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PHYSIOLOGICAL AND BIOMECHANICAL RESPONSES TO THREE DIFFERENT LANDING SURFACES DURING STEP AEROBICS

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ABSTRACT

PHYSIOLOGICAL AND BIOMECHANICAL RESPONSES TO THREE DIFFERENT LANDING SURFACES DURING STEP AEROBICS **William A. Skelly, Lynn A. Darby, Kristen Phillips**. **JEP**online. 2003;6(2):70-79. Using a padded landing surface during step aerobics has the potential to both reduce impact forces and increase energy cost. Eleven college-aged females performed 8-min trials [2-min of each step: basic step, alternate lead (AL), knee raise (KR), and step kick (SK)] on three surfaces. Surface conditions were uncovered force platform (FP) and FP covered with each of two different pads of medium-density foam [0.025 m (Thick) & 0.010 m (Thin)]. Data for oxygen consumption (VO_2), heart rate (HR), ratings of perceived exertion (RPE), maximum vertical ground reaction force (VGRF), rear-foot motion, and time of foot contact (TFC) were collected and a landing surface questionnaire was administered to obtain subjective perceptions of surfaces. Two-way repeated measures ANOVAs (STEP [3] × SURFACE [3]) were calculated. There were no significant differences for any variables among the surfaces. Significant differences were detected for VO_2 (AL<KR,SK), HR (AL<KR<SK), ROM (AL>SK), and TFC (AL>KR,SK) among the step movements. Subjects preferred stepping on the thick pad, felt less safe on the thin pad, and perceived more lower extremity stress landing on the uncovered force platform. The addition of two different density padded surfaces to the surfaces of two force platforms did not elicit differences in physiological or biomechanical force variables during 8 min of different actions used in step aerobics.

Key Words: step exercise, ground reaction forces, rear-foot range of motion

INTRODUCTION

Step aerobics routines can be choreographed at intensities sufficient to improve cardiorespiratory fitness (1,2, 3). Several components of a step aerobics routine can be manipulated to change the intensity of step workouts: 1) bench height (1,4), 2) stepping cadence (4) and 3) step movements (5). Bench heights usually range from 6 to 12 in (15.2 to 30.5 cm), and normal stepping cadences vary from 30 to 32 cycles/min (120 to 128 metronome beats/min). Different stepping patterns such as the basic step, knee raise, straddle jump, and lunges are used to vary the intensity of the workout and the muscle groups involved in the step exercise.

Manipulations of these components of a step aerobics routine can alter the loads placed on the body, thereby increasing or decreasing the risk of injury. The most common overuse injuries found in aerobic dance and/or step aerobics are patello-femoral problems (6) and medial tibial syndromes, commonly known as shin splints (6, 7, 8). Different step movements and impact styles can contribute to differences in ground reaction forces, which constitute the repetitive forces placed on the feet. These forces are also transmitted to the ankle, knee, and hip joints and into the joints of the spine. Scharff-Olson et al. (9) have reported that the basic step, as a traditional stepping pattern, showed lower ground reaction forces than the travel step, an example of a propulsive stepping pattern. Peak impact forces for low- and high-intensity aerobic dance (i.e., front knee lifts) have been reported to be 0.98 BW and 1.98 BW, respectively (10). When a step bench is added, greater mean peak vertical impact forces of 1.57 BW have been reported for experienced instructors performing the "basic" and "knee raise travel" steps on an 8-in step at 30 cycles/min (11).

Footwear and floor surfaces have also been assumed to contribute to injury rates in various impact-related activities. Research on footwear has addressed biomechanical measurements comparing different types of shoe materials on applied forces and foot motion during running and jumping. In some of these, the ground reaction forces were not changed by shoe materials or even between shod and barefoot conditions (12,13,14) while another revealed increased impact force with a harder shoe (15).

