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Superior Running Economy in Obese Compared to Normal-  
Weight Males at Metabolically Comparable Work Rates.

A thesis presented in fulfilment of the requirements for the  
degree of

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James Andrew Stewart

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## Abbreviations

AT – Anaerobic Threshold

%BF - body fat percentage

BLa – Blood Lactate Accumulation

BMI - body mass index

CRF – Cardiorespiratory Fitness

CVD – Cardiovascular Disease

EE – Exercise Economy

FFM - Fat free mass

GET – Gas exchange threshold

GXT- graded exercise test

HDL – high density lipoprotein cholesterol

HR – Heart rate

HRmax – maximum heart rate

LT – Lactate Threshold

NWU- Normal Weight Unfit

OB - Obese

OBF – Obese Fit

RE – Running Economy

RPE - ratings of perceived exertion

TC - total cholesterol

$\dot{V}O_2$  - oxygen consumption

$\dot{V}O_{2peak}$  - peak oxygen consumption (85% HRmax in GXT)

$\dot{V}O_{2max}$  - maximal oxygen consumption

% $\dot{V}O_2$  - percent of  $\dot{V}O_2$  in proportion to maximal value

$\dot{V}_E$  - Minute ventilation

VT - ventilatory threshold

40%  $\Delta$  - 40% of the difference between VT and  $\dot{V}O_{2peak}$

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## Abstract

**Introduction:** During weight bearing physical activities such as walking or running, obese individuals generally expend more total energy than their lighter counterparts. Running economy (RE) is an important physiological measure in the sports performance field and is defined as the aerobic capacity per kilogram of body mass required to sustain a given submaximal running speed. RE can also help us assess how other individuals would cope with a certain intensity of activity. Superior RE is seen in elite endurance athletes by using less oxygen per kilogram of body mass at a given speed. Fit/trained individuals display a superior RE compared to unfit/untrained individuals. Normal weight subjects have previously been shown to display a superior RE than obese individuals; furthermore, low cardiorespiratory fitness (CRF) is an important reversible cardiovascular disease risk factor, while obesity is a major risk factor for non-communicable diseases. Although RE has previously been assessed at absolute exercise intensities to compare between groups, (i.e. obese vs. normal weight) individuals exercise at a metabolic rate that is scaled to body size and relativised for fitness level. **Purpose:** To assess RE and the physiological responses of normal weight-unfit (NWU) and obese-fit (OBF) adult males during treadmill running when relative exercise intensities are selected. It was hypothesised that the RE of OBF would be superior to that observed for NWU. **Methods:** Healthy NWU ( $n = 12$ ,  $38.2 \pm 9.1$  yrs,  $77.3 \pm 6.4$  kg,  $24.0 \pm 1.3$  kg·m<sup>-2</sup>) and OBF ( $n = 11$ ,  $38.5 \pm 6.0$  yrs,  $103.8 \pm 8.0$  kg,  $33.3 \pm 2.2$  kg·m<sup>-2</sup>) volunteered for the study. Following risk stratification assessment for coronary artery disease and a treadmill walking ECG, participants completed two laboratory based tests. Participants firstly completed a submaximal incremental graded exercise test up to 85% HR<sub>max</sub> (age predicted) on a treadmill. Individual linear regression analysis was then used to predict maximal aerobic power ( $\dot{V}O_{2max}$ ) for each participant. Following a minimum 72 hour recovery period, participants then completed a further test at two independent intensities: ventilatory threshold (VT) and 40% delta ( $\Delta$ ) as identified from the GXT. Each independent intensity was sustained for 6 minutes duration, separated by 5 minutes of standing recovery. Physiological markers (Heart Rate [HR], oxygen uptake [ $\dot{V}O_2$ ], minute ventilation [ $\dot{V}_E$ ] and respiratory exchange ratio [RER]) were continuously monitored, while the ratings of perceived exertion (RPE) and stride rate were recorded at 3 minutes and at the completion of each exercise stage. **Results:** OBF elicited a significantly higher running speed at VT ( $8.5$  vs.  $7.6$  km·h<sup>-1</sup>;  $P < 0.01$ ) and at 40%  $\Delta$  ( $10.1$  vs.  $8.8$  km·h<sup>-1</sup>;  $P < 0.01$ ) compared to NWU

respectively. OBF displayed a significantly superior (lower) RE ( $210.7 \pm 8.0$  vs.  $253.2 \pm 7.6$  mL·kg<sup>-1</sup>·km<sup>-1</sup>;  $P = 0.001$ ), than in NWU respectively. No significant differences were observed between VT and 40%  $\Delta$  ( $P > 0.05$ ). When RE was assessed relative to fat free mass (FFM), no differences were found between OBF and NWU ( $P > 0.05$ ). However, a significant difference in RE was observed at VT compared to 40%  $\Delta$  ( $322.3 \pm 7.3$  &  $368.8 \pm 8.9$  mL·FFM<sup>-1</sup>·km<sup>-1</sup>, respectively;  $P < 0.001$ ). **Conclusion:** Despite running at a faster speed, fit and obese individuals displayed a superior running economy compared to normal weight unfit individuals during treadmill running at relative moderate and heavy exercise intensities when expressed as mL·kg<sup>-1</sup>·km<sup>-1</sup>. When expressed relative to fat free mass (mL·FFM<sup>-1</sup>·km<sup>-1</sup>) no differences in RE were observed between groups. Fitness and training status rather than weight status may be more of an important moderating factor when examining differences in RE between individuals. The proposed mechanisms for the results remain unclear. It is acknowledged that greater subject numbers including obese unfit and normal weight fit would have allowed for a more valid interpretation of the present findings. From a public health perspective these results indicate that increasing physical activity and fitness level should be a priority for adults engaging in an exercise programme more so than weight loss, as superior economy could reduce the relative level of physical exertion during everyday tasks.

## 1. Introduction

Regular aerobic exercise enhances Cardiorespiratory Fitness (CRF) by making the systems that deliver oxygen to the working muscles more efficient and powerful. (Pollock et al., 1998). Maximal oxygen uptake ( $\dot{V}O_{2max}$ ) is used to determine an individual's maximal aerobic power and is seen as an important predictor of endurance exercise performance (Bassett & Howley, 2000; Joyner & Coyle, 2008). Three other physiological factors important to running performance are running economy (RE), lactate threshold (LT) and the  $\dot{V}O_2$  kinetic response (Jones & Carter, 2000). Running economy is defined as the relative aerobic capacity per kilogram of body mass required to sustain a given submaximal running speed (Conley & Krahenbuhl, 1980).

Superior RE is associated with a low net metabolic rate therefore, using less energy and less oxygen per kilogram of body weight compared to those with poor RE (Jones & Carter, 2000; Morgan, Martin, & Krahenbuhl, 1989; Saunders, Pyne, Telford, & Hawley, 2004). From a performance perspective, in athletes with a similar aerobic capacity, the individual with the superior RE will be more efficient, using less oxygen than their competitors at a given running speed. Importantly for performance, less heat will be produced, muscle glycogen will be spared, therefore, delaying fatigue and having the ability to maintain a faster speed or run faster near the end of the race. Many different factors effect RE, including training, environment, physiology, biomechanics and anthropometry, therefore, large differences in RE are observed between individuals (Saunders et al., 2004).

Running economy has been assessed to determine the effects of training status, age, sex and body mass (Bourdin, Pastene, Germain, & Lacour, 1993). Trained/fit individuals have a superior RE compared to untrained/unfit subjects (Morgan et al., 1995; Saunders et al., 2004) while among well trained subjects, no significant variation in the oxygen cost of

running is observed (Helgerud, StÅ-Ren, & Hoff, 2010). Obese (OB) individuals typically have a poor exercise economy when compared to normal weight (NW) individuals during treadmill exercise, when expressed relative to body mass (Chen, Acra, Donahue, Sun, & Buchowski, 2004; Hulens, Vansant, Lysens, Claessens, & Muls, 2001; Lafortuna et al., 2008), which should be of no surprise considering obese subjects would typically present as untrained compared to NW. However, some studies have found no difference in exercise economy (EE) between sedentary to moderately active NW and OB subjects during treadmill exercise (Browning, Baker, Herron, & Kram, 2006; Browning, Reynolds, Board, Walters, & Reiser, 2013). Similarly, in non-physically active populations, no differences are reported in EE between NW and overweight/obese subjects (Hulens et al., 2001; LeCheminant, Heden, Smith, & Covington, 2009).

When comparing the mass related energy cost of exercise between subjects, many studies have applied an absolute intensity to compare obese/overweight and NW subjects (Browning et al., 2006; Browning et al., 2013; Chen et al., 2004; Hulens et al., 2001; Lafortuna et al., 2008; LeCheminant et al., 2009; McMurray & Ondrak, 2011; Taboga et al., 2012). This assumes individuals who exercise at the same speed are exercising at the same relative intensity; therefore the use of relative intensities to quantify running economy in past research can be argued (Fletcher, Esau, & MacIntosh, 2009; Rowland, 2012; Weyand, Smith, Puyau, & Butte, 2010). For example, an absolute treadmill running speed of  $10 \text{ km}\cdot\text{h}^{-1}$  for a fit/active participant may be consistent with a physiological response at a moderate intensity at or below the ventilatory threshold (VT)<sup>1</sup>. However, another unfit/inactive participant may find this intensity far more challenging, exercising above VT in the heavy exercise domain, resulting in a greater  $\text{O}_2$  cost, lactate accumulation and the earlier onset of fatigue.

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<sup>1</sup> Ventilatory Threshold is the  $\dot{V}\text{O}_2$  or speed representing an incremental and rapid rise in  $\dot{V}\text{CO}_2$  as the result of lactic acid accumulation

The comparison of exercise economy at an absolute intensity, whether relativised for other markers of size (stride frequency, fat free mass) or not, may be considered to be flawed (Fletcher et al., 2009). A consistently valid way of comparing running economy between individuals is to determine exercise intensities (i.e., low, moderate, & heavy) relative to the individual through respiratory variables or BLa responses (Fletcher et al., 2009; Rowland, 2012). When comparing RE between individuals, the intensity should be relative to the subject for two key reasons; an absolute running speed does not acknowledge differences in speed at ventilatory threshold and differences in substrate utilisation that are associated with different exercise intensities relative to an individual's  $\dot{V}O_{2\max}$  (Fletcher et al., 2009).

A comparison of RE at metabolically comparable work rates between obese and normal weight adults is yet to occur. Recent unpublished work (Lambrick et al., 2013 Unpublished Data) found obese children to have a superior RE compared to NW at metabolically comparable moderate and heavy work rates. In recreational and competitive runners, no differences in RE were found between groups at metabolically comparable work rates (VT), despite the recreational runners having a significantly higher BF% and body fat mass (Mooses et al., 2013).

The aim of the present study was to compare RE between fit and regularly active obese subjects with normal weight unfit and inactive subjects. The main difference of this research is the use of independent exercise intensities both moderate (VT) and heavy (40%  $\Delta$ ), for each individual. It is hypothesised that with the use of fitness and relative exercise intensities, Obese-Fit (OBF) subjects will display a superior exercise economy compared to Normal Weight-Unfit (NWU) individuals. This will remain for both independent exercise intensities.

## 2. Review of Literature

### **2.1 Running Economy**

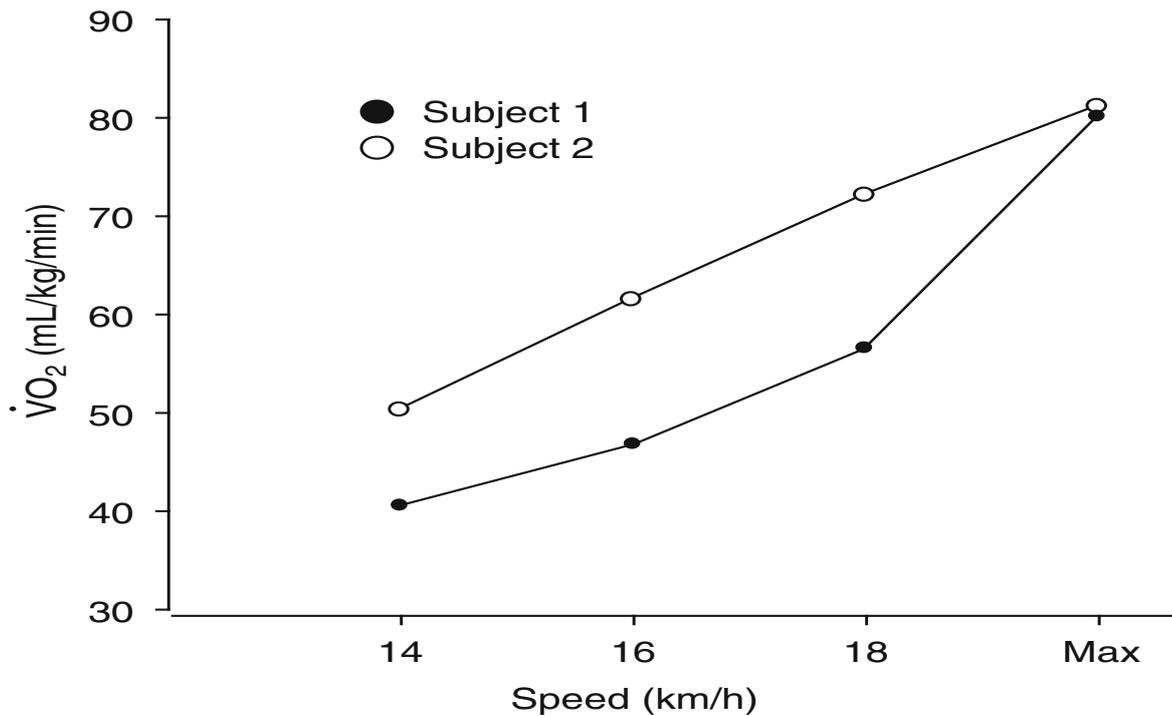
#### *2.1.1 Physiological overview of performance parameters*

Maximal oxygen uptake ( $\dot{V}O_{2\max}$ ), lactate threshold, the  $\dot{V}O_2$  kinetic response and Running Economy (RE) (Jones & Poole, 2005) are seen as the major factors that determine endurance exercise performance, with  $\dot{V}O_{2\max}$  predominantly regarded as the gold standard when measuring improvements in cardiorespiratory fitness (CRF) (Jones & Carter, 2000; Joyner & Coyle, 2008).  $\dot{V}O_{2\max}$  is defined as the maximal oxygen consumption that reflects the aerobic physical fitness of an individual (Joyner & Coyle, 2008). Values are 50-100% greater in champion endurance trained athletes compared to normally active healthy young subjects (Joyner & Coyle, 2008). A higher  $\dot{V}O_{2\max}$  may be the result of regular endurance exercise training, during which adaptations can be observed including; increased cardiac output, total body haemoglobin, increased muscle blood flow and oxygen extraction (Bassett & Howley, 2000).

The lactate threshold is the running speed or power output at which a sudden increase in blood lactate accumulation (BLa) occurs as the maximum rate of fat oxidation is inadequate to meet the rising ATP demands increasing motor unit recruitment, as the exercise moves from low to moderate and high intensities (Holloszy & Coyle, 1984). Untrained subjects typically show no increase in BLa until around 60% of  $\dot{V}O_{2\max}$ , while trained individuals this value can be 75-90% of  $\dot{V}O_{2\max}$  (Joyner & Coyle, 2008). The  $\dot{V}O_2$  kinetic response is shown in the early stages of exercise as an immediate increase in ATP production in the active skeletal muscles is required. However, in the initial stages of exercise, the  $\dot{V}O_2$  to meet the demand for ATP increases relatively slowly, with a steady state  $\dot{V}O_2$  being achieved in around 2-3 minutes provided the exercise is below ventilatory threshold (VT)

(Carter et al., 2000). This has important implications when subjects are compared in regards to RE at given work rates. Individuals must exercise at the same relative intensity in relation to the physiological markers such as the VT (Fletcher et al., 2009).

Running economy is the energy demand required for a given submaximal running velocity (Saunders et al., 2004). This is typically measured while treadmill running in laboratory conditions. RE can be determined by the steady-state oxygen consumption ( $\dot{V}O_2$ ) required per kilogram (kg) of body weight at a given velocity and is often expressed as  $\text{mL}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$ . The  $\dot{V}O_2$  reflects the amount of ATP used in a given task when aerobic metabolism provides the majority of the energy for that task (Fletcher et al., 2009). Runners who have good RE, will use less oxygen than those with an inferior RE at a given running velocity (Saunders et al., 2004). Figure 2.1 illustrates the effect good RE can have on running performance. In this case of two international level 10 km runners, who have similar  $\dot{V}O_{2\text{max}}$  levels, the athlete who uses the least oxygen at a given running speed (Subject 1) displays a superior economy, which in turn was shown to elicit a 1 minute faster 10 km race time yet the athletes have similar  $\dot{V}O_{2\text{max}}$  values. There is a strong relationship between RE and endurance running performance, with RE being a better predictor of performance than  $\dot{V}O_{2\text{max}}$  among subjects with similar  $\dot{V}O_{2\text{max}}$  (Conley & Krahenbuhl, 1980).

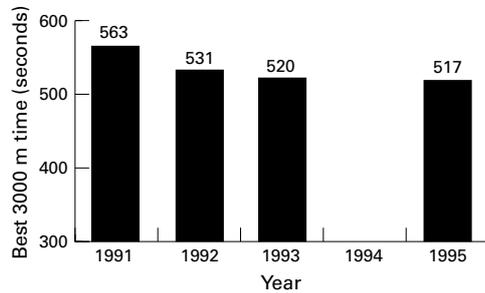


**Figure 2.1** Comparison of oxygen uptake  $\dot{V}O_2$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) in two international calibre 10 km runners, one with good economy (subject 1) and the other with poor economy (subject 2). From Saunders et al. (2004) Factors affecting running economy in trained distance runners. *Sports Medicine*, 34(7), Pg 467.

