‘Comparison Of Four Different VO2max Exercise Testing Protocols.’

Abstract

Different exercise protocols prompt different physiological mechanisms before VO_{2max}. This investigation aims to analyse and compare four different tests, both constant load and incremental, in order to determine the most valid and accurate for assessing VO_{2max}. Ten subjects completed four different maximal VO_{2max} tests over a four-week period, with various physiological variables being recorded immediately prior to volitional exhaustion (VO_2, RER, lactate and HR). Mean scores for each variable for each test were compared to conclude that in contradiction to current literature, the incremental treadmill test did not elicit the highest VO_2, but the incremental cycle ergometer test. Exercise economy and lactate build up were two variables having major implications upon the validity of the four protocols. It is probable that none of the four tests presented a totally accurate VO_{2max}. Several flaws were noted in the data collection procedure and extension studies should be used to support the conclusions drawn.

Introduction

This investigation involves the comparison of four different exercise tests and their validation in providing quantitative results of VO_{2max}. The tests involved are the: ‘constant load cycle-ergometer test’; ‘incremental cycle-ergometer test; multi-stage fitness test and the incremental treadmill test. These tests are all very common in clinical and field fitness testing, therefore the conclusions drawn from this investigation will have direct, practical implications and applications to ‘real world’ sport.

During periods of exercise Hill and Lupton (1923) noted that subjects require additional oxygen to compensate for the additional ATP production and hydrolysis, in

relation to rest. They also noted that a plateau occurs in the rate of oxygen consumption (VO_2) even though exercise intensity increases, leading them to the assumption that there is a maximal rate of oxygen consumption and utilisation, or VO_{2max}. Hill and Lupton (1924) concluded that circulatory and pulmonary systems being unable to provide sufficient O_2 to mitochondria caused VO_{2max}. Later work by Saltin and Strange (1992) supports this view.

During regular exercise it is improbable that VO_{2max} will be achieved and so the highest rate of O_2 consumption recorded during exercise is known as VO_{2peak}.

More contemporary research by Tim Noakes (1996) contradicts Hill and Lupton's (1923) theory. He claims that a plateau in VO_2 does not always occur, and so he believes a linear relationship between exercise intensity and VO_2 is more accurate. Noakes would argue that muscular/peripheral factors are to blame for any incidents of plateau, and that VO_2 is not limited. He believes the functions of muscles simply prevent VO_2 from increasing further, and therefore VO_{2max} does not exist. The discrediting of Hill and Lupton's work by Noakes is based upon the view that Hill only demonstrated experiments that illustrated a plateau and that he did not supply enough experimental evidence to support the theory of the VO_2 plateau.

The debate between the causes of VO_{2max} as being central/circulatory or peripheral/muscular is generally weighted towards the 'central' argument. According to Wagner (1992), the O_2 supply to mitochondria is dependent upon the diffusion gradient, and with Honig et al (1992) proving that the surface area of mitochondria is five hundred times that of the capillaries, the diffusion gradient supports Hill and Lupton's theory of circulatory limits to VO_2.

The more recent beliefs of Noakes are widely criticised by many existing physiologists who claim that Noakes based his ideas on the work of Myers et al (1990) who said that only thirty three percent of subjects showed a plateau when tested, and that Myers et al only used six subjects, and so it is in fact Noakes' work that is unsupported.

Froelicher et al (1974) have conducted studies showing variable percentages of subjects actually eliciting a VO_2 plateau during exercise, which would support Myers et al (1990). Froelicher et al however, attributed the variances to the protocols used, rather than the inexistence of VO_{2max}, contradicting Myers et al, and moreover, Noakes.

Noakes used the absence of a plateau in many cases to promote the idea that VO_2 is not limited and would continue to increase with exercise intensity if muscular function did not prevent subjects from continued exercise. Rowell (1986) provides evidence to discredit Noakes by claiming that a plateau is not the only determinant of VO_{2max}, and that Noakes has neglected other physiological indicators that would suggest a maximal VO_2.

BASES (1997) published a criterion to act as a 'checklist' to aid physiologists in the identification of VO_{2max}. The criterion comprises of: a plateau in VO_2; a final respiratory exchange ratio (RER) > 1.15; a final heart rate within 10bpm of predicted maximum; post-exercise blood lactate concentration > 8mmol/l; subject fatigue or volitional exhaustion and finally a perceived exertion rating of 19 or greater on a 6-20 Borg Scale.

