

Perceived exertion and metabolic cost during progressive and randomized walking protocols

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Abstract

The objective of the study was to ascertain whether selected physiological responses and the perception of effort varied during four different walk protocols where speed increased progressively 3, 4, 5, 6, and 7 km.hr⁻¹ (progressive treadmill walk (PTW); and progressive land walk (PLW); or where the participant adjusted to random changes of speed e.g. 6, 4, 7, 3, and 5 km.hr⁻¹ during a randomized treadmill walk (RTW); and a randomized land walk (RLW). Mean stature and mass of the seven participants was 1.75m and 70kg respectively, with a mean body fat of 15%. Metabolic measures included heart rate, relative oxygen uptake, ventilation, respiration frequency, which increased in a linear fashion up to 6 km.hr⁻¹, however at 7 km.hr⁻¹ there was a significant increase in metabolic response notably during the PLW, and to a similar, although lesser extent in RLW, probably as a consequence of the loss of kinetic energy when turning at each cone in order to maintain the speed during each shuttle. Respiration frequency appeared to be a more sensitive indicator of physical exertion, exhibiting a rapid elevation at 6 km.hr⁻¹. The perception of effort during each mode and at each speed was largely congruent during each walk protocol.

Keywords: Walking, ratings of perceived exertion, metabolic, progressive and random.

1 Introduction

Whilst many people take for granted the ability to walk, it is in fact a complex ambulatory movement that has been famously described as “a series of catastrophes narrowly averted” (Steindlar, 1955). There has been a substantial amount of research, notably the early work by Cavagna and associates that sought to understand human gait, and this included studies on the mechanics of walking, in terms of the interactions that occur between the body and the ground, which are responsible for the kinetic and potential energy changes that account for a large fraction of the mechanical work that the muscles must do to undertake locomotion (Cavagna et al., 1963; Cavagna & Margaria, 1966; Cavagna et al., 1976). Other walking studies have investigated the effect and influence of stature, mass, age, gender, along with cognitive and perceptual

parameters, in both normal and hemiplegic subjects (Turnbull, 1993; Samson et al., 2001; Shkuratova et al., 2004; Woollacott and Shumway-Cook., 2002).

According to Lejeune et al. (1988) the mechanics and energetics of locomotion have been thoroughly investigated predominantly in the laboratory on hard, level, non-slippery surfaces. These include the work of researchers such as Cotes and Meade (1960) and Giovoni and Goldman (1971). However, Lejeune makes the assertion that these surfaces bear little resemblance to those actually occurring in nature, which prompted studies on surfaces of varying compliance and hardness, for example sand (Davies & MacKinnon, 2006) and snow (Heinonen et al., 1959), while other researchers focused on the effects of footwear during walking (Jones et al., 1984; Jones et al., 1986). However, there appears to be a lack of research that has sought to better understand the perceptual and physiological experience of randomized variations in walking speed, arguably more typical of an individual's walking pattern during a normal day. Therefore this study investigated the effects of walking protocols that are characterized by progressive and incremental increases in speed (on a hard and level walk surface and on a treadmill) and compare these with those that are characterized by randomized changes in speed (on a hard and level walking surface and on a treadmill). It is contended that selected walking speeds during habitual daily activities are not progressive, incremental or constant, but rather a sequence of randomly assigned phases of acceleration and deceleration. Thus the paucity of research into randomized walking speeds when compared to incremental and progressive walk protocols (archetypal of laboratory based tests) formed the primary focus for this paper.

2 Methods

The seven participants included three males and four females. Body mass and stature were recorded. Skinfold thickness was recorded to the nearest 0.1mm using a Harpenden caliper (British Indicator HSC Body 918760, United Kingdom). Skinfolds from four sites (suprailiac, abdominal, thigh, tricep) on the right hand side of the body were substituted into an equation to predict percent body fat (Brozek *et al.* 1963).

