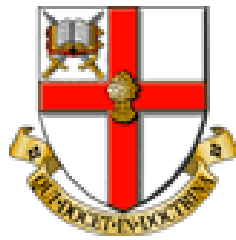


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Reliability and validity of the Chester treadmill walk test for the prediction of aerobic capacity

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Reliability and Validity of the Chester Treadmill Walk Test for the prediction of Aerobic Capacity

*Dissertation submitted in accordance with the requirements of
University of Chester for the degree of Master of Science.*

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Abstract

Purpose: To assess the validity and reliability of the Chester Treadmill Walk test (CTWT) for the prediction of aerobic capacity.

Method: Four males and three females aged 25.1 (± 3.3) years old that were active and healthy volunteered to take part in this study. The CTWT was carried out on two separate days and on the third occasion participants completed a maximal test called the Bruce Protocol treadmill test. Each day of testing was separated by no longer than seven days. Heart rate and RPE were measured during the sub-maximal testing and heart rate, RPE and VO_2 were measured during the maximal testing.

Results: The bias $\pm 95\%$ limits of agreement technique was used to assess the validity of the CTWT against the maximal testing. No significant differences were found between trial one and maximal testing (0.226) and between trial two and maximal testing (0.252). The CTWT showed over-estimations in VO_{2max} in trial one and trial two by $4.0 \pm 15.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $4.8 \pm 19.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ respectively. Trial one, two and maximal testing obtained VO_{2max} mean values of 49.5 ± 7.8 , 50.3 ± 8.4 and $45.5 \pm 10.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ respectively. 95% LoA technique found an over-estimation of HRmax by $6.4 \pm 14.6 \text{ beats/min}$, with no significant difference found (0.062). ICC and 95% LoA techniques were used to assess VO_2 ($-0.8 \pm 5.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$), HR ($3.0 \pm 2.8 \text{ bpm}$) and RPE (-0.2 ± 0.6) reliability between trial one and trial two. ICC of 0.95, 0.99 and 0.99 were found between trial one and two in VO_2 , HR and RPE respectively.

Conclusions: It is questionable whether or not the CTWT is a valid sub-maximal test to conduct, however it was found to be a reliable test. VO_{2max} was over-estimated

in both trials when compared to actual $\text{VO}_{2\text{max}}$ but positive relationships were found between the HR and RPE values in trial one and trial two.

Declaration

This work is original and has not been previously
submitted in support of a Degree, qualification or
other course.

Signed

Date

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1. Introduction

Aerobic capacity (VO_{2max}) is the maximum rate at which oxygen can be consumed. It is expressed as millilitres of oxygen consumed per minute per kilogram of body weight ($ml \cdot kg^{-1} \cdot min^{-1}$) and exists as a valuable tool for measuring cardiovascular fitness. VO_{2max} is calculated by the product of arterial-venous oxygen difference $[(a-\bar{v}) O_2 \text{ diff}]$ and maximal cardiac output (\dot{Q}_{max}). Typical values for an adult male range from 35-40 $ml \cdot kg^{-1} \cdot min^{-1}$, for females between 25-30 $ml \cdot kg^{-1} \cdot min^{-1}$ and for cardiac patients as low as 15-20 $ml \cdot kg^{-1} \cdot min^{-1}$ (Stevenson, Wilsher & Sykes, 2008; McArdle, Katch & Katch, 2001). In order to record an accurate reading of VO_{2max} , a test must be conducted which follows a progressive approach to take the individual to maximal exertion, such as volitional exhaustion (Gaskill, Ruby, Walker, Sanchez, Serfass & Leon, 2001).

Cardiovascular fitness is the efficiency of the main organs in the body in delivering oxygen to the working muscles to maintain prolonged physical activity (Grant, Corbett, Amjadt, Wilson & Aitchison, 1995; American College of Sports Medicine, 2005; Paliczka, Nichols & Boreham, 1987) Those who have a higher VO_{2max} can work at a more intense level than those with a lower VO_{2max} and therefore it is important to measure an individual's fitness level. Not only is it important for those elite athletes competing in endurance events, but those who are involved in high intensity situations such as members of the emergency services and the military who require high levels of fitness.

