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THE EFFECT OF MANIPULATED STRIDE FREQUENCY ON RUNNING ECONOMY IN EXPERIENCED DISTANCE RUNNERS DURING A SUB-MAXIMAL BOUT OF ACTIVITY
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Abstract

**Objective** - The present study set out to report the influence of stride frequency (SF) on running economy using subjects more representative of the beneficial population. **Methods** – Six male distance runners (mean ± σ) (age 21 ± 1.1) completed two separate laboratory based running trials at three differing, controlled stride frequencies. Exhaled gas, ratings of perceived exertion (RPE), heart rates (HR) and personal views were recorded. **Results** – The running economy of the group was found to increase at both increased SF (65.4 ± 4.1 ml·kg⁻¹·min⁻¹) and decreased SF (63.8 ± 5.2 ml·kg⁻¹·min⁻¹) bouts from preferred SF (61.8 ± 1.6 ml·kg⁻¹·min⁻¹) **Conclusions** – These findings demonstrate these distance runners preferred stride cadence is most aerobically economic when compared to a ten percent faster or slower rate.
CHAPTER I
INTRODUCTION
Introduction

When training for and competing in distance running events such as the five and ten kilometre (km) race, many factors have been established in order to gain a successful performance (Coyle, 1999). Saunders et al., (2004a) indicated the importance of $\dot{V}O_{2\text{max}}$ in distance running but other important factors for endurance capacity are known. Daniels, (2005) and Joyner and Coyle, (2008) highlighted the three main factors affecting performance as the maximal amount of oxygen an athlete can utilize ($\dot{V}O_{2\text{max}}$), the speed or percentage (%) of $\dot{V}O_{2\text{max}}$ at which lactate accumulates (lactate threshold [LT]) and efficiency/economy. Finding ways to increase these three main variables in an attempt to increase performance has directed physiologists down many directions of research.

However given sheer literature volume running economy has been studied less than other influential factors ($\dot{V}O_{2\text{max}}$, LT) and given its importance there a few strategies aimed at the improvement of running economy in athletes (Foster and Lucia, 2007).

1.1 Key Terms

Exercise economy describes the quantity of work achieved during a given intensity relative to performance quality and is most commonly assessed through oxygen uptake / utilisation ($\dot{V}O_2$) (McArdle et al., 2006). $\dot{V}O_2$ is often given as an absolute measure as litres of oxygen consumption per minute of collection (L·min$^{-1}$).

Running economy can be defined as the aerobic demand ($\dot{V}O_2$) during steady-state for a bout of sub-maximal running (Morgan and Craib, 1992; Anderson, 1996; Jensen et al., 1999; Kilding et al., 2007) and is usually described relatively using the confines of an athletes’ weight as ml·kg$^{-1}$·min$^{-1}$ (Daniels, 2005).

Other important physiological factors to consider when assessing the economical cost of an activity include; the body’s aerobic metabolism and by-product expulsion through carbon dioxide ($\dot{V}CO_2$ L·min$^{-1}$). Along with the respiratory exchange ratio (RER) as an indicator of substrate utilization ($\dot{V}O_2 : \dot{V}CO_2$ ratios) and stresses on the cardiovascular system (heart rate [HR beats·min$^{-1}$] and expired ventilation [$V_E$...
Finally psychological stresses may play an important factor whenever assessing an athletes’ work rate so a rating of perceived exertion (RPE) has often been used (Borg, 1998).

Many articles have described running economy as a multi-factorial area (Daniels, 1985; Williams and Cavanagh, 1987; Noakes, 2002; Berg, 2003; Saunders et al., 2004a; Hunter and Smith, 2007; Karp, 2008) indicating complexity in finding a single influential factor to improving exercise economy in distance runners. Most papers have focused on factors affecting economy, without exploring the optimal figures for an improved competitive performance (Anderson, 1996). While most coaches suggest small changes in the runners form to improve performance, Williams and Cavanagh, (1987) claimed there to be a lack of quantitative information suggesting which factors of running style improve performance.

The two main factors in kinetics that increase a runners economy are both stride characteristics; frequency and length (Brown and Ferrigno, 2005) with running speed a product of stride frequency and length (Donati, 1995). Both areas have been researched but generally through observation rather than manipulation, the conflicting research for both leads to unanswered questions about which is the most influential factor, if one exists at all.

For the purpose of this study stride length (SL) refers to the measurement of an athletes stride usually given in the literature as centimetres (cm) and stride frequency, rate or cadence (SF) describes the number of running foot strikes taken per minute of activity. (Brown and Ferrigno, 2005; Price, 2005; McArdle et al., 2006)

The population being tested for the study labelled ‘experienced runners’ described athletes with ≥ 2 years of running experience who were currently training for between 3 and 10 km races, this ensured they had a habitual stride frequency they were comfortable with.
1.2 Areas of study

The importance of running economy in endurance events and into real world competition is established in previous studies, demonstrating a positively correlated relationship between running economy and endurance performance. (Conley and Krahenbuhl, 1980; Bulbulian et al., 1986; Bailey and Pate, 1991; Daniels and Daniels, 1992; Anderson, 1996; Jones et al., 2000; Saunders et al., 2004b)

Studies have also shown that running economy may be a better predictor of performance in endurance trained athletes than $\dot{VO}_{2\text{max}}$. (Costill et al., 1973; Krahenbuhl et al., 1989; Morgan et al., 1989a; Morgan et al., 1989b; Paavolainen, 1999) This indicates a need for athletes of similar $\dot{VO}_{2\text{max}}$ scores to have knowledge of their running economy as a better indicator of aerobic and race fitness (Morgan et al., 1989b) comparative to rival athletes’. This highlights the importance of finding optimal running economy to aid an athletes’ race form, McArdle et al. (2006) demonstrated a positive correlation ($r = 0.82$) between 10 km race time and running economy.

Stride characteristics including stride frequency during exercise with regards to economy are of importance; Noakes, (2002) highlighted “more economical runners...glide over the ground with very little vertical oscillation”. Minetti et al., (1996) stated a similar problem for high stride frequencies as work rate increases with the increased stride frequencies initiated by the increased muscular contractions per minute. This indicates every runner has an optimally economic stride frequency as; fewer strides per minute would cause greater bounding for a set speed.

Naturally chosen stride frequencies during walking has been found to not always be the most economical “Although it is generally hypothesized that freely chosen behaviors are optimal...our data show that this is not always the case in human gait.” (Danion et al., 2003) Given how stride variability increases with speed in locomotion and during running (McArdle et al., 2006), it may be the case that running accentuates the problem, thus finding an optimally economic rate could save an increased amount of energy during locomotion being wasted.

There is a limited amount of research which examined the relationship of stride frequency and running economy Grant et al., (2006 [unpublished data]) found
running participants at their natural stride frequency produced the second lowest oxygen consumption / second most economical at the given speed. Drawing attention to the fact most athletes may not be running at their most economical stride frequency. Unnithan and Eston, (1990) researched the relationship between stride frequency and running economy of children and adults however no specific endurance athlete population has been tested to date.

Nelson and Gregor, (1976) discussed how distance runners reduce their stride frequency during activity, believing this optimized running economy as increasing stride length was deemed the greater enhancer of speed. However Noakes, (2002) prescribed runners shorten stride length in order to increase running economy, with Beck, (2005) deeming most experienced runners choose a stride either longer or shorter than the economic optimum.

Clearly there are gaps in the research area for running economy and stride characteristics, especially for the sample population of competitive runners – with whom the data is most relevant when concerning energy expenditure over an extended period of time. Also the argument of stride length versus stride frequency has been raised with papers flagging the importance of both, the more thoroughly researched of the two being stride length.