Participants were required to walk at speeds of 3, 4, 5, 6 and 7 km per hour during the two walk conditions that were both incremental and progressive, namely the progressive treadmill walk (PTW); and the progressive land walk (PLW); whilst the other two walk conditions, which included the randomized treadmill walk (RTW); and the randomized land walk (RLW) required the subjects to respond to random alterations in walk speed, for example 6, 4, 7, 3, and 5 km.hr⁻¹ (please note that each randomized walk condition was different)

The progressive modulations in walking speed employed in this study were developed by Davies (1999) and Davies & MacKinnon (2006). The notion of using a shuttle type walk protocol was premised on the principles developed by Leger et al. (1988) for the 20 m shuttle run test, which is a predictive test of aerobic capacity. In the present study, the walk protocol entailed the participants being required to walk between two markers in a time of 8 seconds. The time to walk between the markers remained constant at 8 seconds, while each increase in walking speed was accompanied by an increase in the distance between the markers. Therefore, the initial walk speed of 3 km.hr⁻¹ required the participants to walk in a straight line between two markers over a distance of 6.75 m in

8 seconds and then back and forth between the two markers. Each subsequent increase in walking speed (4, 5, 6 and 7 km/h) was achieved by lengthening the distance between the markers (see Figure 1).

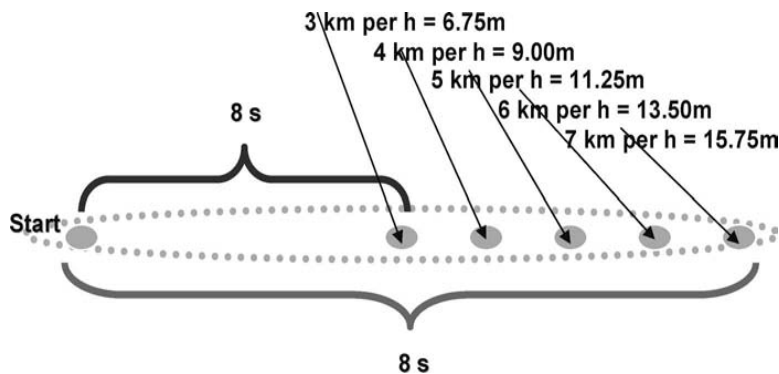


Figure 1. Schematic representation of the walk protocol

Physiological parameters measured included heart rate measured at 5 second intervals by a Polar heart rate monitor (Polar Electro Oy, Kempele, Finland), while O₂ uptake, CO₂ exhalation, ventilation (VE) and relative O₂ uptake were sampled every 10 s and determined by a gas analyzer (COSMED Quark b², Italy) and treadmill walk protocols were performed on a Technogym® Runrace treadmill. Before each test gas analyzers were calibrated with gas mixtures of known concentrations.

Perceptions of effort during the four walk protocols were provided by the participants indicating their Rating of Perceived Exertion (RPE) according to the 15-point Borg scale (1998). Participants were informed about the purpose of the Borg scale, and the meaning of the verbal anchors that correlate with numerical indications of efforts e.g. light, hard etc. The participants were asked to indicate their perception of effort via the RPE scale twice during the final minute of walking at the prescribed speed (when the subject was exhibiting steady state metabolic response).

Although data were recorded continuously at each speed level, only data collected during physiological steady states, as evidenced by oxygen uptake and heart rate were statistically analysed. Thus, at each speed level, (3, 4, 5, 6 and 7 km.hr⁻¹) and in each compared condition (Progressive Treadmill Walk - PTW, Progressive Land Walk - PLW, Randomized Land Walk - RLW, Randomized Treadmill Walk - RTW), the data capture for statistical purposes was typically representative of steady state physiological data, collected in the latter stages of the speed level. Once 3 minutes of steady state data had been collected, the participant was required to increase and/or adjust walking speed to the next speed level, whereupon data were analyzed for statistical comparison when the participants achieved a steady rate condition. This process was repeated at each speed level, in the four differing test conditions and was concluded when the participants had completed walking at each speed level i.e. 3, 4, 5, 6, and 7 km.hr⁻¹ (whether it was progressive or randomized sequence of speed changes).

It should be noted that a limitation of the study was the relatively small number of participants whose data could be utilized for analysis. This was due to technical problems with metabolic equipment, along with some participants not completing all four protocols correctly (in accordance with the methodology). Thus the data trends are described in terms of the collective responses per speed modulation per walk mode and subjected to descriptive statistical analysis and Repeated Measures Analysis of Variance.

3 Results

The mean stature and mass of the seven participants (both male and female) was 1.75 m and 75kg respectively, with a mean body fat of 15%.