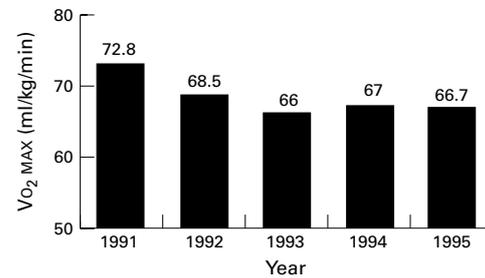
### 2.1.2 Running economy and performance

A strong association exists between RE and distance running performance (Saunders et al., 2004). The importance of running economy to athletic performance is suitably demonstrated by Jones (1998). In this study, the researcher monitored the physiological and performance changes of an Olympic distance runner over a 5 year period. While  $\dot{V}O_{2\text{max}}$  is considered to be highly predictive of endurance exercise performance, it is often the focus of demonstrating a training effect (Bassett & Howley, 2000), Jones (1998) demonstrated that an 8% improvement in 3000 m running performance (Figure 2.2A) was evident despite a 9% decrease in  $\dot{V}O_{2\text{max}}$  (Figure 2.2B). When considering the individual's exercise efficiency, an 11% improvement in RE was observed (Figure 2.2C), as shown by a reduced oxygen

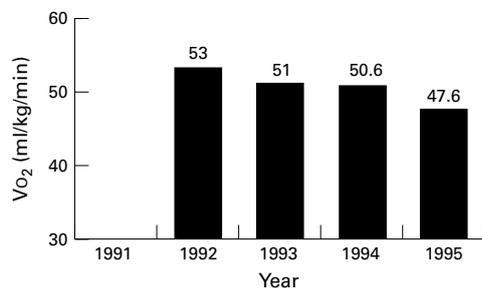
consumption at  $16 \text{ km}\cdot\text{h}^{-1}$ . The improved RE in this subject, offset the lack of improvement (decrease) in  $\dot{V}O_{2\text{max}}$ . This can be shown by the greater estimated velocity at  $\dot{V}O_{2\text{max}}$  (Figure 2.2D), which improved from  $19 \text{ km}\cdot\text{h}^{-1}$  to  $20.4 \text{ km}\cdot\text{h}^{-1}$  over a 5 year period.



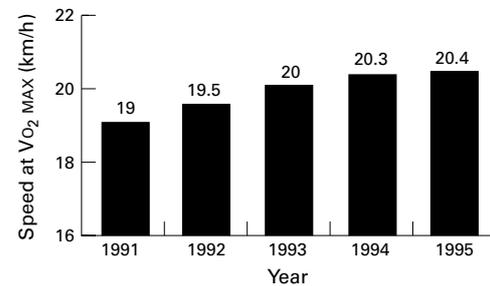
A. Improvement in 3000m run time.



B. Changes in  $\dot{V}O_{2\text{max}}$ .



C. Changes in  $\dot{V}O_2$  at  $16 \text{ km}\cdot\text{h}^{-1}$ , 1% incline.

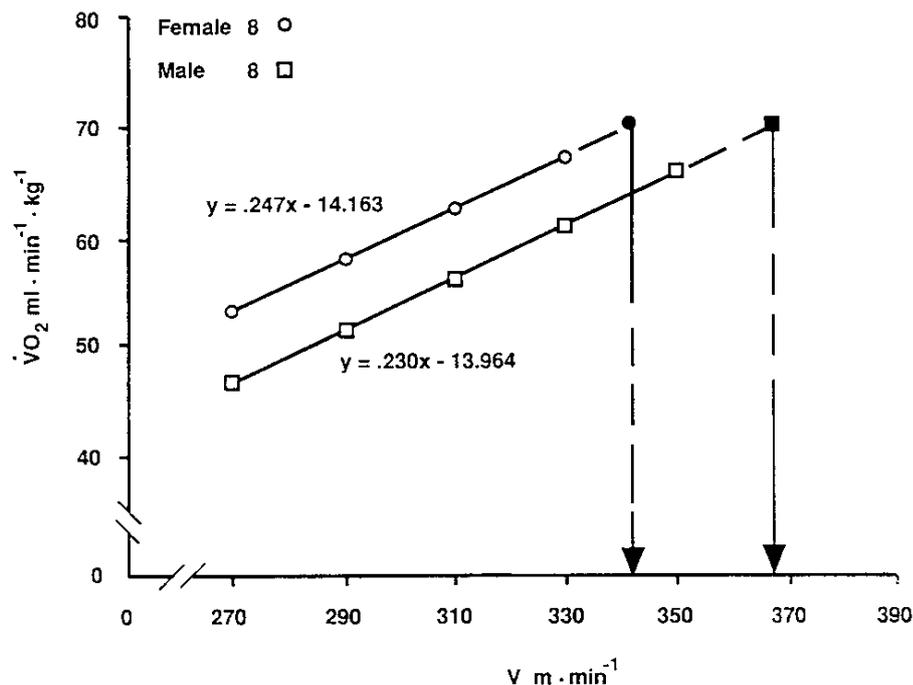


D. Changes in estimated running speed at  $\dot{V}O_{2\text{max}}$ .

**Figure 2.2** Physiological and performance measures over 5 years. Jones, Andrew M. (1998). A five year physiological case study of an Olympic runner. *British Journal of Sports Medicine*, 32. 39-43.

Similarly, a 7 year case study of a six time Grand Champion of the Tour de France displayed that the physiological factor most relevant to the increase in performance from age 21-28, was an 8% improvement in muscular efficiency (Coyle, 2005). In this longitudinal study, improved performance was also attributed to a reduction in body weight and body fat percentage (BF%) of approximately 7%, resulting in an 18% improvement in steady state power output per kg of body weight at a given  $\dot{V}O_2$ .

Daniels and Daniels (1992) compared male and female subjects with similar  $\dot{V}O_{2\max}$ , with males eliciting a superior RE compared to females. Figure 2.3 shows the greater economy of the male subjects as evident by the reduced oxygen cost at the given running velocity. The authors also estimated the velocity at  $\dot{V}O_{2\max}$  as shown by the perpendicular lines drawn down from the  $\dot{V}O_{2\max}$  values. The males had a higher velocity at  $\dot{V}O_{2\max}$  ( $\text{m}\cdot\text{min}^{-1}$ ) and a lower  $\dot{V}O_2$  ( $\text{mL}\cdot\text{min}^{-1}\cdot\text{kg}^{-1}$ ) at all submaximal running speeds. These differences occurred despite the same  $\dot{V}O_{2\max}$  scores, displaying an enhanced ability to maintain oxidative phosphorylation in males compared to female subjects. Similarly, the same study also found that in subjects with similar RE, the male subjects had a 14% higher  $\dot{V}O_{2\max}$  resulting in a 14% greater velocity at  $\dot{V}O_{2\max}$  compared with female subjects. This shows the interaction of  $\dot{V}O_{2\max}$  and RE in determining the running velocity that can be maintained by oxidative phosphorylation (Bassett & Howley, 2000).

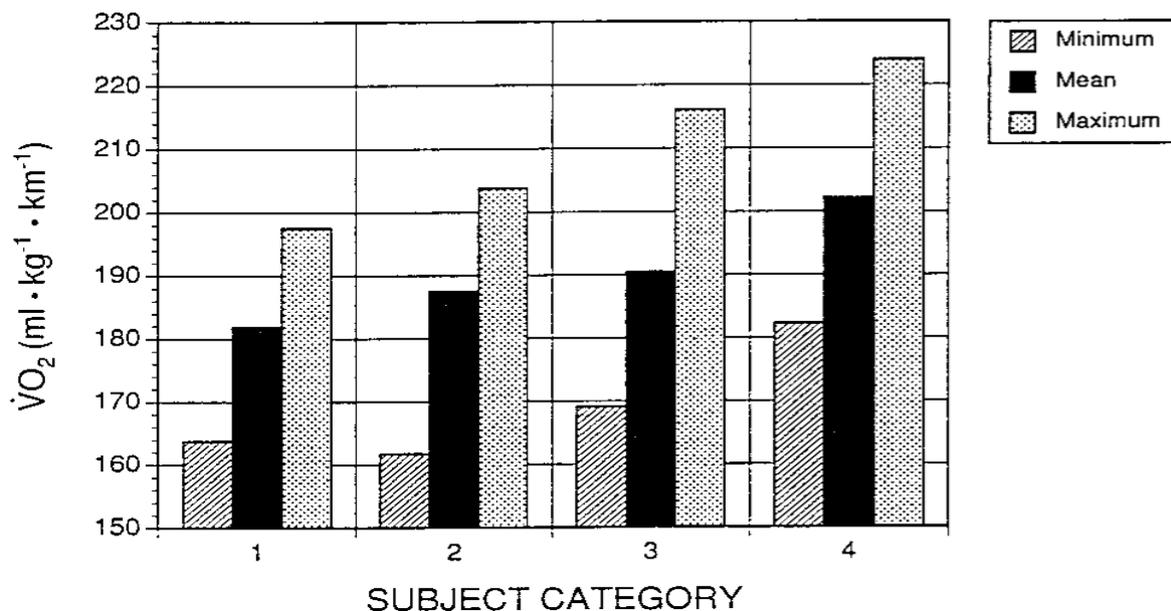


**Figure 2.3** Comparison of male and female runners of equal  $\dot{V}O_{2\max}$ . The males are significantly favored in economy and in Velocity at  $\dot{V}O_{2\max}$ . Daniels, J. and N. Daniels. Running economy of elite male and elite female runners. *Medicine & Science in Sports & Exercise*. 24:483–489, 1992.

There is considerable variation among individuals in the oxygen cost of running at a given speed (Bransford & Howley, 1977; Morgan et al., 1995). Early studies on RE found that among a group of highly trained and experienced runners with similar  $\dot{V}O_{2\max}$  and abilities, two thirds of the variation observed in a 10 km race performance was explained by variations in RE (Conley & Krahenbuhl, 1980). They also reported no significant relationship ( $r = -0.12$ ) between  $\dot{V}O_{2\max}$  and performance. In this particular study subjects performed three submaximal runs for 6 minutes each at 14.5, 15.5 and 17.7  $\text{km}\cdot\text{h}^{-1}$ , with three minutes rest between successive exercise bouts. The absolute speeds were chosen to allow for comparisons with earlier studies. The authors concluded that other factors accounting for the variation in performance may be inter-individual differences in muscle fibre type, anaerobic threshold and blood lactate tolerance.

Figure 2.4 shows the variation in RE between elite athletes and untrained individuals. The elite group (Category 1) of runners have a superior running economy compared to all other groups, while all groups were better than the untrained individuals (Category 4). Between the most economical subject and the least economical within each group, subjects varied in RE by an average of 20% and was remarkably similar between groups (Morgan et al., 1995). This was the first study to take fitness into account when comparing RE between individuals and groups, with economy trial speeds for the untrained subjects ranged from 9.3-13.6  $\text{km}\cdot\text{h}^{-1}$  for 7 minutes, while the trained subjects performed at considerably faster speeds 9.6-19.8  $\text{km}\cdot\text{h}^{-1}$  for 6-10 minutes. The  $\dot{V}O_2$  value selected for analysis between individuals, represented similar relative exercise intensities (Approx 70%  $\dot{V}O_{2\max}$ ), reducing the contribution of non-aerobic metabolism. The subjects in this study were matched for height, but age and body weight were significantly different between groups. The average BMI in the heaviest group (untrained) was still  $< 25.0 \text{ kg}\cdot\text{m}^{-2}$ . Collectively the results from Morgan et al., (1995) provided evidence that better or worse economy is not necessarily a function of

training or level of performance and that anatomical and physiological characteristics may also play a role. Differences in RE are attributed to variation in physiological ( $\dot{V}O_{2\max}$  and metabolic factors), biomechanical (flexibility, elastic stored energy and other mechanical factors) and anthropometry (bodyweight, body composition and limb morphology) (Saunders et al., 2004).



**Figure 2.4** Minimum, mean, and maximum aerobic demand running economy values for elite runners (Category 1), sub-elite runners (Category 2), good runners (Category 3), and untrained subjects (Category 4). Morgan, D. W., D. R. Bransford, D. L. Costill, et al. Variation in the aerobic demand of running among trained and untrained subjects. *Medicine & Science in Sports & Exercise*. 27:404–409, 1995.

### 2.1.3 Effect of Training Status on Running Economy

It is widely accepted that trained individuals have a superior RE compared to untrained subjects (Bransford & Howley, 1977; Dolgener, 1982; Morgan et al., 1995). It has also been found that long distance runners are more economical than middle distance runners (Daniels & Daniels, 1992). However, when running at speeds above 19 km · hr<sup>-1</sup>, marathon runners were less economical than middle distance (800/1500m) runners, yet at slower speeds

marathoners displayed the superior RE. This shows that the specificity of training relative to given running speed also affects the measurement of RE.

As the result of regular endurance training, individuals may adopt a more economical running style due to important physiological adaptations (Nelson & Gregor, 1976). Endurance training results in increases in the morphology and functionality of muscle mitochondria (Saunders et al., 2004). This change leads to increases in the respiratory capacity and permits trained individuals to use less oxygen per mitochondrial chain for a given submaximal running speed, enhancing running performance through a slower utilisation of muscle glycogen (Holloszy & Coyle, 1984). The expression of fast-twitch muscle fibres to a slow-twitch phenotype as well as a high percentage of slow twitch fibres result in a lower energy demand for a particular level of force (Williams & Cavanagh, 1987). It has been previously reported that the percentage of type IIa muscle fibres in the gastrocnemius muscle in sedentary women is positively correlated with walking economy (Hunter et al., 2005). In subjects with a high proportion of type IIa energetically inefficient muscle fibres, the inferior RE is a result of the higher oxygen demand from these fibres (Hunter et al., 2005). Conversely type I muscle fibres are more economical than type II (Hunter et al 2001, Coyle 1992).

A decrease in  $\dot{V}O_2$  for a given running velocity, results in a reduced respiratory energy demand allowing more energy reserved for the active skeletal muscles (Franch, Madsen, Djurhuus, & Pedersen, 1998). Training also improves whole body mechanical efficiency which reduces the whole body energy demand, enhancing RE (Williams & Cavanagh, 1987). Running elicits a significant stretch of the muscle (quadriceps, hamstrings, gluteals, gastrocnemius and soleus) prior to contraction and there is potential to capture mechanical energy within the elastic elements of tissue (Joyner & Coyle, 2008). Increased

musculo-tendonous stiffness leads to increased storage and return of elastic energy resulting in reduced oxygen consumption and enhanced economy by the skeletal muscles (Craib et al., 1996; Saunders et al., 2004).

An inverse relationship has been found between  $\dot{V}O_{2\max}$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) and RE (Sawyer et al., 2010). It is suggested by Noakes & Tucker (2004), that among competitive runners of similar performance characteristics this relationship will always be inverse as the individuals with a lower  $\dot{V}O_{2\max}$  will compensate at a given intensity with a high movement economy to able to achieve the same performance level (Morgan & Daniels, 1994, Noakes & Tucker, 2004), suggesting that CRF and RE are inversely related. However, it has been found that the energy cost of muscle contraction was not different in trained and untrained subjects who differed significantly in  $\dot{V}O_{2\max}$  (67.1 vs. 42.3  $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  respectively) (Layec et al., 2009). Therefore if the energy cost of contraction is similar regardless of fitness level, other factors such as body mass may account for differences in RE among individuals.

Little recent attention has been given to untrained/unfit normal weight individuals in regards to running economy. Early work focused on the differences in running economy between trained and untrained adult males (Bransford & Howley, 1977; Morgan et al., 1995). Bransford and Howley (1977) found that trained runners had a significantly lower  $\dot{V}O_2$  compared to untrained males at a given running velocity. They also found differences among male and female subjects, with trained females and untrained males having a lower  $\dot{V}O_2$  compared to untrained females. The researchers performed all running at set speeds and therefore the aforementioned results are not surprising as the relative intensity for the trained runners and male subjects, would have been significantly lower as represented by the lower  $\dot{V}O_2$  in the trained male runners compared to all other groups.

When comparing RE between groups, most studies have used endurance trained athletes or recreational level runners. Typical endurance training involves low intensity, high distance and high volumes of training and as a result superior RE in long distance runners is attributed to lower vertical displacement of the centre of mass (CoM) attributed to neuromuscular adaptations (Saunders et al., 2004). In highly trained endurance athletes enhancements in RE as the result of training are harder to achieve (Billat, Flechet, Petit, Muriaux, & Koralsztein, 1999). The reported enhancement of running economy as the result of training is typically only seen when untrained or moderately trained subjects have been selected whereby improvements in fitness will be greater compared to already highly trained subjects (Conley & Krahenbuhl, 1980; Franch et al., 1998).

In well trained distance runners, no differences were found in the oxygen cost of running at velocities representing 60 to 90% of  $\dot{V}O_{2\max}$  (Helgerud et al., 2010). In this particular study, the relative intensities were not individually run at for each subject. The authors utilised data from a maximal aerobic speed test and plotted  $\dot{V}O_2$  data vs. running velocity. This produced a regression equation to find the cost of running at different relative speeds. While this is a novel approach to assessing RE, the  $\dot{V}O_2$  kinetic response during a GXT is affected by relative intensity among individuals and this does not allow for a steady state  $\dot{V}O_2$  to be achieved or analysed, therefore a valid interpretation of this data should be viewed with caution.

RE has also been shown to be influenced by the type of training individuals may undertake. Interval training is typically performed at a vigorous intensity to enhance endurance exercise performance (Saunders et al., 2004). Investigators have compared the influence of continuous distance running (20-30 minute continuous run), long interval training (4 min run, 2 minute rest, repeated 4-6 times) and short interval training (15 sec run,

15 second rest, 30-40 repetitions) on the RE of untrained and moderately trained subjects (Franch et al., 1998). RE was significantly improved in distance running (3.1%) and long interval training (3%), but limited benefits were observed in the short interval group (0.9%). The authors stated that improvements in RE were due to a ventilatory adaptations, specifically reducing the ventilatory demand at a given submaximal velocity. The oxygen cost of the respiration itself can be up to 15% of total  $\dot{V}O_2$  (Aaron, Seow, Johnson, & Dempsey, 1992). This suggests that to improve RE, continuous and long interval training modalities are superior compared to short interval training (Franch et al., 1998).

Other methods of training that provoke enhancements in RE have included strength training, altitude exposure and training in a hot environment (Saunders et al., 2004). While altitude exposure and training in the heat are typically sought after for elite performers, many individuals seeking to increase their fitness will typically use strength (resistance) or endurance based training. In trained subjects, heavy resistance training has been found to enhance RE (Johnson, Quinn, Kertzer, & Vroman, 1997; Storen, Helgerud, Stoa, & Hoff, 2008). Typical strength training leads to improvements in RE, however, the additional effect of carrying excess weight in obese subjects results in a chronic strength training stimuli (Salvadeo et al., 2010). It could be therefore argued that obese individuals are constantly improving RE through everyday ambulation, yet it is the common belief that obesity inhibits RE (Chen et al., 2004; Hulens et al., 2001; Lafortuna et al., 2008). The proposed mechanisms for strength training improving RE include; enhanced use of elasticity through improved neuromuscular function (Paavolainen, Häkkinen, Hämmäläinen, Nummela, & Rusko, 1999), and improved co-ordination and changes in recruitment patterns of more efficient type I muscle fibres (Hunter et al., 2005; Hunter, Newcomer, Larson-Meyer, Bamman, & Weinsier, 2001).

