form of locomotion (gait, running, jumps) positively influence human movement system. During regular physical training the loads are applied to bone in their long axis which positively affects bone structure and thickness (Będziński 1997). Another positive effect of this kind of activity is an increase in muscular force of lower limb. On the other hand, if volume and intensity are too high they may cause undesirable effects like overloads of movement system leading to injuries.

Step aerobics is a form of fitness. Basic elements in step aerobics are performed on special step bench, while the intensity of training is controlled by the changes in step heights and music tempo. The changes in music tempo influence the frequency and velocity of steps repetitions. It has been shown that an increase in the velocity of running can cause an increase in ground reaction forces (RICARD & VEATCH [8]). It can be assumed that an increase in music tempo influencing the frequency in step aerobics

will also increase the ground reaction forces, which leads to altered loads of movement system. Subject's skill level can be the other major factor modifying loads of movement system (TSIOKANOS & KELLIS [13]). The results of our own experiments show that in the case of people possessing correct exercise technique an increase in music tempo does not significantly change ground reaction forces (RUTKOWSKA-KUCHARSKA & SZPALA [9]).

The aim of this study was to test the influence of step height and music tempo on the loads affecting human movement during step exercise. In order to test the risk of knee joint injury, the results were compared to basic forms of locomotion and climbing stairs.

2. Material and methods

Sixteen healthy female students of the University School of Physical Education in Wrocław took part in the experiment. Each subject signed an informed consent form. All the subjects are professionally qualified fitness instructors and have experience in step aerobics.

Ground reaction forces (GRF) were measured on a force plate under different step height and music tempo conditions. All the subjects were selected to have the leading right leg. The average age of subjects was 21, average body height was 164.9 cm and average body mass was 60.1 kg.

The moving task consisted of 11 "basic steps" performed on the Reebok step bench. The basic step consists in stepping up the platform with right foot, adding the left one, stepping down with the right foot and bringing down the left again. The movement was repeated 10 times by the subjects. On the 11th trial the subject was instructed to remain on the platform for additional 5 seconds for her weight measurement.

The step height and music tempo were altered so that 9 combinations of moving task were performed by each subject. We dealt with three step heights, i.e., 15, 20 and 25 cm, and three music tempos, i.e., 126, 132 and 138 bpm (bits per minute). The step height and music tempo were chosen randomly by each person. Subjects were barefoot to maintain similar measurement conditions.

The Kistler force plate (with the frequency of 250 Hz) was used for the ground reaction force measurement. The force plate was put under the step bench.

The example GRF characteristics (figure 1) begins with the first foot contact of the right foot (with the characteristic shock absorption artefact in the force signal), then the transfer of the body weight to the step bench. It is associated with the upper movement of the body center of gravity (COG) and the emergence of the first peak force – F_1 . While the left foot comes into contact with the platform body, COG must drop down and then rise again to maintain the straight posture of the subject's body (the 2nd peak force – F_2 occurs). While transferring the weight to the left foot (the

right begins stepping down), shortly after the F_2 , the third peak force – F_3 occurs. The step is terminated with the right foot brought down to the ground (COG lowers for the third time) and while the opposite foot joins the right one it pushes the platform for the fourth and last time (F_4). The step cycle then terminates.

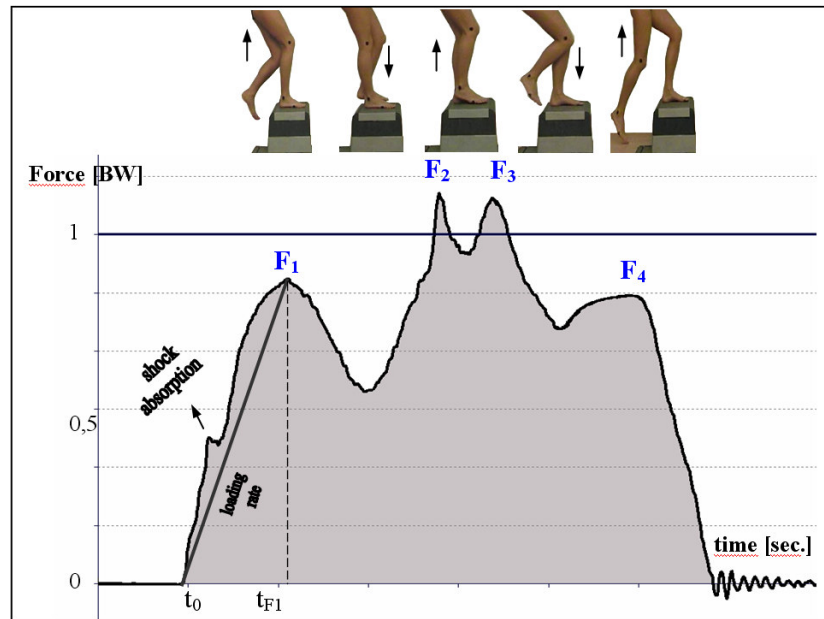


Fig. 1. A “ghost-shaped” time characteristics of normalized ground reaction force for one cycle of the “basic step”. F_1 , F_2 , F_3 , F_4 are the GRF peaks responsible for the upper horizontal acceleration of the center of body mass. See text for details

The loading rate (LR) of the force is the parameter often associated with the overloading of the joints of lower limbs. LR is determined by the ratio of an increase in the force (from the foot contact to F_1) to the change of time at which the increase occurred, that is:

$$LR = \frac{F_1}{t_{F1} - t_0},$$

where t_0 is the first foot contact time.