3.1 Heart rate response

The progressive land walk (PLW) elicited a significantly ($p < 0.05$) lower heart rate response at 3 km.hr⁻¹ when compared to the PTW, RLW and RTW; this trend was also apparent at 4 km.hr⁻¹ with a significantly lower heart rate during PLW when compared to PTW. During speed modulations of 5 km.hr⁻¹ and 6 km.hr⁻¹ the heart rate responses were similar in all walk modes, however at 7 km.hr⁻¹ the PLW elicited the highest mean heart rate at 170 beats/minute (bpm), while the RTW elicited the lowest heart rate at 141 bpm. This difference between PLW and RTW was significant as well as between PTW and RTW; along with RTW with RLW (See Figure 2).

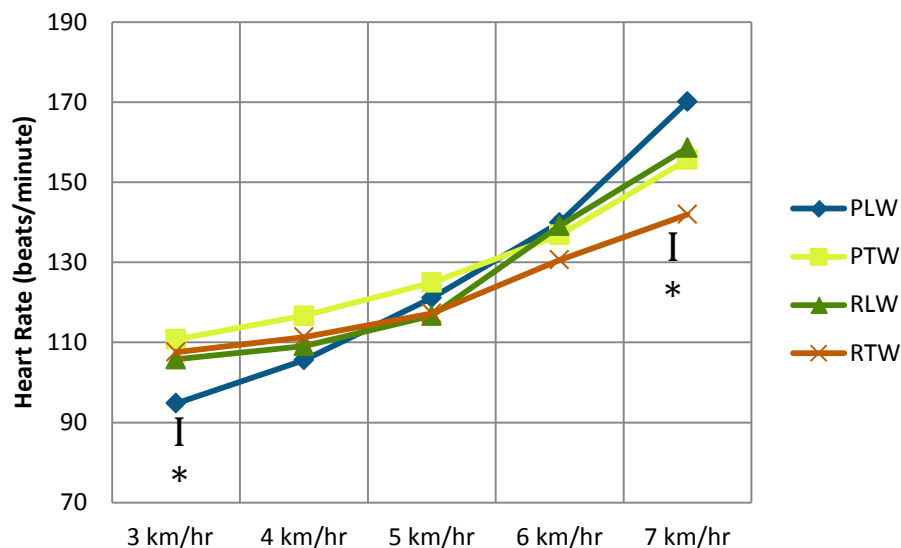


Figure 2. Heart rate responses at various walking speeds during the four experimental conditions (* = $P < 0.05$).

3.2 Relative oxygen consumption

While the PTW elicited relatively higher relative oxygen uptake, this was not unexpected as this often happens during exercise on a treadmill, especially in the earlier phase of the test (see Figure 3). However, at walk speeds of 4, 5 and 6 km.hr⁻¹ there was

a consistent linear increase in relative oxygen uptake in each of the four modes, with PTW continuing to be slightly elevated. It is noteworthy that at 7 km.hr⁻¹ the progressive land walk (PLW), which includes the most pronounced phases of acceleration, deceleration due to turning at each cone elicited significantly ($p<0.05$) higher relative oxygen uptake compared with PTW, RLW and RTW.

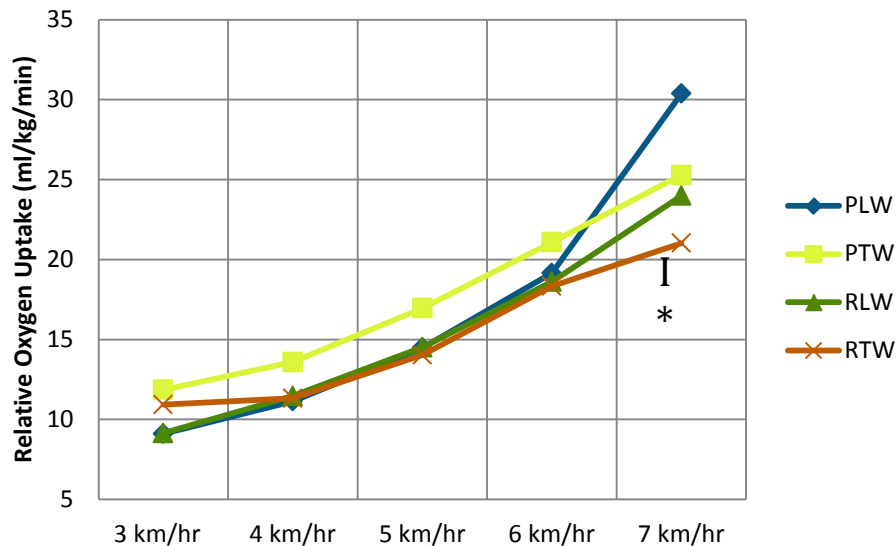


Figure 3. Relative oxygen uptake for all experimental conditions at different speeds (* = $P<0.05$).

