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ESTIMATING THE TOTAL ENERGY COSTS OF A BRIEF 1-MINUTE BOUT OF HEAVY BAG PUNCHING

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ABSTRACT

Introduction: We compared a one minute total energy cost estimate – aerobic and anaerobic, exercise and recovery - with published per minute exercise-only oxygen uptake measures for pugilistic exercise. Material and Methods: Ten male subjects completed testing: 25.6 ± 3.5 years; ht 180.5 ± 8.0 cm; wt 80.7 ± 8.4 kg. The punching exercise (using wrapped hands and 16 oz. gloves) included: 6 rapid punches to a hanging heavyweight bag followed by a brief pause for a total of 16 sets; in all 96 punches were completed within 61.5 ± 5.3 sec of exercise. The protocol was repeated twice and an average net cost of the 2 trials was reported. Results and Discussion: Aerobic exercise costs were 33.1 kJ ± 5.5 (7.9 ± 1.3 kcal), anaerobic energy costs were 37.1 ± 8.9 kJ (8.9 ± 2.1 kcal), excess post-exercise oxygen consumption (EPOC) was 83.4 ± 15.8 kJ (19.9 ± 3.8 kcal) and total energy costs were 153.7 ± 20.1 kJ (36.7 ± 4.8 kcal). For brief intense pugilistic exercise, our total energy cost estimate was as much as 4.5-fold greater than previously published per minute exercise oxygen uptake rates. It is concluded that the steady state modeling of energy costs should not be judiciously applied to brief, intense, non-steady state, intermittent exercise.

Keywords: intermittent exercise, pugilism, oxygen uptake, anaerobic energy costs, EPOC

ESTIMACIÓN DEL COSTE TOTAL DE ENERGÍA DE GOLPEO DE SACOS PESADOS DURANTE 1 MINUTO

RESUMEN

Introducción: Comparamos una estimación del coste total de energía en un minuto (aeróbico y anaeróbico, ejercicio y recuperación) con medidas de consumo de oxígeno estimadas por minuto para el ejercicio pugilístico. Material y métodos: Diez sujetos varones completaron las pruebas: 25.6 ± 3.5 años; ht 180.5 ± 8.0 cm; peso 80.7 ± 8.4 kg. El ejercicio de golpeo (con las manos envueltas y los guantes de 16 oz) incluyó: 6 golpes rápidos en una bolsa de peso pesado colgada, seguida de una breve pausa para un total de 16 series; en total, los 96 golpes se completaron en 61.5 ± 5.3 segundos de ejercicio. El protocolo se repitió dos veces y se obtuvo un coste promedio neto de los 2 ensayos. Resultados y discusión: los costes del ejercicio aeróbico fueron 33.1 kJ ± 5.5 (7.9 ± 1.3 kcal), los costes de energía anaeróbica fueron 37.1 ± 8.9 kJ (8.9 ± 2.1 kcal), el consumo excesivo de oxígeno post-ejercicio (EPOC) fue 83.4 ± 15.8 kJ (19.9 ± 3.8 kcal) y los costes totales de energía fueron 153.7 ± 20.1 kJ (36.7 ± 4.8 kcal). Para un ejercicio pugilístico intenso breve, nuestra estimación del coste total de energía fue tanto como 4.5 veces mayor que las tasas de consumo de oxígeno por ejercicio estimadas por minuto. Se concluye que el modelo de estimación del coste de energía no debe aplicarse a un ejercicio breve, intenso, no estacionario e intermitente.

Palabras clave: ejercicio intermitente, pugilismo, consumo de oxígeno, costos de energía anaeróbica, EPOC

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INTRODUCTION

Most published estimates of exercise energy costs are provided as a single measure of oxygen uptake in an averaged per minute format, this is indeed the standard presentation for low to moderate intensity steady state aerobic exercise. As an example, walking at ~3.0 miles hr^{-1} (~5.0 km hr^{-1}) "burns" approximately 4.0 kcal min^{-1}. Another form of presentation is found as a cost per task format: the cost to walk or run a mile for example, where an approximate cost of about 100 kcal $mile^{-1}$ is depicted (Steudel-Numbers, Wall-Scheffler, 2009). While certainly valid for continuous, steady state, low to moderate intensity aerobic exercise, steady state oxygen uptake estimates also have been applied to brief, intermittent, non-steady state, high intensity exercise and yet this application lacks specific justification (Scott, 2010; Scott, Reis, 2016). Steady state methodology extrapolates oxygen uptake measurements from low to moderately intense exercise to the realm of brief and explosive higher intensity exercise where oxygen uptake and power output may no longer be proportional. Moreover, at relatively low levels of a maximum voluntary contraction (force), oxygen delivery to working skeletal muscle is compromised, questioning the use of a "steady state" to estimate the energy costs of intermittent resistance training, for example (Tamaki et al., 1994). Steady state methodology also does not include anaerobic or aerobic recovery energy cost estimates and these two components can make large contributions to brief, intense, intermittent exercise (Scott, Reis, 2016). While almost universal in use, validation is in fact non-existent with the application of steady state methods to the estimation of energy costs for brief intense intermittent exercise and so we asked the question: which might best describe the energy cost of brief and intense exercise: per minute oxygen uptake measurements during exercise or, a per task estimate consisting of aerobic and anaerobic, exercise and recovery costs?