1.3 Hypothesis

Null hypotheses:

H₀a Changes in an athletes’ stride frequency does not produce an increased utilisation of $\dot{V}O_2$ during a sub-maximal bout of treadmill running in experienced distance runners

H₀b Changes to an athletes’ stride frequency does not create an increased production of $\dot{V}CO_2$ during a sub-maximal bout of treadmill running in experienced distance runners

H₀c Changes in an athletes’ stride frequency does not elicit an increased $\dot{V}E$ during a sub-maximal bout of treadmill running in experienced distance runners
H₀₀ Stride frequency manipulation has no effect on an athletes’ heart rate

H₀ₑ Stride frequency manipulation has no effect on an athletes’ rate of perceived exertion

The aim of this study was to see if a manipulated stride frequency affected running economy in endurance runners, at sub-maximal (steady state) levels by measuring utilised \( \dot{VO}_2 \), compared with their naturally chosen stride frequency.
CHAPTER II

LITERATURE REVIEW
Literature Review

Factors limiting performance in endurance events include muscular, neurological and psychological areas, factors that limit performance for distance running have been evaluated by the literature and are distinguished as the three main sub-groups of \( \dot{V}O_{2\text{max}} \), running economy and lactate threshold (Daniels, 2005; Joyner and Coyle, 2008).

Increased exercise economy in athletes demonstrates a muscular and circulatory system adapted to exercising at higher levels for a lower oxygen consumption at sub-maximal levels, compared to athletes not trained for endurance events (McArdle et al., 2006). As high level endurance events have been determined primarily by smaller and smaller differences in aerobic fitness, oxygen and energy availability (Wilber, 2007). Finding factors to increase economy and thusly improving energy conservation, even slightly at competitive speeds, could outline ways to increase competitive performance.

2.1 Exercise economy

Economy has an important role in most sports that require a high percentage of an athletes’ \( \dot{V}O_{2\text{max}} \) for long periods of time. As good economy can result in lower energy expenditure for a similar amount of work, this decrease in physical and metabolic stress soon adds up in a competitive environment. Jones, (2007) explained the aerobic system produced the primary energy production, when dealing with oxygen uptake at sub-maximal speeds (i.e. running economy). 5 and 10 km races at elite levels required an energetic level of 96 and 92% \( \dot{V}O_{2\text{max}} \) respectively (Londeree, 1986). Indicating the longer the distance the less important the anaerobic system is ergo running economy has greater importance with greater race distance.

Alternatively it can mean a higher amount of work for the same energy cost, leading to an increasing sub-maximal speed. Such advantages lead to victories in sports such as swimming, cycling and running, where the importance of efficiency and economy of movement are proven.
Naturally occurring cadences and stroke rates have been evaluated for cycling and swimming respectively; findings relating to cycling have shown chosen cadences were not optimal (Brisswalter et al., 2000) indicating the possibility for optimization. This is also true of runners as established by Williams and Cavanagh, (1987). The cost of swimming economy is dictated by stroke rate and stroke length (Kjendlic et al., 2004), much like a runners stride frequency and length. In swimming stroke rate corresponds significantly with $\dot{V}O_2$ (Wakayoshi et al., 1995) however such studies are limited in a running setting observing stride rate. Logically with the correlation found by Wakayoshi et al., (1995) (0.995, p < 0.01) there is a possibility that stride frequency has just as important a role in a running economy setting.

Cycling studies have also highlighted the finding that higher cadences tend to produce a greater economy for the same workload (Lucia et al., 2004). Although runners do not have their bodyweight supported during exercise there remains a possibility that these higher rates of movement suit a reduced oxygen cost for any activity, be it cycling, walking or running.

Exercise economy as a factor of running performance identification has been clearly established in the literature (Conley and Krahenbuhl, 1980; Hagan et al., 1981; Daniels, 1985; Williams and Cavanagh, 1987; Anderson, 1996; McArdle et al., 2006) especially when dealing with high performance athletes who share a similar range of $\dot{V}O_{2\text{max}}$ scores. (Costill et al., 1973; Bailey and Pate, 1991; Morgan and Craib, 1992) As better economy demonstrates a reduced amount of oxygen used for the task in hand (Saunders et al., 2004b), opposed to using energy to fuel superfluous movements not vital to increasing running speed (Saunders et al., 2004a).

### 2.2 Economy in running

Running economy has been established as an indicator of endurance fitness in its own right (Morgan et al., 1989b; Morgan and Craib, 1991; Berg, 2003; Saunders et al., 2004a; Saunders et al., 2004b). So testing subjects can come as a set of sub maximal exercise bouts to indicate running economy of the athlete and therefore performance without testing $\dot{V}O_{2\text{max}}$. This is backed up by Morgan and Daniels, (1994) who stated the $\dot{V}O_{2\text{max}}$ capacity of an athlete does not represent their running
economy, so measuring $\bar{VO}_{2\text{max}}$ would appear irrelevant in a purely economic al study.

2.3 Factors affecting Running Economy

The athletes’ basic kinematics, velocity and fundamental aspect of economy are determined by two factors, stride length (SL) and stride frequency (SF) (Mercer et al., 2002; Hunter and Smith, 2007). Eston and Reilly, (2005) discussed a U-shaped concept exhibiting the relationship between running economy and stride length and frequency. Findings illustrated that the relationship curve was flatter towards an athletes’ preferred cadence and that this naturally chosen running frequency was close to the optimum stride length and frequency for economy. It was also understood that small deviations in these variables have little or no effect on economy, highlighting the need to research how dictated stride frequencies influence and impact upon running economy through larger changes in stride rates when examining possible performance enhancing effects.

Foster and Lucia, (2007) indicated the affecting factors of economy; weight (runners are relatively small people, which when holding a cardio-vascular system comparative to a larger athlete will have a higher economy). Training status and training type (altitude training has been shown to improve economy, as has training at a higher percentage of their $\bar{VO}_{2\text{max}}$).

The most population specific paper for a university population studied 10 college runners over five years, specifically observing changes in SL, SF and stride time. Nelson and Gregor, (1976) studied the runners on a treadmill and filmed the athletes to see if any difference occurred over the time they spent training as students. Findings indicated all observed aspects changed with the greater training frequencies completed by the students, this could be seen as runners gaining experience and producing self-optimized running styles specific to their own biomechanical assets.

Although no particular pattern was established with the group as a whole, some runners increased their SL while frequency decreased and visa versa. Generally observations showed more runners decreased SL and increased SF. This could
explain the theory that optimizing ground contact time and vertical oscillations by increasing SF’s (Noakes, 2002; Brown and Ferrigno, 2005) are generally the more important factors when increasing speeds and performance.

Changes in stride characteristics were explored again by Cavanagh and Williams, (1982) who changed subjects’ gait to +/- 20% of their natural cadence. These changes produced an increased mean $\dot{V}O_2$ of 2.6 and 3.4 ml·kg$^{-1}$·min$^{-1}$ respectively (at 3.83 meters per second (m·s$^{-1}$)). The study concluded that natural gait was therefore the most economical, however in light of recent research (Eston and Reilly, 2005; Grant et al., 2006) a 20% gait manipulation may have been too great a change to produce better economical characteristics.

The study used 10 recreational runners, who were tested over five days for thirty minutes a day, with dictated SL’s being evaluated on two subsequent days. This seems like an over elaborate study time for runners who were not classed as experienced, as original scores may have been affected over the course of the project with factors such as treadmill familiarity increasing (Gore, 2000).

Cavanagh and Williams, (1982) followed up Högberg, (1952) who studied a 17% change however this study only looked at one subject, so with such a small sample it is difficult to apply any findings to the greater population. With the dictated strides, the figures read as a 12% increase in $\dot{V}O_2$ for over-striding and a 6% increase when under-striding. It was reasoned that the subjects freely chosen SL was optimal, when measuring economy. Even though stride characteristics between runners can be variable a 17% change still seemed excessive for the subject, and a one-subject study does not reflect the population as a whole at all.

The present study will aim to accommodate for a greater number of participants to try and establish whether in a running population there is a trend for the best stride frequency characteristic as with Nelson and Gregor, (1976). Rather than looking at individual rates, as generalised data is more useful to the specific group (i.e. runners) than single cases for the application of findings.