3.3 Ventilation (VE)

The ventilation (VE) responses (see Figure 4) follow a similar trend to the relative oxygen uptake, with significant difference between PLW with RLW and RTW at 3 km.hr⁻¹. What was most obvious again were the elevated scores during the progressive land walk (PLW) and random land walk (RLW) at 7 km.hr⁻¹, which appear to be the result of the shuttle type protocol involving increasing phases of acceleration and deceleration at each cone.

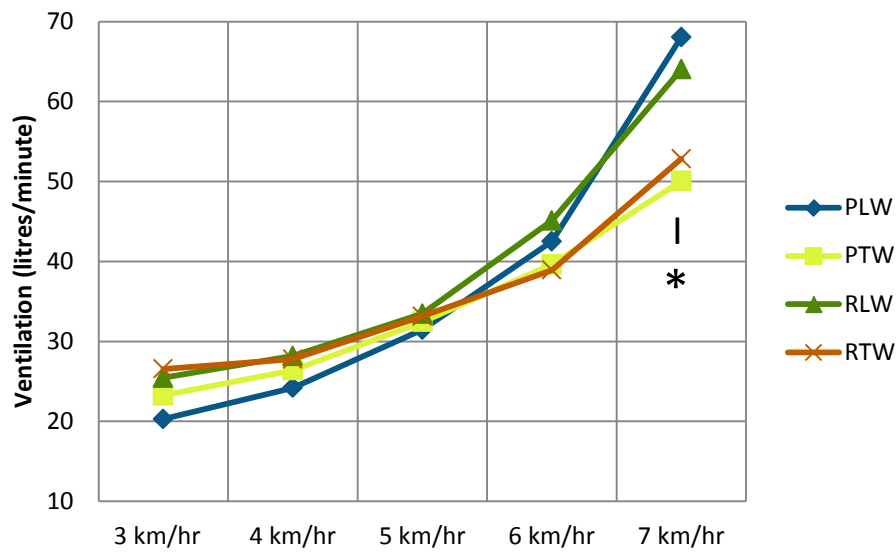


Figure 4. Ventilation (VE): total volume of inspired air for all experimental conditions at different speeds (* = $P < 0.05$).

3.4 Respiration frequency (Rf)

The metabolic measures also included respiration frequency (Rf) (see Figure 5). Whilst the responses by participants in the four walking modes are similar at 3 and 4 $\text{km}\cdot\text{hr}^{-1}$, it is interesting to observe that at 5 $\text{km}\cdot\text{hr}^{-1}$ the PLW elicits a significantly stronger breathing frequency response. At 6 $\text{km}\cdot\text{hr}^{-1}$ both shuttle walk modes (PLW and RLW) are characterized by significantly faster breathing frequencies when compared to the treadmill modes (PTW and RTW); this trend is continued at 7 $\text{km}\cdot\text{hr}^{-1}$ for both land shuttle walk modes PLW and RLW, resulting in the highest breaths per minute at 38.4 and 37.2 respectively. These values were significantly higher than those obtained from the treadmill modes of walking (PTW and RTW).

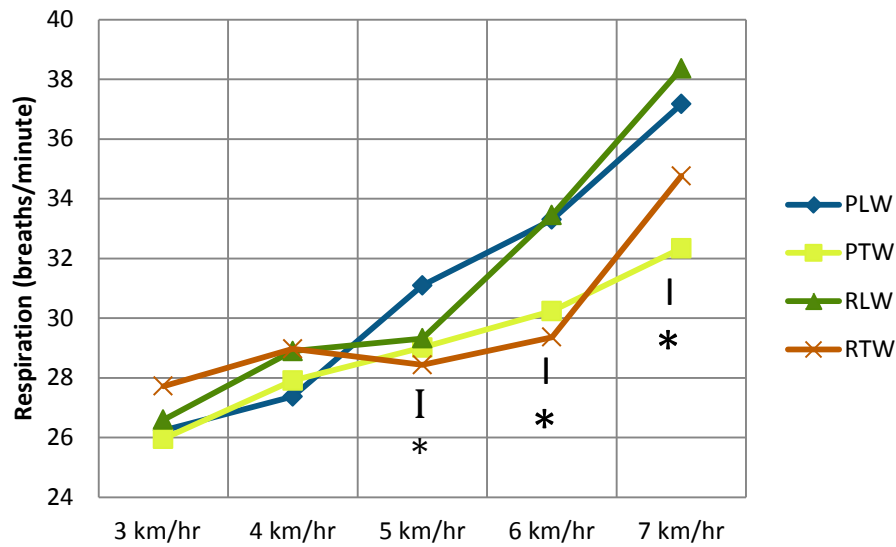


Figure 5. Respiration frequency (Rf) for all experimental conditions at different speeds (* = $P < 0.05$).