Likewise, changing the landing surface, expected to affect injury rates through altering the deformation pattern, has revealed differing results depending on the activity and type of padding. In gymnastics, with addition of relatively thick padding materials that are typically used, peak ground reaction force was increased and hip and knee flexion decreased (16). Neither overall kinematics nor ground reaction forces were altered when runners encountered an abrupt change in surface padding characteristics (13), but during an extended run on a softer floor surface, peak ground reaction forces were decreased with increased surface stiffness (17). In dance movements, plantar pressures were increased on a comparatively less-compliant floor material (18).

Thus, it may be hypothesized that using a compliant surface may decrease the applied forces; however, if the surface is too compliant the energy cost of the activity might be increased. For example, the energy cost of walking on sand, a compliant and moveable surface, has been reported as 2.1-2.7 times greater than the cost of walking on a hard surface (19). Further, it has been reported that the greater the depth of the foot impression in snow during walking, the greater the energy cost (20). At speeds of 2.4 km/hr (1.49 mi/hr) and 4.0 km/hr (2.5 mi/hr), and a footprint depth of 10 cm (4 in), energy cost of walking in snow was increased 1.87 times and 2.37 times as compared to walking on a flat, hard surface, respectively. In running on surfaces of different stiffness, stiffer surfaces (i.e., stiffness from 75.4 to 945.7 kN/m) decreased the energy cost of running (17).

Therefore, using a padded landing surface during step aerobics has the potential to both reduce impact forces and increase energy cost. In one study reporting the effects of three different impact-attenuating landing surfaces on the metabolic cost of step aerobics, a non-significant trend toward increased VO_2 with increased landing surface compliance was observed (21). Subjective responses revealed the effects of the three different landing surfaces for step aerobics on participants' perceptions of injury. Participants felt safer on surfaces that were less compressible but compressibility did not affect their perceptions of lower extremity stress that contributes to the risk of injury. However, McKeever did not measure biomechanical variables such as ground reaction forces and rear-foot motion that could help to quantify the actual potential for reducing overuse or stress related injuries when performing step aerobics on different impact-attenuating surfaces (21). Therefore, the purpose of the current study was to compare the physiological and biomechanical responses of college-age females landing on three different surfaces during three different step movements.

METHODS

Participants

The sample consisted of 11 college-aged female volunteers who were presently enrolled in a step aerobics class or had been enrolled within the last year. All participants gave written informed consent according to University protocol.

Experimental Design

A repeated measures design was used with each participant completing three exercise sessions of 8-min each. Sessions were varied by: (a) landing surface (SURFACE; i.e., force platform surface covered with no pad, a thin pad, a thick pad) and (b) step movement (STEP; i.e., alternate lead, knee raise, step kick). The orders of the three surfaces and the three step movements being tested were counterbalanced within SURFACE and within STEP to control for any cross over effects or fatigue effects. The same order of step movements was used throughout all three exercise sessions per participant. The dependent variables were absolute oxygen consumption (VO_2), relative VO_2, heart rate (HR), ratings of perceived exertion (RPE), maximum vertical ground reaction force (VGRF), total time of foot contact (TFC), and rear-foot range of motion (ROM). A questionnaire to assess the participants' subjective perceptions of difficulty, stability, and lower extremity stress was administered to each participant after her exercise session.

Procedure

Orientation and physical assessments

Prior to testing, the participants were oriented to the lab equipment and familiarized with the test protocols. Participants practiced walking and jogging on the treadmill with the headgear and practiced each step movement for the step aerobics testing sessions by following a videotaped recording. At a separate testing session, participants completed a maximal graded exercise treadmill test. Metabolic and standard 12-lead electrocardiogram (EKG) data were collected. The treadmill protocol began with a warm-up for 3 min at a speed of 3.0 mi/hr and a grade of 0%. Speed and grade were then increased by 1.0 mi/hr and by 2% grade, respectively, at the end of each 3-min stage. Termination of the test occurred when participants met one of the following VO_2max criteria: RER>1.0, heart rate in excess of 190 beats/min, or failure of VO_2 to increase with increasing workloads (27). At this testing session body composition was determined using the formula of Jackson et al. (22) to predict % body fat from three skinfold caliper measurements (see Table 2).