Williams and Cavanagh, (1987) investigated running mechanics, running economy and performance in 31 runners after screening 125. These 31 chosen athletes were considered suitable as they could run at the required 3.57 m·s$^{-1}$ with a blood lactate of
≤ 2 m·Mols, producing a great deal of work compared with random sampling athletes, but increasing homogeneity in the group. Douglas bags were used to collect \( \dot{V}_E \) during a \( \dot{V} \text{O}_{2\text{submax}} \) bout, this produced economy scores that varied considerably between runners.

As a general guideline though, it was established lower vertical oscillation in the centre of mass at preferred stride rates lends itself to the more economical runner, backing up the theory from Nelson and Gregor, (1976) of self-optimization. They also believed changing a single aspect of a runner’s style could lead to a lowered running economy overall, providing evidence only altering stride frequency could lead to changes in running economy as investigated by Grant et al., (2006).

Finally in terms of the possibility of decreasing oxygen costs with increased stride optimization Donati, (1995) took twenty-five high level sprinters and achieved a change in their stride length to find a new and more optimal stride length / frequency for sprinting – whether a similar outcome could be achieved for distance running was discussed below.

### 2.3.1 Stride length

Although studies have researched the entity of stride characteristics as a whole, there is less research focusing on manipulating the specific factors of SL or SF as a separate entity, in distance runners.

McArdle et al., (2006) discussed how SL increases more than frequency below 23 km·h\(^{-1}\) velocities, as runners cover more ground per stride to increasing speed. But the use of improving running economy via SL manipulation was also refuted by Price, (2005), who eluded that after a point, over striding resulted in a ‘diminishing rate of return’ with subjects experiencing braking forces.

Morgan, et al., (1994) assessed whether distance runners with uneconomical preferred step lengths could be trained towards their optimal, nine subjects who exhibited naturally uneconomical SF’s (mean optimal step length [OSL] = -9.81% from P; mean change in \( \dot{V} \text{O}_2 \) [P – OSL] = 1.46 ml·kg\(^{-1}\)·min\(^{-1}\)) were trained during 30 minute treadmill sessions using optimal SL’s for 3 weeks. Subjects changed their
SL’s through audio and visual feedback matching OSL, while findings showed the experiment group had a significantly ($P \leq 0.05$) greater shift in $P$ toward OSL and a decrease in economy at their new $P$.

Morgan et al., (1994) concluded short-term audio and visual stimuli can be effective in optimizing SL thus lowering aerobic demand among distance runners exhibiting uneconomical $P$ showing runners are able to change their stride given audible stimulus. This study did not however indicate how they achieved their proposed OSL, so the present study looked at a range (+ and – of strides) when assessing athletes to establish any economical changes.

Problems with increasing SL were found to include increasing shock on the lower limb, especially the knee (Derrick et al., 1998). This highlights potential biomechanical risks when runners over-step to gain greater distance per stride aiming for greater economy. "The energy absorbed during the impact portion of the running cycle also increased with stride length. Muscles that cross the knee joint showed the greatest adjustment in response to increased shock." (Derrick et al., 1998)

There is additional research that indicated SL adjustment caused problems from Dallam et al., (2005), the paper focused on the possibility of altering running technique and therefore running economy in 16 triathletes, using the "pose method" of running. Findings indicated a decrease in SL ($p < 0.05$), vertical oscillation ($p < 0.05$) but a mean increase in oxygen consumption ($p < 0.01$) showing how an increase in SL can actually decrease running economy in triathletes.

Eston et al., (2001) and Mercer et al., (2002) bought up additional problems with changing a subjects SL from P with muscle damage and shock magnitude. Eston et al., (2001) assessed maximal isometric force and perceived muscle soreness post-test, which revealed over-striding perceived most soreness while the under-striding retained most strength. This was also observed by Mercer et al., (2002) when looking at correlations between peak head shock and stride length ($p = 0.71$) and frequency changes ($p = 0.40$). Showing a more significant correlation between shock
and stride length provides warning as to the effects this may have on athletes’ muscles and joints.

Research in this area has been described as “fruitless”, (Bailey and Pate, 1991) leading away from this factor and solely onto SF.

**2.3.2 Stride frequency**

SF has been reasoned as the factor of choice when increasing running speeds. Brown and Ferrigno, (2005) reasoned as athletes could only expend energy into forward movement when in contact with the ground. Thusly the more ground contacts per minute the greater force as a percentage is exerted into forward momentum. This is acknowledged by the concept that “Runners are advised to shorten stride length to improve economy” (Berg, 2003), indicating that to achieve the same speeds an athlete would be running with a higher stride rate to compensate for the decreasing stride length.

SF as an aspect of performance is generally undefined in terms of competition levels as it cannot really be affected. McArdle et al., (2006) identified that to increase running speed athletes can increase SL, SF or increase both. SL has been established within literature to affect speed (Högberg, 1952; Cavanagh and Williams, 1982; Derrick et al., 1998) possibly because at higher speeds an increased force is created to carry the athlete over more ground, lending them to increase stride length. However it is less well documented as to whether an increase or decrease in oxygen consumption occurs during running for adapted stride frequencies.

In walking studies, $\dot{V}O_2$ consumption has been shown to become altered with varying stride characteristics by 10 to 20% (Hreljac and Martin, 1993). The study demonstrated how greater vertical oscillation away from the participants preferred cadence produces greater $O_2$ consumption, finding self selected stride characteristics to have the greatest economy of movement.

Unnithan and Eston, (1990) found that, in children, increased stride frequency produced greater biomechanical energy costs. Insinuating more muscle fatigue would occur during training and racing with the increase in muscular work from
contractions per minute. Converting this finding to runners may lead to a less economical athletic performance, possibly decreasing overall race execution.

Current research has only culminated to one study of note looking into the relationship between running economy and stride frequency manipulation in mature, active subjects. Grant et al., (2006) described how the stride manipulations of plus and minus, 5 and 10% of subjects natural running cadence affects running economy, compared to their P. Participants ran at 90% of their LT listening to a metronome through speakers for cadence pacing, five times for 8 minutes and 15 seconds for each bout, resting for 10 minutes between each bout.

The study took four measures of expired \( \dot{V}O_2 \) via Douglas bags and found the most economical cadence was + 5% of their P (40.7 \( \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \)), P itself measured as the second most economical (41.5 \( \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \)) with + 10% (41.9 \( \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \)) coming third, followed by - 5% and - 10% (42.3 \( \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \) and 44.0 \( \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1} \)) respectively.

Hunter and Smith, (2007) also dictated stride frequencies, but chose a 4 and 8% difference either side of P during 2 minute stages. Both studies demonstrated a preferred stride frequency was not always optimal in running reporting P and optimal stride frequencies were closely related but not identical, as with stride length commentary.

With Grant et al., (2006) there seems to be a pattern that increasing stride frequency lends itself to better economy of movement comparative to decreasing the stride frequency; Noakes, (2002) believed this could be explained through deceased vertical oscillations during locomotion. With the P in Grant et al., (2006) not showing the greatest economical locomotion for running an issue is highlighted for finding whether this extends into distance runners and if so, which stride cadence / frequency is most economical for them.

The economical cost of changing an athletes’ stride frequency has rarely been published as a single factor, possibly due to the multi-factorial nature of economy assumed by the literature (Bailey and Pate, 1991; Berg, 2003; Saunders et al., 2004a) but it is generally assumed that a runner of higher ability will have developed the
most economical personal frequency for themselves, however most evidence is conflicting.

2.4 Literature Conclusions

The literature showed performance implication studies for runners was generally more than 10 years old, establishing there was an issue data was out-of-date, if not unspecific for SF all together. There is also a lack of SF data as an aspect of competitive performance, rather it has been left as a comparison between populations and not focused on a specific group. As injury risks for endurance sports are a major concern, with the quantity of training required by athletes, it would appear investigating stride frequency may be more attractive for distance runners, with stride length generating a greater risk (Eston et al., 2001; Mercer et al., 2002).