3.5 Ratings of perceived exertion (RPE)

The perception of exertion (RPE) (see Figure 6) during each mode and at each speed increased in a generally linear fashion with little variation between walk modes, although there was some variance during the random walk protocols, as the participants adjusted to unexpected walk speeds. The results illustrate that the perception of effort was consistently highest during the PTW, followed by PLW.

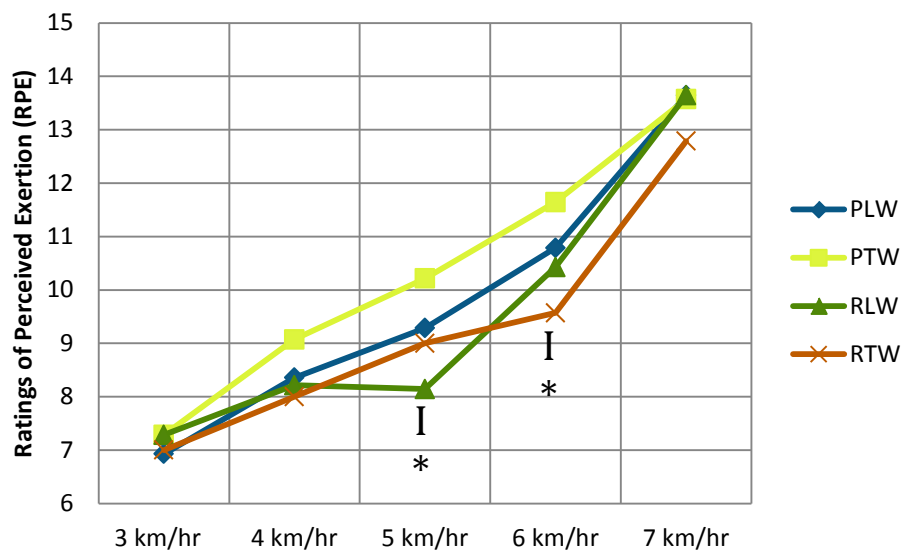


Figure 6. Ratings of Perceived Exertion (RPE) for all experimental conditions at different speeds (* = $P < 0.05$).

4 Discussion

The results from this study provide some interesting insights into the effects that differing walking protocols have on a person's physical perceptions and metabolic responses. It is generally accepted that most physical tests that seek to ascertain fitness and/or aerobic performance are progressive and incremental in nature. There is an underlying assumption however, that as long as one walks and/or runs at a certain constant speed for at least 3-4 minutes that a physiological steady rate will be typically achieved, for example regular heart rate, irrespective of whether one assigns these speeds progressively or randomly (McArdle et al., 1991). In other words, if one walks at 5 km.hr⁻¹ for 3-4 minutes then the metabolic stress experienced and associated perception of effort will be invariable the same, whether the participant arrived at this speed by progressive increments e.g. 3, 4, and then 5 km.hr⁻¹, or whether they had walked at speeds in a random sequence e.g. 6, 3 and the 5 km.hr⁻¹.

In this study four walk protocols were employed, namely progressive treadmill walk (PTW), progressive land walk (PLW), randomized treadmill walk (RTW), along with a randomized land walk (RLW). In overall terms the perceptual and metabolic responses were largely congruent up to 6 km.hr⁻¹ demonstrating a largely steady linear increase, with the exception of respiration frequency (Rf). It was clear that Rf at 5km.hr⁻¹, as well as 6 km.hr⁻¹ and 7 km.hr⁻¹ demonstrated a substantive divergence between the land walk protocols (both progressive and random) compared with the treadmill protocols (progressive and random). Previous research that investigated breathlessness and exercise suggests that this response may provide a more immediate indicator of physical strain than other metabolic responses, such as heart rate and oxygen uptake (Davies, 1997). It is therefore of interest to exercise physiologists and ergonomists that breathing frequency appears to provide the best real-time gauge of physiological response during exercise and/or physical work of an aerobic nature, furthermore because the perception of breathlessness is generally more easily understood, it may also act as a more accurate perceptual tool during exercise testing.