VO_{2max} is often regarded as the most important aspect of fitness due to its benefit to such a wide variety of sports and exercises. Demarie et al (2000) stated that the percentage of VO_{2max} maintained during training is linked to the rate at which

physiological adaptations occur. Therefore, the accurate calculation of maximal oxygen uptake is essential for the applied use of designing the most effective training programme to benefit individual athletes.

There are many different tests employed by exercise physiologists, sports coaches and physical trainers to assess VO_{2max} in athletes, but as earlier references to the work of Froelicher et al (1974) illustrates, the protocol for testing VO_{2max} can often influence the results obtained, and whether VO_{2max} or VO_{2peak} is represented. Therefore it is essential that valid and accurate tests be used when assessing VO_{2max}, if the results are to have any reliable and practical function or relevance.

This investigation involves the comparison of four exercise tests, each designed to provide accurate VO_{2max} values. The comparison is of validity and therefore, by definition, do the results obtained actually reflect VO_{2max} or are they influenced by physiological responses at high intensity exercise. Research into the physiological demands of these tests and into previous studies involving these tests, is therefore, quite pertinent to this study.

Although all tests used in this investigation have the same objective, there are two types of test employed, incremental and constant load, and for each there are different strengths and weaknesses in terms of validity. Incremental tests, according to Kuipers et al (2003), have a weakness in that stage duration can influence the results. Long stage duration can lead to premature fatigue and volitional exhaustion before VO_{2max} (Crouter et al (2001), therefore, results show VO_{2peak} and are invalid. However Kuipers et al (2003) also say that stage durations between one and six minutes do not influence VO_2

plateau and so the tests in this investigation, all of which remain in this time frame, should be immune to such influences.

The notion of differences in VO_{2max} values elicited by different tests, is confirmed by Basset and Boulay (2003), who proved that incremental treadmill tests provide significantly higher values than incremental cycle-ergometer tests. Suggesting that cycle-ergometer tests do not accurately reflect $VO_{2max,}$ but reflect VO_{2peak}, hence there could be debate over the validity of VO_{2max} values obtained from them. Kirchoff and Sill (1967) compliment these thoughts with studies providing similar results. Crouter et al's (2001) research on premature fatigue could explain this trend. The demands of cycle-ergometer tests are focused entirely on the legs and so lactate build up is concentrated there, hence fatigue of the legs may precede VO_{2max}. Hawley et al (1992) claimed that in their study involving cycle-ergometer tests, 63% of subjects did not reach VO_2 plateau due to premature fatigue and volitional exhaustion, caused by acidosis in the legs.

Premature volitional exhaustion could also be an invalidating factor of the MSFT, proposed by Leger and Lambert (1982) and developed by Ramsbottom et al (1988). This test comprises of 20m shuttle runs being completed at a gradually increasing pace, set by an audiotape. Several shuttles are completed before a verbal cue from the tape alerts subjects of progression to an increased intensity stage of several more shuttles. With verbal cues preceding the next increment, it has been recognised that subjects do not run until absolute exhaustion, instead many discontinue at a pre-determined target or at the end of a level to avoid the next increment (Wilkinson et al 1998). If such behaviour should lead to sub-optimal performance, then VO_{2max} values translated from the test are not truthful and therefore invalid. This is a predictive VO_{2max} test, which by definition

introduces some doubt to the reliability of the test, coupled with sub-optimal performance, the results become unreliable.

Another variable of the tests that could influence the value of VO_{2max} obtained is exercise economy (Costill et al 1971). During treadmill exercise, Pokan et al (1995) noticed that mechanical or neuromuscular constraints led to the flattening of tidal volume and maximal pulmonary ventilation as a result of exercise economy. The MSFT will probably be the most affected by exercise economy variances because the ergometers used in the other tests somewhat inhibit inter-subject economy variances, enhancing reliability.

This investigation will provide an in-depth discussion into the validity of four VO_{2max} tests. There is ongoing debate in exercise physiological circles into the exact causes of VO_{2max} and the results from this investigation could provide support for the arguments proposed by Hill (1923) or those by Noakes (1995). This study could possibly have an indirect influence on the conclusion of this debate. More practical applications of this test relate to the development of fitness-programmes, which can be dependent upon accurate fitness testing methods. More accurate programmes designed from this research could lead to advancements in the fitness of individual athletes and therefore athletic performance.