The literature established a possibility that if too much difference in stride frequency was forced upon the participants, not only would the data be less likely to be optimal (Williams and Cavanagh, 1992) they may also be injured as a result of the testing (with an increased shock and braking force [Price, 2005]). Given this issue, a maximum % change in SF needs to be established while being substantial enough to elicit any positive change in economy. Grant et al., (2006) reported 5 and 10% changes, while Cavanagh and Williams, (1982) dictated a 20% alteration. With this in mind a 10% change seemed most balanced between requirements.

Research has not yet established a clear mechanical profile of an economic runner with regard to gait, kinematics and the kinetics of running (Anderson, 1996). But has indicated when SL has been freely chosen over considerable training time (as with distance running) this results in low vertical oscillation of body centre of mass (Noakes, 2002). However there has yet been the same with SF, signifying a possible researching opportunity into any possible optimal ‘profile’ in distance runners.

This paper focused on SF as the primary variable to running economy in trained athletes as it has been left primarily to assumption that a natural SF is the best for an athletes’ performance in any distance (Eston and Reilly, 2005). But given the nature
economy plays in endurance running it would appear most suited to this field for research.
CHAPTER III

METHODOLOGY
Methodology

3.1 Pilot Study
A pilot study was carried out prior to the main test, on a single healthy male whose characteristics were similar to the experimental group (age 20, 5 / 10 km runner), the subject did not take part in the resulting study. The test was used to gain knowledge of how different % changes in preferred (P) stride rates (SF) affected the athletes running style and whether it was a suitable change of SF (determined by the participant’s verbal feedback).

It was completed on a treadmill using a predetermined timetable (see Appendix A.) which implemented the main test protocols variables (1% incline, 16.1 km·h⁻¹). A 5, 10 and 20% change in SF was tested with the two extremes being deemed too slight and too great respectively for the speeds required to run at, so the 10% change was accepted for the study.

SF’s were dictated by the same metronome as was used ultimately in the study (TU-80, Boss, China) with the audibility being deemed acceptable for the highest test speeds of 16.1 km·h⁻¹. Rest periods were considered adequate taking into account observed heart rate dropping back down to around 80 b·min⁻¹ between bouts.

3.2 Participant details
Participants were recruited from the University of Wales Institute Cardiff (U.W.I.C.) and were all healthy males, (mean ± σ) age 21 (± 1.1), all with a minimum of 2 years running experience prior to testing. Subjects were currently in training for endurance (3, 5 or 10 km) running races and all habitually affiliated with running at least at club level. Subjects were instructed not to eat 3 hours or train 24 hours prior to testing and were informed of any inherent risks or dangers, before giving full written consent (see Appendix C.) and completing a physical activity readiness questionnaire (PAR-Q [see Appendix B.]) prior to testing. The study was granted ethical approval by the UWIC ethics committee.
3.3 Procedures
The study comprised of two separate laboratory appointments per subject, the two visits were different in protocol but both visits involved sub-maximal bouts of exercise on a powered treadmill (Model Quasar 4.0, Cosmos h/p/cosmos sports Germany) set at a 1% incline to more accurately emulate road running. (Jones and Doust, 1996)

Before testing began Douglas bags (Hans Rudolph, Inc. USA) had been evacuated of air with the evacuation system (Harvard Dry Gas Meter) and gas analysis equipment (Servomex Group Ltd, Sussex, England) was checked to have been calibrated by the laboratory technicians. The stopwatch (Fast Time, Cranlea, Birmingham, UK), mouthpiece, flexible air-hose and nose-clip (Hans Rudolph, Inc. USA) were all collected, attaching the hose to the mouthpiece and Douglas bag set-up. The metronome (TU-80, Boss, China) was affixed to the treadmill close enough to the participant so they could hear it at the 16.1 km·h⁻¹ speeds for stride pacing reference.

3.3.1 Test 1
On arrival to the laboratory participants were briefed again on the procedures, height (Holtain Ltd, Pembs), weight (770 SECA, Germany) temperature and atmospheric pressure (TH809, Radiant Innovation Inc. China) measurements were recorded before equipping subjects with a heart rate monitor and chest strap (Polar S610i, Electro Oy, Finland). Heart rate was recorded continuously through both tests with resting heart rate figures comprising of a minute straddling the treadmill prior to exercise.

Participants warmed up for 5 minutes at 9 km·h⁻¹, before engaging for 5 minutes at the 16.1 km·h⁻¹ test speed (Weston et al., 2000., Winter et al., 2007) this first bout (quality check) was used for subjects to become familiarised with the equipment, with stride frequency being measured (unknown to the subjects) during this first 16.1 km·h⁻¹ set. It was also appropriate to collect expired gas at 3:00 minutes for 30 s to analyse any intra-individual variations between tests as highlighted by Saunders et al., (2004a) who stated well controlled studies can produce test-retest diversity of 1.5-5 %.
Expired gas was collected during the bout for 30 s at 3:00 minutes so the subject had established a heart rate plateau and therefore physiological steady state (Wilmore and Costill, 1999). The nose clip, mouthpiece and Douglas bag set up was used with the flexible air hose being held by the administrator to stop it interfering with the running pattern of participants. Following collection the articles were removed until the next collection phase.

Subjects preferred stride frequency (P) was counted as foot strikes per minute between minutes 3:45-4:45 and recorded for later test manipulation. Hunter and Smith (2007) found that experienced runners stride characteristics change during running in an attempt to optimize stride frequency (SF), this indicated that SF’s reach steady state much like with physiological responses.

After the 5 minute quality check bout to record expired gas and P, subjects were given 10 minutes to recover, involving 5 minutes active recovery at 5 km·h\(^{-1}\) and then 5 minutes passive recovery, ensuring subjects returned to resting levels before the next test was initiated. That ensured multiple bout induced fatigue did not interfere with exercise economy (Bailey and Pate, 1991). P +/- 10% was calculated as below and then rounded up or down to the nearest nominator and entered into the metronome.

\[
P + 10\% (+SF) = \left(\frac{P}{10} + 10\right) + P \\
P - 10\% (-SF) = \left(\frac{P}{10} - 10\right) - P
\]

The second bout of activity involved the first of 3 dictated stride frequencies for 5 minutes at the 16.1 km·h\(^{-1}\) test pace, using a metronome set at either P, +SF or –SF unknown to the subjects. The study used a random order procedure to negate any learning effect (see appendix). Subjects were not informed of which SF they were running at so qualitative feedback and rate of perceived exertion (RPE) scores were not knowingly biased. Scores were collected by using the 15 point Borg scale (Borg, 1998) after each 5 minute bout; determining any difference in the sensed effort needed at the 3 rates. Expired gas was collected for 30 s at 1:20, 2:20 and 4:20 minutes.
Participants were handed the mouthpiece and nose clip 15 s prior to gas collection commencing to ensure they were both in place. The Douglas bags were attached to the mouth piece via the air hose which lead to a tap valve (Hans Rudolph, Inc. USA) atop each bag comprising of a two way valve which when turned, commenced collection of expired gas ($\dot{V}_E$) into the bag.

Once 30 s had passed the valve was turned back to the off (horizontal) position and the mouth piece and nose clip were removed from the runner. This occurred every time gas was to be collected until all testing bouts were completed, the bags were then taken to the gas analysis system where the expired oxygen ($\% \dot{V}O_2$) and carbon dioxide ($\% \dot{V}CO_2$) levels were measured for 30 s and the data recorded. The bags were then taken to the evacuation system where total $\dot{V}_E$ (L) measurements were taken and recorded, an additional litre was added to every $\dot{V}_E$ measurement to compensate for the litre lost to the 30 s gas analysis system.

SF was observed throughout to ensure participants remained at the dictated frequency and verbal encouragement was offered as subjects were working at high speeds. After the two 16.1 km·h$^{-1}$ bouts of exercise, subjects controlled a warm down until they felt comfortable to dismount the treadmill.

