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TOTAL ENERGY COSTS OF 3 TABATA-TYPE CALISTHENIC SQUATTING ROUTINES: ISOMETRIC, ISOTONIC AND JUMP

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ABSTRACT

Introduction: We examined the total energy costs – aerobic and anaerobic, exercise and recovery – of three Tabata-style squat routines: isotonic, isometric and plyometric (jump). Our intent was to determine which format elicited the greatest overall cost. Materials and Methods: Four male and three female subjects volunteered (23.7 ± 2.6 years, 170.1 ± 10.3 cm, 68.2 ± 14.6 kg). Isotonic and jump squats were completed in 20 second bouts at a cadence of 2 seconds per squat (10 repetitions each) followed by 10 seconds of recovery; isometric squats were held for the entirety of each 20 second exercise period followed by 10 seconds of recovery – exercise and recovery bouts were repeated 8 times for a total of 4 minutes. Results and Discussion: Jump squats had the greatest overall energy cost at 160.7 ± 56 kJ (38.4 ± 13.4 kcal) followed by isotonic squats at 112.4 ± 24 kJ (26.9 ± 5.7 kcal) ; there was no statistical difference between the two. Isometric squats at 62.4 ± 6 kJ (14.9 ± 1.4 kcal) were significantly lower than both isotonic and jump squats ($p < 0.05$). From an exercise program design standpoint isometric exercises do not appear to represent an appropriate format when attempting to maximize energy costs.

Key Words: aerobic and anaerobic energy costs, excess post-exercise oxygen consumption

RESUMEN

Introducción: Examinamos el coste total energético – aeróbico y anaeróbico, ejercicio y recuperación – de 3 rutinas de sentadillas calisténicas tipo tabata: isométrico, isotónico y pliométrico (salto). Nuestra intención era determinar que formato provocó el mejor coste global. Material y método: Cuatro sujetos masculinos y tres femeninos participaron en el estudio (23.7 ± 2.6 years, 170.1 ± 10.3 cm, 68.2 ± 14.6 kg). Sentadillas con salto y sentadillas isotónicas fueron completadas en series de 20 segundos con una cadencia de 2 segundos por sentadilla (de 10 repeticiones) seguidas por 10 segundos de recuperación; las sentadillas isometricas tuvieron lugar durante la totalidad de los 20 segundos de cada periodo de ejercicio seguidos por 10 segundos de recuperación – series de ejercicio y las series de recuperación fueron repetidas 8 veces durante un total de 4 minutos. Resultados y discusión: las entadillas con salto tuvieron la mayor coste energético en 160.7 ± 56 kJ (38.4 ± 13.4 kcal) seguidas por las sentadillas isotónicas con 112.4 ± 24 kJ (26.9 ± 5.7 kcal); no hubo diferencia estadística entre ambas. Las Sentadillas isométricas con 62.4 ± 6 kJ (14.9 ± 1.4 kcal) fueron significativamente inferiores tanto a las sentadillas isotónicas como a las de salto ($p < 0.05$). Desde el punto de vista del diseño de un programa de ejercicios, los ejercicios isométricos no parecen representar un formato apropiado cuando se intenta maximizar los costes de energía.

Palabras clave: costes de energía aeróbicos y anaeróbicos, exceso de consumo de oxígeno post-ejercicio

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INTRODUCTION

At present one of the more popular formats of exercise involves brief high intensity bouts (lasting 20 s) coupled to a brief recovery period (of 10 s) that is repeated six to eight times. Known as Tabata training, the routine was originally developed using a cycling ergometer, but has been subsequently applied to a vast range of exercise and activities (Tabata et al., 1997). While the potential for both increased aerobic and anaerobic performance after an extended period of Tabata-type training is clear, the overall energy costs of these routines are less well known. An energy expenditure estimate of 13.4 $kcal \cdot min^{-1}$ (54 kcal in 4 minutes) has been recently reported for an all-out Tabata jump squat routine, with recovery further adding to that cost (Olson, 2013).

While higher intensity intermittent exercise has been shown to be an acceptable and perhaps even optimal method of body fat reduction as compared to lower intensity steady state exercise (Hunter et al, 1998; Boutcher, 2011), questions also arise regarding the associated perceived exertion. As an example, De Feo (2013) proposes a more moderate exercise intensity, especially within an obese population, because a lower perceived exertion might improve self-efficacy, mood and subsequently drop-out rates. On the other hand, high intensity exercise typically elicits a shorter workout time as compared to moderate intensity exercise and that can serve to motivate exercisers to continue their routine (avoiding drop-out) (Heinrich et al., 2014).

Our intent for the present investigation was to compare 3 Tabata-style calisthenic squat routines – isometric, isotonic, and plyometric (jump) – in an attempt to determine which elicits the greatest overall energy costs. Perceived exertion also was documented for the 3 exercise trials.

METHOD

Four male and three female volunteers (23.7 ± 2.6 years, 170.1 ± 10.3 cm, 68.2 ± 14.6 kg) were informed of the risks associated with participation and signed an informed consent document approved by the University's Human Subject Institutional Review Board before any data were collected.