Concurrent heavy resistance training and endurance training have also been found to enhance RE (Aagaard & Andersen, 2010; Millet, Jaouen, Borrani, & Candau, 2002). The underlying adaptive response to concurrent training is thought to be from an increased proportion of type IIa muscle fibres, which are more fatigue resistant than type IIb yet are still highly capable of producing high contractile power (Aagaard et al., 2011). Typical strength training would induce muscle hypertrophy, yet when combined with an endurance training stimuli it is thought to blunt this effect (Aagaard & Andersen, 2010). These combined effects result in an elevated capillary density to muscle fibre ratio, which enhances oxygen delivery and free fatty uptake in to the muscle cell, in turn reducing glycogen breakdown, potentially leading to a greater time to exhaustion (delaying fatigue), thus enhancing endurance performance (Aagaard, Simonsen, Andersen, Magnusson, & Dyhre-Poulsen, 2002; Bell, Petersen, Wessel, Bagnall, & Quinney, 1991).

#### *2.1.4 Effect of body mass on running economy*

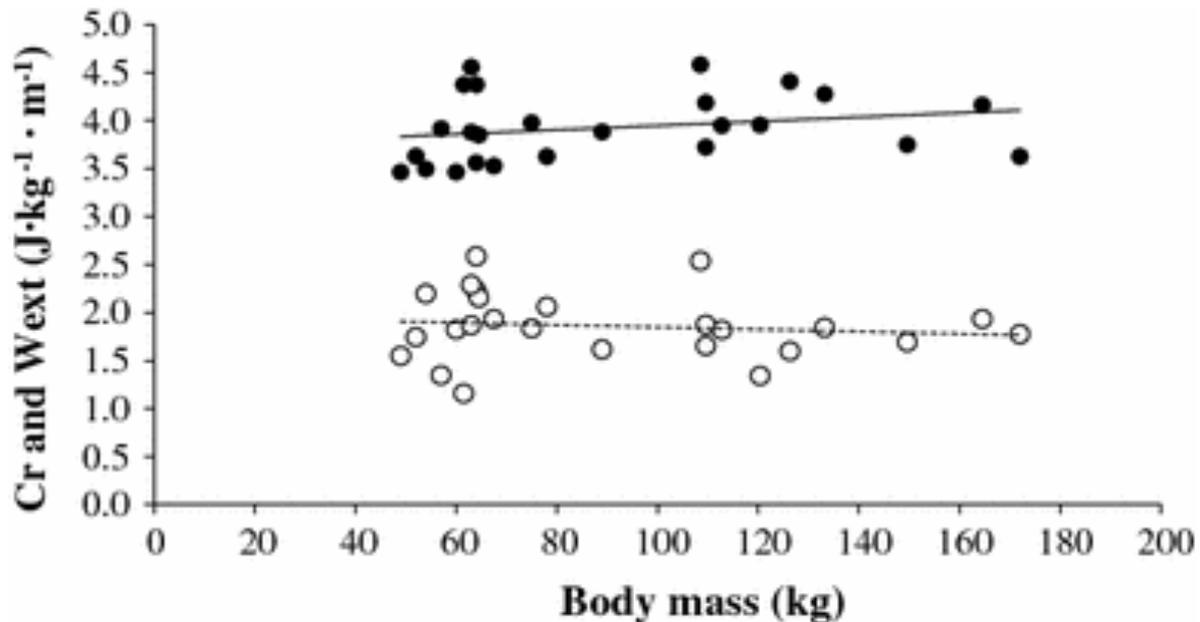
One of the main influencing factors on the inter-individual differences of running economy is considered to be body mass (Saunders et al., 2004). In distance trained runners some authors have found that an increase in body mass is associated with a decrease in the energy cost of running (Bourdin et al., 1993; Maldonado, Mujika, & Padilla, 2002; Pate, Macera, Bailey, Bartoli, & Powell, 1992). This may be attributed to increased energy storage and reutilisation during the concentric contraction of the leg muscles (Williams, 1987). Other research has shown obesity to be associated with an increase in the total energy cost of running signifying poor economy (Lafortuna et al., 2008; Taboga et al., 2012). However when the energy cost is expressed per kg of body weight, no differences are found among a range of population groups (Browning et al., 2013; LeCheminant et al., 2009; Mooses et al., 2013).

One aspect that remains unclear is whether variations in RE between obese and normal weight subjects are the result of differences in overall body mass or more specifically body fat content. During walking, the variance of body mass has been shown to explain 82-92% of the variance in metabolic rate (Lafortuna et al., 2008). In adolescent boys matched for body weight but differing in fat mass, no differences were found in the energy cost during treadmill walking (Ayub & Bar-Or, 2003). Total body mass rather than adiposity was found to represent 62-89% of the variance in energy expenditure, with differences in adiposity representing only 2-16% of the variance (Ayub & Bar-Or, 2003). Some researchers have expressed energy expenditure relative to fat free mass (FFM) in order to determine if excess non-metabolically active fat mass affects weight-related energy expenditure (Ayub & Bar-Or, 2003; LeCheminant et al., 2009), with no significant differences observed.

In a range of recent studies, RE has been measured as the energy cost ( $\text{J}\cdot\text{kg}^{-1}\cdot\text{m}^{-1}$ ), or have utilized the average relative oxygen consumption ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) required to walk or jog at a given speed (Browning et al., 2013; Lafortuna et al., 2008; LeCheminant et al., 2009; Taboga et al., 2012). When comparing normal weight and overweight/obese females during treadmill jogging at  $8\text{ km}\cdot\text{h}^{-1}$ , LeCheminant *et al.*, (2009) found no difference in RE between groups.  $\dot{V}\text{O}_{2\text{max}}$  was greater in the normal weight subjects compared to overweight/obese ( $38.5 \pm 5.6$  &  $31.9 \pm 3.2\text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , respectively) and as a result of the set jog/running speed, RER and  $\% \dot{V}\text{O}_{2\text{max}}$  in the obese subjects displayed that they were working at a higher relative exercise intensity with a greater contribution from anaerobic metabolism and less from aerobic metabolism during the exercise test. Therefore, the main finding of increased energy expenditure in the overweight/obese subjects is not surprising. RPE was also approaching significance between groups; with the overweight/obese reporting an end RPE of  $15.1 \pm 3.0$  compared to  $13.0 \pm 2.2$  in normal weights. The groups were exercising at different relative exercise intensities with the normal weight subjects finding the set treadmill

jog speed of  $8 \text{ km}\cdot\text{h}^{-1}$  relatively easy compared to overweight/obese subjects. RE was measured and reported in this study as the average relative oxygen consumption ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) during the walk and jog with no significant differences found between groups. However the resulting average  $\dot{V}\text{O}_2$  during the jog was approaching significance with the normal weight subjects having a higher  $\dot{V}\text{O}_2$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) compared to overweight/obese ( $26.7 \pm 1.9$  &  $25.4 \pm 1.6 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , respectively). Had the groups run at relative speeds the results could have shown a significant superior RE in overweight/obese subjects?

Another study compared treadmill running at  $8 \text{ km}\cdot\text{h}^{-1}$  between severely obese (BMI  $41.5 \pm 5.3 \text{ kg}\cdot\text{m}^{-2}$ ) and nonobese females (BMI  $21.6 \pm 2.4 \text{ kg}\cdot\text{m}^{-2}$ ) (Taboga et al., 2012). The authors found the mass specific energy cost ( $\text{J}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) of running was independent of the overall mass of the subject (Figure 2.8). However, the total energy cost of running was significantly greater in obese subjects compared to nonobese ( $528 \pm 86.3$  &  $246.7 \pm 47.6 \text{ J}\cdot\text{min}^{-1}$ , respectively). This is not surprising as the relative intensity of the exercise protocol for obese subjects would have been vastly greater as a percentage of  $\dot{V}\text{O}_{2\text{max}}$  resulting in a greater substrate utilisation and therefore a higher energy cost. The study did not provide physiological ( $\dot{V}\text{O}_2$ , RER, BLA) or perceptual (RPE) data between subject groups. Without this relevant data the relative intensities at which the subjects ran could be vastly different between groups considering the obese group were recruited among hospitalised patients and had severe obesity levels.



**Figure 2.5** Energy cost of running (*full circles*:  $C_r, \text{J}\cdot\text{kg}^{-1}\cdot\text{m}^{-1}$ ) and external mechanical work (*empty circles*:  $W_{\text{ext}}, \text{J}\cdot\text{kg}^{-1}\cdot\text{m}^{-1}$ ) as a function of the overall body mass of the subject. Linear regression for  $C_r$  is described by:  $C_r = 0.002 M + 3.729$ , ( $n = 25$ ,  $R^2 = 0.05$ ,  $p = 0.841$ ). Taboga, P., Lazzar, S., Fessehatsion, R., Agosti, F., Sartorio, A., & di Prampero, P. E. (2012). Energetics and mechanics of running men: the influence of body mass. *European Journal of Applied Physiology*, 112(12), 4027-4033.

Browning *et al.*, (2013) compared sedentary to lightly active obese ( $\text{BMI } 33.9 \pm 3.6 \text{ kg}\cdot\text{m}^{-2}$ ) and nonobese ( $\text{BMI } 21.6 \pm 2.0 \text{ kg}\cdot\text{m}^{-2}$ ) men and women during treadmill walking at 11 varying speeds/grades ( $1.8 - 6.3 \text{ km}\cdot\text{h}^{-1}$ ,  $-3^\circ$  to  $9^\circ$ ). RE was measured and reported in this study as net metabolic rate per kilogram of body weight ( $\text{W}\cdot\text{kg}^{-1}$ ). During the selection of walking speeds, no significant differences were found between groups. While obese subjects had a significantly higher  $\dot{V}\text{O}_2$  ( $\text{L}\cdot\text{min}^{-1}$ ) and gross energy expenditure ( $\text{J}\cdot\text{kg}^{-1}\cdot\text{m}^{-1}$ ) across all speeds and grades, gross energy expenditure per kilogram of body weight was significantly less in obese vs nonobese at all speeds and grades. Net energy expenditure was significantly less (0-6%) in obese vs nonobese at 5 out of 11 speeds and gradients and was used as the measure of exercise economy. However, this does not go by the specific definition of RE. While the velocities are the same between groups, the authors have assumed the energy cost of walking between subjects is not affected by the fitness level of the individual. The obese

subjects were exercising at an 8-15% higher relative intensity resulting in greater substrate utilisation and more anaerobic metabolism, therefore, the results of increased energy expenditure are not surprising. The  $\dot{V}O_{2\text{peak}}$  in this study was significantly lower in the obese subjects compared to nonobese ( $28.9 \pm 6.6$  &  $40.3 \pm 4.6$  mL·kg<sup>-1</sup>·min<sup>-1</sup> respectively). Individual variation in fitness levels must be accounted for when comparing energy expenditure as the relative intensity to  $\dot{V}O_{2\text{max}}$  of the individual effects substrate utilisation and therefore the results should be viewed with caution when relating to exercise economy.

Body mass differences are attributed to the superior movement economy in normal weight compared to obese women during submaximal bicycle ergometry (Hulens et al., 2001). In this study, both groups were identified as having low levels of CRF, with obese subjects having a significantly lower VT despite both groups attaining VT at the same percentage of  $\dot{V}O_{2\text{max}}$ . However during the constant load cycling test at 70 W, the oxygen cost in obese was 78% of peak  $\dot{V}O_2$  compared to 69% in lean women. This indicates that the larger body mass increased the oxygen cost during cycling. In walking at a comfortable pace, the differences have been reported to be even higher, with obese subjects using 50% of their peak  $\dot{V}O_2$  compared to approximately 36% in normal weight females (Mattsson, Larsson, & Rössner, 1997). The greater differences in % peak  $\dot{V}O_2$  between obese and lean during walking compared to cycling is attributed to the weight bearing required during walking whereas body weight (in particular excess fat mass in obese) is supported during cycling.

The effect of adding external mass during submaximal running at 8, 10 and 11 km·h<sup>-1</sup> to active men was assessed to examine the effects on the metabolic cost of exercise (Thorstensson, 1986). The authors found that an increase in body mass of 10% caused a small decrease in net oxygen uptake (ml·kg<sup>-1</sup>·min<sup>-1</sup>) of running at speeds except 8 km·h<sup>-1</sup>. The decrease in oxygen consumption was not correlated with differences in body weight or step

frequency. It was hypothesised that a difference in the utilisation of muscle elastic energy could be apportioned to the dependent changes in running economy. Adding mass (9.3% of total body weight) to normal weight trained male subjects has been found to decrease the mass specific energy cost by running by 5.1% while the total energy cost increased 4.6% (Bourdin, Belli, Arsac, Bosco, & Lacour, 1995). The authors also found no significant relationship between the energy cost of running and body mass, which was in contrast to their previous work (Bourdin et al., 1993). Due to the homogenous nature of the subjects, the authors selected a given speed of  $18 \text{ km}\cdot\text{h}^{-1}$  for all comparisons.

Another factor in the variation of RE in relation to body mass is where the mass is distributed. When adding mass around the shoulders or torso the effective kinematics of the lower limbs are less likely not affected and therefore the elevated mass will be more than the increase in metabolic demand, effectively decreasing the  $\text{O}_2$  cost per kg (Bergh, Sjodin, Forsberg, & Svedenhag, 1991). The aerobic demand is increased by approximately 1% for every kg when added around the trunk. The proposed mechanism for this is due to increased eccentric muscle tendonous loading resulting in increased storage and release of elastic energy reducing the energy demand of the skeletal muscles. However if the mass is added distally such as in the shoes, the aerobic demand increases by approximately 10% due to large kinematic variations (Martin, 1985).

From the above studies we can conclude that RE is yet to be compared between obese and normal weight subjects. Considering the variability in reporting results, the range of absolute speeds, and the severity of obesity, a concise conclusion on how obesity effects RE economy is yet to be determined. In terms of the energy cost of exercise, the results suggest that the obese subjects are able to store elastic energy at each step during running and

walking and re-use it to allow for a reduced energy consumption relative to body mass (Taboga et al., 2012).

## **2.2 Obesity and Fitness**

When examining exercise economy, research has typically utilised a population pool which includes fit subjects (ranging from physical education students to elite level runners) who are of normal body weight classification (Morgan et al., 1995). When RE is compared between obese and normal weight populations, fitness level or the amount of regular, moderate-vigorous intensity exercise is seldom reported, with some obese subjects being recruited from hospitalised outpatients (Hulens et al., 2001; Taboga et al., 2012) or inpatients in a hospital weight loss programme (Lafortuna et al., 2008).

The effect that body mass plays on RE has been discussed with normal weight individuals in some instances having a superior RE compared to obese individuals, while trained or fit subjects display a superior RE compared to untrained/unfit individuals. To date no research has used fit/trained subjects who are obese. From a public health perspective the “fit but fat” or metabolically healthy yet obese, concept has been explored by many researchers (Duncan, 2010; Ortega et al., 2013). It has been argued that losing weight is not essential to get the benefit from physical activity (Weiler, Stamatakis, & Blair, 2010) as many people are discouraged from physical activity as weight loss is relatively poor (Shaw, Gennat, O’Rourke, & Del Mar, 2006).

The “fit but fat” concept implies that cardiovascular fitness attenuates the risk of cardiovascular and metabolic disease independent of BMI, even among obese individuals (Duncan, 2010). With this concept the risk for all cause and cardiovascular mortality is lower in individuals with a high BMI and good CRF, when compared to individuals with normal

BMI and poor fitness. This concept has been supported in a review of recent data (Fogelholm, 2010).

Further research is demonstrating that good fitness can diminish the impact of obesity on morbidity and mortality. This is an important development for obesity prevention programs as exercise has a very small effect on body weight (Shaw et al., 2006). A focus on changing the health status of individuals with other outcome measures rather than the changes in body weight should be encouraged into preventative programs that aid public health (Hainer, Toplak, & Mitrakou, 2008). Cardiorespiratory fitness (CRF) and body fatness are both related to health status including mortality risk. While high body fatness is associated with increased mortality, physically active individuals have a lower risk of mortality by comparison to inactive, with high levels of adiposity and CRF associated with a more protective effect compared to lower adiposity (Lee, Artero, Xuemei Sui, & Blair, 2010; Lee, Sui, Lavie, & Blair, 2012).

Being overweight or obese with high levels of fitness is associated with having a decreased risk of obesity related metabolic complications such as high blood pressure, fasting glucose and triglycerides as well as low HDL cholesterol when compared to normal weight unfit subjects. The proposed mechanisms for the reduction in risk from all cause and CVD mortality for individuals with high CRF result from markers of health including; improved insulin sensitivity, blood lipid and cholesterol profile, body composition, reduced inflammation and blood pressure as well as autonomic nervous system function (Lee et al., 2010).

In a review of 33 studies comprising 102,980 participants each 1-MET increase in CRF (approximately 1km/hr increase in walking/jogging/running speed) was associated with a reduction of 13% from all cause mortality (Kodama et al., 2009). A 1-MET increase in

CRF level is comparable to a decrease of; 7 cm in waist circumference, 5 mmHg in systolic blood pressure, 1 mmol/L in both triglyceride level (in men) and fasting plasma glucose, and a increase of 0.2 mmol/L in HDL cholesterol. However not all studies have reported CRF completely ameliorates the health risks of obesity (Jakicic, Mishler, & Rogers, 2011; McAuley, Pittsley, Myers, Abella, & Froelicher, 2009; Stevens, Cai, Evenson, & Thomas, 2002). Overall the findings suggest that interventions to improve health outcomes in overweight and obese subjects should focus both on weight loss and improvements in CRF.

In adults, obesity is associated with increasing the age related decline in physical function, impairing the quality of life and increasing nursing home admissions (Elkins et al., 2006; Villareal, Banks, Siener, Sinacore, & Klein, 2004). However, keeping physically fit helps reduce the age related decline in physical function (Villareal et al., 2011). RE is an important physiological measure in the sports performance field, but it can also help us assess how other individuals would cope with a certain intensity of activity. When individuals are seeking to lose weight, a change in diet and exercise regime are typical responses, however, not all individuals succeed in losing the desired weight and are discouraged. If the public were more informed about the benefits of improved CRF, including enhancing their ability to perform the activities of daily living, reduced health care costs and improving quality of life through more independent living, a shift from the current obsession with weight loss would occur (Weiler et al., 2010). As most previous RE research is focused towards performance in normal weight subjects or comparing untrained obese with normal weight individuals a comparison between obese fit (OBF) and normal-weight unfit (NWU) is needed to assess the effect of body size and fitness on RE.

### **2.3 Normal Weight and Low Fitness**

The majority of RE research is based around exercise performance with trained/fit subjects having a superior RE compared to untrained/unfit individuals. Subjects representing with low CRF are a greater health risk than obese and fit individuals (McAuley & Blair, 2011). Physical inactivity and low CRF are highly prevalent in modern society. Both inactivity and low CRF are very strong determinants of mortality and morbidity from chronic diseases (Lee et al., 2010). However, numerous studies and large scale meta-analyses have shown that being overweight or obese (implying inactive) with a range of established cardiovascular diseases paradoxically have a better prognosis than lean individuals (Flegal, Graubard, Williamson, & Gail, 2007; Romero-Corral et al., 2006; Uretsky et al., 2007).