Method

With all investigations involving human participation there are ethical issues, including health and safety, to be considered. This investigation involved the use of a number of subjects completing maximal exercise tests leading to extreme fatigue and

often the breach of pain thresholds. Therefore, the precautions and procedures employed to protect the subjects, gave a foundation for the ethical integrity of this study.

All subjects were volunteers and participated willingly with all subjects completing a consent form stating they had volunteered, and did so in good general health, free of any circulatory or pulmonary health problems and free of injury. Due to the maximal nature of the four tests it was essential subjects were healthy and not likely to incur health problems because of the tests.

With subjects exercising until exhaustion it was essential for them to monitored at all times in case any health problems occurred. Potential problems with maximal exercise include fainting, vomiting and dizziness. Subjects were observed at all times in case any doubt over their health arose.

Preliminary data was collected for each subject, and this data was used to provide a general background to assess the reliability and validity of results obtained from the four tests.

Fig 1 – Table of basic subject data.

SUBJECT	**AGE (yrs)**	**GENDER (m/f)**	**HEIGHT (cm)**	**MASS (kg)**	**SPORT**
MC	19	m	173	63.3	Running
GK	22	m	173	108.5	Rugby
AD	19	m	156	67.5	Sprint swim
AI	20	m	177	65	Run/ Football
AH	20	m	180	78.9	Football/rowing
RS	20	m	182	82.8	Rugby
LD	21	m	171	83.4	Cricket
CH	20	m	173	77	Football
JD	21	m	179	77	Football
GH	20	m	187	84	Hockey
MEAN	20.2		1.75	78.74	
Std DEV	0.87		0.08	12.96	

The 'Incremental Cycle-Ergometer Test' involved subjects performing a timed five-minute warm-up on a Monark 824E cycle-ergometer at a work rate of 120watts, succeeded by a brief session lasting a couple of minutes, stretching the major muscle groups involved.

Using the same cycle-ergometer, the subject then pedalled at a frequency of 60rpm during the whole test, with the speed being regulated by the subject observing the speedometer, and by observers encouraging the subject to maintain speed. This ensured the power output for each stage was attained. After three minutes of constant workload, the power output was increased 30watts by adding 0.5kg to the cradle. During the final minute of each three minute stage, expired air was collected using Douglass Bags, nose clips and one way mouth valves, all of which supplied by Harvard Apparatus Ltd. Heart rate was also recorded every 15 seconds when expired air was being collected (using a Polar Accuracy Plus heart rate monitor made by Polar Electro Oy, in Kempele Finland). Each three-minute stage was timed using a stopwatch to enhance reliability.

When the subject felt they were approximately one minute's exercise from total exhaustion they gave a pre-determined signal to alert data collectors of the impending cessation of exercise. At this point expired air was collected and heart rate was monitored until volitional exhaustion forced the subject to stop exercising. Collection of air and heart rate monitoring was done using the same methods as described previously for the end of each stage. Subjects were encouraged and motivated in an attempt to prolong the exercise and reach a more accurate maximum measurement, and if the subject was able to continue exercising for longer than the self-predicted final minute, an accurate record of expired air collection time was taken using a stopwatch to ensure accurate VO_2 values

could be calculated. Five minutes post-exercise, blood lactate measurements were analysed using a small blood sample. The volume of expired air collected at each stage was measured using a Dry Gas meter designed by Harvard Apparatus Ltd, and expired air content was analysed, using a Gas Analyser manufactured by Analytical Development Co Ltd, in Hodderson, England.

The second test conducted was the 'Constant Load VO_{2max} Cycle-Ergometer Test'. The protocol for this test involved an identical warm-up as the first test, and then the subject cycling at 60rpm (on the same ergometer as previously) throughout the duration of the test, with the weight on the cradle and therefore the power output being the same as that of the last stage completed during the 'Incremental Cycle-Ergometer Test' the previous week. Again this test continued until volitional exhaustion and during the final minute of exercise as predicted by the subject, the same protocol was employed as during the final minute of the 'Incremental Cycle-Ergometer Test'. Expired air was collected and analysed using the same equipment and heart rate was monitored with the same equipment.

The 'Incremental Treadmill Exercise Test' involved subjects completing a five-minute warm-up on a Power Jog GX200 Treadmill manufactured by Sport Engineering Ltd in England. As with previous warm-ups, a stretching session took place and brief rest period before the start of exercise. The actual test involved subjects running at a constant 1% gradient on the same treadmill until volitional exhaustion, however the power output was increased every three minutes, by increasing the speed by 2km/h. The test continued until volitional exhaustion but during the final minute of exercise, expired air and heart rate were all measured or collected using identical methods to the previous tests, a five-

minute post-exercise lactate sample also being collected. VO_2, VCO_2 and RER were calculated for each subject on each test using Microsoft Excel and recognised formulae.