Step aerobics routine

Each participant performed one-step aerobics testing session, during which she performed a bout of each of the three steps, on each of the three test surfaces. Each bout consisted of an initial 2-min warm-up and three consecutive 2-min trials using each of the three step movements on one surface. A 5-min rest period was given between each of the 8-min bouts in order to change the landing surfaces, prevent fatigue of participants, and prepare for data collection for the next test. The bench height was 8 in and the cadence was set at 124 beats/min (i.e., 31 cycles of stepping up and down per minute) for each 8-min bout. The step bench was placed longitudinally in front of each participant and slightly removed from the edge of the force platforms to allow them to comfortably step down and land completely on the force platform. The two pads for the alternate surface conditions were medium density open-cell foam—the thinner pad was 0.010 m thick and had a density of 28.0 kg/m^3 and the thicker pad was 0.025 m thick and had a density of 31.2 kg/m^3. To ensure that an 8-in vertical travel was maintained, the height of the bench was increased for the padded surfaces by shimming with an appropriate thickness of plywood sheets. The height of the shim was determined by measuring the thickness of the pad when maximally deformed by a participant of average characteristics. Participants wore comfortable, non-restricting clothes and the same low-top shoes for each session.

The step movements used in the routine included the basic step (BS) for the warm-up, alternate lead (AL), knee raise (KR), and step kick (SK). The basic step involved stepping with the right foot onto the bench, bringing the left foot up, stepping down with the right foot, bringing the left foot back down, and then repeating the sequence. The alternate lead was the same as the basic step except alternating the lead foot on each sequence. The knee raise involved stepping with the left foot onto the bench, raising the right foot past the step in the sagittal plane (right hip and knee at a 90 angle), landing with the right foot, bringing the left foot down, and repeating by alternating the lead foot. Step kicks involved stepping onto the bench with the left foot, raising the right foot past the bench in the sagittal plane (right hip joint flexed at a 90 angle), completing the lift with a “kick” (extension of the right knee joint), landing on the right foot, bringing the left foot back down, and repeating the sequence by alternating the lead foot. In order to limit arm movement, each participant was instructed to move her arms naturally at her side to maintain balance. Each participant performed the routine to a video of an experienced step aerobics instructor to ensure that the step movements were executed properly and similarly for each session.

Physiological instrumentation

Electrocardiograph data for the maximal graded exercise test were collected using a Quinton 4000 electrocardiograph. Metabolic data (VO_2max, VO_2, VCO_2, V_E, and RER) for the maximal graded exercise test and submaximal step aerobics test were measured using a Sensormedics 2900 metabolic measurement cart. The metabolic cart was calibrated using medical gases of certified concentrations and a calibrated (3-L) syringe. Each participant was attached to the metabolic cart via a Hans Rudolph two-way nonrebreathing respiratory valve and 7-ft respiratory tubing. Metabolic data were collected every 20 s during the testing periods. Steady state data, defined as no greater than a 2.1 ml/kg/min variation in the 20-s values for the final minute of both testing periods, were used in the statistical analysis.

Heart rate determined using the Quinton 4000 was recorded every minute for the maximal graded exercise test. For the submaximal step aerobics test, HR was measured every 30 s using a Polar Vantage XL Heart Rate Monitor. Ratings of perceived exertion (RPE) were recorded at the end of each stage of the maximal test and at minute 1:30 of the submaximal step aerobics test using the Borg category scale (23). Participants were given standardized instructions for use of the RPE scale.

Biomechanical instrumentation

Ground reaction forces were measured using one of two force platforms (Advanced Mechanical Technology, Inc.) mounted side-by-side and flush with the floor surface. Vertical, mediolateral, and anteroposterior force components and moments about the respective axes were collected. The participants were monitored throughout the test in order to ensure that each foot landed entirely on its respective force platform. The alternate landing surfaces in the padded conditions were placed over both force platforms during testing and secured to the force platforms by Velcro strips. The ground reaction forces were recorded at 300 Hz for 6 s three to four times during each of the three 2-min trials of step movements. The 6-s recordings included at least two full cycles of the given step sequence. Force measurements used in this analysis were taken when the right foot contacted the right force platform during a landing movement.

