NAME: GEORGE ASHDOWN

UNIVERSITY NUMBER: ST05002143

DEPARTMENT: PHYSIOLOGY

INSTITUTION: UNIVERSITY OF WALES INSTITUTE, CARDIFF (UWIC)
THE EFFECT OF MANIPULATED STRIDE FREQUENCY ON RUNNING ECONOMY IN EXPERIENCED DISTANCE RUNNERS DURING A SUB-MAXIMAL BOUT OF ACTIVITY
CONTENTS

1. Introduction ...................................................... p 1
   1.1 Key Terms
   1.2 Areas of Study
   1.3 Hypotheses

2. Literature review .................................................. p 6
   2.1 Exercise Economy
   2.2 Economy in Running
   2.3 Factors Affecting Running Economy
      2.3.1 Stride Length
      2.3.2 Stride Frequency
   2.4 Literature Conclusions

3. Methodology ........................................................... p 15
   3.1 Pilot Study
   3.2 Participant Details
   3.3 Procedures
      3.3.1 Test 1
      3.3.2 Test 2
      3.3.3 Douglas Bags
      3.3.4 Gas Analysis
3.4 Applied Methods, Reliability and Validity

3.5 Statistics

4. Results ................................................................. p 24

4.1 Environment and participant data
4.2 Test data
4.3 ANOVA Analysis
4.4 Economy data

5. Discussion .............................................................. p 28

5.1 Main Findings
5.2 Hypotheses Review
5.3 Previous Research
5.4 Implications

6. Conclusions ........................................................... p 35

6.1 Limitations and Observations
6.2 Closing statement and Future Research

7. Appendices ............................................................ p 37

Appendix A Pilot Study Timetable
Appendix B Informed Consent Form
Appendix C Physical Activity Readiness Questionnaire

8. Reference List ........................................................ p 42
TABLES

1. Subjects anthropometric results

2. VO$_2$ data for Quality Tests 1 and 2 at 16.1 km·h$^{-1}$

3. Physiological from across the three dictated stride trials at 16.1 km·h$^{-1}$

4. Ratings of Perceived Exertion Scores

5. Within-subject effect Sphericity assumed
FIGURES

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

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

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All athletes that participated in the study

Laboratory Technicians, D. Newcombe and M. Stembridge

My family
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 [\( V_E \)]...
L·min⁻¹). 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 \( \text{VO}_2\text{max} \). (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 \( \text{VO}_2\text{max} \) 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:

$H_{0a}$ 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

$H_{0b}$ 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

$H_{0c}$ 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 $\dot{V}O_2$, compared with their naturally chosen stride frequency.
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.

\[
P + 10\% (+SF) = \left( P + 10 \right) + P
\]

\[
P - 10\% (-SF) = \left( P - 10 \right) - P
\]

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% $V_2max$ 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’ \( \dot{V}O_2, \dot{V}CO_2, \dot{V}E \) 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 \( \dot{V}O_2, \dot{V}CO_2, \dot{V}E \) 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 O₂. 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 CO₂ 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 ($\dot{V}O_2 (p = 0.48)$, $\dot{V}CO_2 (p = 0.38)$, $\dot{V}E (p = 0.93)$ 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>$\dot{V}CO_2$</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 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.
### 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.

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**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.**

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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…………………………………………………….

42
CHAPTER VIII REFERENCES


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