Physical inactivity has been shown to be a main factor in the global energetic imbalance resulting in the current obesity pandemic and increase in metabolic disorders such as insulin resistance. Evidence suggests that insulin resistance can occur after very short exposure to inactivity (1-7 days) without any fat gain or energetic imbalance (Gratas-Delamarche, Derbré, Vincent, & Cillard, 2013). Worldwide it has been estimated that physical inactivity causes 9% of premature mortality and 6% of the burden of disease from coronary heart disease (Lee et al., 2012). They also reported that for a 10% reduction on the number of physically inactive 533,000 deaths could be averted each year.

The effect that poor fitness and inactivity can have on the activities of daily living is a major concern for the ageing population, with inactivity shown to be the strongest predictor of functional limitations later in life compared to chronic disease or social unengagement with life (Meisner, Dogra, Logan, Baker, & Weir, 2010). Investigating RE in unfit individuals at physiological relative moderate and heavy exercise intensities could help us to

understand the difficulties associated with being unfit and the effects this could have in completing simple tasks associated with independent living.

#### **2.4 Methodological Considerations for Assessing Running Economy**

When assessing RE between subjects of different fitness levels and body sizes, research has typically been based around the use of absolute exercise intensities. This may account for the variation of 30-40% in RE when expressed  $\text{ml}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$  (Joyner & Coyle, 2008). LeCheminant *et al.*, (2009) and Taboga *et al.*, (2012) used  $8 \text{ km}\cdot\text{h}^{-1}$  to compare obese and normal weight subjects during treadmill running. However the interpretation of these results may be an “artefact of the laboratory testing protocol” as highlighted by Rowland’s (2012, p. 502). When comparing the mass related energy expenditure or oxygen consumption between groups at the same absolute exercise intensity, exercise economy should be interpreted relative to body size, rather than normalising for absolute exercise intensities. In reality individuals do not exercise at the same intensity, instead they scale their activity to fitness level and body size (Rowland, 2012) and as such the use of absolute intensities quantifying exercise economy within the scientific literature can be disputed. The given speed of  $8 \text{ km}\cdot\text{h}^{-1}$  should be viewed with caution as this may be perceived to be a slow speed, causing negative impacts on running gait therefore decreasing muscular efficiency.

Some studies have measured energy expenditure at a given speed to determine RE among differing populations from obese and untrained to elite level runners (LeCheminant *et al.*, 2009; Saunders *et al.*, 2004; Taboga *et al.*, 2012). It is well documented that substrate use among individuals is affected by changes in the relative velocity of running (Costill, Fink, Getchell, Ivy, & Witzmann, 1979). Fat oxidation at any given absolute running speed is related to  $\dot{V}O_{2\text{max}}$ ; therefore runners with a higher  $\dot{V}O_{2\text{max}}$  may require higher  $\dot{V}O_2$  due to the greater reliance on fat utilisation (Fletcher *et al.*, 2009). In addition training status, pre

exercise diet, resting muscles glycogen stores, hormone concentrations and muscle fibre composition may also affect RER at a given intensity (Goedecke et al., 2000).

Pate *et al.*, (1992) found when an absolute speed is selected to compare RE among 188 habitual distance runners,, a wide range of relative intensities: 46-91% of  $\dot{V}O_{2\max}$  are found. The result of a given speed leads to some subjects exercising in the moderate intensity (below VT) where a steady state  $\dot{V}O_2$  is achieved rapidly in around 2-3 minutes while others who are less fit or unaccustomed to running may find the given speed more challenging exercising above VT. The authors also suggested that by comparing athletes at the same absolute speed, some may find the speed appreciably lower than a typical training intensity; therefore faster runners may be less economical due to mechanical or neuromuscular factors.

To overcome this methodological error in the past literature the use of relative exercise intensities need to be addressed. To date very few studies have used relative exercise intensities to compare running economy between groups. Lambrick *et al.*, (2013 Unpublished Data), compared RE in normal weight (NW) and obese (OB) children for 6 minutes at both moderate (90% VT) and heavy (40% delta) exercise intensities, separated by 5 minutes of recovery. OB children displayed superior RE ~13-15% compared to NW ( $210 \pm 29$  cf.  $233 \pm 29$  ml·kg<sup>-1</sup>·km<sup>-1</sup> respectively). The OB subjects also displayed a lower  $\dot{V}O_2$ ·stride<sup>-1</sup> (mL·kg<sup>-1</sup>·stride<sup>-1</sup>) than NW. While not being statistically different, NW children exercised at a mean running speed of ~0.6 km·h<sup>-1</sup> greater than OB children (8.3 km·h<sup>-1</sup> cf. 7.7 km·h<sup>-1</sup>, respectively). More importantly, had both groups exercised at an absolute running speed of 8.3 km·h<sup>-1</sup>, OB subjects would have been exercising above GET (heavy intensity), while NW subjects would have been exercising at 90% GET (moderate intensity), therefore an inferior RE would have been expected from the OB subjects.

Mosses *et al.*, (2013) compared RE and body composition between competitive (CR) and recreational (RR) level distance runners. The subjects performed two 2000 m on an indoor running track while wearing a portable oxygen analyser at speeds representative of VT1 and VT2<sup>2</sup>. Running speed was monitored by maintaining the HR associated with the corresponding ventilatory thresholds. Recreational runners had a significantly higher total body fat mass (kg) and upper leg fat mass (kg). No significant differences were found between CR and RR for RE at VT1 ( $231.72 \pm 23.82$  &  $229.72 \pm 25.95$  mL·kg<sup>-1</sup>·km<sup>-1</sup> respectively) or VT2 ( $232.80 \pm 16.87$  &  $233.96 \pm 15.44$  mL·kg<sup>-1</sup>·km<sup>-1</sup> respectively). RE relative to fat free mass or per stride were not reported in this study. While there were significant differences in  $\dot{V}O_{2\max}$  (mL·kg·min<sup>-1</sup>) between groups, both were well above superior nature when compared to normative data (Thompson, Gordon, & Pescatello, 2010) showing that both groups were of a highly trained status. While no differences in RE were reported the performance of the elite runners was superior.

### ***2.5 Focus of the Study***

The primary focus of this study was to assess the effects of fitness and fatness on running economy. Previous research has clearly shown that normal weight fit or trained subjects display an enhanced RE compared to their lesser trained or untrained counterparts but have compared absolute running intensities between individuals and groups. Research has also shown that body mass can cause differences in exercise economy between normal weight and obese populations but these have been implemented at absolute rather than relative exercise intensities (Fletcher *et al.*, 2009).

To our knowledge no previous research has used obese adult male subjects with high levels of cardiovascular fitness to compare RE with normal weight unfit subjects. The notion

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<sup>2</sup> VT2 – Intensity that accompanies a second rise in ventilation

of an obese yet fit individual is not commonly thought of with one recent study among US adults reporting 8.9% meeting the criteria to be classified as fit and fat among a cohort of 4,675 adults (Duncan, 2010). Encouraging a focus on improving fitness rather than the modern day global obsession with weight loss, should be the target of allied health care professionals.

Normal weight healthy male subjects with no reported previous regular physical activity have not previously been researched in regards to RE when comparing obese fit subjects, with many studies comparing highly trained or elite vs. recreational athletes or no mention of activity levels or physiological variables of their untrained subjects. In the few studies that have compared RE in obese vs. normal weight individuals, predominantly unfit obese subjects have been used with little reporting on regular physical activity level or physiological variables in relation to fitness level.

Due to limitations in the previous research in RE the effects of specific exercise intensities still remains unclear. This study will aim to avoid this methodological concern by examining the effect of fitness and body mass on the exercise economy of individuals at relative [moderate (VT) and high (40%  $\Delta$ )] exercise intensities.

## **2.6 Hypothesis**

### *Null hypotheses:*

H0<sub>1</sub> There will be no difference in running economy between obese fit and normal weight unfit subjects

H0<sub>2</sub> There will be no differences in running economy between moderate and heavy intensity exercise

H0<sub>3</sub> There will be no differences in running economy at moderate and heavy intensity exercise, regardless of the study conditions (OBF or NWU).

### *Experimental Hypothesis:*

H1<sub>1</sub> The running economy of fit-obese individuals will be superior to that observed for unfit-normal weight individuals

H1<sub>2</sub> The running economy elicited during moderate intensity exercise will be superior to heavy intensity exercise

H1<sub>3</sub> There will be a superior running economy at moderate intensity exercise, compared to heavy intensity exercise regardless of the study conditions (fit-obese & unfit-normal weight).

### 3. Method

#### **3.1 Participants**

Twelve normal weight but unfit (NWU) subjects ( $38.2 \pm 9.1$  y;  $179.9 \pm 5.2$  cm;  $77.3 \pm 6.4$  kg;  $24.0 \pm 1.3$  kg·m<sup>-2</sup>;  $16.3 \pm 18.3$  %BF) and eleven obese and fit (OBF) males ( $38.5 \pm 6.0$  y;  $176.2 \pm 7.2$  cm;  $103.8 \pm 8.0$  kg;  $33.3 \pm 2.2$  kg·m<sup>-2</sup>;  $16.3 \pm 29.2$  %BF) volunteered for the study. Normal weight was classified as a Body Mass Index (BMI) between 18.5 and 25 kg·m<sup>-2</sup>, while obese subjects represented a BMI between  $> 30$  kg·m<sup>-2</sup> (class I & II obese). Unfit males were classified by not meeting the ACSM recommendations for healthy adults of physical activity for 30 minutes, 5 days a week over the last 6 months (Haskell et al., 2007). Regular walking was not classified as being physically active. Fit males were categorised as being physically active, taking part in at least 20 minutes of regular, vigorous exercise on at least 3 occasions per week over the last 6 months (Haskell et al., 2007). All subjects were free from orthopaedic complications, metabolic and cardio respiratory disorders, and provided informed consent to participate in the study (Appendix B). Prior to initial physical testing, participants completed a pre exercise health questionnaire (Appendix C) and an ACSM (2010) coronary artery disease (CAD) risk stratification assessment (Appendix D) which included the following measures; blood glucose, blood lipid profile (total cholesterol, high-density lipoproteins), blood pressure, smoking history and family history of cardiovascular diseases. If two or more high risk factors were identified, the subject was able to take part in the study following GP referral (Appendix E). If abnormally high risk factors (i.e. hypertension  $\geq$  Stage 1) were identified from the CAD risk stratification measures, in accordance with the ACSM (2010) guidelines, participants were not eligible to participate in the study. The study was conducted following ethical approval from the Central Regional Ethics Committee (Appendix A).

### 3.2 Procedure

Participants took part in three treadmill based exercise tests within a thermo-neutral laboratory environment (temperature  $20.9 \pm 2.1$  °C, humidity  $39.6 \pm 11.3\%$  and pressure  $788.1 \pm 26.3$  mmHg). All tests were performed with a minimum of 72 hours recovery between consecutive tests. All subjects were advised of no vigorous exercise 24 hours prior to testing, no energy consumption 90 minutes before testing and no caffeinated drinks on the day of testing. These tests included an exercise ECG stress test, a graded exercise test to 85% of age-predicted maximal HR and a sub-maximal exercise test to assess each participant's running economy at a moderate and heavy exercise intensity. Anthropometric data were collected at the initial session including; standing height, measured to the nearest 0.1cm (SECA, Hamburg, Germany), body weight measured to the nearest 0.1kg and body fat percentage measured via bioelectrical impedance analysis (BIA) (Tanita, Bc-533 innerScan, Tokyo, Japan). Waist and hip girth measurements were also taken in accordance with ISAK guidelines (Lufkin W606PM, Apex Tools Group, Maryland, USA). During the graded exercise test (GXT) and RE tests, the treadmill (True 825, Fitness Technologies, St Louis, USA) was set at 1% incline throughout the testing procedure to reflect the energetic cost of outdoor running (Jones & Doust, 1996). During the GXT and RE tests, participants wore a facemask to allow respiratory variables; oxygen uptake ( $\dot{V}O_2$ ), carbon dioxide ( $\dot{V}CO_2$ ), minute ventilation ( $\dot{V}_E$ ) and RER to be recorded throughout each stage. On-line respiratory gas analysis occurred via a breath-by-breath automatic gas exchange system (SensorMedics, Corporation, Yorba Linda, CA, USA) and then binned into 10 second data points. Volume and gas calibration were performed in accordance with manufacturer's guidelines prior to the start of each test. Gas calibrations against known quantities of gas (4% carbon dioxide, 16% oxygen) were implemented to produce a <1% error. Criteria for termination of the tests were 85% max HR in the first instance or volitional exhaustion.

### 3.2.1 Exercise ECG

To determine a participant's suitability to take part in the GXT and RE tests, each participant completed a peak and/or symptom limited exercise ECG using the modified Bruce protocol <sup>3</sup> (Thompson, Gordon, & Pescatello, 2009). The test was terminated when the participant reached a heart rate equivalent to 85% of age-predicted maximum, if the participant reported volitional exhaustion, or if specific physiological responses were observed from the exercise ECG trace (i.e., ST depression of 2 mm, frequent premature ventricular contractions). The participant's heart rate and ECG were continuously recorded, while blood pressure and perceived exertion, using the Borg 6-20 RPE scale (Borg, 1998) were obtained in the final 30 s of each 3-min stage of the exercise test. Heart rate was monitored using an ECG trace (Schiller, USA). On completion of the test, participants completed a 3-min active recovery at a low-intensity (equivalent to stage 1 of the exercise test), before having a post-exercise ECG and blood pressure assessment. Heart rate (ECG, heart rate monitors & pulse rate), were monitored at the completion of both of these stages. Further inclusion in the study required successful completion of the test to 85% of age-predicted maximum HR, with no cardiac or respiratory stress contraindications.

### 3.2.2 Sub-Maximal Graded Exercise Test to Predict Maximal Functional Capacity

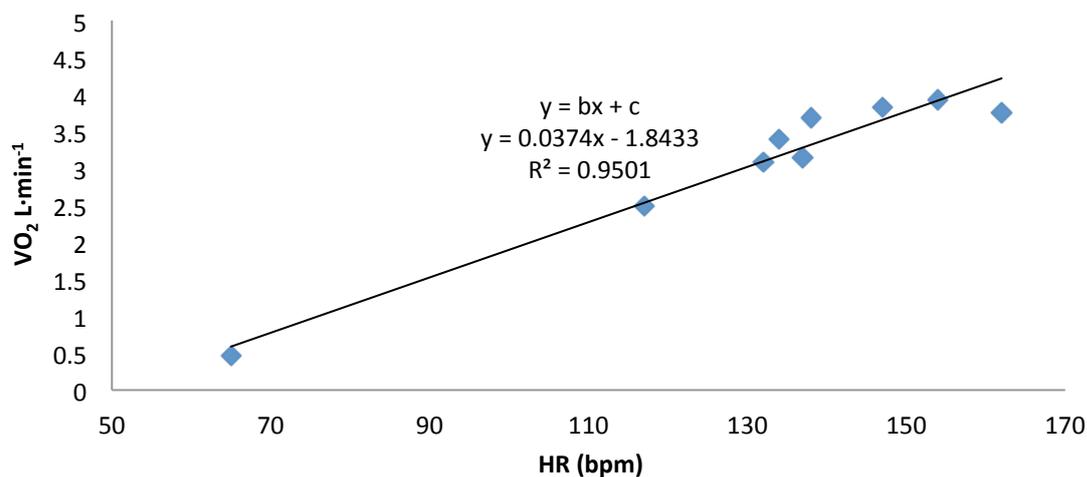
The submaximal GXT was used to: i) predict each individual's maximal functional capacity (i.e. maximal oxygen uptake:  $\dot{V}O_2\text{max}$ ), and ii) determine individual ventilatory thresholds (VT). Prior to commencing the test, participants were familiarised with a range of speeds (4-10 km·h<sup>-1</sup>) varying depending on the subject to reflect running and walking on the treadmill. This test was continuous and incremental, commencing at a speed deemed

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<sup>3</sup> Modified Bruce Protocol, 3 minute stages on a motorized treadmill, Stage 1: 2.74 km·hr<sup>-1</sup> 0% incline, Stage 2: 2.74 km·hr<sup>-1</sup> 5% incline, Stage 3: 2.74 km·hr<sup>-1</sup> 10% incline, Stage 4: 4.02 km·hr<sup>-1</sup> 12% incline, Stage 5: 5.47 km·hr<sup>-1</sup> 14% incline, Stage 6: 6.76 km·hr<sup>-1</sup> 16% incline, Stage 7: 8.05 km·hr<sup>-1</sup> 18% incline.

appropriate to allow an anticipated duration of between 8-12 minutes as determined during the exercise ECG walking test and familiarisation. This was approximately 6-10 km·h<sup>-1</sup> depending on fitness level and prior running experience among participants. The speed of the treadmill was increased by either 0.2 km·h<sup>-1</sup> every 30 seconds or 0.1 km·h<sup>-1</sup> every 20 seconds depending on the initial HR response to running. The aim of this varied protocol was to ensure each subject reached 85 % of their age predicted maximal heart rate in approximately 8-12 minutes. Heart rate (Polar Electro T31, Kempele, Finland) and oxygen uptake were continuously recorded throughout the GXT. Perceived exertion (Borg 6-20 RPE scale) was recorded every two minutes.

The results from the GXT were used to determine each individual's predicted absolute  $\dot{V}O_{2\max}$  (L·min<sup>-1</sup>). Using linear regression analysis ( $y = bx + c$ ); whereby  $y$  is the  $\dot{V}O_{2\max}$ ,  $b$  is the slope of the heart rate versus oxygen uptake regression line,  $x$  is the subject age predicted maximal heart rate (220-age), and  $c$  is the constant, a predicted  $\dot{V}O_{2\max}$  was obtained for each individual subject (Figure 3.1). Absolute values were then adjusted for body mass (kg) to obtain a relative  $\dot{V}O_{2\max}$  (mL·kg<sup>-1</sup>·min<sup>-1</sup>) and  $\dot{V}O_{2\max}$ -Fat Free Mass (mL·FFM<sup>-1</sup>·min<sup>-1</sup>).  $\dot{V}O_{2\text{peak}}$  (L·min<sup>-1</sup>) was recorded as the highest value obtained during the GXT.