The measured parameters of the first peak force (F_1) and loading rate of F_1 were averaged over 10 trials, and standard deviation was calculated. The ground reaction force was normalized in respect to body weight to objectively compare the results between subjects. Non-parametrical Wilcoxon test of variance for independent samples was used to test the significance of the results.

3. Results

Data analysis showed the influence of the step height and music tempo on the maximum values of vertical ground reaction forces (F_1). It was proved that with the increase in the step height the vertical ground reaction force decreases. This regularity is independent of the music tempo. Statistical analysis showed a significant influence of the step height on the values of ground reaction forces. However, the change in the music tempo did not cause the change in the ground reaction forces in exercises with different step heights (figure 2). The other parameter describing loads of movement system during movement is the rate of increasing the ground reaction forces (loading rate). During the change in music tempo an increase in LR took place, but only in two cases it was significant (between 132 and 138 bpm at 15 and 20 cm step heights) (figures 3 and 4). The change in step height appeared to have a significant influence on the change in LR in the conditions compared. It was insignificant only at 15 and 20 cm height and at 138 bpm music tempo. A general tendency of LR to decrease with an increase in step height can be noticed.

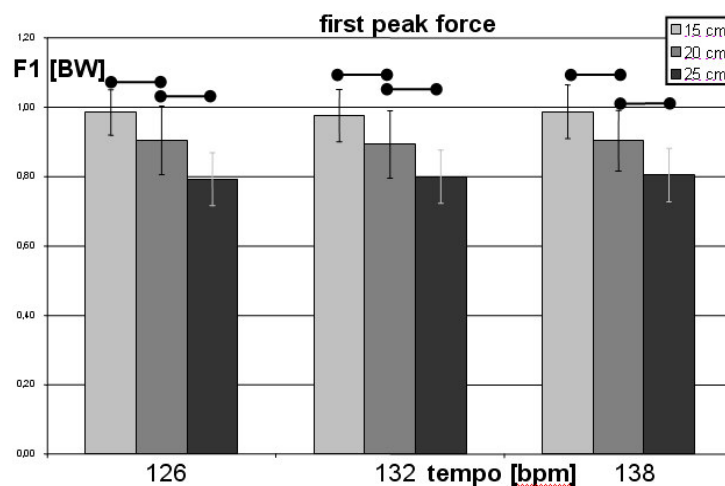


Fig. 2. The first peak force as the function of step height and music tempo. Significant differences ($p < 0.05$) between step heights are marked with dashes

Because the exercise on step bench is based on natural form of locomotion (like gait and running) the ground reaction forces achieved in the experiment were compared to the results in gait, climbing stairs and running at different velocities reported by other authors.

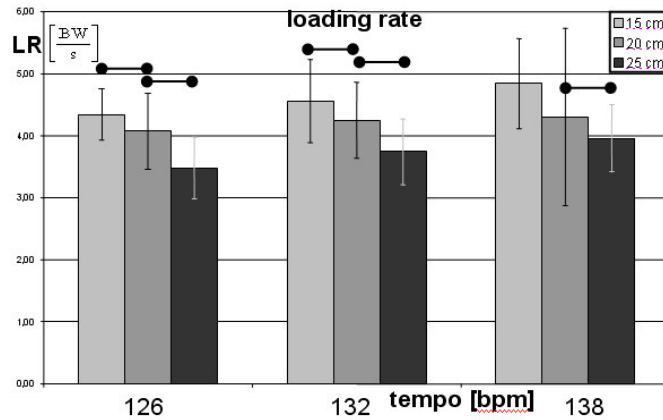


Fig. 3. Loading rate of the GRF as the function of step height. Significant differences ($p < 0.05$) between step heights and music tempi are marked with dashes

