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Technical Note

Effects of Different Surfaces on Metabolic Cost During Repetitive Jumping: A Pilot Study

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ABSTRACT

International Journal of Exercise Science 16(2): 866-874, 2023. The purpose of this pilot study was to determine if there is a difference in metabolic cost when jumping on platforms of varying thickness, as well as whether a difference exists in metabolic cost between genders exists on the different platforms. Fourteen participants (seven males and seven females) completed three repetitive jumping trials on the DigiJump machine. Each trial was performed at a cadence of 120 jumps per minute and at a minimum height of 1/2″ per jump. Trials were completed on platforms of 1/2″, 3/8″, and 1/4″ thickness. Participants were instructed to jump as long as possible while maintaining the prescribed cadence or until fifteen minutes had elapsed. There were no differences observed in metabolic cost or exertion for all participants or between genders as indicated by oxygen consumption, respiratory exchange ratio, upper leg RPE, or lower leg RPE. There were also no differences for durations of exercise the participants were able to sustain on the machine. However, when comparing data between genders, a significant interaction was observed in total body RPE across the three platforms (p = .009) and in HR on the 1/2″ platform (p = .018). Results from this study indicate that metabolic cost is similar during repetitive jumping regardless of platform rigidity or gender. However, post-trial comments from participants did show preferences towards specific platforms, though this was not apparent in exercise duration.

KEY WORDS: Platform, cadence, VO_2, heart rate, DigiJump

INTRODUCTION

There are a number of different methods that may be employed to attain the physical activity recommendations suggested by the American College of Sports Medicine (ACSM). Activities such as cycling, jogging, swimming, and walking are among the most popular as they are readily accessible, cost-effective, and highly individualized by allowing people to self-select duration and intensity of exercise. ACSM recommends that for one to maintain health and reduce risk for chronic disease, healthy adults should engage in 150 minutes of moderate intensity exercise per week (1, 7). In addition to those activities listed above, another mode that may be used to meet ACSM's recommended guidelines is repetitive jumping.

Repetitive jumping, in the form of rope skipping, is often seen in elementary school children. This is an intense activity where the heart rate has been observed to rise significantly above resting values after only two minutes of jumping (11, 17). Previous research has also shown that repetitive jumping can elicit a substantial caloric expenditure due to both anaerobic and aerobic metabolic demand and, interestingly, jumping cadence does not appear to affect physiological stress (5, 8, 9, 11, 16, 20). The significant aerobic demand from repetitive jumping mirrors other aerobic activities in reducing one's risk factors for chronic disease (4, 10, 19), while also conferring improvements in bone and joint health, particularly in the lower extremities (6, 13). Most of the previous research has examined repetitive jumping with participants turning and skipping a rope (5, 8, 9, 16, 20). However, a machine called the DigiJump has been developed specifically for the purpose of repetitive jumping.

The DigiJump allows one to use repetitive jumping for exercise or training without the limitations of jumping rope. As described previously by Lyons, et al. (11), "This device allows one to jump at a pre-determined rate (jumps per minute) and at a pre-determined height per jump, while not having to utilize one's hands and arms, thus possibly reducing localized fatigue and enabling one to continue exercising longer and more consistently. Also, as the jumping rate is governed by a series of lights and audible beeps, one may continue to exercise even if the person has an error. In traditional rope jumping, when the rope catches the foot, one must stop exercising and then start again" (11). There have been only three previously published studies using the DigiJump as an exercise modality. A 2008 study by Sivley, et al., examined the test-retest reliability of this device, the aforementioned 2010 study by Lyons, et al., evaluated the differences in metabolic demand between different jumping cadences, and a 2020 study, also by Lyons, et al., examined steady state metabolic cost of exercise on the DigiJump (11, 12, 18). Furthermore, the DigiJump may also have applicability for sport-specific training purposes which require jumping, such as basketball, volleyball, or soccer, as well as rehabilitative purposes for these same types of athletes when recovering from injury. The different platform thicknesses provided by the DigiJump may be useful as early pilot data indicated that participants showed preferences across the platforms; some preferred the thinner, more "spring-like" platform while some preferred the thicker, more rigid platform. However, little research on this novel device currently exists.