A lack of a standardized method for the estimation of the energy costs of non-steady state exercise has resulted in a far-ranging data set within the scientific literature for pugilistic-type activity, extending from per minute values to METs to costs per completed task. However, most reported costs reflect a steady state per minute average of oxygen uptake measurements. The current investigation focused on an overall or total - aerobic and anaerobic, exercise and recovery - cost per task estimate reported in kcals, in comparison with published per minute exercise oxygen uptake measures (comparisons with the published literature use an average body mass of 80.7 kg, as was found with our subject population).

METHOD

Ten male volunteers 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 data were collected. The subjects' physical characteristics were: age 25.6 ± 3.5 (yr), height 180.5 ± 8.0 (cm), and body weight 80.7 ± 8.4 (kg) (mean ± SD).

We had access to a convenience sample of inexperienced young men who were learning to train with a heavy bag and volunteered to participate in our study. Subjects were trained by a USA boxing certified instructor; testing only took place after competency was achieved (under approval of the instructor). Participant's hands and wrists were encased with cloth wrapping and inserted into 16 ounce gloves. The 30.8 kg bag was suspended from the ceiling and manually held in place during the punching trials. Each punching task consisted of 6 rapid punches followed by a brief pause to re-establish proper position in front of the bag. The 6 punch sequence was repeated for a total of 16 sets in an attempt to complete the task in 60 sec; a total of 96 punches was actually completed within 61.5 ± 5.3 sec of exercise (range: 57.0-72.5 sec). Each subject completed the task twice, on different days, and an average of these data was reported.

Subjects fasted at least 4 hours prior to testing and did not exercise on the day of testing. Warm-up before the testing session consisted of gloved subjects hitting the hand-pads of the instructor for 10 minutes. Two tests were completed on separate days by each subject and averaged to report a single value. 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). Ventilation was calibrated using a 3-L syringe. Oxygen uptake was measured real-time in 15 sec 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. On completion of the exercise, subjects were immediately seated and excess post-exercise oxygen consumption (EPOC) was recorded until 2 consecutive 15 sec measurements fell below 5.0 mL·kg·min^{-1} (a typical standing, resting VO_2). Energy cost conversions for exercise were completed as 1L VO_2 = 21.1 kJ and for recovery as 1L VO_2 = 19.6 kJ; assuming glucose as a fuel during exercise and lactic acid and fats as the fuel of recovery, respectively (Scott, 2010).

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 minutes into seated recovery as part of 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 (Margaria et al., 1964).

Statistical analyses were completed using SigmaPlot 12.0. All data were averaged and reported in descriptive format Comparisons were made using ANOVA and the appropriate post-hoc test (as determined by the SigmaPlot program). Normal distribution was tested using a Kolmogorov-Smirnov test. For non-parameteric conditions a Kruskal-Wallis one-way analysis of variance (ANOVA). With normally distributed data a one-way ANOVA with Holm-Sidak post-hoc testing was performed. Level of significance was set at $p = 0.05$.

RESULTS

Aerobic exercise costs were 33.1 kJ ± 5.5 (7.9 ± 1.3 kcal). Anaerobic energy costs based on blood lactate were 37.1 ± 8.9 kJ (8.9 ± 2.1 kcal). Aerobic exercise and anaerobic energy costs were not significantly different. EPOC was 83.4 ± 15.8 kJ (19.9 ± 3.8 kcal). Total energy costs were 153.7 ± 20.1 kJ (36.7 ± 4.8 kcal). In comparison to both exercise aerobic and anaerobic costs, EPOC was the largest component ($p < 0.05$). Likewise, the summed aerobic exercise and anaerobic cost (70.2 kJ or 16.8 kcal) was significantly less than recovery (EPOC) cost (83.4 kJ or 19.9 kcal) ($p = 0.02$).

TABLE 1

One minute energy cost comparisons within the published literature.