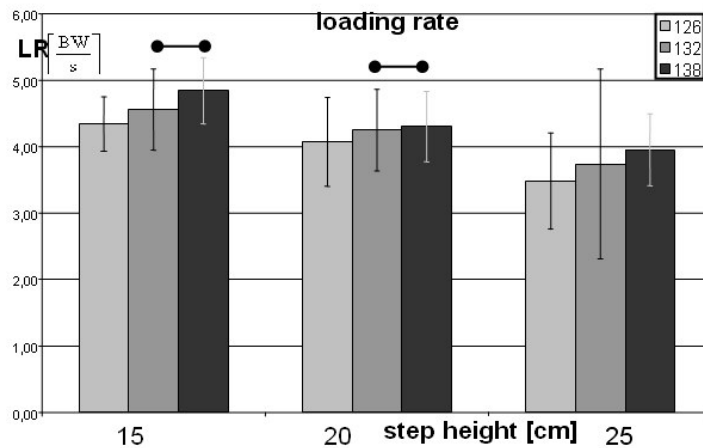


Fig. 4. Loading rate of the GRF as the function of music tempo. Significant differences ($p < 0.05$) between step heights and music tempi are marked with dashes

4. Conclusions

The magnitude of the twin force peaks during level gait was reported to be between 1.1 and 1.3 BW. The parameters of vertical GRF on stairs are not readily available, because only few authors have reported their data. Generally, the “M”-shaped curve known from level walking is reported to be altered in the case of stairs, the value of the second maximum becoming larger than that of the first during stair ascent and the

value of the first maximum becoming larger than that of the second during stair descent. The maximum values of GRF were found to be between 1.2 and 1.7 BW for stair ascent and between 1.4 and 2 BW, reaching up to 2.6 BW in some cases, for stair descent (the table). Age is found to be the factor which should be considered, because young people walk faster and produce larger vertical GRF maxima during level walking and stair ascent than the middle- and old-age people.

Table. GRF outcome variables summarized a peak force and loading rate by various authors

Authors	Conditions	Peak force [BW]	Loading rate [BW/s]
McCRORY et al. [7]	level walking, control group	1.02	5.22
	level walking, affected limb	1.06	5.03
	level walking, healthy limb	1.05	6.21
CHRISTINA and CAVANAGH [2]	stair ascent (up)	1.40	13.87
	stair descent (down)	1.48	14.01
STACOFF et al. [11]	level gait (average velocity, 1.40 m/s)	1.19	7.92
	stair ascent:		
	flat stairs	1.12	6.09
	standard stairs	1.12	5.79
	steep stairs	1.14	5.34
	stair descent:		
	flat stairs	1.49	11.81
standard stairs	1.56	12.79	
steep stairs	1.57	13.64	
SCHAFFNER et al. [10]	normal gravity (1 G), control:		
	walking, 3 mph (4.82 km/h)	1.17	7.29
	running, 7 mph (11.26 km/h)	2.38	46.0
	walking, weightless (0 G), U.S. harness:		
	walking, 3 mph	0.93	8.51
running, 7 mph	1.68	41.17	

Biomechanical research has shown that the ground reaction forces (GRF) experienced during bench stepping are smaller than these generated in running and directly related to the step height and the type of manoeuvre. The peak force (F_1) and loading rate (LR) were found to be significantly smaller than peak force and loading rate in level gait reported by McCRORY et al. [7], regardless of the step height. Compared to the same parameters in step climbing reported by CHRISTINA and CAVANAGH [2]

(1.4 BW) the values of F_1 obtained in our study (0.9 BW) were much smaller. MACHADO et al. [5] in the exercise with basic step and step with kneeraising at the smaller step height reported the peak GRF of the order of 1.71 (basic step) and 1.62 (kneeraising step). This difference might arise due to much older participants (61 years) who took part in the experiment. In other words, one might suppose that in

elderly population, the peak force GRF generated in step exercise is much greater than that in climbing stairs (STACOFF et al. [11]).

Step height is the parameter that should be considered in step exercise. An increase in step height significantly reduces the loading rate and the peak force acting on the subjects' joints. MAYBURY and WATERFIELD [6] have arrived to the similar conclusions. They used step bench with step heights of 6, 8 and 10 inches (15, 20 and 25 cm, respectively) and 120 bpm music tempo. Such a discrepancy in the results between authors may be due to various damping properties of the material of step benches. On the other hand, it might be connected with the movement technique.

According to our results there is no significant influence of music tempo on the peak GRF in the step exercise. However, the loading rate is directly proportional to the step frequency (music tempo). Moreover, RUTKOWSKA-KUCHARSKA and SZPALA [9] have found that the step technique affects the load represented by the peak force acting at the joints. The higher the step rate (music tempo), the greater its effect on the joint loading.

Final conclusions:

1. The maximum ground reaction force and its loading rate in step aerobics are significantly lower than GRF in level walking and climbing stairs reported in literature, which can be explained by damping properties of step bench.

2. The maximum step force and loading rate significantly decrease with an increase in the step height.

3. The step rate (music tempo) does not influence significantly the value of maximum force, but it does influence the loading rate of the force in the bench stepping (at the step height of 15 and 20 cm and at high step rate).

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