An extensive literature search revealed no prior research investigating repetitive jumping on platforms of varying thicknesses and rigidity. The DigiJump allows for repetitive jumping on platforms of 1/2", 3/8", and 1/4" with a decrease in rigidity as platform thicknesses decrease. To our knowledge, impact of variability in platform thickness and rigidity on amortization phase is unknown. However, the different platforms may affect amortization phase as the thinner platforms may provide a "spring-like effect," which was supported by pilot trials indicating that there may be a difference in metabolic demand when jumping on platforms of differing thickness. Additionally, there also may be a difference in platform preference between participants based on platform thickness. Therefore, the purpose of this pilot study was to evaluate the effect of different platform thicknesses on the metabolic demand during repetitive jumping, as well as to determine if there was a preference of a specific type of platform between participants based on descriptive characteristics. Hypotheses were a: there would be a greater metabolic demand with thicker, more rigid platforms; b: participants would exhibit longer exercise durations and indicate stronger preferences for thinner, less rigid platforms; and c: there would be similar metabolic costs between genders during repetitive jumping exercise across platforms of varying thicknesses.

METHODS

Participants

Fourteen participants (seven males and seven females) with a mean age of 21.9 ± .66 years volunteered to complete this study. Participants were obtained from the university population and included only individuals who were already participating in at least 30 minutes of moderate intensity recreational physical activity on a minimum of five days per week. Participants were excluded from participation if they had any prior lower-body joint (hip, knee, or ankle) injury which required surgery. Each participant completed a Health Status Questionnaire (HSQ) and a Physical Activity Readiness Questionnaire (PAR-Q) to screen for any health risk, and ACSM guidelines were used to eliminate any potential participants with known risk factors (1). Participants also understood and signed a written informed consent document according to the requirements of the university's Institutional Review Board. This study was conducted fully in accordance with the ethical standards of the International Journal of Exercise Science (14).

Protocol

All research trials were performed on a DigiJump machine. The DigiJump is an exercise machine designed to utilize repetitive jumping as aerobic exercise, similar to jumping rope (Figure 1). During all trials, metabolic measurements were obtained using a two-way, low resistance breathing valve and an appropriate respiratory mask, covering the nose and mouth. Expired gases were analyzed breath by breath using a Vacumed Vista Mini-CPX (Vacumed, Ventura, CA). Heart rate (HR) was monitored each minute during testing using telemetry (Polar Vantage XL, Port Washington, NY). Oxygen and carbon dioxide analyzers were calibrated prior to each test, using appropriate calibration gases of known concentrations. The flowmeter was calibrated using a Hans Rudolph (Series 4900) 3.0 L Calibration Syringe (Kansas City, MO). Rating of perceived exertion (RPE) for upper and lower body was obtained at the end of each minute during each test, according to the Borg 15-point scale (2). For analysis purposes, all measured values reflect an average of the final three minutes for each participant.