### 3.3.2 Test 2

After the standardised warm up of 9 km·h$^{-1}$ for 5 minutes subjects began the second quality check (5 minutes at 16.1 km·h$^{-1}$ including the 30 s gas sample at 3:00 minutes). Participants were again rested for 10 minutes, with 5 minute of active recovery at 5 km·h$^{-1}$ and 5 minutes of passive recovery. Then the second dictated SF was performed for 5 minutes, expired gas was again measured for 30 s after 1:20, 2:20 and 4:20 minutes and RPE scores for the exercise bouts were recorded. After a further 10 minute recovery period of 5 minute of active recovery at 5 km·h$^{-1}$ and 5 minutes of passive recovery the third and final dictated SF bout was completed. Subjects then controlled a warm down until they felt comfortable to dismount the treadmill with gas collection and RPE procedures remaining as before.
3.3.3 Douglas bags

Although the Douglas bag method is an offline system, it suits the steady state gas exchange analysis used in the study (James et al., 2007), as second by second oxygen kinetics data were not required during the sub-maximal bouts. However Douglas bags did not directly measure inspired air ($V_I$), instead the study used a gas calculation model (Egan, D. Excel spreadsheet).

Douglas bag error was minimised through a sound application of methods, whereby accurate timing of sample collection was vital (valves were opened at the first exhale of the subject during the collection phase), checking for leaks (in bag, valves and mask) occurred before every test and gas temperature and ambient pressures were used to calibrated units to dry air using the gas calculation model. Laboratory conditions (temperature ($°C$) and ambient pressure (mmHg)) were recorded and inputted into the gas calculation equation, along with subject variables (height (cm), weight (kg)).

3.3.4 Gas Analysis

When assessing work economy James, et al., (2007) outlined figures can be processed using the pulmonary gas exchange including the variables oxygen uptake ($\dot{V}O_2$), expired carbon dioxide ($\dot{V}CO_2$) and expired minute ventilation ($\dot{V}_E$).

Expired gas was collected in Douglas bags to assess oxygen utilisation and carbon dioxide production using the Gas analysis system and analysed no later than 15 minutes after being collected.

Calculating $\dot{V}O_2$ (L·min$^{-1}$), $\dot{V}CO_2$ (L·min$^{-1}$), $\dot{V}_E$ (STPD L·min$^{-1}$) and RER data was attained through the gas calculation model. To convert $\dot{V}O_2$ scores to the running economy unit ml·kg$^{-1}$·min$^{-1}$ the following equation was implemented:

$$\frac{\dot{V}O_2 \times 1000}{mass \ (kg)}$$

To convert $\dot{V}O_2$ scores to the running economy unit ml·km$^{-1}$·min$^{-1}$ the following equation was implemented:

$$\frac{\dot{V}O_2 \times 1000}{treadmill \ velocity \ (km \cdot h \ - \ 1)}$$
3.4 Applied Methods, Reliability and Validity

All testing was done in the same room using the same equipment for both tests; each participant was tested at the same time of day with tests taking place no later than eight days apart for every subject.

Both Anderson, (1996) and Astorino, (2006) validated running economy as the physiological criterion measure for the efficiency of performance, it has also been identified as a critical element of overall distance running performance (Astorino, 2006, found the strong relationship of \( r = 0.90, p<0.01 \) between high speed running economy and \( \dot{V}_{O_{2\text{max}}} \)).

Pre-test factors were considered, these included training, diet and health, footwear, equipment familiarity and the lab environment (Gore, 2000). Familiarity of treadmill running was considered in the first test, where participants were asked (if uncomfortable) to freely use the treadmill at a selection of running speeds before testing. Health was established with a PARQ, and the environment was monitored by a thermometer and barometer.

Footwear was considered as it has been established shoe weight may affect the running economy of the participants (Anderson, 1996; Gore, 2000; Noakes, 2002; Berg, 2003). With this in mind athletes were asked to use their preferred race shoe throughout testing; increasing external validity by mirroring race kit. This also produced more internally valid results through designating one shoe and therefore weight for each of the subjects’ data sets.

The measurement of heart rate (HR) and expired gas (\( \dot{V}_E \)) has been established by Pate et al., (1992) exhibiting HR and \( \dot{V}_E \) as important components of economy and for establishing a participants’ steady state condition. Bailey and Pate, (1991) also established these variables as the two most useful internal factors that contribute to running economy.

Treadmill speeds were set for all participants to allow increased cross-examination result validity (Schache, 2006). These speeds consisted of 9 km·h\(^{-1}\) for the warm-up so as to ease subjects into the 16.1 km·h\(^{-1}\) economy data collection phases. This is
backed up by James et al., (2007) who outlined the common way of assessing running economy was to look at $\dot{V}O_2$ in ml·kg$^{-1}$·min$^{-1}$ at 16 km·h$^{-1}$ with a 1% gradient (i.e. 6:00 min·mile$^{-1}$ pace). Daniels and Daniels (1992) recommended economy data be collected at above 90% $V_O2_{max}$ which for an experienced 3, 5 or 10 km male runner would be considered around 16.1 kph, as an accurate pace for participant athletes to both train and race at.

When measuring running economy Morgan et al., (1989a) found athletes are expected to plateau aerobically and attain steady state after 3 minutes. Another indicator of sub-maximal levels consists of a respiratory exchange ratio (RER) of $> 1.00$. So when measuring expired gases and preferred stride frequencies steady state data collection occurred after 3 minutes to allow runners to settle into both running intensity and stride. All respiratory and physiological data was then analysed as shown in the statistical section.

To indicate whether a dictated or P stride frequency had any bearing on comfort Borg’s RPE scale (Borg, 1998) was implemented to assess perceived exertion, the scale was used as it had also been found to possess a “strong positive associations with physiological variables, such as oxygen uptake ...and... heart rate” (Lamb et al., 1999). The athletes’ views were also recorded qualitatively to help observe any preference in being dictated a stride frequency in the discussion.

Morgan et al., (1991) stated a controlled testing environment results in no need for multiple trials when gathering consistent measures of running economy for experienced male runners. Demonstrating expired gas could be measured once per visit as a control measurement and then taken again during the dictated stride frequency bouts without losing as much reliability through the small sample quantities compared with a less accurate physiological measure.

3.5 Statistics

The study implemented a 95% confidence interval.
Analysis of the data was undertaken using the Statistical Package for the Social Sciences (SPSS 12.0.1, SPSS Inc.), a paired t-test was used to compare the two related \( \dot{V}_O_2 \) scores from quality checks one and two to indicate any difference between the means and evaluate how much variation and random / systematic error there was between tests that could impact on results. Pearson’s product moment correlation coefficient was used for the parametric data sets (Vincent, 1999), for the correlation between the two means to indicate how well the data sets mirrored each other (thus reducing error) (Howitt and Cramer, 2003). If the lower-upper confidence interval passed through zero, it was deemed the sample represented the population (Fields, 2000).

Subjects’ \( \dot{V}_O_2, \dot{V}_C O_2, \dot{V}_E \) and HR data was examined with a one-way analysis of variance (ANOVA) for repeated measures, this indicated whether two or more scores had statistically significant means (i.e. are different from each other, indicating different strides had an effect). An ANOVA was relevant to this study as it assumed all participants had contributed to all data sets, and that Pearson’s correlated coefficient was ‘large’ (Howitt and Cramer, 2003). Bonferroni’s adjustment was used during the calculation as it adjusted the \( p \) value to correct for any error inflation that occur when comparing the same set of subjects (familywise error rate) (Vincent, 1999).

If Mauchly’s test of Sphericity was not reported as significantly different \( (p \geq 0.05) \) then the within-subject contrast output acknowledged would be ‘Sphericity Assumed’ (Fields, 2000). The significance of the F-value had to be \( p \leq 0.05 \) to highlight there was a difference between mean sets of results. If a difference was found, a related t-test would then be used as there were three sets of data, to find exactly where the variations lay (Howitt and Cramer, 2003). Although the population was not normally distributed (i.e. a sporting population), it would have little effect on the F-value of ANOVA, so the test was considered robust (Vincent, 1999) as long as the test met Sphericity.

