Journal of Science and Medicine in Sport 17 (2014) 387–393

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Validity of a combined heart rate and motion sensor for the measurement of free-living energy expenditure in very active individuals

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ARTICLE INFO

Article history:
Received 4 December 2012
Received in revised form 18 July 2013
Accepted 10 September 2013
Available online 18 September 2013

Keywords:
Athletes
Energy requirements
Doubly labelled water
Indirect calorimetry
Heart rate monitoring
Accelerometry

ABSTRACT

Objectives: The correct assessment of energy expenditure in very active individuals is important to ensure that dietary energy intake is sufficient. We aimed to validate a combined heart rate (HR) and motion sensor in estimating total (TEE) and activity energy expenditure (AEE) in males and females with high physical activity levels.
Design: Cross-sectional.
Methods: Doubly-labelled water (DLW) was used to assess 7-day TEE in 12 male and female elite junior basketball players, aged 16–17 years. Resting energy expenditure (REE) was assessed with indirect calorimetry and AEE was calculated (AEE = TEE-RMR-0.1 × TEE). Simultaneously, TEE and AEE were measured by combined HR and motion sensing. Individual HR calibration was performed with step-test. TEE and AEE were estimated from accelerometry and HR with individual ($ACC + HR_{step}$) and group calibration ($ACC + HR_{group}$).
Results: No mean differences were found between TEE and AEE from the $ACC + HR_{step}$ and $ACC + HR_{group}$ with DLW. TEE values (kJ/day) from $ACC + HR_{group}$ and $ACC + HR_{step}$ explained TEE from DLW by ~60% and 53%, respectively whereas AEE (kJ/day) estimated by $ACC + HR_{group}$ and $ACC + HR_{step}$ explained 53% and 41% of the variability of AEE from the reference method. Concordance correlation coefficients for TEE and AEE using $ACC + HR_{group}$ were 0.74 and 0.69, correspondingly while for $ACC + HR_{step}$ values of 0.69 and 0.45 were found. Large limits of agreement were found for TEE and AEE using both $ACC + HR_{group}$ and $ACC + HR_{step}$.
Conclusions: ACC + HR models are a valid alternative to estimate TEE but not AEE in a group of highly active individuals however the considerable rate of equipment failure (~50%) limits its usefulness.

1. Introduction

Physical activity energy expenditure (AEE) is the most variable component of total energy expenditure (TEE). In very active individuals daily TEE can be twice as much as resting energy expenditure,[1] and during heavy sustained exercise in the Tour de France a fivefold increase has been described.[2] With limited energy intake, lean tissue will be used as fuel resulting in loss of strength and endurance that may compromise immune, endocrine, and musculoskeletal function.[3] Energy deficient females can develop a cluster of conditions named "female athlete triad", leading to amenorrhea, osteopenia, and premature osteoporosis, among others.[4] Very active individuals are more likely to be chronically energy deficient, thus it is important to precisely measure energy expenditure (EE) to identify individual energy requirements.[5]

Doubly labelled water (DLW) is the gold standard to assess TEE in free-living individuals and it has frequently been used in highly trained athletes.[6,7] However the analytical procedures involved in dilution techniques are time-consuming, expensive, and involve complex methods and specialized technicians, excluding its routine use for EE assessment.[8] Other alternative, objective, and valid methods to assess EE need to be validated in a population with high levels of EE.

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http://dx.doi.org/10.1016/j.jsams.2013.09.006

Motion sensors and heart rate (HR) monitors provide objective estimates of physical activity, however both present limitations. Motion sensors, worn on the hip are not capable of detecting upper body movements, changes in grade during walking and running, and free weight exercises,[9] and evidence exists that the relation between accelerometry and physical activity intensity (PAI) is affected at higher intensities.[10,11] For partially solving this problem, other wearing locations have been proposed, especially at the ankle and wrist placements. However, limb-worn motion sensors provide similar EE outcome values as the hip-worn motion sensors, during free-living conditions.[12] In active individuals HR is often used as a physiological objective variable, directly associated with oxygen consumption, though the association between EE and HR can be influenced by other factors.[13] Moreover HR does not present a good accuracy in estimating EE of individuals with high physical activity levels. The use of both methods combined may provide more accurate measures of EE.[14] A monitor combining HR and accelerometry into a single device has been developed[14] and validated,[15,16] though its validity in very active individuals has not been examined.

The aim of our investigation was to assess the validity of a combined HR and motion sensor in estimating free-living TEE and AEE in very active males and females using DLW as the reference method.

2. Methods

Twelve male and 12 female basketball players from the Portuguese Junior National Team volunteered to participate, however only 12 participants had valid records of the combined HR and motion sensor, therefore 4 males (2 guards and 2 forwards) and 8 females (2 guards, 4 forwards and 2 centres) were used in this study. Therefore, 8 males and 4 females were excluded for not having valid records of the combined monitor.