**Figure 3.1** Example of the linear regression used to determine individual  $\dot{V}O_{2\max}$  ( $L \cdot \text{min}^{-1}$ )

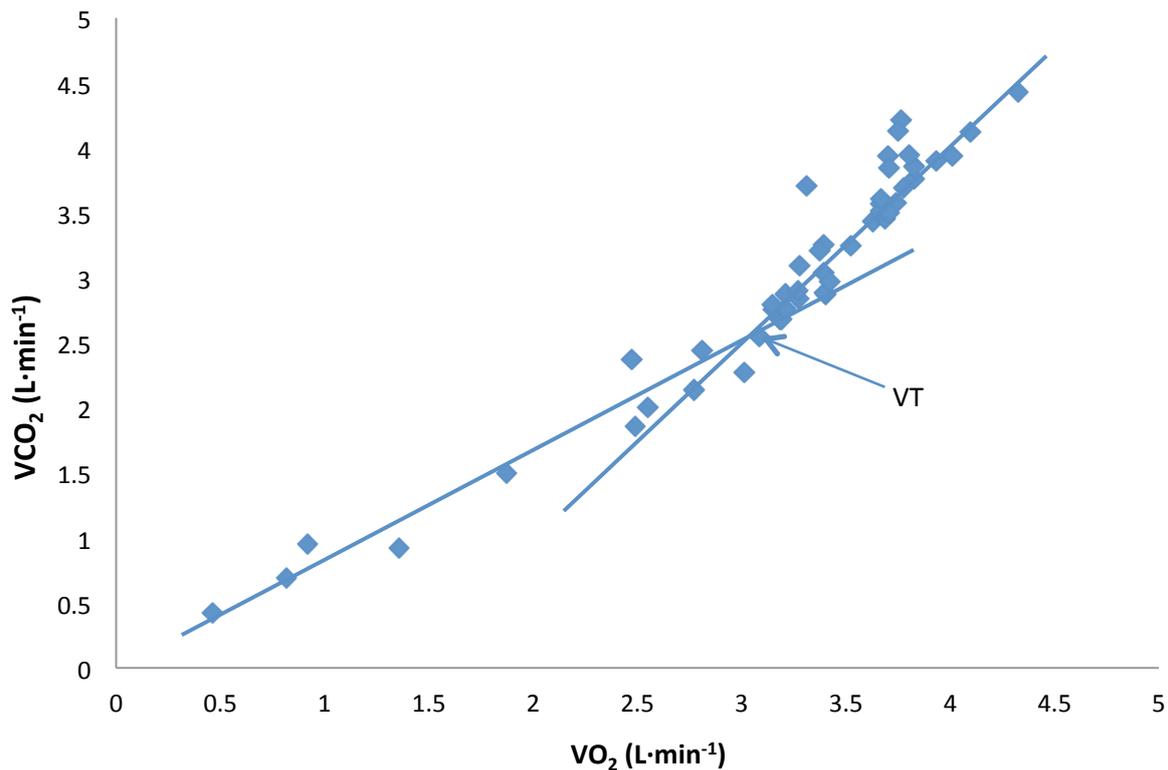
### 3.2.3 Calculating Moderate (VT) and Heavy (40% $\Delta$ ) Intensities for Submaximal Test

The V-Slope method (Beaver, Wasserman & Whipp, 1986) was used in this study with data from the GXT to plot  $\dot{V}CO_2$  ( $L \cdot \text{min}^{-1}$ ) over  $\dot{V}O_2$  ( $L \cdot \text{min}^{-1}$ ) (Figure 3.2). The V-slope method was used as a non-invasive estimate of individual lactate thresholds. The point identified as VT represents an incremental rise in  $\dot{V}CO_2$  ( $L \cdot \text{min}^{-1}$ ) as the result of lactic acid accumulation and a shift from aerobic to anaerobic metabolism. This shift signifies a change from a moderate to heavy exercise intensity. The corresponding  $\dot{V}O_2$  at VT was used as a reference point to determine the running speed associated with VT. 40%  $\Delta$  was calculated as the difference between VT and predicted absolute  $\dot{V}O_{2\max}$  ( $L \cdot \text{min}^{-1}$ ).

$$40\% \Delta = ((\dot{V}O_{2\max} - \dot{V}O_2 @ \text{VT}) \times 0.40) + \dot{V}O_2 @ \text{VT}$$

The corresponding  $\dot{V}O_2$  at 40%  $\Delta$  was used to determine the running speed associated with 40%  $\Delta$ . These intensities were chosen to reflect moderate and heavy metabolic work rates and to ensure each participant exercised at equivalent relative exercise intensities when comparing RE. The speeds were assessed by associating the corresponding  $\dot{V}O_2$  at VT and

40%  $\Delta$  for each individual by two researchers and used for the subsequent exercise economy tests.



**Figure 3.2** Example of the V-slope method used to determine VT.

#### 3.2.4 Submaximal Exercise Economy Test

To assess RE, participants exercised at three different speeds. A standardised warm-up of treadmill walking at  $5\text{km}\cdot\text{h}^{-1}$  was performed across all subjects for 6 minutes. The other two speeds to assess RE, equivalent to the individuals VT and 40%  $\Delta$ , were also assessed for 6 minutes to ensure that the oxygen cost for a given running velocity was at a steady-state oxygen consumption. To obtain baseline levels ( $\dot{V}\text{O}_2$ ,  $\dot{V}\text{CO}_2$ ,  $\dot{V}_E$ , RER and HR) 5 minutes of stationary standing occurred prior to the warm up and each RE trial. Respiratory variables ( $\dot{V}\text{O}_2$ ,  $\dot{V}\text{CO}_2$ ,  $\dot{V}_E$ , and RER) were monitored breath by breath throughout the testing and binned every 10 seconds for statistical analysis. HR was recorded during each minute at every stage. Blood lactate was measured prior-to and following each exercise stage. RPE

(Borg 6-20 RPE scale; Borg, 1998) was recorded at 3 minutes and at the completion of each exercise stage. Stride rate was recorded for 30 seconds midway (3 minute) and at the end of each exercise stage.

### 3.3 Data Analyses

#### 3.2.1 $\dot{V}O_2$ Values Used in Statistical Analysis

Sub-maximal  $\dot{V}O_2$  values were reported as the net difference in  $\dot{V}O_2$  between the actual  $\dot{V}O_2$  reported during VT and 40% delta, and the resting  $\dot{V}O_2$  values prior to each exercise intensity. Oxygen consumption values were expressed relative to body mass ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), in proportion to fat-free mass ( $\text{mL}\cdot\text{FFM}^{-1}\cdot\text{min}^{-1}$ ), and in relation to stride frequency ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{stride}^{-1}$ ). This is in accordance with previous research (Ayub & Bar-Or, 2003; Lambrick et al., 2013 Unpublished Data).

#### 3.3.2 Calculation of RE.

The effect of body mass on RE was calculated for each exercise intensity (VT & 40%  $\Delta$ ) using the following equation (Bassett & Howley, 2000; Foster & Lucia, 2007).

$$\text{Running economy (ml}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}) = \frac{\dot{V}O_2 (\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1})}{[(\text{speed (km}\cdot\text{h}^{-1}) \text{ at VT \& 40\% } \Delta)/60]}$$

Although RE may also be expressed in relation to the mass specific energy expenditure ( $\text{J}\cdot\text{kg}^{-1}\cdot\text{m}^{-1}$ ) (Weyand et al., 2010, Browning et al., 2013) In the present study RE was measured as the mass specific oxygen uptake required for a submaximal exercise intensity ( $\text{ml}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$ ) and is commonly applied in the literature (Conley & Krahenbuhl, 1980, Mooses et al., 2013, Lambrick et al., 2013 Unpublished Data)

### 3.3.3 Statistical Analysis

Independent sample *t* tests were used to compare the following anthropometric measures; height, weight, BMI, %BF, waist and hip girth, between BMI conditions (NWU, OBF). Levene's test for equality of variance was used to assess the variance in values between Conditions. A similar analysis was conducted to assess CAD (DSP, SBP, TC, HDL, TC:HDL & BG)<sup>4</sup>, physiological ( $\dot{V}\text{O}_2$ ,  $\dot{V}\text{CO}_2$ ,  $\dot{V}_E$ , RER, HR, & Bla) and perceptual (RPE) markers on completion of the GXT, and the running speeds at VT and 40%  $\Delta$  between Conditions were also analysed. The effects of groups (OBF vs NWU) on anthropometric, CAD and GXT variables were tested using independent sample *t* test for equality of means.

A series of two-way repeated measure ANOVA's: Intensity (VT and 40%  $\Delta$ ) by Condition (NWU, OBF), were conducted to compare running economy and physiological ( $\dot{V}\text{O}_2$ ,  $\dot{V}\text{CO}_2$ ,  $\dot{V}_E$ , RER, HR, & Bla), perceptual (RPE) and physical (stride frequency) responses during from the submaximal test between NWU and OBF participants. In the preceding analyses, if Mauchly's test of sphericity was violated a Greenhouse-Geisser correction factor was employed. Where a significant interaction was located, a Tukeys honestly significant difference (HSD) test was implemented. The Tukeys HSD calculates the minimum raw score mean difference that must be attained to declare significance between any two groups

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<sup>4</sup> DSP – Diastolic Blood Pressure, SBP – Systolic Blood Pressure, TC – Total Cholesterol, HDL – High Density Lipoprotein, TC:HDL – Ratio of TC to HDL, BG – Blood Glucose

(Vincent, 1999). Alpha was set at 0.05. All data were analysed using the statistical package SPSS for Windows, PC software, version 20.0.

## 4. Results

### 4.1. Anthropometric

Descriptive information for NWU and OBF are presented in Table 4.1. Significant differences were found for body mass ( $t_{(21)} = 8.8$ ,  $P < 0.001$ ), BMI ( $t_{(16)} = 12.2$ ,  $P < 0.001$ ), % BF ( $t_{(21)} = 6.7$ ,  $P < 0.001$ ), waist ( $t_{(21)} = 8.2$ ,  $P < 0.001$ ), hip ( $t_{(21)} = 5.4$ ,  $P < 0.001$ ) and fat-free mass ( $t_{(21)} = 0.09$ ,  $P < 0.001$ ), with OBF eliciting greater values for each of the measures compared to NWU. There were no significant differences for age and height between conditions ( $P > 0.05$ ).

**Table 4.1** Descriptive data for NWU and OBF males.

	NWU (n =12)	OBF (n = 11)
<b>Age (years)</b>	38.2 ± 9.1	38.5 ± 6.0
<b>Height (m)</b>	1.79 ± 0.05	1.76 ± 0.07
<b>Body Mass (kg)</b>	77.3 ± 6.4	103.8 ± 8.0*
<b>BMI (kg·m<sup>-2</sup>)</b>	24.0 ± 1.3	33.3 ± 2.2*
<b>Body Fat (%)</b>	18.3 ± 2.9	29.2 ± 4.8*
<b>Waist (cm)</b>	84.3 ± 6.7	107.3 ± 6.7*
<b>Hip (cm)</b>	93.7 ± 7.9	108.9 ± 5.1*
<b>Fat Free Mass (kg)</b>	61.0 ± 4.8	70.3 ± 5.4*

\*Significant difference between BMI conditions ( $P < 0.001$ ) Values are Mean ± SD

### 4.2 Coronary Artery Disease risk factors

CAD risk factor information for NWU and OBF is presented in Table 4.2. Significant differences were found between diastolic blood pressure (DBP) ( $t_{(21)} = 2.5$ ,  $P < 0.05$ ), systolic blood pressure (SBP) ( $t_{(21)} = 2.4$ ,  $P < 0.05$ ), high density lipoprotein (HDL) ( $t_{(21)} = -2.7$ ,  $P <$

0.05), and total cholesterol to HDL ratio (TC:HDL) ( $t_{(14.1)} = 2.2$ ,  $P < 0.05$ ). No significant differences were found between TC and Blood Glucose ( $P > 0.05$ ).

**Table 4.2** Coronary artery disease risk factors for NWU and OBF males.

	NWU	OBF
<b>DBP (mmHg)</b>	81.3 ± 6.2	88.5 ± 7.5*
<b>SBP (mmHg)</b>	126 ± 11	137 ± 12*
<b>TC (mmol·L<sup>-1</sup>)</b>	4.4 ± 0.9	4.6 ± 1.0
<b>HDL (mmol·L<sup>-1</sup>)</b>	1.2 ± 0.2	1.0 ± 0.2*
<b>TC:HDL Ratio</b>	3.7 ± 0.9	5.0 ± 1.8*
<b>Blood Glucose (mmol·L<sup>-1</sup>)</b>	5.6 ± 0.9	5.0 ± 0.7
<b>Smoking Status</b>	n = 4 (33%)	n = 0

\*Significantly different between BMI conditions ( $P < 0.05$ ). Values are Mean ± SD

A total of 25 people were considered for inclusion in the study. All subjects were presenting with at least on CAD risk factor (Obese or Sedentary) as required for eligibility in the study. Two subjects were excluded due to abnormally high CAD risk factors. Following the CAD risk assessment, 23 were eligible for further participation on to the GXT. Four subjects presented with two or more risk factors with GP referral allowing further participation in the study.

### 4.3 GXT

Table 4.3 displays the final stage physiological variables during the GXT to 85% HR<sub>max</sub>. Significant differences were observed between groups for  $\dot{V}O_{2peak}$  (L·min<sup>-1</sup>) ( $t_{(21)} = 4.7$ ,  $P < 0.05$ ), age predicted absolute  $\dot{V}O_{2max}$  (L·min<sup>-1</sup>) ( $t_{(21)} = 4.4$ ,  $P < 0.05$ ),  $\dot{V}O_{2max}^{FFM}$  (mL·FFM<sup>-1</sup>·min<sup>-1</sup>) ( $t_{(21)} = 2.7$ ,  $P < 0.05$ ), peak speed ( $t_{(21)} = 3.3$ ,  $P < 0.05$ ) and  $\dot{V}_E$  (L·min<sup>-1</sup>)

( $t_{(21)} = 2.7$ ,  $P < 0.05$ ), with OBF having higher values in the final stage of the GXT. No significant differences were found in GXT duration (minutes), relative  $\dot{V}O_{2\max}$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), HR,  $R^2$ , RER, RPE,  $\text{BLa}_{\text{peak}}$  and  $\text{BLa}_{\text{rest}}$  between conditions in the final stage of the GXT ( $P > 0.05$ ; Table 3).

**Table 4.3** Final stage physiological variables to 85%  $\text{HR}_{\max}$ .

	NWU	OBF
<b>GXT Duration (minutes)</b>	9.6 ± 2.3	10.8 ± 3.0
$\dot{V}O_{2\max}$ ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) (relative)	44.4 ± 6.4	45.4 ± 6.9
$\dot{V}O_{2\max}^{\text{FFM}}$ ( $\text{mL}\cdot\text{FFM}^{-1}\cdot\text{min}^{-1}$ )	56.3 ± 8.5	67.1 ± 10.5*
$\dot{V}_E$ ( $\text{L}\cdot\text{min}^{-1}$ )	81.9 ± 19.9	101.8 ± 14.9*
<b>RER</b>	1.00 ± 0.05	1.02 ± 0.06
<b>RPE</b>	15.0 ± 1.2	16.1 ± 1.4
<b>HR max (<math>\text{b}\cdot\text{min}^{-1}</math>)</b>	180.5 ± 6.3	180.3 ± 4.3
<b>Peak Speed (<math>\text{km}\cdot\text{h}^{-1}</math>)</b>	9.7 ± 1.1	11.2 ± 1.1*
<b><math>\text{BLa}_{\text{rest}}</math> (<math>\text{mmol}\cdot\text{L}</math>)</b>	1.6 ± 0.4	1.7 ± 0.7
<b><math>\text{BLa}_{\text{peak}}</math> (<math>\text{mmol}\cdot\text{L}</math>)</b>	5.4 ± 2.3	5.7 ± 2.1

\*Significantly different between BMI conditions ( $P < 0.05$ ) Values are Mean ± SD

#### 4.3.1 Physiological markers at moderate (VT) and high intensity (40% $\Delta$ ) obtained from the GXT.

Physiological variables at VT & 40%  $\Delta$  for NWU and OBF are presented in Table 4.4. Significant differences were found in absolute  $\dot{V}O_2$  ( $\text{L}\cdot\text{min}^{-1}$ ) ( $t_{(21)} = 3.3$ ,  $P > 0.05$ ), running speed ( $\text{km}\cdot\text{h}^{-1}$ ) ( $t_{(21)} = 3.3$ ,  $P > 0.001$ ) and ventilation ( $\text{L}\cdot\text{min}$ ) ( $t_{(21)} = 2.1$ ,  $P > 0.05$ ) at VT & 40%  $\Delta$ . OBF individuals elicited higher running speeds at both VT & 40%  $\Delta$ , higher absolute

$\dot{V}O_2$  ( $L \cdot \text{min}^{-1}$ ) and higher ventilation ( $L \cdot \text{min}^{-1}$ ) Independent t-tests showed no differences in relative  $\dot{V}O_2$ , RER and HR between BMI conditions during the GXT ( $P > 0.05$ ; Table 4.4).