If a significant difference was reported between \( \dot{V}_O_2, \dot{V}_C O_2, \dot{V}_E \) or HR by the ANOVA output a paired t-test was used to establish where the differences lied, this
was done using expired gas outcomes, analysing -SF with P, +SF with P and –SF with +SF. This would indicate if one dictated stride frequency was more preferable in terms of oxygen utilization than the other two.

The study’s independent variable was the SF maintained by the runners and the dependent variable was the runners exercise economy at the various calculated SF’s.
CHAPTER VI

RESULTS
Results

4.1 Environment and participant data

Laboratory environmental factors were recorded before each test as 19.4 ± 0.2 degrees centigrade (°C) with pressure indicated as 760 millimetres of mercury (mmHg).

Table 1. Subjects anthropometric results

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>21 ± 1.1</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.4 ± 6.8</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>65.9 ± 7.7</td>
</tr>
</tbody>
</table>

Note. Results are means ± standard deviation (σ).

4.2 Test data

Table 2. VO2 data for Quality Tests 1 and 2 at 16.1 km·h\(^{-1}\)

<table>
<thead>
<tr>
<th>Stage</th>
<th>VO₂ (L·min(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Check 1</td>
<td>3.99 ± 0.60</td>
</tr>
<tr>
<td>Quality Check 2</td>
<td>3.87 ± 0.58</td>
</tr>
</tbody>
</table>

Note. Results are means ± σ.

The resulting mean VO₂ data during the quality check (QT) treadmill bouts for the first and second laboratory visits are shown in Table 2. The QT sample differences did not differ significantly (\(t = 0.74, df = 5,\) two-tailed \(p > 0.05\)). A Pearson’s correlation coefficient between the two VO₂ variables reported a strong but non-significant correlation (0.76 \((p > 0.05))\). This demonstrated any notable change in the subjects’ subsequent VO₂ scores for the same-day tests were likely down to the dictated stride frequency factor.
Table 3. Physiological from across the three dictated stride trials at 16.1 km·h⁻¹

<table>
<thead>
<tr>
<th>Stride stage</th>
<th>$\dot{V}O_2$ (L·min⁻¹)</th>
<th>$\dot{V}CO_2$ (L·min⁻¹)</th>
<th>$\dot{V}E$ (L·min⁻¹)</th>
<th>RER</th>
<th>HR (b·min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub 10 %</td>
<td>4.19 ± 0.37</td>
<td>3.80 ± 0.48</td>
<td>91.40 ± 19.38</td>
<td>0.91 ± 0.07</td>
<td>171 ± 11</td>
</tr>
<tr>
<td>Preferred</td>
<td>4.08 ± 0.48</td>
<td>3.64 ± 0.56</td>
<td>88.47 ± 13.60</td>
<td>0.90 ± 0.10</td>
<td>170 ± 13</td>
</tr>
<tr>
<td>Plus 10 %</td>
<td>4.31 ± 0.57</td>
<td>4.00 ± 0.68</td>
<td>95.57 ± 17.00</td>
<td>0.93 ± 0.10</td>
<td>172 ± 9</td>
</tr>
</tbody>
</table>

Note. Results are means ± σ.

Table 3 shows ventilation values given as an absolute unit. Mean $\dot{V}O_2$ data was lowest at the subjects P, the fastest stride rate of +SF elicited the highest consumption of $O_2$. While the slower rate of -SF produced a value somewhere between the two. $\dot{V}CO_2$ values demonstrated a similar pattern with the smallest mean amount of production occurring at the P stage, while a greater amount of $CO_2$ was exhaled during the +SF stage.

$\dot{V}E$, RER and HR all exhibited the same relationship, P always displaying the lowest and most economical measures. The greatest absolute response was from $\dot{V}E$ where a 7.1 L·min⁻¹ mean difference from P to +SF was incurred.

RPE scores from all trials are shown in Table 4, quality check scores were identical when expressed as a group mean. Whereas these values changed for all dictated trials, greatest for the –SF and +SF.

Table 4. Ratings of Perceived Exertion Scores

<table>
<thead>
<tr>
<th>Stage</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality Check 1</td>
<td>13 ± 2</td>
</tr>
<tr>
<td>Quality Check 2</td>
<td>13 ± 2</td>
</tr>
<tr>
<td>Sub 10 %</td>
<td>15 ± 3</td>
</tr>
<tr>
<td>Preferred</td>
<td>14 ± 3</td>
</tr>
<tr>
<td>Plus 10 %</td>
<td>15 ± 3</td>
</tr>
</tbody>
</table>

Note. Results are means ± σ all given to nearest nominator.
4.3 ANOVA Analysis

After putting mean physiological data for the three stride stages through a one-way ANOVA with repeated measures, Mauchly's Test of Sphericity found significance ($p > 0.05$) for all data ($\dot{V}_O_2 \ (p = 0.48), \dot{V}_C_O_2 \ (p = 0.38), \dot{V}_E \ (p = 0.93)$ and HR ($p = 0.77$)). Sphericity was assumed for the within-subjects effect. No statistically significant difference was reported from the within-subject effect output shown in table 4.

Table 5. Within-subject effect Sphericity assumed

<table>
<thead>
<tr>
<th></th>
<th>$\dot{V}_O_2$</th>
<th>$\dot{V}_C_O_2$</th>
<th>$\dot{V}_E$</th>
<th>HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>F-value</td>
<td>0.995*</td>
<td>2.009*</td>
<td>1.366*</td>
<td>0.199*</td>
</tr>
</tbody>
</table>

Note. * indicates $p > 0.05$

4.4 Economy data

Post conversion of the $\dot{V}_O_2$ data produced Figures 1 and 2 illustrating the increasing oxygen cost of running at – 10 % and + 10 % respectively in terms of the weight relative economy unit (ml·kg⁻¹·min⁻¹) and oxygen cost per km (ml·km⁻¹·min⁻¹).
Figure 1. Economy data given as mean ± σ for the three stride trials tested at 16.1 km·h⁻¹

Figure 2. Economy data given as mean ± σ for the three stride trials tested at 16.1 km·h⁻¹
CHAPTER V

DISCUSSION
Discussion

The present study looked at how a change about the preferred cadence (P) of an athlete stride frequency (SF) affected the running economy at a sub-maximal velocity in a group of habitual runners.

5.1 Main Findings

The main finding of this study was that the SF’s of habitual runners would appear the most economical when expressed as the relative units of measure (figure 1 and 2) compared with a 10 percent change. A mean increase was exhibited with all subjects \( \dot{V}O_2 \), \( \dot{V}CO_2 \) production and \( \dot{V}E \) (table 3). All values increased during all metronome dictated SF stages, when compared with the initial quality check bouts \( \dot{V}O_2 \) scores (table 2).

The most marked increase was found during the 10% alterations. The least economical was +SF (65.4 ± 4.1 ml·kg\(^{-1}\)·min\(^{-1}\)) followed by -SF (63.8 ± 5.2 ml·kg\(^{-1}\)·min\(^{-1}\)) and finally the most economical being P (61.8 ± 1.6 ml·kg\(^{-1}\)·min\(^{-1}\)). The standard deviation shows a proportion of the athletes struggled at both -SF and +SF, as higher values indicate a greater range, but both values are clearly higher than P. However no physiological indicator was proven to be statistically significant (table 5).

Mean (RER) during all bouts (table 3) remained below 1.00 indicating all runners were working at predominantly aerobic levels. This gives confidence that any changes observed in the data can be reported as a genuine change in economy, rather than athletes relying more on other metabolic (i.e. anaerobic) systems.

Although all data altered between bouts the greatest exponent of this change was \( \dot{V}E \) which generated a mean increase of 7.1 L·min\(^{-1}\) (table 3) as a result of running at a +SF change from P.

The changes to expired volume have been theorised as a running rhythm issue causing increased or decreased ventilation responses. Both the faster and slower stride rates bought about change from P, but +SF produced the greatest increase.
This could be explained by athletes trying to mimic the changes of their stride with their breathing, that is, a higher rate of steps induced a higher breathing rate (Martin and Coe, 1997).