It has been previously reported that treadmill walking and running is likely to induce higher metabolic responses when compared to the same ambulatory locomotion performed on land (Wall & Charteris, 1981; Olivier, 1988) and this trend was reflected in the present study, and may be indicative of habituation issues; this is because for some individuals the experience of walking and/or running on a treadmill may be perceived to be unusual and artificial, and may induce an elevated physiological response.

Interestingly the most distinctive and elevated physiological and respiratory responses were evidenced during the later phases of the two land walk protocols (PLW and RLW); it is tentatively speculated that this may be due to the increases in acceleration and deceleration phases in the shuttle walk protocols and the loss of kinetic energy when turning at each cone and an increase in energy expenditure in order to maintain the speed. Unlike a typical walk or run exercise test for aerobic capacity and/or aerobic prediction (VO₂ max), especially on treadmills, which are typically characterised by progressive and incremental increases in speed, the shuttle type protocols, including the multi-stage 20 m shuttle run test for aerobic fitness test (Leger et al. 1988) require

individuals to make rapid and repeated changes in direction. Previous work by Davies & MacKinnon (2006) observed that the walk shuttle methodology has an increasingly pronounced effect on physiological response at speeds of 6 km.hr^{-1} and faster. It appears that the increased loss of kinetic energy during the deceleration phase at higher walk speeds, requires the participant to compensate for this during the acceleration phase, thus engaging the anaerobic systems earlier, and placing additional physiological strain in order to maintain overall walk speed. Furthermore, especially during the progressive land walk protocols; there is an accumulative effect and increasing need for participants to compensate at each higher walk speed for loss of kinetic energy at each turn. This loss of kinetic energy is likely to manifest in a more pronounced physiological response, notably the rapid escalation in respiratory response, followed by increased oxygen uptake and elevated heart rate. The differential in physiological response between the land walk protocols that employed a shuttle methodology compared with the treadmill protocols was most clearly evidenced at a walk speed of 7 km.hr^{-1} when analyzing the heart rate, relative oxygen uptake, ventilation, respiratory frequency and perceptual responses (see Figures 2, 3, 4, 5 and 6).

5 Conclusions

In general terms it appears that irrespective of the walking protocol employed, namely Progressive Land Walk (PLW), Progressive Treadmill Walk (PTW), Randomized Land Walk (RLW) and Randomized Treadmill Walk (RTW) the metabolic responses and the perceptions of effort (RPE) followed a typical increasing linear trend that is typically associated with variations in walk speed and each variable was largely similar, irrespective of walking mode at speeds of 3, 4, 5 and 6 km.hr^{-1} .

There were some variations that warrant a mention, in as much that the progressive land walk (PLW) generally elicited a generally lower physiological and perceptual response than the other modes at the initial walk speed of 3 km.hr^{-1} . It is suggested that this was because this particular mode of walking was the most 'normal' and 'familiar' to the participants, thus they walked with less inhibition, when compared to the treadmill and randomized walk speed protocols.

However, in contrast at the 7 km.hr^{-1} condition, the two land walking modes (PLW and RLW) which utilized a shuttle walk methodology exhibited significantly higher physiological and respiratory responses (heart rate, oxygen uptake, ventilation, and respiration frequency). It is suggested that this significant elevation of physiological and respiratory responses during the land walk modes can be attributed to the increases in acceleration and deceleration phases during the shuttle walk protocols and the loss of kinetic energy when turning at each cone and an associated increase in energy expenditure in order to maintain the speed.

Another relevant finding was that respiratory frequency (Rf) provided some interesting insights during testing. Firstly it would appear that respiration frequency provides a primary and more immediate indicator of exertion during walking. This was evident in the elevated respiratory frequency response at a walk speed of 5 and 6 km.hr^{-1} during the progressive land walk protocol, when compared to oxygen uptake and heart rate response. It is tentatively suggested that respiration frequency may be a more sensitive indicator of exertion, and appears to have been an early indicator of elevations in

metabolic cost (heart rate, oxygen uptake and ventilation) as well as RPE that would manifest at 7 km.hr⁻¹.

It is recommended that additional research is undertaken with larger study sample, and greater focus placed on improved kinematics and biomechanical analysis during shuttle walk/run methodologies, characterized by repeated phases of deceleration and acceleration in shuttle walk and/or run exercise protocols.

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