**Table 4.4** Physiological variables at VT & 40%  $\Delta$  obtained from the GXT.

	NWU		OBF	
	VT	40% $\Delta$	VT	40% $\Delta$
Speed ( $\text{km} \cdot \text{h}^{-1}$ )	7.6 $\pm$ 0.6	8.8 $\pm$ 1.0	8.5 $\pm$ 0.8*	10.1 $\pm$ 1.0**
$\dot{V}O_2$ ( $L \cdot \text{min}^{-1}$ )	2.4 $\pm$ 0.4	2.8 $\pm$ 0.5	3.1 $\pm$ 0.4*	3.7 $\pm$ 0.5*
$\dot{V}O_2$ ( $\text{ml} \cdot \text{kg} \cdot \text{min}^{-1}$ )	30.6 $\pm$ 4.5	35.8 $\pm$ 4.7	29.1 $\pm$ 4.0	33.0 $\pm$ 10.8
$V_E$ ( $L \cdot \text{min}$ )	57.7 $\pm$ 13.7	72.9 $\pm$ 16.3	68.9 $\pm$ 11.2*	88.8 $\pm$ 12.5*
RER	0.92 $\pm$ 0.07	0.97 $\pm$ 0.05	0.87 $\pm$ 0.06	0.94 $\pm$ 0.05
HR ( $\text{b} \cdot \text{min}^{-1}$ )	139 $\pm$ 7	156 $\pm$ 7	139 $\pm$ 11	155 $\pm$ 9

\*Significantly different between BMI conditions ( $P < 0.05$ ). Values are Mean  $\pm$  SD

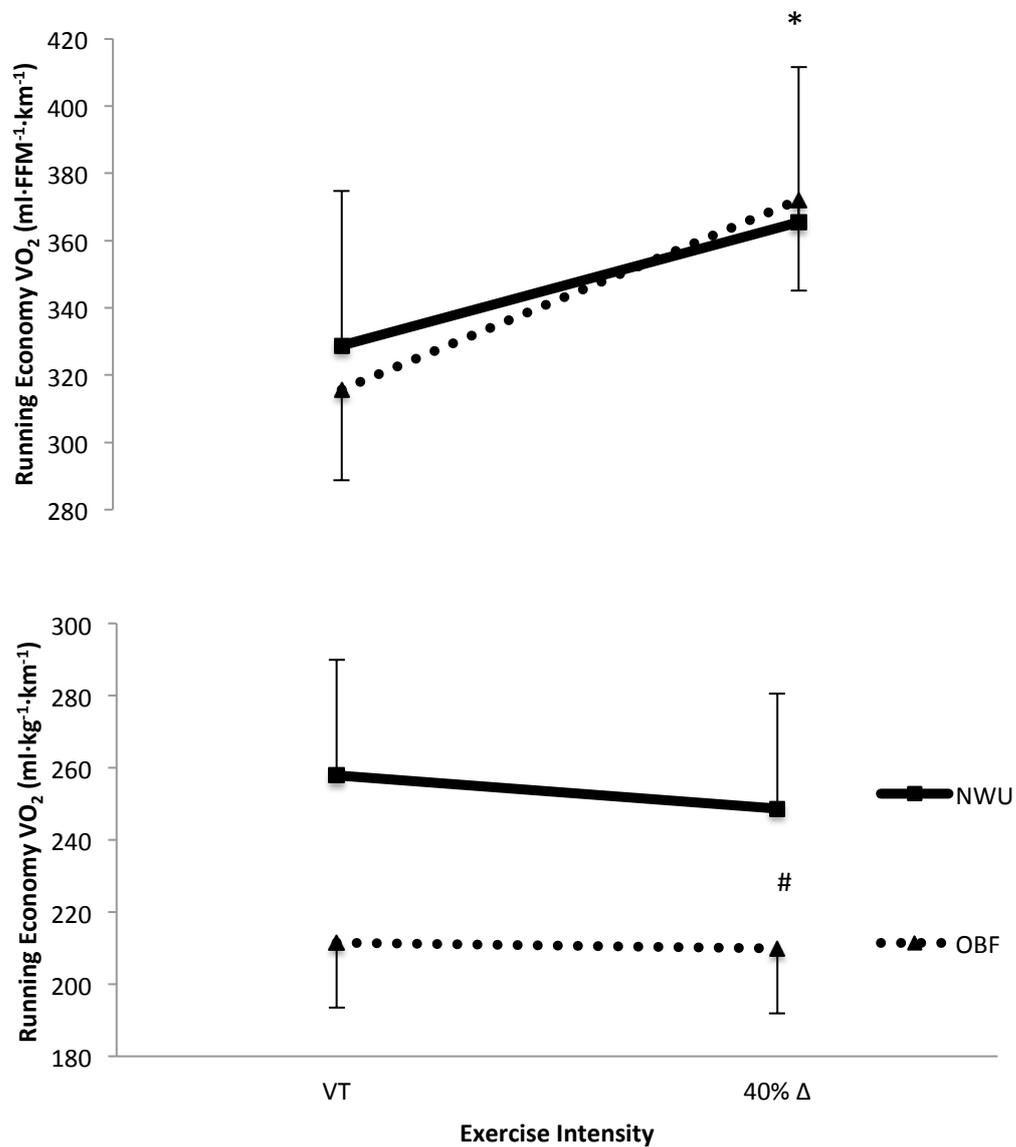
\*\*Significantly different between BMI conditions ( $P < 0.01$ )

#### 4.4 Constant Load Running Economy Test

##### 4.4.1 Running Economy

A significant Condition ( $F_{(1,21)} = 14.9$ ,  $P < 0.01$ ) main effect was observed when assessing RE  $\text{mL} \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$  (Figure 4.1). RE was lower in OBF than in NWU males ( $210.0 \pm 8.0$  &  $253.2 \pm 7.6$   $\text{mL} \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$  respectively). There were no Intensity main effects or Intensity by Condition interactions when RE was expressed relative to body mass  $\text{mL} \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$  ( $P > 0.05$ ). There was a significant intensity ( $F_{(1,21)} = 1957.9$   $P < 0.001$ ) main effect when RE was expressed relative to FFM with a superior RE reported at VT compared to 40%  $\Delta$  ( $322.3 \pm 7.3$  &  $368.8 \pm 8.9$   $\text{ml} \cdot \text{FFM}^{-1} \cdot \text{km}^{-1}$  respectively; (Figure 4.1). There were no

Condition main effects or Intensity by Condition interactions when RE was expressed relative to fat free mass ( $\text{mL} \cdot \text{FFM}^{-1} \cdot \text{km}^{-1}$ ) ( $P > 0.05$ ).



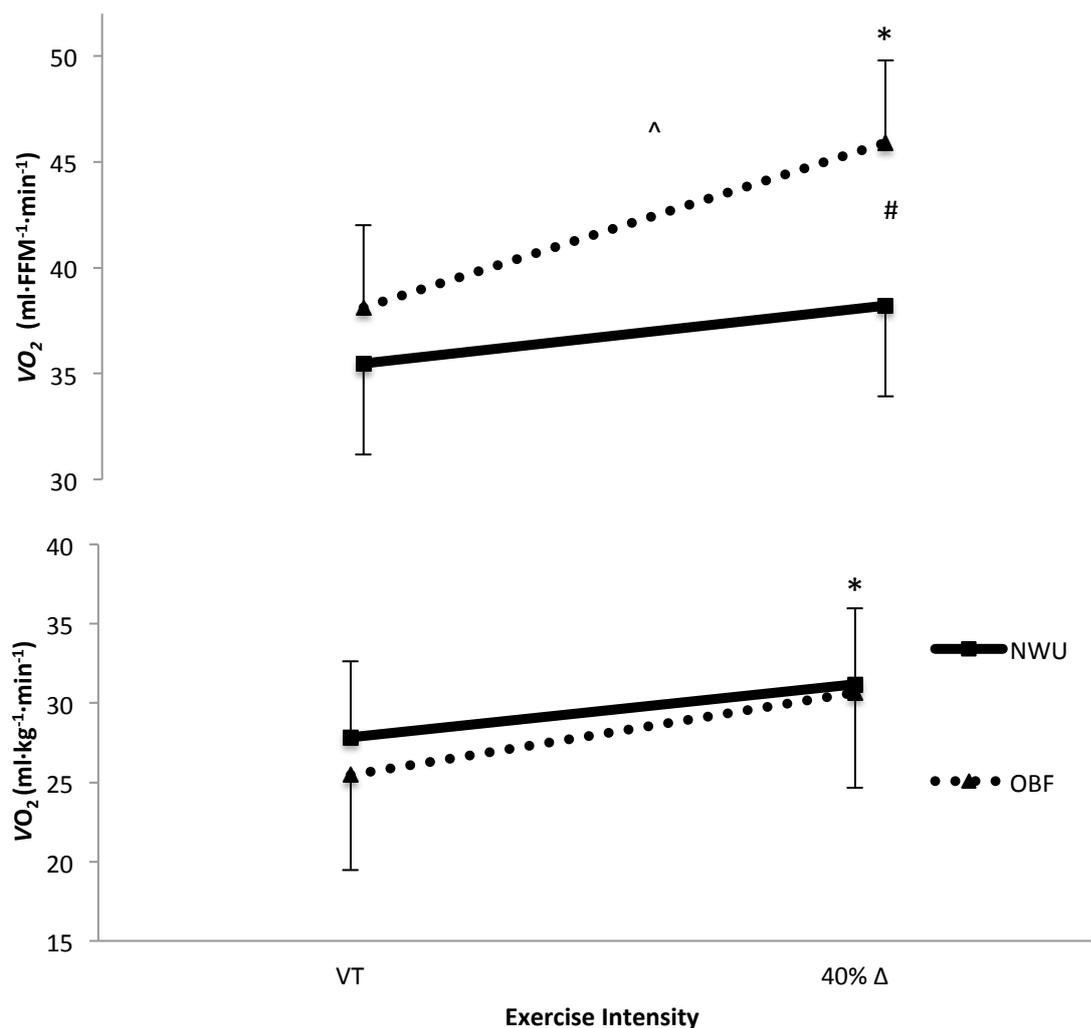
**Figure 4.1** Running Economy between NWU (solid line) and OBF (dashed line) males at VT and 40%  $\Delta$ .

\*Significant intensity main effect ( $P < 0.001$ )

#Significant Condition main effect ( $P < 0.01$ )

#### 4.4.2 Physiological marker; $\dot{V}O_2$

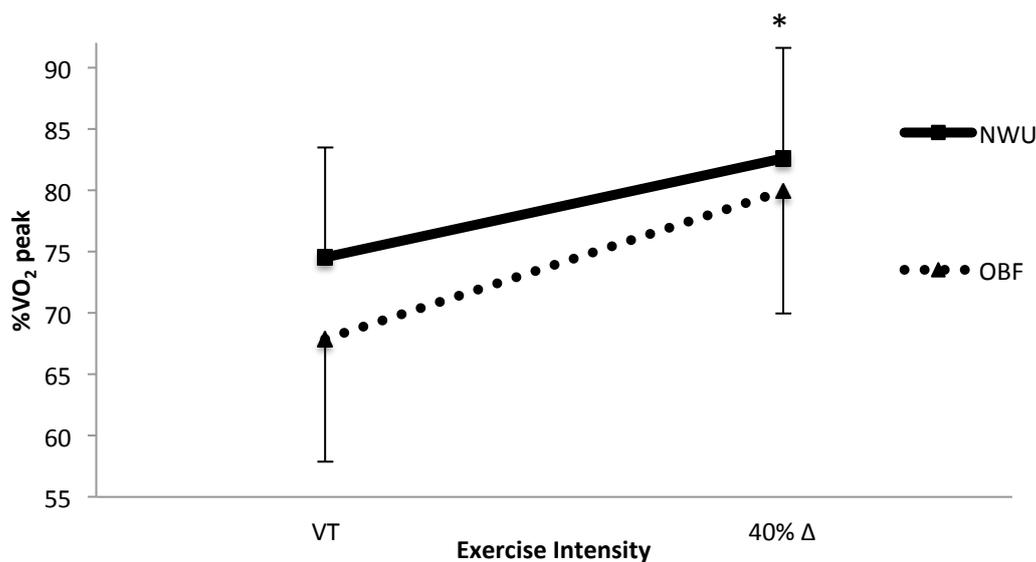
An Intensity by Condition interaction was found for  $\dot{V}O_2^{\text{FFM}}$  ( $\text{mL}\cdot\text{FFM}^{-1}\cdot\text{min}^{-1}$ ) ( $F_{(1,21)} = 9.2$   $P < 0.05$ ) (Figure 4.2). Post-hoc analysis demonstrated that the rate of change in  $\dot{V}O_2^{\text{FFM}}$  from VT to 40%  $\Delta$  was statistically higher in OBF ( $38.1 \pm 1.3$  &  $45.9 \pm 1.7$   $\text{mL}\cdot\text{FFM}^{-1}\cdot\text{min}^{-1}$  respectively) compared to NWU ( $35.5 \pm 1.2$  &  $38.2 \pm 1.6$   $\text{mL}\cdot\text{FFM}^{-1}\cdot\text{min}^{-1}$  respectively). When  $\dot{V}O_2$  values were expressed relative to total body mass ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), a significant intensity ( $F_{(1,21)} = 23.5$   $P < 0.001$ ) main effect was found with  $\dot{V}O_2$  significantly lower at VT compared to 40%  $\Delta$  ( $26.7 \pm 3.3$  &  $30.7 \pm 4.1$   $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$  respectively). No significant differences were found between the Conditions (Figure 4.2) ( $P > 0.05$ ). No significant Condition by Intensity interactions were found for relative  $\dot{V}O_2$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) ( $P > 0.05$ ).



**Figure 4.2**  $\dot{V}O_2$  ( $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) &  $\dot{V}O_2^{\text{FFM}}$  ( $\text{mL} \cdot \text{FFM}^{-1} \cdot \text{min}^{-1}$ )  
 \*Significant Intensity main effect ( $P < 0.001$ )  
 #Significant Condition main effect ( $P < 0.001$ )  
 ^ Significant interaction (Intensity x Condition) ( $P < 0.01$ )

#### 4.4.3 Physiological marker; percent of $\dot{V}O_2$

As expected, an intensity main effect was observed for percent  $\dot{V}O_2$  ( $F_{(1,21)} = 71.2$   $P < 0.001$ ) with a lower value reported at VT compared to 40%  $\Delta$  ( $71.2 \pm 2.1$  &  $81.3 \pm 2.3\%$ , respectively). While not significant between conditions, NWU worked at a higher percent  $\dot{V}O_2$  at both intensities, with only small differences between groups ( $73.9 \pm 3.1$  &  $78.5 \pm 3.0$  respectively) ( $P > 0.05$ ).



**Figure 4.3** Percent  $\dot{V}O_2$  at VT and 40%  $\Delta$  between OBF and NWU groups.

\* Significant Intensity main effect ( $P < 0.001$ )

#### 4.4.3 Physiological & perceptual markers; $\dot{V}_E$ , RER, HR, Bla and RPE

As expected, two-way ANOVA's revealed significant intensity main effects for HR ( $F_{(1,21)} = 174.6$   $P < 0.001$ ),  $\dot{V}_E$  ( $F_{(1,21)} = 100.28$   $P < 0.001$ ),  $RPE_{20}$  ( $F_{(1,21)} = 83.1$   $P < 0.001$ ) and BLa ( $F_{(1,21)} = 26.5$   $P < 0.001$ ), with lower values at VT compared to 40%  $\Delta$  (Table 4.5). RER was approaching significance ( $P = 0.058$ ). There were no Condition main effects or Intensity by Condition interactions found for all aforementioned variables.  $\dot{V}_E$  was approaching significance for a condition effect ( $P = 0.06$ ).

**Table 4.5** Various physiological parameters between NWU and OBF males at VT and 40%  $\Delta$ 

	NWU		OBF	
	VT	40% $\Delta$	VT	40% $\Delta$
<b>HR (b·min<sup>-1</sup>)</b>	147 ± 10	162 ± 11**	139 ± 9	154 ± 11**
<b>V<sub>E</sub> (L·min)</b>	63.5 ± 12.1	75.2 ± 13.9**	72.0 ± 12.4	86.8 ± 13.4**
<b>RER</b>	0.96 ± 0.04	0.97 ± 0.07	0.92 ± 0.05	0.95 ± 0.07
<b>RPE</b>	12.8 ± 1.5	14.3 ± 1.9**	12.5 ± 0.8	14.6 ± 1.1**
<b>BLa (mmol·L<sup>-1</sup>)</b>	3.5 ± 1.4	4.4 ± 1.9**	2.8 ± 1.4	4.5 ± 2.4**

\* Significant Intensity main effect ( $P < 0.05$ ). Values are Mean ± SD

\*\*Significant Intensity main effect ( $P < 0.001$ )

#### 4.5 Stride frequency and $\dot{V}O_2$ per stride

There was a significant Intensity ( $F_{(1,21)} = 80.3$   $P < 0.001$ ) main effect for SF ( $77.1 \pm 1.0$  &  $80.7 \pm 1.1$ ), with more strides taken at 40%  $\Delta$  compared to VT. No Condition main effect or Intensity by Condition interactions were found for SF ( $P > 0.05$ ). An Intensity main effect was found for relative  $\dot{V}O_2$  per stride ( $\text{mL} \cdot \text{kg}^{-1} \cdot \text{stride}^{-1}$ ) ( $F_{(1,21)} = 32.5$   $P < 0.001$ ), with  $\dot{V}O_2$  per Stride lower at VT compared to 40%  $\Delta$  ( $0.41 \pm 0.01$  &  $0.45 \pm 0.01$   $\text{mL} \cdot \text{kg}^{-1} \cdot \text{stride}^{-1}$  respectively). No significant condition effect was found between OBF and NWU ( $0.4 \pm 0.02$  &  $0.45 \pm 0.02$   $\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  per stride respectively) ( $P > 0.05$ ).

An intensity main effect was found for relative  $\dot{V}O_2^{\text{FFM}}$  per stride ( $\text{mL} \cdot \text{FFM}^{-1} \cdot \text{stride}^{-1}$ ) ( $F_{(1,21)} = 38.1$   $P < 0.001$ ).  $\dot{V}O_2^{\text{FFM}}$  per stride was lower at VT compared to 40%  $\Delta$  ( $0.56 \pm 0.02$  &  $0.61 \pm 0.02$   $\text{mL} \cdot \text{FFM}^{-1} \cdot \text{stride}^{-1}$  respectively). An intensity by condition interaction was approaching significance ( $P = 0.056$ ). OBF subjects trending towards a greater rate of change in  $\dot{V}O_2^{\text{FFM}}$  per stride ( $\text{mL} \cdot \text{FFM}^{-1} \cdot \text{stride}^{-1}$ ) compared to NWU between VT and 40%  $\Delta$  (OBF

$0.57 \pm 0.02$  &  $0.64 \pm 0.02$  mL·FFM<sup>-1</sup>·stride<sup>-1</sup> and NWU  $0.56 \pm 0.02$  &  $0.59 \pm 0.02$  mL·FFM<sup>-1</sup>·stride<sup>-1</sup> respectively).

**Table 4.6** Stride Frequency and  $\dot{V}O_2$  per stride between NWU and OBF males at VT and 40%  $\Delta$ .

	NWU		OBF	
	VT	40% $\Delta$	VT	40% $\Delta$
<b>SF (steps)</b>	$78.7 \pm 3.3$	$82.7 \pm 3.5^*$	$75.4 \pm 6.1$	$78.8 \pm 6.3^*$
<b><math>\dot{V}O_2</math> per stride (ml·kg<sup>-1</sup>·stride<sup>-1</sup>)</b>	$0.38 \pm 0.05$	$0.43 \pm 0.06^*$	$0.44 \pm 0.08$	$0.46 \pm 0.08^*$
<b><math>\dot{V}O_2^{\text{FFM}}</math> per stride (ml·FFM<sup>-1</sup>·stride<sup>-1</sup>)</b>	$0.57 \pm 0.06$	$0.64 \pm 0.07^*$	$0.56 \pm 0.09$	$0.59 \pm 0.09^*$

\*Significant intensity main effect ( $P < 0.001$ ). Values are Mean  $\pm$  SD

## 5. Discussion

This study compared running economy between OBF and NWU males during relative moderate (VT) and high intensity (40%  $\Delta$ ) treadmill exercise. The main findings confirm the first study hypothesis (H1<sub>1</sub>). This study demonstrated that at relative exercise intensities, OBF individuals have a superior running economy relative to total body mass ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$ ) compared to NWU. The second hypothesis (H1<sub>2</sub>) that the RE elicited during moderate intensity exercise will be superior to heavy intensity exercise is rejected when expressed relative to total body mass. However this hypothesis remained true when RE was expressed relative to FFM with moderate intensity exercise eliciting a superior RE compared to the heavy exercise domain. Additionally, we fail to accept (H1<sub>3</sub>) that there would be superior (less) RE RE relative to total body mass at moderate compared to heavy intensity exercise regardless of the study conditions (fit-obese & unfit-normal weight).