Another reason for the reported changes to $V_E$ may be signified through a physiological response linked with the increase in $VCO_2$ (table 3). As the body’s blood concentration of carbon dioxide increases it responds automatically by stimulating respiratory kinetics. Thus explaining the growth of total expired air.

The changes found in $VO_2$ and $VCO_2$ are seen to be interlinked, in the sense that any changes that are made by the energy systems to fulfil the metabolic cost of movement responds by increasing both the oxygen consumption and carbon dioxide production and exhalation.

HR means remained within 2 beats·min$^{-1}$ for the three dictated stride bouts, indicating a similar stress on the cardiac system as it worked at a fixed, steady percentage of all the participants’ capacities. Although 170 beats·min$^{-1}$ could be considered a high rate for a general population, the study’s utilisation of an endurance trained population makes this claim disputable. The groups’ aerobic ability at these high speeds is endorsed by their RER scores (table 3). These scores signify athletes were all metabolising energy aerobically due to their ongoing training for and chronic adaptation to endurance running.

Although physiological variables are the exclusive factors when concerning running economy, psychological factors can still affect a runners’ performance because of this RPE scores and qualitative viewpoints were recorded. Mean RPE levels (table 4) were higher for all metronome controlled bouts, including the athletes preferred cadences. Conversely there is still a greater increase from 13 “Moderately hard” during the quality checks to 15 “Hard” on the two 10% SF changes.

The qualitative data for the -SF stages were perceived by the athletes as being generally bouncy, and hard to find a rhythm for. Whereas the P dictated stage was viewed by some taller athletes to be harder than the +SF stage and uncomfortable by some. The +SF bout was scrutinised as being hard to keep to (muscularly), getting choppier with fatigue. Some thought their breathing was too frequent, with these athletes claiming to use their stride rates to pace breathing frequency. So any change
from the preferred levels would have subsequent effects on ventilation (Martin and Coe, 1997).

Overall most athletes perceived all metronome controlled bouts to be more unnatural than the quality checks which were free from control. There did seem to be a general preference for the taller athletes to stride out and the shorter athletes to increase their stride rate.

Both sets of economy data (figure 1 and 2) illustrate an apparent difference between the stride rates. The preferred stride rate exhibited the smallest oxygen cost of the three mirroring all the other recorded physiological and psychological factors. There is also a clear indication that the +SF parameter produces the most uneconomical running style. This preference could be put down to the fact that competitive runners tend to be smaller individuals (Foster and Lucia, 2007) than the general population. This may lend their style to an already fast leg turnover, with a 10 percent increase representing too extreme a change.

5.2 Hypotheses review

Although all measured factors presented changes during the manipulated stride frequency bouts, no statistical significance was established, so all null hypotheses (H0a, H0b, H0c, H0d and H0e) are accepted.

5.3 Previous research

The study’s findings provide the research area with information into the influence of directed stride frequency and running economy, with scope into the population of experienced distance runners.

Prior research agrees with the current study’s conclusions that a subjects preferred stride frequency appear to suit the athlete given all the factors that make up their stride pattern. Both Högberg, (1952) and Cavanagh and Williams, (1982) reported experimental deviations away from preferred stride characteristics increased a
subjects \( \dot{V}O_2 \) uptake. This was also found to be the case when testing an athletic population.

Anderson (1996) believed gait patterns of longer +SL (-SF) induce braking force on the runner (as they have to adapt their running to stretch out and in so doing land heel first). This leads to increased vertical oscillation and increased range of movement producing increased friction and stiffness. -SL’s (+SF) that are too short are believed to increase work through higher frequencies of movement (Unnithan and Eston, 1990). These beliefs were backed up by the findings that higher \( \dot{V}O_2 \) scores were exhibited for + and –SF (table 3 and figure 1).

The belief in most research has indicated a self-optimisation occurred in athletes so they ran more economically (Högberg, 1952; Nelson and Gregor, 1976; Cavanagh and Williams, 1982) this study resulted in similar findings indicative of previous research. The study’s findings also agree with the proposed U-shaped model (Eston and Reilly, 2005), although an understanding of whether the economical plateau changes for different populations would prove useful for future research.

Most previous literature concurs with the outcomes of this study however Beck (2005) ascertained athletes select a SF that is not concurrent with their optimum rate. This is agreed with by the results from Grant et al., (2006) who established a mean decrease in oxygen cost with a 5 % increase in stride frequency. As Grant et al., (2006) used a smaller change in SF there are clearly smaller differences between preferred SF and optimal SF (Hunter and Smith, 2007) than was tested for in this study.

As reported previously RPE scores were consistently higher for metronome dictated P, this could be interpreted as a fatiguing athlete self-optimises their running style due to fatigue (Hunter and Smith, 2007). Thusly their SF will not be perfectly constant and unsuited to matching the metronomes uniform beat as the athlete tires.

It has not be recognised whether previous research collected qualitative data to report what subjects perceived during testing, but this study found viewpoints generally back up arguments accumulated from aforementioned research. It was found – 10% of SF caused some perceived discomfort (Anderson, 1996).
Although there is yet to be a set of figures describing the optimal gait characteristics used by elite runners (Anderson, 1996), this could be seen as a futile endeavour given the number of factors to consider and the physiological and biomechanical variations found in athletes.

### 5.4 Implications

Within the sport of distance running, economy has been established as a major factor in successful performers (Jones, 2007; Joyner and Coyle, 2008). SL and SF have been established as a dictating factor in kinetics (Mercer et al., 2002; Brown and Ferrigno, 2005) so research in this area has been interested in how changes in these variables may influence a better performance.

The $\hat{V}O_2$ variations found when changing a runner's SF could be interpreted as an increased demand on the muscular system (Lucia et al., 2004). With the faster stride characteristics seeming easier for smaller runners as slowing cadence appears to be easier for taller runners. These preferences could be explained by athletes’ lower limb ranges of movement, or more accurately, an athlete’s ability to extend or restrict their usual leg swing.

**Coaches**

When providing technical feedback to athletes, coaches usually apply the technique of a “perfect” or “elite” model usually taken from a successful elite performer. Although this may work for some athletes, coaches may want to consider employing a separate model for each athlete rather than trying to make each athlete fit a specific model. Especially if coaches take biomechanical variables (i.e. height) into account and match them up with similar elite counterparts. This would see more benefit to uneconomical athletes as preferred stride characteristics vary between every athlete.

Coaches should also possess knowledge that modifying SF could affect the cost of running ($\hat{V}O_2$) and that SF can dictate breathes taken per minute if the athlete uses stride characteristics as a reference of rhythm. This could work as an advantage if athletes are able to cope with the changes, but a drastic change can see athletes loosing breathing and running rhythm.
**Athletes**

Although the running style for most athletes remains an autonomous series of coordinated movements, they require a knowledge of which style best suits their physique and anthropometric attributes. With regard to the taller segment of the running population, they lend themselves to longer strides biomechanically with the larger absolute range of movement. However, the greater number of smaller runners in the population should look to maintain SF as smaller, lighter athletes can cope better with a faster turnover.

Overall chosen styles of running should be seen as the economical optimum in an experienced running population and other factors affecting running economy may need to be optimised.

**Training**

The psychological factor in running has been established previously, this study has highlighted the possibility habitual runners are uncomfortable being dictated any stride characteristic (table 4). So when applying a new technique to less efficient runners to increase economy, it should be noted that gradually introducing these changes may facilitate a greater response by the athlete as they increase their running skill.

Increasing running economy has been linked to many factors, such as altitude training, working at higher levels of the athletes $\dot{V}O_{2max}$ and including strength training or plyometric work (Foster and Lucia, 2007). Maximal SF’s and SL’s have been argued as being dictated by the athletes ability to increase or decrease leg speed and translate these muscular forces into the ground (Weyand *et al.*, 2000). Both views commend strength training as an important factor for running economy.

