Assessment of free-living energy expenditure

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Introduction

Measurement and understanding of energy expenditure (EE) is important for many applications, such as researchers trying to characterise an intervention, or practitioners/clinicians attempting to establish energy demands of an athlete or patient. As one half of the energy balance equation, energy expenditure plays a critical part in both the short-term regulation of physiology and the longer-term regulation of energy balance, ultimately determining body mass and composition.

The three main components of energy expenditure comprise:

Resting Metabolic Rate (RMR), which is the largest single component of EE in most individuals and is the energy required by the body at rest. RMR can be assessed using laboratory methods for the determination of EE (see Compher et al 2006 for considerations). However, in most cases, RMR is estimated using prediction equations commonly based on sex, age, height and mass. Specific equations may be required, as accuracy can be population-dependent (Bedogni et al 2019).

Diet-Induced Thermogenesis (DIT), which represents increased expenditure above RMR due to food intake and is the smallest component of EE. In free-living contexts, DIT is commonly assumed to be 10% of energy intake (or expenditure, if an individual is in energy balance) (Westerterp 2004).

Physical Activity Energy Expenditure (PAEE), which is expenditure above rest associated with bodily movement and is the most malleable component of EE. Inter-individual differences can be considerable due to variation in physical activity behaviour (see Physical Activity chapter for details) and, thus, this Chapter will specifically focus on categories of methods for assessing PAEE as the most variable sub-component of EE.

Methods for assessing PAEE

Due to the rapid evolution of technologies and large volume of measurement devices, this section will consider general principles and guidance relating to broad approaches for determining PAEE in ambulatory adults. Historically, measurement of PAEE was often based upon various self-report measures, but these instruments are constrained to ranking of individuals at best. Individuals tend to over-report PAEE, with the degree also varying dependent upon participant characteristics, resulting in systematic and random errors. As such, these instruments have extremely limited use for determining absolute EE or PAEE (see Dhurandhar et al 2015 for critique). Therefore, subsequent focus will predominantly be on device-based measures of EE/PAEE.

Doubly labelled water (DLW): DLW is widely considered the “gold standard” measure of free-living EE and often used for method validation. DLW relies upon measurement of labelled isotope elimination as a way of determining carbon dioxide production (and, indirectly, metabolic rate). Access to DLW is limited because specialised centres are needed to analyse samples, and cost is prohibitive for many applications. If the objective is the most accurate assessment of total EE during a free-living period (e.g., 7-14 days), and budget is not a consideration, DLW is the best choice. However, DLW is not perfect, a key limitation being despite accurate *total* EE estimation (PAEE is derived by subtracting RMR and DIT), DLW provides no information on the intensities or distributions of physical activity (see Westerterp 2017 for DLW overview).

Heart rate monitors: The use of heart rate (HR) is based upon the relatively linear relationship between HR and EE in most individuals and is relatively accessible. Accuracy of EE estimation from HR is best during moderate to high intensity activity, and on an individual level is improved with calibration of the HR-EE relationship around the Flex-HR concept that uses a threshold HR to differentiate between separate "resting" and "active" HR-EE relationships (Leonard 2003).

Accelerometers: Accelerometers can be used to convert movement "counts" to PAEE estimates using various (potentially proprietary) models specific to devices/populations. Some devices have been validated against DLW in adults (White et al 2016, 2019). Accelerometers were historically hip/waist mounted but are increasingly worn at other locations (e.g., wrist). Accelerometers are inexpensive, generally easy to use, and often the device of choice for small to medium size research studies.

Combined devices: Due to theoretically independent limitations associated with accelerometry (e.g., specific activities not generating acceleration) and HR (e.g., values changing due to confounding factors such as stress), the combination of these measurements has been suggested. This technique requires mathematical modelling to balance estimation between accelerometry or HR based on pre-determined criteria (Brage et al 2004). Such combined instruments are commercially-available but practitioners could, in principle, develop their own approach using a carefully synchronised HR monitor and accelerometer. This is an area of innovation, particularly within the commercial sector, and new devices are drawing on other (combined) physiological measures to try and improve estimation of PAEE.

Consumer devices: In applied settings, practitioners are likely to encounter many different consumer devices, often marketed with an array of sensors. These devices are also increasingly utilised in research settings, with some blurring of the lines between "research" and "consumer" devices. As a note of caution, the precise methodology is usually proprietary and, due to the pace of product development, independent validation is often unavailable. While these commercial devices to date do not seem to match estimates of EE from research devices (O'Driscoll et al 2020), they are often affordable for practitioners. Some devices provide reasonable estimates that may be useful for observing behaviour changes, but users should be aware of potentially large variation between devices (Chowdhury et al 2017).

Expression of energy expenditure data

Depending on the application, the most straightforward expression of EE is total kilojoules or kilocalories expended ("calories" to lay individuals). However, users should consider that body size substantially influences total EE estimates, so benchmarking between individuals is often advisable using normalised data. A common method of normalisation is to use Physical Activity Level (PAL), which represents total EE (DIT+RMR+PAEE) divided by RMR, giving comparability across individuals (Figure 1). PAL could theoretically be as low as 1.10 in a bed-bound individual, with most individuals falling between 1.40 and 2.00 (see FAO/WHO/UNU 2004 for population benchmarks). In extremely active individuals (e.g., athletes) the greatest *sustainable* EE is represented by a PAL of ~2.5, due to the corresponding limit on energy intake (Thurber et al, 2019), but PAL may be much higher for short periods.

Considerations for application

From a pragmatic perspective, the choice of EE measure is likely to be determined by logistical restrictions. Researchers are likely to have more options than practitioners, but some underlying principles apply across all settings. Potential users should consider the necessary monitoring duration to achieve desired objectives for daily wear time (illustration in Physical Activity chapter), and number and nature (weekday/weekend) of representative measurement days (Scheers et al 2012). Practitioners should bear in mind that, while many approaches produce reasonable group-level EE estimates often sufficient for research interventions (see Dowd et al 2018 for a comprehensive performance overview of validity and reliability of techniques), and are deemed "validated" on that basis, caution is advised in attempting to provide individual-level information (e.g., exact dietary prescription). All methods struggle to provide highly accurate and precise individual-level estimates of EE, even the "gold standard" measure of DLW, where discrepancy to indirect calorimetry can be up to ~20% for an individual (Melanson et al 2018). Practitioners working in specific populations (i.e., clinical, paediatric etc.) should establish methods as valid and appropriate for their context. Users may decide that, whilst accurate EE estimates might be desired, the reproducibility of measures is more important to monitor or track changes over time. In this scenario, devices with poorer accuracy could be used if measurements are reproducible, but users should bear in mind that absolute estimates of PAEE are unlikely to be 'true' and some behaviours will have been (systematically) over- or under-recorded due to variability in measurement accuracy for different activities (Chowdhury et al 2017).

As technology develops, the volume and sophistication of options is likely to increase, and researchers and practitioners alike will have opportunities (and challenges) to make the most appropriate choices to capitalise on the many benefits from the measurement of energy expenditure.

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Figure 1. Illustration of the possible relative contribution and variability of Physical Activity Energy Expenditure.

An example individual with an RMR of 1500 kcal/d and a wide range of theoretical physical activity energy expenditures (PAEE). The PAL values represent an extremely sedentary lifestyle that may be related to a movement limiting pathology (1.2), a low active lifestyle (1.6), the lower boundary of a highly active lifestyle (2.0) and reaching the upper limit of a sustainable lifestyle (2.4). It should be noted that the majority of the population falls within a PAL range of 1.4-2.0. DIT has been assumed at 10% of TEE.

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