The superior RE in OBF subjects occurred while running at a 15% greater speed. OBF males consumed approximately 17% less oxygen per kilogram of body mass per kilometre compared to their NWU counterparts. These findings contradict the currently accepted and previous findings that obese have an inferior RE compared to normal weight subjects during treadmill exercise (Ayub & Bar-Or, 2003; Browning et al., 2006). The differences in the present study could be attributed to the superior fitness level in our obese subjects, as in agreement with previous studies, fit subjects have a superior RE compared to unfit (Bransford & Howley, 1977; Dolgener, 1982; Morgan et al., 1995). In relative terms there were no differences in  $\dot{V}O_{2\text{max}}$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) between groups, however, the absolute  $\dot{V}O_{2\text{max}}$  ( $\text{L}\cdot\text{min}^{-1}$ ) was 38% higher in our obese compared to normal weight subjects. The

differences observed in the current study may be attributed to the sound study design which allowed OBF and NWU subjects to be assessed at metabolically comparable work rates.

When our results are compared to competitive and recreational runners (Mooses et al., 2013), our OBF subjects displayed a superior RE ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$ ) at a moderate relative exercise intensity VT (212 vs. 231.7 & 230 in OBF vs. Competitive and Recreational runners respectively at VT). However due to the highly trained nature of their subjects the running speed at VT for competitive runners was  $13.2 \text{ km}\cdot\text{h}^{-1}$  and  $12.2 \text{ km}\cdot\text{h}^{-1}$  compared to our OBF subjects running at  $8.5 \text{ km}\cdot\text{h}^{-1}$ . Similar to our finding, they also found no differences in RE when comparing moderate to heavy relative exercise intensities. Mooses *et al.*, (2013) also found no differences in RE between competitive and recreational runners who did differ in  $\dot{V}O_{2\text{max}}$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ).

## 5.1 Exercise Economy

### 5.1.1 Effect of body mass

In the current study OBF were significantly more economical, consuming less oxygen at both a moderate, VT (18%) and heavy, 40%  $\Delta$  (16%) than NWU subjects. Similar findings have recently been found in obese children, who displayed a superior RE (approximately 10%) relative to today body mass ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$ ) compared to normal weight children during treadmill running at relative moderate and heavy exercise intensities (Lambrick *et al.*, 2013 Unpublished Data). The proposed mechanisms for the above results include differences in muscle fibre type and increased tendon stiffness. In groups of competitive and recreational runners of equal body mass but differing in BF%, no differences in RE were observed while running at comparable relative exercise intensities (Mooses et al., 2013), yet in the present study our OBF subjects displayed a significantly superior RE compared to NWU, while

presenting with a higher body mass and BF%. They concluded that RE is influenced more by specific training rather than body composition.

Interestingly the OBF subjects displayed the superior running economy while running at significantly higher speeds; 8.5 & 10.1 vs. 7.6 & 8.8 km·h<sup>-1</sup> at VT and 40% Δ respectively. If all subjects were to exercise at a given velocity of 8 km·hr<sup>-1</sup>, 82% of the OBF subjects would have been exercising at an intensity below VT while 67% of the NWU subjects would be exercising above VT further enhancing the superior RE in the OBF subjects. This could have yielded significantly different results between our subject groups.

We are confident that our data is representative of similar relative exercise intensities with no differences in RPE between groups. This indicates that the subjects in our study were being compared at the same relative exercise intensity. LeCheminant *et al.*, (2009) found no differences in RE, despite differences in RPE during treadmill running at 8 km·h<sup>-1</sup> between obese and normal weight women. Our data are also supported by no differences in HR between groups of similar age groups, while other studies have found significantly higher HR in obese compared to normal weight subjects during treadmill walking and running (Volpe Ayub and Bar-Or, 2003, Larfortuna et al 2008).

Comparison between this study and previous findings is challenging as running economy has largely been reported from submaximal  $\dot{V}O_2$ , at pre determined exercise intensities. In addition, many authors have reported the energy cost of running calculated on the basis of an O<sub>2</sub> energy equivalent estimated from RER values (Lafortuna et al., 2008; LeCheminant et al., 2009; Taboga et al., 2012). Using RER at an absolute intensity does not take in to consideration that the most unfit subjects will be exercising at a relatively higher percentage of  $\dot{V}O_{2max}$  resulting in greater energy consumption and therefore reporting

differences in RE can be questioned. The protocol in the present study allows for a more valid interpretation of RE between our select groups.

When RE was expressed relative to fat-free mass ( $\text{mL} \cdot \text{FFM}^{-1} \cdot \text{km}^{-1}$ ), no differences between groups were observed. This has also been reported in previous research in obese and normal weight children (Lambrick *et al.*, 2013 Unpublished Data). The differences in RE when expressed  $\text{mL} \cdot \text{kg}^{-1} \cdot \text{km}^{-1}$  may therefore be attributed to overall fat mass, as removing the metabolically inactive adipose tissue from the calculations, resulted in equal RE between groups. Other researchers have also concluded that it is total body mass rather than adiposity that determines the inferior RE in obese compared to normal weight counterparts (Ayub & Bar-Or, 2003; McMurray & Ondrak, 2011). However, others have found that during treadmill walking the excess body mass associated with obesity accounts for a 13% higher cost of transport resulting in inferior RE compared to NW (Lafortuna *et al.*, 2008). This suggests that biomechanical features may also characterise obese individuals, with differences in locomotor movements and the storage and recovery of elastic energy (Lafortuna *et al.*, 2008).

The exact mechanisms behind differences in running economy among individuals in the present study remains unclear as previous research has suggested both physiological and biomechanical factors (Saunders *et al.*, 2004). As the result of resistance and endurance training, increased tendon stiffness is associated with superior RE (Albracht & Arampatzis, 2013; Dumke, Pfaffenroth, McBride, & McCauley, 2010; Fletcher, Esau, & MacIntosh, 2010; Hunter *et al.*, 2008). The mechanism is largely speculative, but it is proposed that increased tendon stiffness results in increased storage and return of elastic energy therefore, reducing the energetic cost of muscular contraction (Albracht & Arampatzis, 2013; Fletcher *et al.*, 2010). While no measures of tendon stiffness were part of the present study the ability to store and re-use elastic energy from eccentric muscle contractions has been attributed to enhanced RE (Williams & Cavanagh, 1987). It is conceivable that increased musculo-tendon

stiffness (in particular the achilles) contributed to the superior RE in the obese subjects, as a result of the chronic strength “training” through their greater total body mass (Dumke et al., 2010; Hunter et al., 2008). These underlying mechanisms need to be further studied on the effect obesity plays on RE at relative exercise intensities.

### 5.1.2 Effect of fitness

The importance of fitness in the present study should not be overlooked. We used fit obese subjects who engaged in regular vigorous aerobic exercise on at least 3 occasions per week. Our finding of superior economy in fit subjects is similar to previous findings (Bransford & Howley, 1977; Morgan et al., 1995). Our population groups are typically overlooked within the scientific literature, compared to elite or recreational athletes as used in the majority of sports science research studies (Bransford & Howley, 1977; Morgan et al., 1995).

Due to the present study protocol using metabolically comparable exercise intensities, we believe our results lead to a valid interpretation of running economy. Previous comparative studies have used a given running speed, or  $\% \dot{V}O_{2\max}$  exercise intensities to analyse differences in RE, however as the  $\dot{V}O_2$  response to exercise reflects total body skeletal muscle metabolism this method cannot guarantee metabolically comparable work rates between subjects. In trained vs. untrained individuals an absolute running speed elicits a superior RE in trained subjects (Bransford & Howley, 1977; Morgan et al., 1995). Saunders *et al.*, (2004) suggested that economical runners are able to perform at a lower  $\% \dot{V}O_{2\max}$  while at a given intensity. In our study while not significant, OBF subjects utilised a lower  $\% \dot{V}O_{2\max}$  compared to NWU at relative exercise intensities, while running at significantly higher speeds. The ability to use a lower fraction of  $\dot{V}O_{2\max}$  at a relative intensity results in a

lower BLa response, allowing an individual to maintain that intensity for longer (Conley & Krahenbuhl, 1980).

Previous research during treadmill running at  $8 \text{ km}\cdot\text{h}^{-1}$  demonstrated no differences in running economy between obese and normal weight women (LeCheminant et al., 2009). The authors commented that this was of no surprise as both groups were untrained, suggesting that fitness or training status may play an important role in RE differences between groups. We found that our OBF subjects displayed a superior RE compared to NWU subjects. In absolute terms ( $\text{L}\cdot\text{min}^{-1}$ ) OBF displayed a higher  $\dot{V}O_{2\text{max}}$  compared to NWU, however when expressed relative to body mass ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) no differences were found between groups.

In our study, no differences were found in relative fitness levels [ $\dot{V}O_{2\text{max}}$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ )] between groups, yet at relative exercise intensities OBF displayed a superior RE compared to NWU. Sawyer *et al.*, (2010) found that RE is inversely associated with  $\dot{V}O_{2\text{max}}$ , when expressed relative to total body mass ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), yet in our study we found a significantly superior RE in OBF subjects with no significant differences in relative fitness levels when expressed relative to body weight. Our findings are in contrast to much of the literature showing that individuals with a higher  $\dot{V}O_{2\text{max}}$  typically have a superior RE compared to those with a low  $\dot{V}O_{2\text{max}}$  (Morgan et al., 1995; Saunders et al., 2004).

We accept that there are methodological reasons for our novel findings, as previous research has not always compared individuals at a absolute intensity therefore, the results of superior RE in those with a higher  $\dot{V}O_{2\text{max}}$  are not surprising. Physiologically it may be that as a result of training in OBF, adaptations have occurred, allowing for the more efficient use of  $O_2$  including, muscle fibre distribution, oxidative enzyme activity, enhanced mitochondrial morphology and functionality (Saunders et al., 2004). However large variations in RE have been found in trained and untrained subjects therefore we cannot be certain that the superior

fitness of our OBF is responsible for the results of the present study (Morgan et al., 1995). In addition biomechanical factors may have attributed with increased tendon stiffness allowing for increased storage and release of eccentric muscle action, therefore decreasing the energy requirements of the active skeletal muscles (Fletcher et al., 2010). These changes could explain the superior RE in the OBF however, no muscle biopsies were performed in the present study therefore we cannot be certain of this adaptation. Further research is required to determine the mechanisms for our findings.

From a public health perspective, these results indicate that increasing physical activity and fitness level should be the priority for adults engaging in an exercise programme, more so than weight loss, as superior RE could reduce the relative perceived level of physical exertion during everyday tasks. Obesity is often associated with increased risk of developing metabolic and orthopaedic conditions which negatively impact on motor function and activities of daily living (Nantel, Mathieu, & Prince, 2010). However, our results indicate that the OBF would cope better physiologically with a given relative intensity of activity compared to NWU. While inactivity is strongly associated with a rise in the current worldwide obesity rates (WHO, 2013), the cardiometabolic benefits of increasing physical activity including reducing the risk of hypertension, diabetes and other CVD as well as reduced musculoskeletal conditions should be highlighted for all weight classes (Ortega et al., 2013).

## **5.2 Physiological markers**

In the present study,  $\dot{V}O_2$  was reported at relative exercise intensities. When expressed relative to body weight ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), no significant differences in  $\dot{V}O_2$  were found between groups at either moderate or heavy workloads. This is indeed a novel finding as our OBF subjects were using the similar amounts of  $O_2$  per kilogram of body weight while

running at higher speeds. This could be attributed to the superior fitness of our OBF subjects. However, Mooses *et al.*, (2013) reported no difference in  $\dot{V}O_2$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) at VT when comparing competitive and recreational runners at relative workloads. However, the competitive runners did have a significantly higher  $\dot{V}O_{2\text{max}}$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), and a lower BF% yet no differences in BMI.

When expressed relative to FFM [ $\dot{V}O_2^{\text{FFM}}$  ( $\text{mL}\cdot\text{FFM}^{-1}\cdot\text{min}^{-1}$ )], OBF utilised more  $O_2$  per kilogram of FFM at both moderate and heavy workloads compared to NWU as well as a greater rate of change from moderate to heavy exercise intensities. This indicates a maladaptive response to the excess fat mass as when expressed to overall body mass ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) no differences were found. The reasons for no differences in  $\dot{V}O_2$  when expressed relative to total body mass remain unclear, yet it has been proposed that through concurrent endurance training and “default” strength training through excess body mass, biomechanical and physiological adaptations are responsible for enhancing RE (Foster & Lucia, 2007). These include increased tendon stiffness, enhanced stride length, increased type 1 muscle fibre distribution and increases in the respiratory capacity of skeletal muscle through changes in the structure and function of mitochondria (Saunders *et al.*, 2004).

As expected a lower % of  $\dot{V}O_{2\text{max}}$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ), was utilised at a moderate exercise intensity (VT) compared to a heavy exercise, this was observed in both groups and is in agreement with previous research (Billat *et al.*, 1999). While no significant differences were found between groups our OBF subjects performed at a lower % of  $\dot{V}O_{2\text{max}}$  compared to NWU (74 vs. 79 %, respectively). At a given exercise intensity the athlete with the superior RE is able to run at a lower % of  $\dot{V}O_{2\text{max}}$  which has also been shown in the present study (Saunders *et al.*, 2004).

A significant intensity effect was found for HR when exercising at a moderate work load compared to heavy which is to be expected. In our study we found no differences in HR and RER between groups. We believe the reason for this is due to our methodology using relative exercise intensities allowing for differences in fitness levels to be accounted for. As our groups were not significantly different in age, HR data remained similar between groups at relative exercise intensities. These findings are in contrast to other researchers who reported significantly higher HR (Ayub & Bar-Or, 2003; Lafortuna et al., 2008; LeCheminant et al., 2009) and RER (LeCheminant et al., 2009), in obese subjects compared to normal weight during treadmill exercise at a given intensity.

Blood lactate responses between the groups were similar with higher BLa recorded during heavy exercise compared to moderate. This is in agreement with previous research (Crescitelli & Taylor, 1944; Hurley et al., 1984). At a given intensity of exercise, trained subjects will typically display a decreased BLa compared to untrained (Hurley et al., 1984), yet in the present study we had no difference between groups despite the difference in physical activity levels. This can be attributed to our sound study design utilizing relative exercise intensities.

Some studies have reported that  $\dot{V}_E$  at a given intensity is higher in obese compared to normal weight subjects (Ayub & Bar-Or, 2003). In the present study we found no difference when relative exercise intensities are selected however this result was approaching significance ( $P = 0.06$ ). Due to increased breathing rate resulting in increased  $O_2$  cost during exercise, it has been suggested that inferior RE may be attributed to increased  $\dot{V}_E$  (Saunders et al., 2004). However as no differences were observed in  $\dot{V}_E$  between groups, most likely due to our study design, ventilation rates may not be an underlying reason for differences in RE between groups.

No differences were found between subject groups for RPE at relative intensities. As HR and RPE are closely associated we are not surprised by these results. In studies comparing RE at a given intensity between obese and normal weight, differences in RPE (while not significant) have been found (LeCheminant et al., 2009). This is not surprising as a given intensity of exercise does not take in to account individual variation in fitness level (Fletcher et al., 2009; Rowland, 2012), therefore less fit and untrained subjects will perceive the intensity of the exercise to be greater. This is important, as many individuals who begin an exercise programme often struggle with sudden increases in activity and compare themselves to with other regular exercises.

In our study we found no differences in stride frequency between groups, however more strides were taken in both groups during heavy compared to moderate intensity exercise. Previous work has found that superior (less) RE is negatively correlated with stride frequency at a given velocity (Tartaruga et al., 2012; Williams & Cavanagh, 1987), yet in the present study our OBF subjects displayed a superior RE despite no differences in SF. However our OBF subjects were running significantly faster, therefore, were running with a greater stride length compared to NWU. While stride frequency is negatively correlated with RE, ( $r = -0.61$ ), stride length is positively correlated with RE ( $r = 0.61$ ) (Nummela et al 2007). It has been proposed that increases in stride length indicate an adaptation through training or a greater process of energy optimisation (Tartaruga et al., 2012). Both  $\dot{V}O_2$  per stride ( $\text{ml}\cdot\text{kg}^{-1}\cdot\text{stride}^{-1}$ ) and  $\dot{V}O_2^{\text{FFM}}$  per stride were not different between groups. This is in accordance with previous research (Aull, Rowe, Hickner, Malinauskas, & Mahar, 2008) which found no differences in the energy cost per stride at low speeds between normal weight and obese females.

From a health perspective, the superior RE displayed in our OBF compared to NWU subjects indicate that increasing physical activity and fitness level should be the priority for adults engaging in an exercise programme. Having enhanced RE and overall movement economy, can reduce the relative perceived level of physical exertion during everyday tasks. It is well researched that exercise helps reduce the age related decline in physical function, reducing the impacts of significant functional impairments by increasing and/or maintaining aerobic capacity, while resistance training improves central nervous system recruitment of muscle fibres and can increase muscle mass (Kirkendall & Garrett, 1998; Rogers & Evans, 1993; Stratton, Levy, Cerqueira, Schwartz, & Abrass, 1994). With the increasing health problems associated with an ageing population, health practitioners should not only advise on the benefits of weight loss to reduce HR, blood pressure and cholesterol, but stress the importance of loss of function through being inactive and having low CRF.

#### **5.4 Limitations**

This study compared only, NWU and OBF subjects whereas including NW fit and OB unfit would have provided a better indication of whether fitness or fatness is the mediating factor for variations in RE between groups. In light of the novel findings of the present study, particular limitations are recognised: i) the ability to perform a  $\dot{V}O_{2\max}$  test during the GXT would have confirmed definitively the maximal aerobic capacity of each subject, however in the present study we performed to 85% of age predicted  $HR_{\max}$  (Poole, Barstow, McDonough, & Jones, 2008). ii) While all tests were performed with the minimum 72 hours rest between consecutive visits, the time between consecutive tests was up to 17 days for some subjects due to researcher and subjects availability. In addition pre test diet in the present study was not controlled for yet all subjects were advised of no vigorous exercise 24 hours prior to testing, no energy consumption 90 minutes before testing and no caffeinated

drinks on the day of testing. It would have been more valid to have the subjects in the fasted state to reduce the effects on respiratory variables ( $\dot{V}O_2$ ,  $\dot{V}_E$ , and RER) (Bergman & Brooks, 1999; Koubi et al., 1991).

Comparing fit subjects who partake in regular structured aerobic exercise with unfit individuals who do not possess the natural or familiar ability to run could also be a factor for our unique results. The majority of (82%) OBF subjects in the present study had reported previous treadmill running in the last 6 months, while some of our NWU subjects had only reported treadmill walking (17%) or no experience what so ever with a treadmill (83%). While all of our subjects had previously become familiar with treadmill walking during the initial stages of research project (Bruce Protocol), only a short period of time (up to 5 minutes) was given to become familiar with treadmill running. It has been reported that in subjects unfamiliar with treadmill running it can take up to 9 minutes (White, Gilchrist, & Christina, 2002) with a minimum of 6 minutes (Lavcanska, Taylor, & Schache, 2005) at a comfortable steady state to have similar kinematics to over ground running. As such, two GXT's could have allowed for sufficient familiarisation with treadmill running. In addition, to enhance the reliability of the constant speed submaximal running tests, longer durations could have been utilised.