Each subject visited the laboratory on seven separate occasions; the first visit was for the provision of informed consent, the collection of age, height and weight data and a practice routine (that included the use of the metabolic cart, headgear and mouthpiece). During this visit subjects squatted until the thighs were parallel to the floor. This distance was measured using a Function Mobility Screening (FMS) device and a rubber cord was stretched underneath and slightly touching the buttocks during the squat to provide the user with orientation during testing in accordance with the depth of each squat. During the following 6 visits subjects were randomly assigned to one of 3 types of

Tabata-style calisthenic squat routines: 10 jump squats coordinated evenly throughout each 20 second exercise period, 10 isotonic movement squats (at a 1 second down, 1 second up cadence for 20 seconds), and an isometric squat held for a period of 20 seconds; jump and isotonic squats cadence was made auditory with a metronome. Each 20 second exercise period was followed by 10 seconds of standing recovery; each exercise and recovery period was repeated eight times for a total period of 4 minutes. On completion of all exercises and recovery periods, subjects were immediately seated and excess post-exercise oxygen consumption (EPOC) was recorded until 2 consecutive 15 sec measurements fell below 5.0 $mL \cdot kg \cdot min^{-1}$ (a typical standing, resting VO_2).

Subjects fasted overnight and did not exercise before testing took place. The 3 squat routines were randomly completed a total of two times on separate days and were averaged to report a single value (6 tests overall for each subject). Oxygen uptake was measured using a metabolic cart (MMS-2400, PavoMedics, Sandy, Utah) that was calibrated a minimum of two times immediately prior to testing, using room air and calibration gas (16.1% O_2, 3.9% CO_2). Gas exchange was collected via breathing tube, headgear, mouthpiece and noseclip apparatus. Ventilation was calibrated using a 3-L syringe. Oxygen uptake was measured real-time in 15 second sampling periods during the exercise and subsequent recovery on the computer screen; tabular data for calculations were summed every minute as LO_2 (not L min^{-1}). Before each test, standing resting oxygen uptake was averaged over a 5 min period and was subsequently subtracted from exercise and recovery values to report net aerobic costs. Energy cost conversions for each 20 sec exercise and 10 sec recovery period were completed as 1L VO_2 = 20.6 kJ (4.9 kcal) (assuming glucose oxidation for 2/3 of every minute and fat and lactate oxidation for the remaining 1/3 minute). Excess post-exercise oxygen consumption (EPOC) was converted to kilojoules as 1L VO_2 = 19.6 kJ (4.7 kcal) (assuming fat and lactate oxidation) (Scott, 2011).

Anaerobic energy costs were determined as the difference (delta) between averaged duplicate resting and peak blood lactate measures taken from a finger-stick (Lactate Pro, Arkray Inc., Kyoto, Japan). Peak blood lactate was measured as being 2.5 minutes into seated recovery as determined by a pilot project. Blood lactate measurements (mmol) were subsequently converted to oxygen equivalent estimates as 3.0 ml O_2 kg^{-1} body weight per mmol of (delta) blood lactate then multiplied with a conversion of 1L VO_2 = 21.1 kJ (5.0 kcal).

Statistical Analyses

Statistical analyses were completed using SigmaPlot 12.0. Normality (normal distribution) was tested using a Kolmogorov-Smirnov test. For non-parametric condition a Kruskal-Wallis one-way analysis of variance (ANOVA) was utilized. With normally distributed data a one-way ANOVA with Holm-Sidak post-hoc testing was completed. All data reported in the manuscript or in the descriptive format of mean ± standard deviation. Level of significance was set at p = 0.05.

RESULTS

Total energy costs - including aerobic and anaerobic during the Tabata routines and aerobic during EPOC – were significantly higher for the jump squat 160.7 ± 56.2 kJ (38.4 ± 13.4) and isotonic squat 112.4 ± 24.0 kJ (26.9 ± 5.7 kcal) as compared to the isometric squat 62.4 ± 5.7 kJ (14.9 ± 1.4 kcal) (p = 0.001) (Table 1).

A rating of perceived exertion (on the 6-20 Borg scale) revealed the highest scores for the jump squat 13.8 ± 0.8 and isometric squat (13.4 ± 1.1) as compared to the isotonic squat (10.7 ± 1.1) (p = 0.001).

The largest aerobic energy cost component was for the 4 minute periods of exercise and recovery, being significantly lower for the isometric squat 34.9 ± 3.5 kJ (8.3 ± 0.8 kcal) as compared to the jump squat 104.3 ± 43.3 kJ (24.9 ± 10.3 kcal) and isotonic squat 82.5 ± 20.6 kJ (19.7 ± 4.9 kcal) (p < 0.003).

The second largest aerobic energy cost component was EPOC, being significantly greater for the jump squat 33.1 ± 9.3 kJ (7.9 ± 2.2 kcal) and isotonic squat 21.1 ± 3.6 kJ (5.0 ± 0.9 kcal) as compared to the isometric squat 16.5 ± 2.3 kJ (3.9 ± 0.5 kcal) (p < 0.003) (Table 1).