Rear-foot motion was measured in the frontal plane using two-dimensional motion analysis. A video camera (Panasonic 5100H5) set at 60 Hz was placed 8.35 m behind the participant in order to videotape the posterior aspect of the participants’ legs. The field of view included from the force platform to above each participant’s waist. Reflective markers were placed on the lower leg and foot in the following locations: A) located 15 cm above marker B in the center of the leg; B) located on the Achilles tendon just above the heel cap of the shoe; C) located on the upper part of the heel cap so that the line between CD and the horizontal form an angle of 90º in the unloaded shoe; and D) located in the center of the shoe sole (24). The angles obtained were the respective angles of the lower leg and rear-foot relative to a right horizontal at the distal point and the relative angle measuring counterclockwise from the foot segment to the leg.

Six participants were selected for rear-foot range of motion analysis such that the order of presentation of SURFACE was counterbalanced. For these, two trials of each STEP X SURFACE condition were digitized for an interval from at least four frames before touchdown until at least four frames after the foot had stopped which included the time when the opposite foot was lifted from the step. Digitizing, optimal cubic spline smoothing, and angle calculations were performed using Peak Motion Measurement System software (version 5.3.0). Rearfoot range of motion was calculated as the maximum excursion of the rear-foot relative to the leg.

Subjective Assessment Questionnaire

After completion of all tests each participant was asked to respond to questions about the landing surfaces (Table 1). Participants were given written and verbal instructions to answer each of the questions with a number that corresponded to the exercises just completed. Responses numbered 1, 2, and 3 corresponded to the order of surfaces for that participant, and number 4 corresponded to an answer of "no preference, not applicable, or no opinion." Responses were later coded to the actual surfaces for each participant.

Table 1: Subjective Assessment Questionnaire

Please answer the following questions by circling the appropriate number. The number 1 corresponds to the first exercise completed, number 2 corresponds to the second completed exercise, number 3 to the third completed exercise, and number 4 to an answer of "no preference, not applicable, or no opinion".

1. ***If you were to begin an exercise program that incorporated the use of bench stepping as a means of aerobic conditioning, on which (if any) would you prefer to step?***

   1 2 3 4

2. ***If you were to begin an exercise program that incorporated the use of bench stepping as a means of aerobic conditioning, on which surface (if any) would you <u>least</u> prefer?***

   1 2 3 4

3. ***In terms of overall exertion, which of the surfaces was <u>most</u> difficult?***

   1 2 3 4

4. ***In terms of overall exertion, which of the surface was <u>least</u> difficult?***

   1 2 3 4

5. ***In terms of control and stability, on which surface did you feel the safest?***

   1 2 3 4

6. ***In terms of control and stability, on which surface did you feel the <u>least</u> safe?***

   1 2 3 4

7. ***In terms of lower extremity (knee, ankle, and foot) stress, which of the surfaces did you feel were the <u>most</u> strenuous?***

   1 2 3 4

Statistical Analyses

Two-way, repeated measures (STEP [3] X SURFACE [3]) ANOVAs and descriptive statistics were calculated for measured variables. When significant main effects were found, appropriate Tukey's HSD *post hoc* tests were calculated. Alpha was set *a priori* at $p \leq 0.05$. The meaningfulness of each significant within groups effect was interpreted using proportion of variance explained, effect size (f^2), and *a posteriori* power calculations. Power was calculated for each specific comparison based on the observed f^2 for that comparison (25). Effect sizes for f^2 were interpreted for 0.02, 0.15, and 0.35 as small, medium, and large, respectively (25,26). Values for continuous variables are presented as means with associated standard deviations.

A Chi-Square Goodness of Fit statistic was used to evaluate differences between the expected and observed frequencies of participant responses related to surface preference and participant perceptions of difficulty, stability, and lower extremity stress. Significance was accepted at the p<0.05 level (i.e., χ^2 7.82).

RESULTS

Demographic data and physical characteristics of the participants in this study are presented in Table 2. These participants were college-aged females who were identified to be at "low risk" for adverse responses to exercise (27).