Due to the low levels of fitness in some subjects, the speeds identified at VT were less than  $7 \text{ km}\cdot\text{hr}^{-1}$ . This for some individuals approaches a transition speed of the walk-jog, therefore affecting gait and the ability to move efficiently (Sawyer et al., 2010). While all subjects were advised to run regardless of the treadmill speed, this could have attributed to differences in RE between our groups. The treadmill speed was also visible to the subjects during the GXT and submaximal RE tests. This could have pre-determined the perception levels of subjects during treadmill exercise.

As participants were exercising within a heavy intensity domain at 40% delta, the  $\dot{V}O_2$  slow component could have influenced the interpretation of RE (Jones & Carter., 2000). The potential of a slowly rising  $\dot{V}O_2$  response over the course of the 6-minute bout of exercise should not be ignored as exercise above VT does not provide an accurate account of steady state exercise. A speeded  $\dot{V}O_2$  kinetic response at the onset of the RE tests indicates the rapid establishment of tighter intracellular control, allowing for enhanced metabolic control for later exercise (Hochachka, 1992). It has been shown that following 6 weeks of endurance training, a significant increase in the running speed at the maximum lactate steady state is seen by a reduced amplitude in the rising  $\dot{V}O_2$  slow component (Carter, 1999), therefore the superior RE in our OBF subjects may be attributed to the study design. It is also worth noting that the interpretation of RE within this domain may also be moderated by the intensity (i.e. 30% $\Delta$  , 40% $\Delta$  , 50% $\Delta$  would elicit different RE values).

In the present study we found little change in  $\dot{V}O_2$  for OBF between VT and 40% $\Delta$  despite significant differences in HR,  $V_E$ , RPE etc. While it is possible that the speeds identified were not entirely correct, there were significant differences between running speeds for OBF at VT and 40% $\Delta$ . With breath by breath analysis large amounts of noise are often observed between data points. It is acknowledged that this may be attributed to our present findings

### **5.5 Future Research**

It is acknowledged that the low subject numbers in the present study and lack of relative “control” groups being normal weight and fit and in addition obese and unfit undermine the overall findings. However, the aim was to investigate increasingly intriguing and rarely studied population groups of OBF and NWU. Increasing subject numbers would allow for a more valid interpretation of our results, therefore future research should look in to

comparisons between both BMI conditions such as OBF vs NW fit as well as physical activity status comparing NWU vs. OB unfit. We assessed RE only in adult male subjects between the ages of 18-55 years, and are therefore unsure if our findings would transfer to younger and older population groups, as well as in female subjects, therefore, further investigations are required.

In the present study we used the internationally-accepted and common methods of determining our subject's body composition using BIA and weight category using BMI. Future work should aim to make use of more accurate methods to determine lean body mass, bone mineral content, leg segment mass and total fat mass using Dual-energy X-ray Absorptiometry (DXA). However the high costs associated with DXA is a major deterrent, in addition to not being practical in a field setting or small laboratory (Pietrobelli, Rubiano, St-Onge, & Heymsfield, 2004).

The underlying mechanisms behind the results of the present study need to be determined. Including muscle biopsies to analyse muscle fibre type would allow insight into muscle fibre distribution in addition to oxidative enzyme activity. As running involves complex movements across a range of joints in the body, further biomechanical differences using high speed cameras also need to be explored with running, as poor lower limb flexibility have been shown to improve RE, therefore future research should analyse to accurately determine stride frequency, stride length, and vertical oscillations of the CoM (Saunders et al., 2004). In addition to analyse the relationship between RE and the biomechanical and neuromuscular variables, electromyographic signal (EMG) of the working muscles should be assessed to determine power output as evident by an increased amplitude in the EMG signal (Saunders et al., 2004).

While the present study looked at treadmill running differences in economy at relative exercise intensities, further work is required to determine if the differences apply to walking and also running on the ground. However, the relative intensity in question has been associated with the arbitrary “comfortable” walking pace for each subject (Browning et al., 2006). We have also only looked at VT and 40% delta, while other intensities below and above VT and beyond  $\dot{V}O_{2\max}$  are yet to be explored.

## 6. Conclusions

This present study demonstrated that despite running at a faster speed, fit and obese individuals display a superior running economy compared to normal weight unfit individuals during treadmill running at relative moderate and heavy exercise intensities when expressed as  $\text{mL}\cdot\text{kg}^{-1}\cdot\text{km}^{-1}$ . No differences were observed between groups when RE was expressed relative to FFM, indicating that fitness may play a bigger role in determining differences in RE rather than body composition. We appropriately expressed RE in  $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ , going by the definition of relative aerobic capacity per kilogram of body weight required to sustain a given submaximal running speed (Conley & Krahenbuhl, 1980; Saunders et al., 2004). We used relative exercise intensities to compare RE between groups, however this definition in future may need to be reconsidered in light of the relative exercise intensities apportioned to subjects in this study.

There were significant differences in the running speed between groups at moderate and heavy workloads, yet no differences were found in relative  $\dot{V}\text{O}_2$  ( $\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) between our groups. Similarly no differences were also found between HR, RPE, RER and  $\dot{V}\text{E}$ , despite the significantly higher running speed of our OBF subjects. No differences in RE were found when expressed relative to stride frequency and oxygen consumption per stride despite a great running speed in the OBF subjects. The exact mechanisms for these findings are yet to be understood. However, it is thought that both physiological (muscle fibre type and respiratory capacity) and biomechanical factors (stride length and joint mechanics) may contribute to the present findings.

From a health perspective these results suggest that increasing physical activity and fitness level should be the priority for adults engaging in an exercise programme more so

than weight loss, as superior economy could reduce the relative level of physical exertion during everyday tasks. Fitness rather than weight status may be more of an important moderating factor when examining differences in RE between individuals and as such, future work should focus on then mechanisms involved in our findings of superior RE in OBF compared to NWU subjects as well as including relative control groups including NW fit and OB unfit subjects.

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## Appendices

### Appendix A



Central Regional Ethics Committee  
c/- Ministry of Health  
PO Box 5013  
1 the Terrace  
Wellington  
Phone: (04) 816 2405  
Email: central\_ethicscommittee@moh.govt.nz

14 September 2011

Mr James Stewart  
2/62 Ghuznee Street  
Te Aro  
Wellington 6011

Dear Mr Stewart

Ethics ref: CEN/11/EXP/074 (please quote in all correspondence)  
Study title: Exercise economy comparisons between obese fit and normal weight unfit males

This expedited study was given ethical approval by the Chairperson of the Central Ethics Committee on the 14<sup>th</sup> of September 2011.

This approval is valid until 1 August 2012, provided that Annual Progress Reports are submitted (see below).

#### Amendments and Protocol Deviations

All significant amendments to this proposal must receive prior approval from the Committee. Significant amendments include (but are not limited to) changes to:

- the researcher responsible for the conduct of the study at a study site
- the addition of an extra study site
- the design or duration of the study
- the method of recruitment
- information sheets and informed consent procedures.

Significant deviations from the approved protocol must be reported to the Committee as soon as possible.

#### Annual Progress Reports and Final Reports

The first Annual Progress Report for this study is due to the Committee by 14 September 2012. The Annual Report Form that should be used is available at [www.ethicscommittees.health.govt.nz](http://www.ethicscommittees.health.govt.nz). Please note that if you do not provide a progress report by this date, ethical approval may be withdrawn.

A Final Report is also required at the conclusion of the study. The Final Report Form is also available at [www.ethicscommittees.health.govt.nz](http://www.ethicscommittees.health.govt.nz).

We wish you all the best with your study.

Yours sincerely

A handwritten signature in black ink, appearing to read 'Awhina Rangiwai', with a horizontal line underneath.

**AWHINA RANGIWAI**  
ADMINISTRATOR  
Central Ethics Committee

**Appendix B****PARTICIPANT CONSENT FORM****Exercise Economy and metabolic fitness comparisons between obese fit and normal weight unfit males.**

I have read and I understand the information sheet dated 15/08/11 for volunteers taking part in the study designed to assess Exercise Economy and metabolic fitness comparisons between obese fit and normal weight unfit males.

Yes  No

I have had the opportunity to discuss this study, and I am satisfied with the answers I have been given.

Yes  No

I have had the opportunity to use whānau support or a friend to help me ask questions and understand the study.

Yes  No

I understand that taking part in this study is voluntary (my choice), and that I may withdraw from the study at any time, and that this will in no way affect my future health care.

Yes  No

I understand that my participation in this study is confidential and that no material that could identify me will be used in any reports on this study.

Yes  No

I understand that the treatment, or investigation, will be stopped if it should appear harmful to me.

Yes  No

I understand that it is my choice if my GP is to be informed of my participation in the study and of any clinically significant abnormal results obtained from the study.

Yes  No

I have had time to consider whether to take part in the study.

Yes  No

I would like the researcher to discuss the outcomes of the study with me.

Yes  No

I ..... hereby consent to take part in this study

Date:.....

Participant's  
Signature:.....

Full name of researcher: Mr James Stewart

Contact phone number for researcher: 021 2255 272

Project explained by: Mr James Stewart

Project role: Principal Investigator

Signature: .....

Date: .....

**Appendix C**

## Pre-Exercise Health Screening Questionnaire

Name: \_\_\_\_\_

Address: \_\_\_\_\_

Phone: \_\_\_\_\_

Age: \_\_\_\_\_

Please read the following questions carefully. If you have any difficulty, please advise the exercise specialist who is conducting the exercise test.

Please answer all of the following questions by ticking only one box for each question:

This questionnaire has been designed to identify the small number of persons (15-69 years of age) for whom physical activity might be inappropriate. The questions are based upon the Physical Activity Readiness Questionnaire (PAR-Q), originally devised by the British Columbia Dept of Health (Canada), as revised by <sup>1</sup>Thomas *et al.* (1992) and <sup>2</sup>Cardinal *et al.* (1996), and with added requirements of the Massey University Human Ethics Committee. The information provided by you on this form will be treated with the strictest confidentiality.

**Qu 1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**

Yes  No

**Qu 2. Do you feel a pain in your chest when you do physical activity?**

Yes  No

**Qu 3. In the past month have you had chest pain when you were not doing physical activity?**

Yes  No

**Qu 4. Do you lose your balance because of dizziness or do you ever lose consciousness?**

Yes  No

**Qu 5. Are you currently using prescription medication?**

Yes  No

**Qu 6. Do you have a bone or joint problem that could be made worse by moderate exercise, particular in the lower back and/or legs?**

Yes  No

**Qu 7. Do you have any pre-existing muscular problems or injuries that may be aggravated by continuous, moderate physical activity?**

Yes  No

**Qu 8. Do you know of any other reason why you should not do physical activity?**

Yes  No

**Qu 9. Have any immediate family members had heart problems prior to the age of 55?**

Yes  No

**Qu 10. Have you been hospitalised recently?**

Yes  No

**Qu 11. Are you diabetic?**

Yes  No

**Qu 12. Do you currently or have you previously had renal and/or hepatic disease?**

Yes  No

**Qu 13. Do you have any infectious disease that may be transmitted in blood?**

Yes  No

**Qu 14. This experiment includes the taking of blood for measuring blood markers of cholesterol and blood lactate and glucose. Do you have any objection to this?**

Yes  No

You should be aware that even amongst healthy persons who undertake regular physical activity there is a risk of sudden death during exercise. Though extremely rare, such cases can occur in people with an undiagnosed heart condition. If you have any reason to suspect that you may have a heart condition that will put you at risk during exercise, you should seek advice from a medical practitioner before undertaking an exercise test.

I have read, understood and completed this questionnaire.

Signature: \_\_\_\_\_ Date: \_\_\_\_\_

#### References

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2. Cardinal BJ, Esters J and Cardinal MK. Evaluation of the revised physical activity readiness questionnaire in older adults. *Med Sci Sports Exerc* 28(4): 468-47

## Appendix D

### ACSM Coronary Artery Disease (M. Tartaruga et al.) Risk Stratification Assessment

*(This document is to guide the researcher through the risk stratification procedures)*

The main purpose of pre-participation screening is to identify individuals at increased risk of cardiovascular injury or death during exercise. To this end, the client should complete the physical activity readiness questionnaire (PAR-Q, attached)

#### Cardiovascular disease risk factor profile

Cardiovascular disease (CVD) is an umbrella term referring to the diseases of the heart and circulatory system. Around 50% of CVD deaths are due to coronary heart disease and around 25% are due to stroke. It is important to determine an individual's CVD risk factor profile because CVD is the main cause of exercise-induced death in middle-aged men. Table 1 lists the risk factors that are typically assessed in determining an individual's CVD risk factor profile.

- Family history is assessed because the presence of premature CVD in first-degree relatives is associated with a two- to six-fold increase in CVD risk. Enter 1 if the client's father or brother suffered a heart attack before 55 or if the client's mother or sister suffered a heart attack before 65 years-of-age.
- The CVD death rate of smokers is at least twice that of non-smokers. Enter 1 if the client has smoked at all in the last six months.
- There is a linear relationship between blood pressure and CVD risk. Measure blood pressure in accordance with the procedures described in Box 1 and enter 1 if systolic blood pressure is  $\geq 140$  mm Hg or if diastolic blood pressure is  $\geq 90$  mmHg.
- Compared to men with desirable cholesterol levels, the six-year CVD death rate is twice as high in men with concentrations  $\geq 5.25$  mmol·l<sup>-1</sup> (Stamler, Wentworth, & Neaton, 1986). Measure total cholesterol in accordance with the procedures described in Box 2 and enter 1 if the fingerprick concentration is  $> 5.2$  mmol·l<sup>-1</sup>.
- Fasting blood glucose is assessed because most diabetics are at increased risk of CVD. Measure blood glucose in accordance with the procedures described in Box 2 and enter 1 if the fingerprick concentration is  $> 6.1$  mmol·l<sup>-1</sup> on at least two separate occasions. Non-fasting blood glucose concentration should be  $< 11.1$  mmol·l<sup>-1</sup>.
- Body mass index (BMI) and waist girth are determined because obesity predisposes to diabetes and heart disease. Measure height, weight and waist girth as described in Box 3 and enter 1 if BMI is greater than 30 kg·m<sup>2</sup> or if waist girth is  $> 102$  cm in men or  $> 88$  cm in women.
- Enter 1 if the client does not undertake 30 minutes of moderate-intensity physical activity on three or more days of the week or if the client is not engaged in a exercise programme consisting of around 20 minutes of vigorous activity on three or more days of the week.
- CVD is not inevitable, but age is an indirect measure of an individual's exposure to other risk factors. Enter 1 if the client is a man older than 45 or a woman older than 55.
- HDL-cholesterol fights atherosclerosis and every 0.026 mmol·l<sup>-1</sup> increase in HDL-C reduces CVD risk by 2–3% (Gordon et al., 1989). Accordingly, high HDL-C is regarded as a 'negative risk factor' and a concentration  $> 1.6$  mmol·l<sup>-1</sup> removes 1 score from the total risk factor count. Enter 0 if HDL-C concentration is unknown.

Subtract the negative risk factor count from the sum of positive risk factors to determine the risk factor score. ‘Low-risk’ individuals are asymptomatic men  $\leq 45$  years and asymptomatic women  $\leq 55$  years whose risk factor score is no more than one. Low-risk individuals can undergo a maximal exercise test and participate in moderate or vigorous exercise training. ‘Moderate-risk’ individuals are asymptomatic men  $> 45$  years, asymptomatic women  $> 55$  years, and, regardless of age, individuals whose risk factor score is two or more. Moderate-risk individuals can undergo a sub-maximal exercise test and can begin a programme of moderate-intensity exercise. It is recommended that moderate-risk individuals undergo a medical examination before engaging in vigorous exercise. ‘High-risk’ individuals are those with signs or symptoms of heart disease, as indicated by any ‘yes’ answer on the PAR-Q. High-risk individuals should consult their GP before engaging in exercise testing or exercise training. Moderate-intensity exercise is that below the lactate threshold, which is equivalent to RPE 12–13 or a positive talk test. Vigorous-intensity exercise is that between the lactate threshold and the lactate turnpoint, which is equivalent to RPE 14–16 or an equivocal talk test (Persinger, Foster, Gibson, Fater, & Porcari, 2004).

**Table 1.** Risk factor counting and interpretation for exercise testing and exercise prescription

	<i>enter 1 for yes or 0 for no</i>
Family history*	_____
Current smoker or smoker in last six months	_____
SBP $\geq 140$ or DBP $\geq 90$ mm Hg	_____
Total cholesterol $> 5.2$ mmol·l <sup>-1</sup>	_____
Fasting blood glucose $\geq 6.1$ mmol·l <sup>-1</sup> †	_____
BMI $\geq 30$ , or waist girth $> 102$ cm in men or $> 88$ cm in women‡	_____
Sedentary§	_____
Age $> 45$ if male or $> 55$ if female	_____
<b>Sum of positive risk factors (A):</b>	<input type="text"/>
HDL-C $> 1.6$ mmol·l <sup>-1</sup>	_____
<b>Negative risk factor count (B):</b>	<input type="text"/>
<b>Risk factor score (A–B):</b>	<input type="text"/>
Do you have an infectious blood borne disease? or have a bleeding disorder.	_____

**Appendix E****GP Referral**

[DATE]

[ADDRESS]

Dear [GP NAME]

**[Re: [CLIENT NAME] BASELINE ASSESSMENT]**

[CLIENT NAME] has agreed to take part in a research study that will assess ‘exercise economy and metabolic fitness comparisons between obese fit and obese unfit males’. [CLIENT NAME] has recently completed a Baseline assessment and risk stratification measures (blood pressure, blood glucose etc).

*Risk stratification:*

<b>BP (supine);</b>	mmHg
<b>Resting HR;</b>	b·min <sup>-1</sup>
<b>Total Cholesterol;</b>	mmol.l <sup>-1</sup>
<b>HDL;</b>	mmol.l <sup>-1</sup>
<b>Non-fasting blood glucose;</b>	mmol.l <sup>-1</sup>
<b>Height;</b>	m
<b>Weight;</b>	kg
<b>BMI;</b>	kg·m <sup>2</sup>

[CLIENT NAME] will complete 3, exercise test 85% or age predicted maximum heart rate on a treadmill (following a warm-up). The second and third tests will require the subject to complete three 6-min exercise stages on the treadmill. Oxygen consumption, heart rate, blood lactate and perceived exertion will be monitored throughout the exercise tests.

As two or more Coronary Artery Disease risk factors have been identified and in accordance with the American College of Sports Medicine (2010) guidelines, do you provide consent for your patient to take part in the low to moderate intensity exercise (please see the attached information sheet) at Massey University’s Physiology laboratory?

I [GP NAME] consent for [CLIENT NAME] to take part in the Massey University research study.

Signed (GP)

Date

\_\_\_\_\_

\_\_\_\_\_

For any queries or further information please contact Dr. James Faulkner

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