Participants reported to the laboratory for testing on three separate mornings between 8:00am – 11:00am, with each testing session separated by 48 – 72 hours. Pilot testing showed no delayed-onset muscle soreness or other residual fatigue that would affect subsequent testing after 48 hours, and none was observed throughout data collection for this study. Prior to testing, participants were instructed to refrain from strenuous activity for a minimum of 48 hours, and from caffeine, nicotine, and alcohol for a minimum of 24 hours. They were also instructed not to consume food for a minimum of eight hours prior to each test. During the first visit a thorough explanation of the study was provided, including familiarization with the machine, along with completion of initial screening documents and instructions regarding subsequent lab sessions. Selected anthropometric measurements (height, weight, and percent body fat) were then obtained. Body composition was assessed via skinfolds using the two-compartment model, and based on age, gender, and the sum of three anatomical sites (males: chest, abdomen, and thigh; females: triceps, suprailiac, and thigh) using Lange skinfold calipers (1, 15). Following a five-minute warm-up on a treadmill, participants then completed one exercise trial on the Digi-Jump, equipped with a jump platform of 1/2", 3/8", or 1/4" thickness. Participants were instructed to jump at a defined cadence of 120 jumps per minute (JPM) (controlled by a metronome built into the machine), and at a minimum height per jump of 1/2" (controlled by an invisible laser which the participants had to clear with each jump or it would flash a red light to cue them to jump higher), until volitional exhaustion, or for a maximum of fifteen minutes. The final two lab visits consisted only of the remaining exercise trials with the appropriate platform thicknesses. Exercise trials were counterbalanced to control for an order effect.

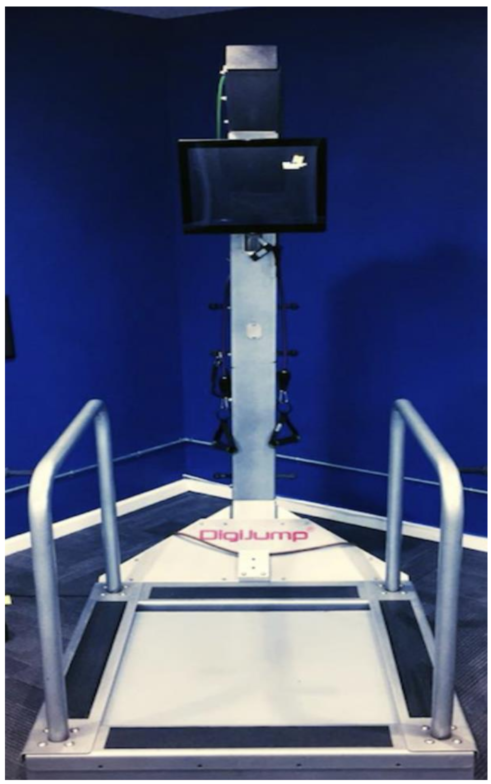

Figure 1. DigiJump machine.

Statistical Analysis
All analyses were performed using the Statistical Package for the Social Sciences (SPSS) software. All data are reported as mean (M) ± standard deviation (SD). Within-subjects one-way analysis of variance (ANOVA) was used to test for differences between participants' responses from the three exercise protocols. Additionally, a between participants 2x3 (gender x platform thickness) repeated measures ANOVA was used to compare variables between genders at varying platform thicknesses. Statistical significance was accepted at $p < 0.05$.

RESULTS

Post-hoc power analysis and effect size were conducted with a sample size of 14 participants, indicating a power of 0.39 and an effect size of 0.48. Participants' descriptive characteristics are displayed in Table 1. Participants were lean (body fat 16 ± 7.6%) and reported being recreationally active on most days of the week, but none were competitive or varsity athletes nor had any participated in a structured aerobic exercise or training program for a minimum of six months prior to the study. Some of the male participants did report regular participation in resistance training, however, which likely accounts for the lower percentage of body fat observed in the male participants (9.7 ± 3.5%).

Table 1. Anthropometric and Descriptive Characteristics (*n* = 14)

Variable	Males (*n* = 7)	Females (*n* = 7)	Combined (*n* = 14)
Height (m)	1.79 ± 0.04	1.69 ± 0.04	1.74 ± 29.08
Weight (kg)	85.08 ± 7.56	66.29 ± 10.66	75.84 ± 13.20
BF (%)	9.71 ± 3.47	22.36 ± 4.48	16.04 ± 7.61
Age (y)	22.00 ± 0.58	21.71 ± 0.76	21.86 ± 0.66