Table 2: Demographic data and physical characteristics of the subjects (N=11)

Variable	*Mean ± SD*
Age (years)	19.4 ± 1.3
Height (cm)	165.9 ± 5.8
Body weight (kg)	64.1 ± 5.6
% Body fat	25.2 ± 3.1
maxVO_2 (ml/kg/min)	40.0 ± 4.6

Physiological Data

There were no interactions between STEP and SURFACE for VO_2, HR or RPE. There were no significant differences in the mean values of VO_2 (f^2=0.0009; 1-β=0.93), HR (f^2=0.001; 1-β=0.93), and RPE (f^2=0.019; 1-β=0.64) among the landing surfaces. Significant differences were found among the step movements for heart rate (HR: F=11.44; p =0.0005; f^2=2.0; 1-β=0.56) and oxygen consumption (VO_2: F=38.36, p=0.0005; f^2=5.0; 1-β=0.94). A Tukey's *post hoc* test revealed that significant differences among all three step movements for HR; and between AL and KR, and AL and SK for VO_2. Physiological responses are summarized in Table 3.

Table 3: Physiological data for steps and surfaces

Variable	*Step Movement*			*Surface*		
	AL	KR	SK	Thin	Thick	Floor
VO_2 [a] (ml/kg/min)	23.8±2.7	26.2±3.3	26.8±3.7	25.8±3.6	25.2±3.9	25.8±3.1
HR [b] (beats/min)	166±17	171±17	174±15	170±17	170±18	171±18
RPE (9-20 scale)	11±2	12±2	12±2	11±2	12±2	12±2

[a] *p* 0.05; AL<KR,SK; KR=SK
[b] *p* 0.05; AL<KR<SK

Biomechanical results

For each of the biomechanical variables, the interaction between STEP and SURFACE was non-significant allowing for interpretation of the main effects. For rearfoot range of motion, the effect of SURFACE was non-significant (ROM: F=1.05; p=0.39; f^2=0.006; 1-β=0.42). The effect of STEP was significant (ROM: F=8.12; p=0.008; f^2=0.5; 1-β=0.57) with AL greater than SK. No significant differences in peak vertical ground reaction force were observed for either STEP (VGRF: F=2.55; p=0.103; f^2=0.019; 1-β=0.60) or SURFACE (F=0.01; p=0.986; f^2=0.00008; 1-β=0.99). A significant effect of STEP was observed for time of foot contact (TFC: F= 2364.58; p<0.0001), but the effect of SURFACE was not significant. Mean values for biomechanical variables are presented in Table 4.

Table 4: Biomechanical data for steps and surfaces

Variable	*Step Movement*			*Surface*		
	AL	KR	SK	Thin	Thick	Floor
ROM [a] (º)	19.6±8.2	14.0±6.5	11.8±4.7	15.1±8.5	16.4±7.3	13.8±5.9
VGRF (N/m)	15.9±2.3	15.7±2.7	16.5±2.9	16.0±2.7	16.1±2.9	16.0±2.5
TFC [b] (s)	1.17±.06	0.66±0.04	0.63±0.04	0.79±0.24	0.78±0.23	0.79±0.24

[a] *p* .05; AL > SK; AL=KR; KR=SK
[b] *p* .05; AL > KR, SK; KR=SK

Subjective Assessment Questionnaire Results

Participants preferred landing on the thicker pad the most (χ^2=7.99) and the thinner pad the least (χ^2=9.66). Participants felt the least safe, in terms of control and stability on the thicker pad (χ^2=18.99). Additionally, participants felt the most lower extremity stress stepping on the uncovered force platform (χ^2=13.66). Frequency of responses and statistical data are reported in Table 5.