The 'Multi-Stage Fitness Test' was the only field test conducted and therefore the collection of expired air was impossible to conduct. This was therefore a predictive, test in terms of VO_{2max}. Subjects were required to run continuously between two points 20m apart, keeping pace with audio cues from a tape recording. The pace of the audio cues increased after every 10 shuttles, and subjects ran until they failed to cross the line on two consecutive shuttles or at volitional exhaustion. Heart rate was recorded immediately after the subject stopped running, using the same method as in other tests. VO_{2max} is determined by the number of shuttles completed at each incremental level of the test. Blood lactate was also analysed five minutes after the cessation of exercise, in identical fashion to other tests.

Analysing the results due to the nature of the protocols was simple. Statistical analysis involved the mean scores and standard deviation from all subjects for each test in relation to VO_2, RER HR and lactate. The mean results gave a foundation upon which to base the comparative discussion.

Results

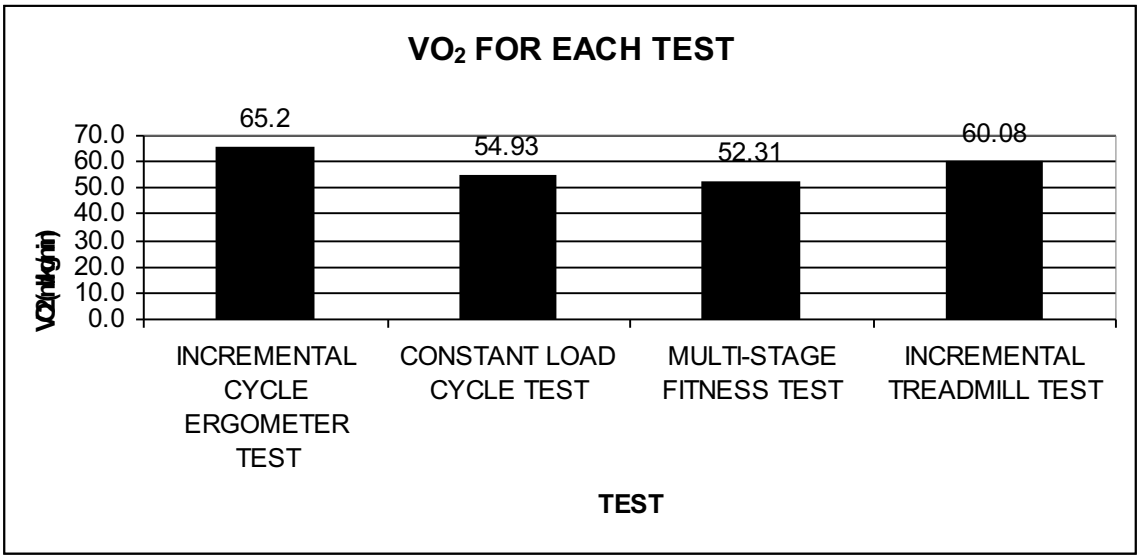

Fig 2 – Comparison of mean VO_2 for each test.

The incremental cycle ergometer test gave the highest mean VO_2 with the incremental treadmill test showing the second highest. These results contradict the literature on the test protocols that typically elicit the highest VO_2. Also, tests using ergometer equipment provide higher VO_2 results than MSFT.