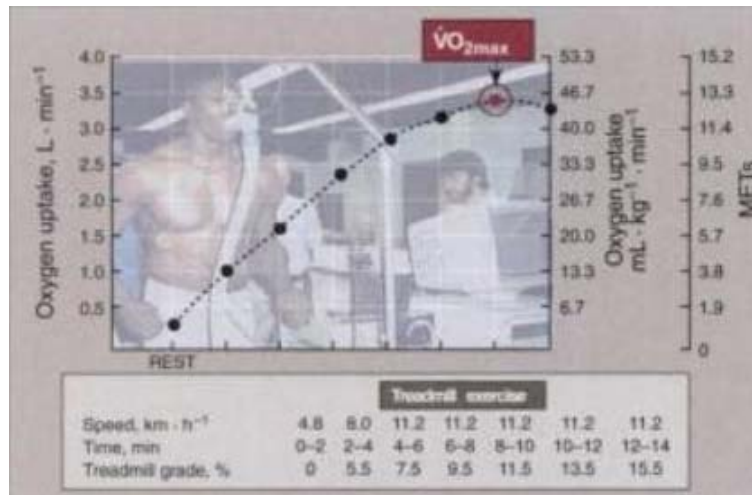


Figure 1 – Oxygen consumption plotted against exercise intensity, with each point representing the average oxygen consumption of 18 males (McArdle et al., 2001).

Figure 1 shows a typical oxygen consumption trend of 18 sedentary males with increasing exercise intensity. The graph shows a plateau of oxygen consumption close to when VO_{2max} is achieved. After attaining peak oxygen consumption, there is a slight fall below VO_{2max} which could be due a number of reasons. It is most likely that the maximal test was stopped due to the termination criteria set before testing took place. This would be based on metabolic and physiologic responses such as volitional exhaustion or reaching an estimated maximum heart rate (HRmax).

The measure of VO_{2max} and the introduction of oxygen plateau during exercise were first discovered in the 1920's by A.V. Hill and colleagues. Hill and Lupton (1923) claimed that oxygen uptake had an upper limit, VO_{2max} was different in every individual and at high speeds (up to $282 \text{ m} \cdot \text{min}^{-1}$), VO_2 reached maximum with maximum effort given. However more recent research has claimed that it is not necessary to observe a plateau in VO_2 as VO_{2max} can be achieved regardless of a plateau occurring (Hawkins, Raven, Snell, Stray-Gundersen & Levine, 2007). Hill and Lupton (1923) did not hypothetically claim that VO_2

reached a plateau and their work became a centre of attention for further investigation in their theories, such as what limits VO_{2max} and how VO_{2max} was achieved at different exercise intensities (Bassett & Howley, 2000; Noates, 2008). It is still not clear however what causes the termination of exercise when actual VO_{2max} has been reached without the plateau and therefore requires further investigation into whether the Hill and Lupton (1923) theory is true.

1.1 Maximal and sub-maximal testing

For an individual who does not carry out much exercise, it can be an eye opener to their current level of fitness and therefore could prescribe an exercise programme to be specifically designed for that individual. In addition this could provide an indication of the health risks the individual is prone to such as high blood pressure and high cholesterol (Sallis, Patterson, Buono & Nader, 1988). Such research has led to the more common use of VO_{2max} tests in a health setting for medical screening (ACSM, 2005).

Direct testing involves the use of more expensive equipment and is the standard method used for measuring actual VO_{2max} . This involves the use of a cycle ergometer or a running treadmill and a complex gas analyser which measures gas inspired and expired directly, such as oxygen consumption. This however requires much expert supervision and is unsuitable for those who cannot undergo maximal exercise; therefore sub-maximal (indirect) testing is a useful alternative. The sub-maximal testing requires less effort, time and equipment, and the results that are produced are closely approximate to those produced by maximal testing.

The Chester Treadmill Walk test (CTWT) is a predicted VO_{2max} test created by Professor K. Sykes at the University of Chester which aims to provide a prediction of an individual's cardiovascular fitness. It has been designed specifically for the Fire Service to find out if an

individual can reach an aerobic fitness standard proposed by Professor K. Sykes of $42 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. This proposition was made as the typical aerobic cost of a fire-fighter is $35 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, which equates to 80% of this $42 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. Therefore for a fireman to be working at 80% of their maximum heart rate (HR_{max}) then $\text{VO}_{2\text{max}}$ would need to be at least $42 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (Stevenson et al., 2008).