Model figures have been sought after from an elite distance running population in an attempt to find a globally applicable set of optimal stride characteristic values. However research to date has found no real trend between athletes, even at the higher end of competitive performance. It has even been discussed that elite athletes took shorter strides as well as findings reporting better runners have longer strides (Anderson, 1996).
This amount of confusion within the literature further indicates that every athlete seems to possess a specialized and unique stride characteristic suited to them. Whereby the multitude of factors theorised (physiological, psychological and biomechanical) all play a role in determining the final nature of an athletes stride parameters of an athlete.
CHAPTER VI

CONCLUSION
Conclusion

6.1 Limitations and Observations

The most apparent limitation of the study was the lack of participants tested, as with most studies of few subjects this undermines any major findings. Even though changes in economy were found they were not statistically significant, due possibly to the small sample size used. The main problem was found with recruitment of subjects, keeping in mind the study only used experienced distance runners currently in training. This is a problem when aiming a study at a specific population the advantage to be gained being it produces more applicable and valid results for the tested population.

The running speed of 16.1 km·h⁻¹ was chosen as the standardised velocity for exercise performance as continuity is key to increasing validity (Schache, 2006) and the speed has been agreed as the criterion speed for measuring economy (James et al., 2007). However it could also have been detrimental when compared with using a percentage of each athlete’s VO₂max, given economy should demonstrate a pace at or below the lactate threshold. These speeds would differ from athlete to athlete just as race times would (William and Cavanagh, 1987). Given the length of testing and what was asked of the participants it was judged more testing would interfere too greatly with the athletes busy training schedules.

Although 16.1 km·h⁻¹ may be too hard to be classed as sub-maximal for certain athletes, the mean RER’s indicate metabolism occurred primarily at an aerobic level for exercise demands (< 1.00). With evidence economy data should be collected at intensities of ≈ 90% of VO₂max (Daniels and Daniels, 1992), all subjects achieved an RER indicating otherwise; this is a credit to the participant’s aerobic capacities as athletes.

6.2 Closing statement and Future Research

The study concludes running economy can be impaired by any change in stride frequency and less impaired by a decrease in stride frequency. Findings from the study have highlighted that the increased time spent training and competing as an
endurance runner, lends the individual the ability to self-optimise to run autonomously close to the most economical gait with regard to stride frequency. For these reasons it is suggested that athletes keep any stride frequency changes to a minimum.

Future research in this area could aim to develop the manipulative levels of stride frequency to the confines of lower percentile changes about the athletes’ preferred and natural cadence.
CHAPTER VII

APPENDICIES
APPENDIX A. Pilot Study Timetable

9 kph - 5 minutes warm-up

16.1 kph – 5 minutes of stride manipulation of plus and minus 5%*

10 minutes rest including 5 minute at 5kph active recovery

16.1 kph – 5 minutes of stride manipulation of plus and minus 10%*

10 minutes rest including 5 minute at 5kph active recovery

16.1 kph – 5 minutes of stride manipulation of plus and minus 20%*

Cool down

Total time; 45 minutes, 15 minutes at test pace

Note. *indicates each stride frequency was tested for 2 minutes.
APPENDIX B.

Informed Consent Form

Subject: 
Name ___________________________ Sex: M / 
F
Date of birth ___________________________

Investigators: ________________________ _______________________
(Student) (Member of Staff)

Ethical Approval Gained? Yes / No

Title of the Study:
The influence of manipulating stride frequency on exercise economy in male endurance runners at bouts of sub-maximal steady state.

Objective and Procedures to be Employed
Before you read and consider the information presented below it is important that you are aware that all of the proposed exercise tests and measurement techniques have been examined by an ethics committee, which has accepted that the proposed study is suitable for use with consenting, human subjects.

Objectives
The major aims of the present study are;

1). Assess whether a naturally chosen stride frequency is the most economical for the athletes performance.

2) To analyse whether a ± 10 % change in stride frequency impacts on running economy.
Exercise protocol
You will be required to visit the laboratory on two separate occasions. The first session is to familiarise yourself with the test environment and guidelines for this testing procedure – you will perform a small amount of sub-maximal exercise which will help you become familiar with the treadmill and face mask. This will consist of a 5 minute warm up at 9 kph and 5 minute control bout at 16.1 kph with expired gas being taken for 30 s at 3:30 minutes. After a 10 minute recovery period the first of three dictated stride patterns will be implemented at 16.1 kph for 5 minutes with gas analysis being taken at 1:20, 2:20 and 4:20 for 30 s.

During the second visit you will perform another two sub maximal treadmill tests at the two remaining stride frequencies. After the standardised warm up, control bout and recovery stage the second stride test takes place, then after a further 10 minute recovery period the third and final stride test begins, again with expired gas being taken. At the end of each test you may stay on the treadmill for an active recovery until you feel recovered enough to dismount.

Respiratory gas analysis will be conducted using the Douglas bags, which will require you to wear a face mask throughout the tests. Values of oxygen consumption, carbon dioxide production and breathing volume will be recorded for 30 s at the intervals stated above.

During the test heart rate will also be measured continuously using a Polar chest strap and wrist watch-like receiver.

Potential Risks
The risks outlined below will only apply to a small number of subjects. However, it is important you are made aware of possible outcomes in order to provide written, informed consent to participate in this study.

During Exercise
Due to the sub maximal effort of the test, there is little risk to you the participant, however in any test requiring physical exertion the possibility of injury is always present, no matter how small. While these risks are very unlikely to be encountered – these must be mentioned for Health and Safety reasons.

Following Exercise
Symptoms may include some light-headedness and disorientation brought on as a result of the physical effort. However, as outlined above, you will be expected to perform an active cool-down in order to facilitate recovery and avoid adverse symptoms including feeling feint, light-headed and nauseous.
Benefits
In becoming involved in this study you will enable us to collect data which forms part of a long-term research programme. The findings will provide us with a better understanding of how the human systems respond to sub maximal exercise and will consequently give you a better understanding of your own economy in running.

The Data
All data collected during the testing will remain anonymous and will be treated with the strictest confidence, although it could form the basis of eventual scientific publications and/or presentations.

NB - The University and its staff accept no liability for any matters arising, either directly or indirectly, from the information and recommendations given to you as a result of the outcomes of your test. It is the responsibility of the athlete to ensure that the Sport Scientist is aware of any medical conditions or other information that might affect either the test itself or the interpretation of the results and subsequent recommendations.

Statement by the Subject
I have been made fully aware of the risks and benefits involved from partaking in the present study. I understand that I am free to withdraw from the study at any time and that the results of the study will be treated anonymously and with total confidentiality.

I have had my attention drawn to the document produced by the American College of Sports Medicine (1997) entitled "Policy Statement Regarding the use of Human Subjects and Informed Consent". It has been made clear to me that if I feel my rights are being infringed and / or my interests are being ignored, neglected or denied, I should inform the chairman of the Cardiff School of Sport Research Ethics Committee who will undertake to investigate my complaint.

Signed: _______________________   Date: ______________________
(Subject’s signature)

I certify that the details of the study have been fully explained and described in writing to
__________________________, and this information has been fully understood by him.

(Subject's name, printed)

Signed: _______________________   Date: ______________________
(Independent witness’ signature)
APPENDIX C.

Physical Activity Readiness Questionnaire (PAR-Q)

Please circle the answers to the following questions:

1. Has your doctor ever said you have heart condition and that you should only do physical activity recommended by a doctor  Yes / No

2. Do you feel pains in the chest when you do physical activity  Yes / No

3. In the past month have you had chest pain when you were not doing physical activity?  Yes / No

4. Do you lose your balance because of dizziness or do you ever lose consciousness?  Yes / No

5. Do you have a bone or joint problem that could be made worse by physical activity?  Yes / No

6. Is your doctor currently prescribing drugs for blood pressure or a heart condition?  Yes/ No

7. Do you know of any other reason why you should not do physical activity?  Yes / No

If you have answered yes to any of these questions, please add details below. Similarly, if there are any situations which will prevent you from exercising write them here

Signed………………………………………………….

Date…………………………………………………….
CHAPTER VIII REFERENCES


Egan, D., (no date) Gas Calculation Spreadsheet, [www.sportsci.org](http://www.sportsci.org), accessed from UWIC Laboratory.