Energy expenditure of the participants was evaluated at the first or second week of the pre-season training period (September) during a 7-day period. The players lived and trained at the National High-Performance Center during the week days. At the end of the week athletes went to their homes and trained with their respective teams on Friday and Saturday. On Sunday afternoon the athletes came back to the training centre. The male and female training regimens while in the training centre consisted of 4 technical-tactical 120 min sessions (1/day), and resistance training for 60 min two times during the week. In addition players participated in one training game in the middle of the week. Apart from the training regimens, athletes went to school every week day and had two 90 min physical education classes during the period of assessment.

Inclusion criteria were: (1) Tanner stage V; (2) ≥10 h training/week; (3) negative test outcomes for performance-enhancing drugs; and (4) not taking any medications or dietary supplements. No females were taking oral contraceptives. Medical screening indicated that all subjects were in good health, without endocrine abnormalities that would limit their participation in the study. All subjects and guardians were informed about the possible risks of the investigation before giving written informed consent to participate. All procedures were approved by the Ethics Committee of the Faculty of Human Kinetics, Technical University of Lisbon, and conducted according to the declaration of Helsinki for human studies of the World Medical Association.

Subjects came to the laboratory in a 12 h fasted state and consumed a normal evening meal the night before testing. Vigorous exercise was not allowed for at least 14 h and caffeine, alcohol or stimulant beverages for at least 24-h before testing began at 08:00 a.m.

Body weight and height were measured to the nearest 0.01 kg and 0.1 cm. Dual energy X-ray absorptiometry (Hologic Explorer-W, software QDR for Windows v.12.4, Waltham, Massachusetts, USA) was used to estimate fat mass (FM) and fat-free mass (FFM).[17] Hologic fan-beam densitometers provide valid body composition estimates in athletes.[18] The coefficient of variation (CV) in our laboratory, based on 10 young active adults (five males and five females) for FM and FFM are 1.7% and 0.8%, respectively.[19]

Resting energy expenditure (REE) measurements were performed by an open-circuit indirect calorimetry through a portable gas analyser (K4b$_2$, Cosmed, Rome, Italy) while participants were lied supine wearing a with a face mask for data collection, as described elsewhere.[7] For data analysis a steady state was defined as a 5-min period with a CV below 10% for $\dot{V}O_2$ and for $\dot{V}CO_2$.[20] The mean $\dot{V}O_2$ and $\dot{V}CO_2$ of a 5-min steady states were used in Weir equation[21] and the period with the lowest REE was considered. The CV for REE in our laboratory is 10%.

Total energy expenditure was measured during a 7-day period by an established procedure using deuterium oxide and 18-oxygen. An oral dose of 0.8 g/kg of total-body water (TBW) of ≈10 atom% (AP) $H_2{}^{18}O$ (Taiyo Nippon Sanso Corporation, Tokyo, Japan), assuming TBW is 61% of body mass, and 0.16 g/kg of TBW of 99.9 AP ^2H_2O (Sigma–Aldrich, Co, St Louis, MO, USA), diluted in 50 ml of water was administered to the subjects. The analytical procedures used to estimate TEE are described elsewhere.[7] The CV for TEE is 4.3%. AEE was calculated as TEE − RMR − 0.1 × TEE, assuming the thermic effect of food is ∼10% of TEE) and physical activity level (PAL) was determined as TEE/REE.

Energy expenditure simultaneously also evaluated with combined HR and motion sensor (Actiheart, Cambridge Neurotechnology Ltd, Cambridge, UK). The monitor was worn using ECG pads on the chest during the same 7-day period that the DLW assessment took place. Participants performed an 8-min step-test (height: 215 mm), the stepping speed ramps linearly increased from 15 to 33 step cycles/min, providing individual HR–EE relationship calibration. From the individual step-test calibration estimated VO_{2max} was derived by the software. The device was started with 60-s epochs and participants were asked to wear the monitor at all times (even during sleep hours) for the 7-consecutive days the DLW assessment were taking place. Data from the monitors were downloaded into to the commercial software (v.4.0.46). The software algorithm allowed data cleaning, recovering, and interpolation of missing and noisy HR. Only participants with 3-valid days were considered for data analysis. A valid day was considered when we had at least 70% of the day (1008 min) with records and not more than 10% of the registered timed with HR recovered by the software. Moreover, if the participants had invalid data during the training hours (registered in a diary) the day was not considered valid. AEE was estimated using energy models, available in the commercial software:

$ACC + HR_{step}$: individual HR calibration model (Group CalJAP2007/Step HR[22]), with HR and accelerometry data;
$ACC + HR_{group}$: group HR calibration model (Group CalJAP2007[22]) with HR and accelerometry data;
HR_{flex}: individual HR calibration model (Group CalJAP2007/Step HR[22]), with HR data;
ACC: accelerometry data.[22]

TEE was estimated adding to the estimated AEE, the thermic effect of food (∼10% of TEE) and REE using the Schofield equation,[23] as suggested by the manufacturer.

Maximal oxygen consumption (VO_{2max}) measurement was performed with a continuous, progressive treadmill running protocol in a laboratory (21–22 °C, relative humidity of 50%). Following a 2-min warm-up (males: 0% grade; 7 km/h speed; females: 0% grade; 6 km/h speed), subjects ran for 2-min (males: 0% grade; 9 km/h speed; males: 0% grade; 8 km/h speed). Speed and grade