Table 2 depicts participants' average cardiometabolic values for the final three minutes of each trial while jumping at a cadence of 120 JPM and at a minimum height per jump of 1/2″ for each of the three platform thicknesses (1/4″, 3/8″, and 1/2″) used for this study. Across all participants, no statistical differences were observed between the three experimental conditions for any of the measured variables (VO_2, HR, RER, differentiated RPE, exercise duration) (all comparisons $p > .05$). When comparing the trials by gender, a significant difference was observed in total body RPE across the three platforms ($p = .009$) (Figure 2) and in HR on the 1/2″ platform ($p = .018$) (Table 2), but no other differences between genders were detected for any measured variable across the three experimental conditions ($p > .05$). Though there were no differences observed in VO_2 or RER, values indicated that repetitive jumping, regardless of platform thickness and jumping at this defined cadence and height per jump, is approximately a 10 MET (metabolic equivalent) activity. RER values ranged from .98 ± .07 (males: 1/4″) – 1.0 ± .09 (males: 1/2″) for all trials, while VO_2 values ranged from 33.3 ± 3.2 ml $\cdot kg^{-1} \cdot min^{-1}$ (females: 3/8″) – 36 ± 3.5 ml $\cdot kg^{-1} \cdot min^{-1}$ (males: 3/8″). Seven of the fourteen participants (four females and three males) completed the full fifteen minutes on all three trials. Interestingly, none of the remaining seven participants were able to complete the full fifteen minutes on any of the three trials.

Table 2. Physiological and perceptual measures across conditions and platform thicknesses.

	Platform Thickness (in)		
Variable	1/4″	3/8″	1/2″
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)			
Males	33.5 ± 2.7	33.3 ± 3.2	34.8 ± 2.7
Females	35.6 ± 3.7	36.0 ± 3.5	36.0 ± 1.8
Combined	34.6 ± 3.3	34.7 ± 3.5	25.4 ± 2.3

Heart Rate (bpm)			
Males	176.3 ± 18.6	179.2 ± 15.9	185.4 ± 13.4
Females	163.2 ± 20.6	165.4 ± 18.5	166.0 ± 13.3*
Combined	169.7 ± 20.0	172.3 ± 18.1	175.7 ± 16.3
RER			
Males	0.99 ± 0.07	0.99 ± 0.06	0.99 ± 0.02
Females	0.98 ± 0.07	1.00 ± 0.07	1.01 ± 0.09
Combined	0.99 ± 0.07	0.99 ± 0.06	1.00 ± 0.06
Upper Leg RPE			
Males	13.2 ± 2.4	13.2 ± 2.9	14.4 ± 2.2
Females	14.8 ± 2.9	14.7 ± 2.9	14.1 ± 3.7
Combined	14.0 ± 2.7	14.0 ± 2.9	14.3 ± 2.9
Lower Leg RPE			
Males	15.5 ± 2.5	14.7 ± 2.6	15.8 ± 2.0
Females	16.8 ± 3.1	15.9 ± 3.2	15.7 ± 3.2
Combined	16.1 ± 2.8	15.3 ± 2.8	15.8 ± 2.5
Duration (min)			
Males	11.9 ± 4.5	12.0 ± 4.4	12.1 ± 4.0
Females	10.7 ± 4.0	10.7 ± 4.2	10.7 ± 4.2
Combined	11.3 ± 4.1	11.4 ± 4.2	11.4 ± 4.0

Note: Values reflect an average of the final three minutes for each participant. *indicates a significant gender difference for heart rate on the 1/2″ platform.

DISCUSSION

The present study examined the potential differences in metabolic cost between jumping at a cadence of 120 JPM on platforms of three different thicknesses (1/4″, 3/8″, 1/2″) using the DigiJump machine. Results were analyzed across all participants as well as between gender. Statistics revealed that for all participants, similar VO_2, HR, RER, and differentiated RPE values were observed between platforms (Table 2). For gender comparisons, no differences were observed in the above variables with two exceptions: a significant platform*gender interaction for total body RPE (Figure 2), and a significant difference in HR for the 1/2″ platform (Table 2). Exercise duration was also similar between all participants and between genders.