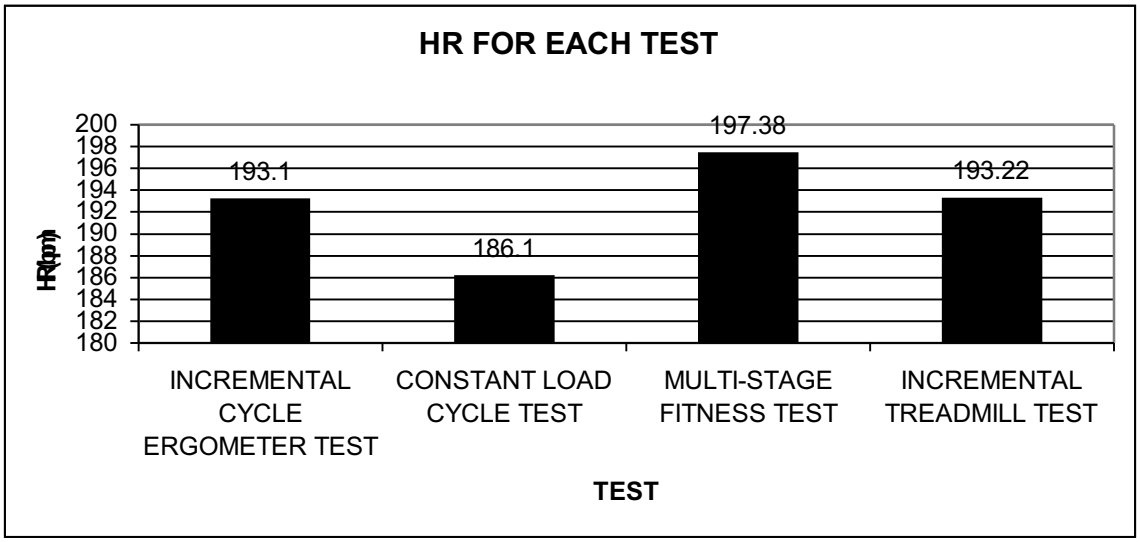

Fig 3 – Comparison of mean HR values for each test.

MSFT gave highest HR, which may be significant due to the fact it showed the lowest VO2. Incremental cycle ergometer and incremental treadmill tests showed similar HR and the constant load cycle test gave by far the lowest HR.

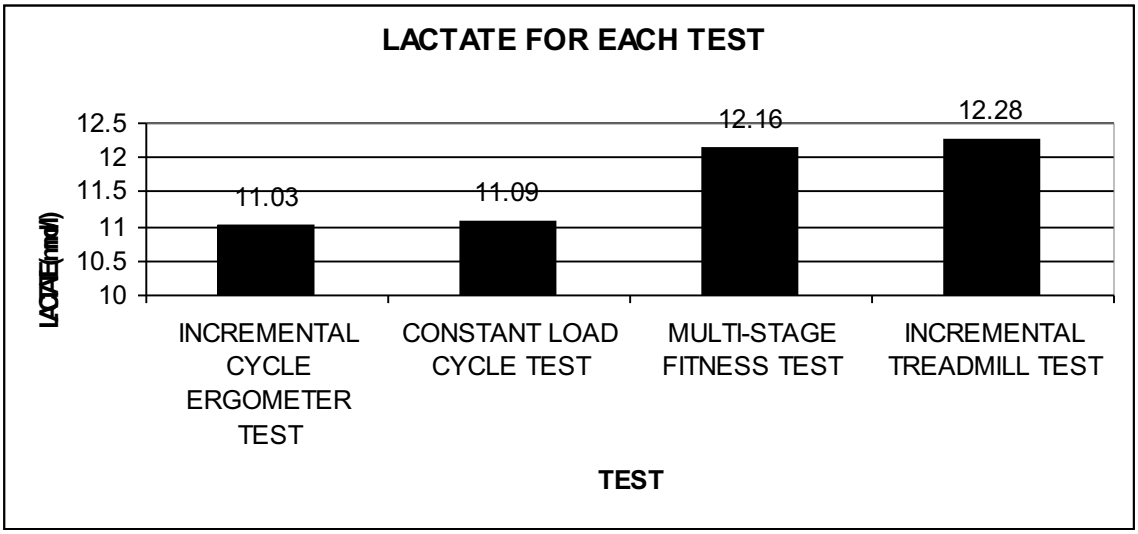

Fig 4 – Comparison of mean lactate values for each test.

Running tests gave the highest lactate measurements and cycling tests the lowest. There could be two reasons for this.