Anaerobic energy costs estimated from blood lactate levels revealed wide variation for each type of squat, statistical significance was found between the jump squat 23.4 ± 12.7 kJ and isotonic squat 8.7 ± 6.8 kJ (p = 0.05) but not the isometric squat 11.0 ± 5.2 kJ (Table 1).

TABLE 1
Energy cost components of 3 Tabata-style calisthenic squat routines.

	Aerobic (kJ)	Anaerobic (kJ)	EPOC (kJ)	Total costs (kJ)
Jump	104.2 ± 43	23.4 ± 13 ^	33.1 ± 9	160.7 ± 56
Isotonic	82.5 ± 21	8.8 ± 7	21.1 ± 4	112.4 ± 24
Isometric	34.9 ± 4 *	11.0 ± 5	16.6 ± 2 *	62.4 ± 6 *

mean ± standard deviations, Aerobic data were recorded as exercise and recovery oxygen uptake throughout each trial (resting oxygen uptake was subtracted from these measurements), Anaerobic data were taken from blood lactate measurements (the difference between resting and peak values), EPOC = excess post-exercise oxygen consumption after the completion of each trial (resting oxygen uptake was subtracted from this measurement).
** = significantly lower than the other squats, ^ = significantly greater than isotonic squat*

DISCUSSION

Analyses of the three calisthenic squat routines indicate that movement has a rather dramatic effect on total energy costs: jump squats at 161 kJ (38 kcal) and isotonic squats at 112 kJ (27 kcal) were both significantly greater as compared to isometric squats at 62 kJ (15 kcal). It appears the stretch-shortening cycle invoked with the jump squat (plyometrics) has the potential to achieve the largest effect on overall energy costs (as well as variability), though statistical significance with the isotonic squat was not found. Application to exercise program design is readily apparent; movement is necessary to maximize overall energy costs.

McArdle and Foglia (1969) first revealed that with resistance-type exercise, isometric contractions produce a lower overall aerobic cost as compared to isotonic weight lifting. Moreover, isometric resistance had per minute oxygen uptake rates that peaked in the first minute of recovery, not during the actual exercise. Surprisingly this latter finding does not appear to have been reported within any text book of exercise science, where oxygen uptake rates are always portrayed as plummeting exponentially toward resting levels the moment exercise stops. Our calisthenics finding, where an outside resistance (or load) was not applied, mirrors those of resistance training: a lower total energy cost for isometric exercise and peak oxygen uptake rates in recovery, *after* the isometric exercise is completed (oxygen uptake rates peaked *during* the jump and isotonic squat routines).

It is of interest that a rating of perceived exertion was highest for the jump and isometric squats as compared to the isotonic squat. Thus, from a perceptual standpoint, holding an isometric contraction requires effort that is not directly associated with overall energy costs. As stated by Marcora (2009), "perception of effort during exercise is independent of afferent feedback from skeletal muscles, heart and lung". While subjects appear to have struggled through the isometric format, total energy costs were in fact minimized.

Since the earliest days of skeletal muscle investigation it was recognized that a non-moving 'contraction' was less costly as compared to when movement took place (see Kushmerick, 1983). More recent research indicates that a continuous isometric contraction by definition does not involve work (the product of force, inertia and displacement) and that the accompanying ATP turnover rates can be much less as compared to isotonic and repeated brief isometric contraction conditions (Newham et al., 1995; Russ et al., 2002; Elder et al., 2006). In terms of exercise program design, isometric exercise may be an excellent choice to promote gains in muscular strength, but in terms of maximizing overall energy costs, isometric exercise does not.

Olson (2013) utilized an all-out effort Tabata jump squat routine and found a caloric cost of 54 kcal within the 4 minute exercise period, with an additional

40 kcal post-exercise; the 56 kcal (234 kJ) difference compared with our jump squats was likely due to the maximal ("all-out") performance intensity required of subjects in the Olson investigation (jump number was not reported). Our subjects needed constant reminders to "jump!" as the routine progressed that likely promoted the largest standard deviation of the 3 squats – leaving the ground at a 10 jumps per 20-s cadence was prioritized (not a maximum jump height or an all-out 'as many jumps as possible' effort). Recognizing that a 4 minute Tabata routine may contribute somewhat minimally to daily energy costs, Emberts et al (2013) used a modified 20-minute routine with a variety of exercises that had an average aerobic cost of 300 kcal (1255 kJ); in terms of their 14.5 kcal·min^{-1} finding, the use of a true 4 minute Tabata routine would have resulted in an energy expenditure of 58 kcal (243 kJ) (post-exercise oxygen consumption was not recorded). Again, energy cost differences with the present study were likely due to the "as many reps as possible" within each 20-s period format as well as the greater perceived exertion of the Emberts et al investigation.

In conclusion, within the structure of a Tabata routine, total energy costs were lowest for isometric as compared to jump (plyometric) and isotonic conditions. In terms of designing an exercise program to maximize overall energy costs, it is apparent that isometric-type exercise does not fulfill that criterion.

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