Though there were no differences observed in VO_2, RER, upper leg RPE, lower leg RPE, or exercise duration across the trials for all participants or between genders, the data clearly indicate that repetitive jumping is a strenuous activity as all trials elicited a metabolic demand of approximately ten METs. This is consistent with previous research on rope skipping and repetitive jumping, which has identified these activities as requiring energy expenditure of 8 – 12 METs (5, 8, 9, 11, 20).

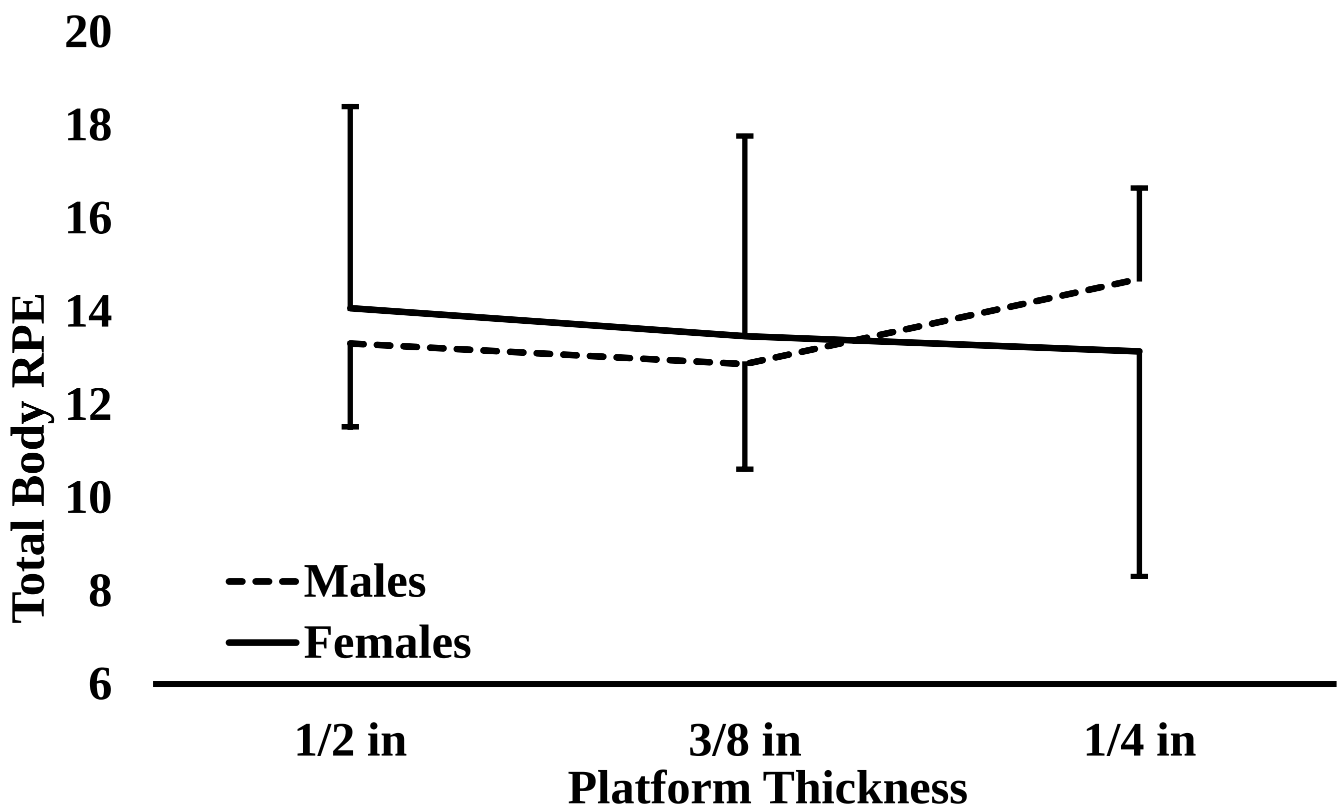

Figure 2. Graphical depiction of significant platform*gender interaction for RPE_{tb} (p = .009).