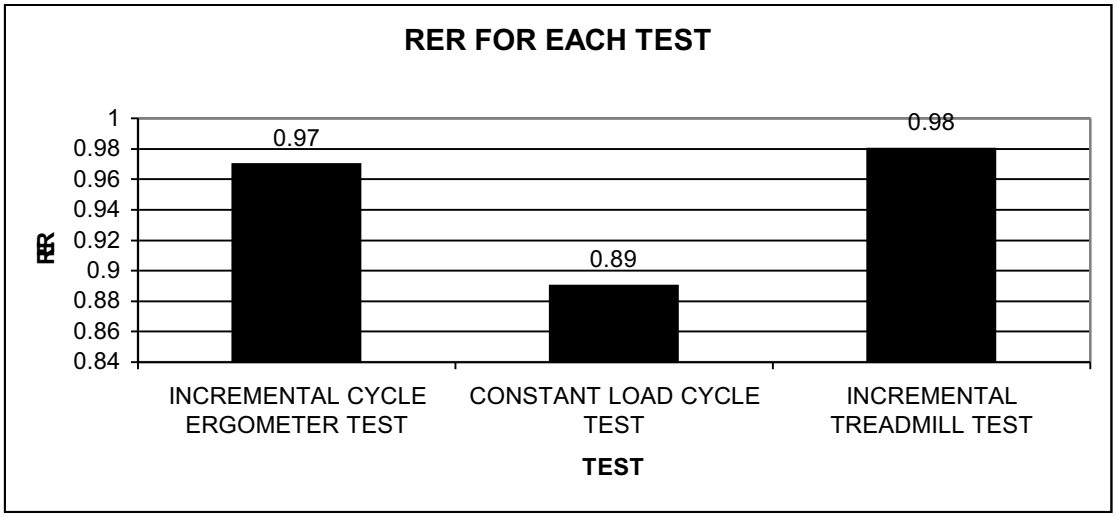

Fig 5 – Comparison of mean RER for each test.

Incremental tests showed the highest RER values with the constant load test being lowest. The protocol for the MSFT did not permit an RER value to be obtained, due to the fact no expired air was collected.

Discussion

The first point of discussion is that the protocol for each test, involved expired air collection only at the end of the tests did not allow a graph of VO_2 over time to be plotted. It is therefore impossible to reliably determine if a plateau in VO_2 occurred. Assumptions/ deductions can be made as to whether a plateau may have occurred but these are unsupported and therefore unreliable, extensions to this investigation should consider this flaw in protocol.

The running tests gave higher lactate measurements (fig 4) than the cycle tests and the measurement protocol could influence this. The cycle tests use almost exclusively the leg muscles prompting lactate build up in the legs. At least some of the blood from the legs will pass the lungs and become oxygenated, or become oxygenated before reaching the sample site in the fingertip. Therefore cycle test lactate measurements may not be reliable compared to running tests, which involve the arms as part of the exercise. For this reason lactate measurements between the different tests are *possibly* unreliable and any conclusions based upon lactate values should be supported by further studies using samples from multiple sites such as the fingertip and the legs, also muscular rather than blood lactate samples would be more appropriate.

In relation to the BASES (1997) VO_{2max} criteria, lactate and exhaustion were the only criteria fulfilled by any test, and it may be important to note that each test recorded lactate levels significantly higher than the 8mmol/l required by BASES (1997) criteria.

The research by Crouter et al (2001) studying premature fatigue through acidosis could be a cause of this in some or all of the tests.

As Figures 3 and 5 show, the incremental cycle test had a HR below predicted maximum and a low RER, suggesting that oxygen supply to the muscles could have been increased and exercise could have continued to elicit a higher VO_2 value. There are three possible explanations for the fact it didn't. The first as previously described is that lactate build up could have caused acidosis and premature fatigue. Figure 4 shows this test to elicit higher lactate levels than required by BASES (1997), and so this theory may have at least some influence, if not total responsibility for volitional exhaustion occurring before HR_{max} and required RER.

The second could involve the motivation of the subjects. Subjects poorly motivated could have shown sub-optimal performance in the test and therefore the test will not have reflected VO_{2max}, but VO_{2peak}. Work by Assmussen and Mazin (1978) has shown part of muscular fatigue to be developed in the CNS, and further studies by Andreacci et al (2002) have shown regular encouragement (motivation) to delay fatigue due to the fact fatigue can be developed in the CNS. Without such motivation, the subjects in this test could have delivered sub-optimal performance, which could account for the low HR and RER at volitional exhaustion in this test. Further studies or repeats of this study should use consistent regular encouragement to limit this variable.

The final conclusion strongly supports the controversial studies by Noakes (1996). The low HR (fig 3) and low RER (fig 5) would suggest O_2 supply to the muscles could have been increased and therefore lactate buffering could have been increased, contradicting the first conclusion that lactate led to premature fatigue. Although the

protocol did not allow for VO_2 to be plotted over time, the HR and RER evidence could be interpreted to illustrate a VO_2 plateau. If true, these results support Noakes' peripheral theory, claiming that muscular factors and not circulatory system limitations are responsible for the VO_{2max} value obtained from this test. The recommendation to modify protocol for extension studies to show VO_2 in relation to time would aid the conclusion of this debate, due to the reliable identification of possible VO_2 plateaux.