Table 5: Analysis of responses to the subjective assessment questionnaire

Question	Response Frequencies				
	Thick	Thin	No pad	No Preference	χ^2
1. Surface most preferred	7	1	3	1	7.99*
2. Surface least preferred	1	8	3	0	9.66*
3. Surface most exertive	2	4	5	1	3.32
4. Surface least exertive	6	4	2	0	3.66
5. Surface most stable	4	1	7	0	6.99
6. Surface least stable	1	10	1	0	18.99*
7. Most strenuous surface	1	2	9	0	13.66*

*$p \leq 0.05$

DISCUSSION

This study was conducted for the purpose of examining physiological and biomechanical responses to landing on three different landing surfaces during three different step movements. Expected changes in peak force and energy cost due to exercising on these padded surfaces were not observed; however, the subjects revealed subjective perceptions about the surfaces that indicated stronger than expected tendencies in their preferences. Among these responses were that they preferred to exercise on the thick pad and that they found the unpadded surface to be the most stressful. In terms of overall exertion, there was a non-significant trend toward considering the thick pad as requiring the most effort and the unpadded surface as requiring the least.

Though some researchers have investigated the effects of shoe materials and floor substrates on applied forces, few have investigated rear-foot motion in relation to landing or running on padded surfaces (13,16). Subjective assessments have been performed to determine feelings of comfort and stability when landing on different surfaces (21,28). Nigg et al. (28) assessed comfort levels when landing from a jump onto nine different surfaces. They found that the surface that exhibited the smallest maximum deformation was the least comfortable, and that surface which showed the maximum deformation was the most comfortable. McKeever (21) subjectively investigated stability rather than comfort and found that participants felt more stable on surfaces that were less compressible. In the present study, participants indicated that they perceived the thinner pad to provide the least stable surface. Non-significant differences in rear-foot range of motion across surfaces are an indicator that the participants did not perform the steps differently and were able to maintain control of inversion/eversion movements of the foot. Even though they felt less control from the supporting surface when landing on the thinner pad, they may have been able to control their landings using preset and/or active muscle tensions in the ankle and foot. And although the ankle ROM was different among the steps, the amount of muscle activation (i.e., energy) necessary to stabilize the foot did not vary enough among the surfaces to be detected using a whole body metabolic system.

In the present study, TFC and ROM were significantly greater for AL compared to KR, and to SK, respectively. Although all steps were performed at the same cadence, the amount of movement that must be performed from one foot-strike to the next varied among steps (i.e., AL, KR, SK). The kinematic factors that may affect landing, such as limb speed and movement of the body center of mass, were not quantified in the present study. In the AL, the subject moves the lower limb only up and down between the floor and the top of the bench with each step performed with the right or left foot. For the KR, the subject must step up onto the platform and flex at the hip until the upper thigh is parallel to the ground. For the SK, the subject must step up onto the platform and "kick" or extend at the knee joint so that the leg moves out in front of the body. Hence, the range of motion traversed by the lower limb is much greater for the SK and KR, and it would be plausible to think that the rear-foot range of motion might be affected in a similar pattern. The current results suggest that the participants may have used some muscular effort in controlling foot movement in these more ballistic movements to the point that ROM was less. In the AL step, position of the foot in landing was less critical and, therefore, not as tightly controlled.

Unlike the moveable surfaces of sand or snow which may increase the energy cost of walking by ~1-3 times that of walking on a hard surface (19, 20), the surfaces in the present study did not affect the energy cost of stepping. Previous studies on bench stepping that have reported significant differences in VO_2 and VGRF due to variations of from 4 to 12 inches in bench height (3). But it is difficult to compare VO_2 and HR among studies because many investigations typically report VO_2 and HR for a "bench step routine" comprised of various step movements.

The present study elicited VO_2 values for these step movements that are slightly lower than those reported by Scharff-Olson et al. (5). In the present study, VO_2 was lower for AL (23.8±2.7 ml/kg/min) as compared to KR (26.2±3.3 ml/kg/min) while Scharff-Olson reported a greater VO_2 (32.5±3.4 ml/kg/min) for AL as compared to KR (30.3±3.0 ml/kg/min). It seems plausible that AL should be similar to BS in that the only change in movement is the alternating of the foot that begins each successive step. Arm movements in the present study were minimized and Sharff-Olson did not report specific information about arm movement.