The CTWT is a progressive 12 minute walk test, set at a speed of 6.2 km/hour on a treadmill, with a 3% gradient increase every two minutes beginning at 0%. This will take place on two separate occasions, with a third day of testing conducted using a maximal test rather than a sub-maximal test. A data collection sheet specifically designed for the CTWT is used to record the results, which is used to estimate the $\text{VO}_{2\text{max}}$ of the participant. The participant is required to wear a Polar heart rate monitor as heart rate (HR) will be measured at each two minute stage of the test. The maximal testing however will require the participant to wear an Oxycon Gas mask in order to measure and analyse actual VO_2 values using an Oxycon Gas analyser. The maximal protocol that will be used is the Bruce protocol treadmill test which increases both speed and gradient at each three minute stage as shown in table 1 (Bruce, 1972).

The CTWT is a suitable exercise for fire-fighters as the leg muscles are pushed to fatigue with the severe increases in gradient, which replicates the use of stairs during an emergency. The test is set at one speed and is relatively easy to train and practice for. Familiarisation with a treadmill is required and the regular exercise that most people carry out imitates jogging or brisk-walking. This indirect method of testing $\text{VO}_{2\text{max}}$ is also advantageous as limited equipment is required with only a treadmill, HR monitor and stopwatch required to administer the test.

Although this study concentrates on one method of indirect testing, there are other tests used to predict VO_{2max} . A test previously produced by Professor K. Sykes involves the use of a 30cm step and a metronome beat, called the Chester Step test (CST).



Figure 2 – Chester Step test equipment (30cm Step, instruction manual, CD and Polar heart rate monitor (Stevenson et al., 2008).

Only limited equipment is required (as shown in figure 2) which consists of a 30cm step, an instruction manual, a CD which gives instructions and the metronome beat, and a polar heart rate monitor. This test was found to be a reliable tool for the assessment of VO_{2max} and was found to be safe and practical under sub-maximal conditions (Buckley, Sim, Eston, Hession & Fox, 2004).

This sub-maximal, multistage test carries many other advantages for its use such as portability, easy calibration and inexpensive, however results can be affected by poor rhythm and careless administration. In relation to the CTWT, similar methods of study design and collecting data are required. The method for estimating HRmax used in both tests is 220 minus the age of the subject (220-age). No gas analyser equipment is required and both heart rate and rating of perceived exertion (RPE) are obtained from each subject. An indirect method which always requires maximal effort is the multistage shuttle run test (bleep test), which uses a field or sports hall with a 20m distance measured to conduct the test. Although

it is easy to administer and can test large numbers at one time, the disadvantages overshadow the advantages as careful pre-test screening is required, a large amount of space is needed and some athletes could pace themselves and mentally prepare themselves better than others.

Both direct and indirect testing will be used in this study in order to compare predicted VO_{2max} values from the CTWT with actual VO_{2max} values from an indirect test called the Bruce Protocol (Bruce, 1972). In the addition of direct and indirect testing, protocol testing can fall under continuous or discontinuous testing (McArdle et al., 2001; Duncan, Howley & Johnson, 1997). Continuous testing does not include rests between increments whereas discontinuous testing uses rest periods between increments. For this study, continuous testing will be used as no rest periods will be employed in between stages.

Table 1 – Bruce Treadmill test protocol information (Bruce, 1972)

Stage	Time (mins)	Speed (km/hr)	Gradient (%)
1	0	2.7	10
2	3	4.0	12
3	6	5.5	14
4	9	6.8	16
5	12	8.1	18
6	15	8.9	20

This treadmill protocol contains a number of stages which after three minute intervals, both the speed of the treadmill and gradient increase (as shown in Table 1). The Bruce protocol is a popular and widely used test by researchers which can be modified quite simply for inactive

individuals such as the elderly and for very active individuals such as elite athletes. Elite athletes could complete the stages given in Table 1 therefore an increased gradient and speed could push the athlete as far as possible. A possible disadvantage is the abrupt increase in exercise intensity between stages, which could result in musculoskeletal difficulties such as lactate accumulation. (McArdle et al., 2001). However with simple modification, the progressive changes in speed and gradient of the treadmill test and widespread use by researchers, the Bruce protocol is a reliable test to conduct for obtaining actual VO_{2max} values (Bruce, Blackman & Jones, 1963; Bruce, 1972).