Ergometer tests showed higher VO_2 values (Fig 2) than the MSFT, possibly due to the fact ergometers limit the movement styles possible, especially the cycle ergometer, making exercise economy is more efficient. Work by Costill et al (1971), Pokan et al (1995) and Jones and Carter (2000) all states that inefficient exercise economy forces a higher VO_2 at same intensity exercise, and the results from this investigation support this. Ergometers with more efficient movement gave higher VO_2 values than the more 'free' MSFT. The highest HR value (Fig 3) and highest lactate (Fig 4) were recorded for the MSFT suggesting that the inefficient exercise associated with this test made lower intensity exercise more demanding and led to fatigue before the achievement of VO_{2max}. For this reason, the MSFT is probably the most unreliable and invalid of the four exercise tests used in terms of eliciting VO_{2max}.

In direct contrast to current literature (Basset and Boulay 2003), the incremental cycle ergometer test produced higher VO_2 values than the incremental treadmill test (fig 2). Basset and Boulay noted that maximal treadmill exercise showed higher HR than maximal cycle ergometer exercise. The HR values for these tests from this investigation were almost identical, suggesting that volitional exhaustion occurred more sub-optimally for the incremental treadmill test than the incremental cycle ergometer test. Subject

motivation could account for this theory, and due to the incremental treadmill test being the fourth completed, it is quite probable that many subjects were less well motivated than for the incremental cycle test, which was the first completed.

It is doubtful that sport specificity caused the higher VO_2 values to be recorded for the incremental cycle test due all but one subject being trained for sports predominantly involving running, and none involving cycling (fig 1), hence physiological adaptations from training to benefit cycling are not present.

Incremental tests gave higher VO_2 values than the constant load test (fig 2) due to physiological mechanisms associated with the different protocols. Constant load tests involve immediate and constant power output of maximal intensity, promoting a very fast build-up of lactate, and due to the maximal power output, a Lactate Steady State is not achieved hence fatigue at a lower VO_2. Hill and Lupton's (1923) circular argument describes how fatigue is due to oxygen deficiency during exercise (lactate build up > oxidative removal of lactate due to O_2 deficiency). Incremental tests increasing from lower power outputs lead to steady state being achieved at lower power outputs. Therefore lactate build up occurs over a greater period of time and more gradually, delaying fatigue due to greater tolerance. Constant load tests promote rapid lactate build up which is more intolerable due to sudden increases in toxicity rather than gradual. Hence incremental tests elicit higher VO_2 values than constant load, and are more accurate/ valid in terms of VO_{2max} testing.

The MSFT showed slightly lower but similar VO_2 scores as the constant load tests, even though it is incremental. Exercise economy and motivation are the most likely causes for this result.

In summary, this investigation showed the incremental cycle ergometer test to elicit the most valid and reliable VO_{2max} value of the four tests, however due to limitations in various aspects of the protocol it is unlikely that any of the tests show a true representation of VO_{2max}. Further studies are needed to correct flaws in procedure and support conclusions drawn from this study. Constant load tests elicit more invalid VO_{2max} scores than incremental tests however tests using ergometers are more valid due to their ability to limit varying exercise economies. It is possible lactate build up led to premature fatigue in all protocols, however the lactate sampling procedure might be unreliable and therefore extended studies would be appropriate if conclusions are to be more reliable.

Word Count: 3789

Appendices

Appendix 1 – Subject consent form.

Bibliography

- Hill A, Lupton H. (1923). 'Muscular exercise, lactic acid and the supply and utilisation of oxygen.' *Queens Journal of Medicine*. **16**:pg 135-171
- Hill A, Long C, Lupton H. (1924). 'Muscular exercise, lactic acid and the supply and utilisation of oxygen – Parts VII-VIII.' *Proc Roy Soc B*. **97**:pg 84-138
- Saltin B, Strange S. (1992) 'Maximal oxygen uptake: "old" and "new" arguments for a cardiovascular limitation.' *Medicine, Science, Sport and Exercise*. **24**:pg 30-37
- Noakes T. (1996). 'Challenging beliefs: there is always something new from South Africa.' Mobiltape of Wolffe Memorial Lecture delivered at *43rd Annual Meeting of American College Of Sports Medicine*. Cincinnati, Ohio.
- Noakes T. (1997). 'Challenging beliefs: ex Africa semper aliquid novi.' *Medicine and Science in Sports and Exercise*. **29**:5 pg 571-590