Activity	Subjects	Cost	Reference
Heavy bag punching	10 men	**36.7 kcal** (61.5 s) (1, ~60 s task)	present study
Karate kata	6 men	**23.7 kcal** (60s) (2, 30 s tasks)	Bussweiller et al 2012
Heavy bag punching	9 men	~38.3 ml · kg^{-1} · min^{-1} (~**15.5 kcal**)	Arseneau et al 2011
Punching bag	?	6 METs	Ainsworth et al 2000
Heavy bag punching	5 men, 5 women	23 ml · kg^{-1} · min^{-1} (~**9.3 kcal**)	Adams et al 1993
Heavy bag punching	7 men, 11 women	~30.5 ml · kg^{-1} · min^{-1} (~**12.3 kcal**)	O'Driscoll et al 1999
SLAMMAN punching	12 men, 6 women	28 ml · kg^{-1} · min^{-1} (~**11.3 kcal**)	Kravitz et al, 2003
Martial arts training	9 men, 9 women	**8.1 kcal**	Glass et al 2002
Boxing training	8 men	**11.2 kcal**	Bellinger et al 1997
Sparring	20 women	**12.7 kcal**	Chatterjee et al 2006

Bold face indicates caloric cost for 80.7 kg subjects over the course of a single minute. Data were collected as cost per task (aerobic and anaerobic, exercise and recovery) for the two top investigations; all other studies collected data as steady state exercise in a per minute oxygen uptake format.

DISCUSSION AND CONCLUSIONS

The compendium of physical activities lists heavy bag punching at 6 METs (Ainsworth et al., 2000). At a body mass of 80.7 kg that would translate into approximately 8.1 kcals per minute. Adams et al (1993) reported an average of 6.5 METs (~ 9.3 kcal min^{-1} for 80.7 kg subjects) with 2 punches per second to a heavy bag for 5 minutes total; the range of oxygen uptake was found to be 8.4 to 39.4 ml kg^{-1} min^{-1} (~3.4 to ~15.9 kcal min^{-1}). Variance of this magnitude reveals the complexity of movement and variation of force inherent to pugilistic activity, further complicating the estimation of energy costs. O'Driscoll et al (1999) revealed heavy bag work at 12.3 kcal min^{-1} (with a 134 bpm cadence) while Kravitz et al (2003) had subjects hitting a SLAMMAN at 96 punches per minute within 2 min rounds at a cost of 11.3 kcal min^{-1}. Arseneau et al (2011) indicated relatively steady oxygen uptake values of 30.4 and 38.3 ml kg^{-1} min^{-1} (~12.3 - 15.5 kcal min^{-1}) for 120 and 180 punches per minute (respectively) to a heavy bag (see Table 1).

In contrast to per minute oxygen uptake exercise-only averaged measures, we found total energy costs – aerobic and anaerobic, exercise and recovery - of 36.7 kcal with 61.5 seconds of highly intense heavy weight bag punching. Comparing exercise-only per minute oxygen uptake measures with overall or total energy costs per task for 1 minute of exercise (followed by seated recovery), a range can be found with the above mentioned and our data set of 8.1 kcal min^{-1} to 36.7 kcal in one minute, respectively; a 4.5-fold difference. As compared to the oxygen consumed during the actual 61.5 seconds of heavy bag punching, the inclusion of an anaerobic (lactic acid) component increased overall costs 24% and with the addition of recovery oxygen uptake a further increase of 54% was established. This compares favourably to a 25% anaerobic and 52% EPOC component in the karate kata investigation of Bussweiler and Hartmann (2012). Clearly, an estimation of both anaerobic and recovery components have the potential to contribute significantly to the estimation of total energy costs for brief higher-intensity exercise.

There are certainly limitations to the present study. Costs per minute (e.g., kcal min^{-1}) and costs per task (hitting a heavy bag for 1 minute) will no doubt differ because of the pacing and punching forces involved (as well as the body mass of the subject); neither punching force nor speed could be properly quantified. Based on such limitations few would knowingly approach, for example, a 5 to 10 minute session of any physical task at the same level of exertion as that completed within a 1 minute all-out period, or shorter. This rationale would appear to support cumulative cost per task descriptions of brief and specific high intensity activity as compared to average per minute values that are typically collected over longer periods of time and at much lower intensities. Future investigations should also examine an entire workout (involving several sets) as opposed to a single component of a complete training session.

Clearly, the lack of a standard methodology in the estimation of energy costs for brief, intense, intermittent exercise is problematic. The present investigation uses per task aerobic and anaerobic, exercise and recovery measurements to estimate total energy costs. Our model has not been validated. The validation of steady state per minute oxygen uptake measurements as the sole estimation of energy costs for brief, intense, non-steady exercise is likewise non-existent. It is suggested however, that a reasonable summed (capacity) per task estimate (not averaged rate) of both aerobic and anaerobic, exercise and recovery costs may better interpret the energy costs of brief, intense, non-steady state exercise.

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