There were no differences observed in HR between the three trials for all participants, or when comparing genders, for the 1/4" or 3/8" platforms. However, repeated measures ANOVA revealed a significant difference in HR between genders on the 1/2" platform (p = .01). From these data, it could be hypothesized that a more rigid platform results in a greater metabolic strain in females, though this was not observed in any other measured variables. As this was the only significant finding, further investigation is warranted to determine its cause. Participants were exercising at 85 – 90% of their age-predicted max HR, which was consistent with previous research on the DigiJump (11). Though VO_{2max} was not measured prior to the jump trials, observed submaximal steady-state VO_2 values suggest participants were engaging in moderate-vigorous intensity aerobic exercise.

While there were no differences observed between the three platforms for the differentiated RPE values, it is interesting to note that observed total body RPE was lowest for all three platforms, followed by upper leg RPE being slightly greater, and lower leg RPE eliciting the highest values. Comments from the participants about lower leg discomfort focused primarily on pain in the anterior tibialis area and on the plantar side of the foot, which is consistent with previous research on the DigiJump (11). Exercise duration was consistent across the trials at approximately eleven minutes for all three platforms. These data speak directly to the secondary purpose of this study, which was to determine if participants preferred a certain platform. While the metabolic data and exercise durations across trials suggest collectively that there were no differences in participant performance between platforms, responses to post-trial questions

(How do you feel? How did that trial compare with your previous trial(s)? Did you notice any differences?) revealed that some participants strongly preferred the "thinner" platform and the associated lower rigidity, while other participants preferred the "thicker," more rigid platform. However, with limited literature on the DigiJump, this warrants further investigation.

Applicability of these results, and practical uses of the DigiJump, are numerous. Repetitive jumping, whether with a jump rope or on a machine of this type, has been shown to elicit strenuous aerobic activity. Therefore, anyone without lower body limitations may utilize this machine to achieve the weekly recommendation for physical activity. As an additional benefit to meeting daily physical activity requirements, exercise on the DigiJump may enhance bone health and reduce risk of osteoporosis (6, 13). Further, this machine may be a valuable resource in two ways for sports that involve jumping, e.g., soccer, volleyball, basketball. First, it may be used as a training device (3). Being able to train while controlling jumping cadence and height per jump could be an effective component for coaches to include in their athletes' off-season training regimens. Also, it may be used for maintaining cardiorespiratory fitness while rehabilitating an upper-body injury, or for sport-specific therapy when recovering from a lower-body injury. Moreover, because this machine has sturdy handlebars, it may be used at low intensities as a component of rehabilitation in lower body injuries. Either way, this machine could potentially accelerate the time necessary for an athlete to "return to play," which is important both to athletes and coaches.

This study was not without limitations. Lactate was not measured, and should be included in future investigations to assess anaerobic contribution to energy expenditure during repetitive jumping. Also, participants were instructed to jump as long as they could while maintaining the prescribed cadence and height per jump up to 15 minutes, at which time they were stopped. Future studies should allow all participants to go to volitional exhaustion to obtain a better understanding of intensity and tolerance of repetitive jumping across people of different fitness levels and genders.

This study investigated repetitive jumping on the DigiJump machine with participants jumping on platforms of varying thickness. While there was no difference in metabolic cost across trials for the different platforms or between genders, there was a general preference towards the least rigid platform in some participants while other participants preferred the platform with the greatest rigidity. However, these preferences did not affect exercise duration. As repetitive jumping has been shown to be a high-impact, strenuous exercise, future research in this area should focus on the effects of repetitive jumping in improving bone and joint health, as well as determining the intensity of self-selected repetitive jumping relative to a person's VO_{2max}.

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