Comparisons of VO_2 among the steps in the present study are similar to those of Calarco et al. (29) who reported a lower VO_2 of 26.2 for the BS as compared to 28.7 for KR. However, VO_2 values for Calarco et al. were for movements performed on a 6-in step. It is difficult to quantify choreography, and there is a need to further describe and standardize both arm and leg movements if comparisons are to be made across studies in the future.

The role of surfaces in dissipating shock may be important in reducing injuries (30). Fiolkowski et al. (18) found a rapid rise in plantar pressure (including both shear and compressive components) while dancing on a tile floor as compared to a stage floor and vinyl mat. The rise in plantar pressure may increase the likelihood of injury because the muscles do not have enough time to contract and absorb forces causing the forces to be transmitted further up the axial skeleton. Based on these considerations, and on earlier subjective preference results (21, 28), the current study examined ground reaction force variables in an attempt to further quantify any subjective feelings of differing stress reported by the participants. Non-significant differences in both peak vertical ground reaction force (VGRF) and time of foot contact (TFC) across the three surfaces are an indication that the participants did not perform the steps differently in accommodating to the padded conditions. Mean VGRF values converted to multiples of body weight ranged from a low of 1.60 up to 1.68 BW for KR and SK, respectively. These values are within the ranges reported for the basic and travel steps using the same bench height and an intermediate stepping rate of 31 cycles/min compared to rates of 30 and 33 cycles/min used by Scharff-Olson et al. (11). They reported mean values for VGRF of 1. 57 and 1.87 BW, respectively, for those rates but did not report differences between steps. If it can be assumed that they did not find statistically significant differences, the current results are very similar in pattern.

Qualitative assessments of floor substrates and padding materials have been performed with some similar results. Nigg et al. (28) investigated deformation of different surfaces after landing from a jump. Less deformation of the surface was associated with larger forces acting on the body, which could lead to a higher incidence of overloading injuries. The surface with a single top layer and an additional rubber pad between first and second sleepers had the largest deformation and was considered the most comfortable. The lowest deformation surface, and least comfortable surface, had only one sleeper system. McKeever (21) observed that subjects who performed step exercise on landing surfaces of varied compressibility found that exercising was easier on a less compressible surface. His subjects also felt that the stability of the surface and control of their movements were greater on the less compressible surfaces. The trend in that study indicated that the two least compressible surfaces were selected in nearly equal proportions to be unstable while the most compressible padding and the bare floor were selected about equally as the most stable. Based on the findings of that study, the tested surfaces followed a continuum from most- to least-compressible with the bare floor surface falling at the least compressible end.

In the current study, the subjective responses did not follow this continuum. The surfaces were selected assuming that the order of responses related to effort, stress, and stability would place them on a continuum that would have the thick pad at one end and the unpadded force platform at the other. In this case, since the pads were made from similar materials, the relative thickness of the pads would relate to the amount of compression available and to the control of the foot during foot contact. The participants selected the thinner pad to be the least safe in terms of control and stability, with a non-significant trend toward selecting the unpadded force platform as the most safe. Also unlike McKeever's results (21), the participants in this study preferred exercising with the thicker pad on the landing surface and least preferred the thinner pad. It is likely that comparison between these studies of floor substrate and surface padding is hampered by the fact that the materials and deformation patterns were different in each.

Conclusions

In spite of evidence that caused an expectation that ground reaction force and energy cost variables might be altered by use of padded landing surfaces, none were observed in this study. The addition of similar pads, except one thinner (i.e., 0.010 m; 28.0 kg/m^3) and one thicker (i.e, 0.025 m; 31.2 kg/m^3), to the landing surface did not alter the impact or energy cost of three different bench stepping techniques. Subjects did report that they felt "least safe" on and "least preferred" the thinner surface while indicating that they also preferred to exercise on a padded surface. It is likely that the surfaces used in this study were so compliant that maximum compression was achieved very quickly. At that point, the padded surfaces acted essentially like the unpadded surface, but the act of compressing these particular materials was not sufficient to elicit definite physiological or biomechanical responses.

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