- Wagner P. (1992). 'Gas exchange and peripheral diffusion limitations.' *Medicine, Science, Sport and Exercise*. **24**:pg 54-58

- Honig C, Connet R, Gayeski T. (1992). 'Oxygen transport and its interaction with metabolism: a systems view of aerobic capacity.' *Medicine, Science, Sport and Exercise*. **24**:pg 47-53

- Cain S. (1995). 'Mechanisms which control VO2 near VO2max: an overview.' *Medicine, Science, Sport and Exercise*. **27**:1 pg 60-64

- Myers J, Walsh D, Sullivan M, Froelicher V. (1990). 'Effect of sampling on variability and plateau in oxygen uptake.' *Journal of Applied Physiology*. **68**:pg 404-410

- Froelicher V, Brammel H, Davis G, Noguera I, Stewart A, Lancaster M. (1974). 'A comparison of three maximal treadmill exercise protocols.' *Journal of Applied Physiology*. **36**:pg 720-725

- Rowell L. (1986). '*Human Circulation: Regulation during physical stress*.' New York. Oxford University Press

- Demarie S, Koralsztein J, Billat V. (2000). 'Time limit and time at VO_{2max}, during a continous and intermittent run.' *Journal of Sports Medicine and Physical Fitness*. **40**:pg 96-102

- Kuipers H, Rietjens G, Verstappen F, Schoenmakers H, Hofman G. (2003). 'Effects of stage duration in incremental running tests on physiological variables.' *International Journal of Sports Medicine*. **24**:pg 486-491

- Basset F, Boulay M. (2003). 'Treadmill and cycle ergometer tests are interchangeable to monitor triathletes annual training.' *Journal of Sports Science and Medicine*. **2**:pg 110-116

- Kirchoff, Sill (1967) cited in Pokan E, Schwaberger G, Hofmann P, Eber B, Topiak H, Gasser R, Fruhwald F, Pessenhofer H, Klein W. (1995) 'Effects of treadmill exercise protocol with constant and ascending grade on levelling-off O_2 uptake and VO_{2max}.' *International Journal of Sports Medicine*. **16**:pg 238-242

- Hawley J, Noakes T. (1992). 'Peak power output predicts maximal oxygen uptake and performance time in trained cyclists.' *European Journal of Applied Physiology*. **65**:pg 79-83

- Leger L, Lambert J. (1982) 'A maximal multi-stage 20m shuttle run test to predict VO2max.' *European Journal of Applied Physiology*. **49**:pg 1-12

- Ramsbottom R, Brewer J, Williams C. (1988). 'A progressive shuttle run test to estimate maximal oxygen uptake.' *British Journal of Sports Medicine*. **22**:pg 141-144

- Wilkinson D, Fallowfield, J, Myers S. (1998) 'A modified incremental shuttle run test for the determination of peak shuttle running speed and the prediction of maximal oxygen uptake.' *Journal of Sports Sciences*. **17**:pg 413-419

- Costill D, Branam G, Eddy D, Sparks K. (1971). 'Determinants of marathon running success.' *International Zeitschrift fur Angewandte Physiologie*. **29**:pg 249-254

- Pokan E, Schwaberger G, Hofmann P, Eber B, Topiak H, Gasser R, Fruhwald F, Pessenhofer H, Klein W. (1995) 'Effects of treadmill exercise protocol with constant and ascending grade on levelling-off O_2 uptake and VO_{2max}.' *International Journal of Sports Medicine*. **16**:pg 238-242

- Asmussen, Mazin (1978). 'Recuperation after muscular fatigue by diverting activities.' *European Journal of Applied Physiology*. **38**:pg1-7

- Andreacci J, LeMura L, Cohen S, Urbansky E, Chelland S, Duvillard S. (2002). 'The effects of frequency of encouragement on performance during maximal exercise testing.' *Journal of Sports Sciences*. **20**:pg 345-352

- Crouter S, Foster C, Esten P, Brice G, Porcari J. (2001). 'Comparison of incremental treadmill and free range running.' *Medicine and Science in Sports and Exercise*. **33**:4 pg 644-647

- Jones A, Carter H. (2000). 'The effect of endurance training on parameters of aerobic fitness.' *Sports Medicine*. **29**:6 pg 373-386