There has been no previous research on the CTWT and therefore this study aims to find a different valid and reliable test that can be used by the general public. As no results can be compared with this test, previous research has been conducted on the similar sub-maximal test called the Chester Step test (CST), where an error margin of 5%-15% was found (Stevens & Sykes, 1996). A study by Buckley et al. (2004) carried out a study into the validity and reliability of the CST, more specific to this study of the CTWT. The results here found that the CST was a reliable tool for the assessment of cardiovascular fitness; however its validity comes under some scrutiny.

Testing consisted of 13 participants who were active in sports and exercise up to three times a week. Participants were required to complete the CST twice on two separate days, with between five and seven days separating the two tests and a final increment treadmill test was administered to obtain actual VO_{2max} values. Participants were made familiar with the test by use of the manual and the instructions given on the cassette tape. Study design was clearly defined with detailed descriptions on when measurements were taken during the test, the use of the RPE Borg's 6-20 scale and all the equipment used for the data collection. Results were recorded on a data collection sheet specifically designed for the CST, where HR was

recorded at the end of each stage and marked on the line where an estimated VO_2 value was calculated, using an equation from the ACSM's guidelines. These points can then be used to produce a line of best fit to predict $\text{VO}_{2\text{max}}$. However it was not clear who collected the results on each occasion and therefore factors such as if the results were out of view of the participant, the exact timing of recording HR, RPE and terminating the test when the termination criteria is met.

The criterion for the termination of the CST was when the participant reached 90% of their HRmax or when the participant declared a RPE of 17. The standard criteria originally used when the CST was created however was to terminate the test when the participant reached either 80% of their HRmax or a RPE of 15. This could have been much harder work for the participant and could have been more mentally draining on the subject. However this could push the participant a little further and therefore provide more results from a greater number of stages in order to predict $\text{VO}_{2\text{max}}$.

The statistical analysis was conducted in SPSS version 10 for windows, using a statistical significance of less than 0.05 in all tests. The statistical techniques used for measuring reliability and validity were clearly described with details of the exact tests and analysis adequately explained. The results consisted of three sections which were a general analyses, assessment of reliability and assessment of validity. Out of all the participants, only seven completed the five stages of the CST and the remaining six completed four stages. It is not clear why only seven completed all five stages as either the testing could have been stopped due to reaching 90% of their HRmax or reaching a RPE of 17. In addition, one subject could not have their heart rate predicted due to faulty equipment, which could produce biased results as an analysis had to be made from the other 12 participants.

The general analyses found significant differences of less than 0.0005 between the four CST stages in RPE, HR and VO_2 between trials one and two. In trial one there were no correlations between height, weight and body mass index (BMI) with VO_2 for any of the four stages, however during trial two there were positive correlations between weight and height with VO_2 with the p-value not exceeding 0.037 in all four of the stages. In addition, these results described by the author are shown in tables and figures which give a clearer understanding of the general analysis given.

The assessment of reliability uses the bias $\pm 95\%$ limits of agreement (LoA) to assess the intertrial reliability of heart rate, RPE and VO_2 at each stage and to assess the test-retest reliability of the CST. Results here found a lower intertrial LoA trend for heart rate and RPE between stages three and four compared with stages one and two and a higher intertrial LoA trend for VO_2 ; however no statistical difference was found. The assessment of validity found more significant results however, as a statistical significance between the actual $\text{VO}_{2\text{max}}$ of trial one and the predicted $\text{VO}_{2\text{max}}$ score was found. The value calculated was $-2.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and showed a p-value of 0.006, which shows a statistical significance in the $\text{VO}_{2\text{max}}$ bias of trial one. The author states the $\text{VO}_{2\text{max}}$ difference between trial two and the actual $\text{VO}_{2\text{max}}$ was $1.9 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, however it is actually $1.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. Although trial two only used 12 of the 13 participants, it is not clear on the table or in the results and therefore could be explained that due to the estimated analysis made. The abstract however summarises the results and states that the difference was $1.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, which suggests an error in the results section.

Many variables are measured and compared together in this paper, with accurate methods of analysis used for every variable. Positive correlations are found between RPE, actual $\text{VO}_{2\text{max}}$ and HRmax in both trials, totalling up to 24 different relationships using Pearson's

correlation coefficients. At the end of every trial, the correlations between the three variables are highest, with the exception of one trial between actual VO_{2max} and RPE, where the correlation is 0.03 less than stage three. However, with high positive correlations throughout, the results suggest that the CST is a reliable test in the assessment of cardiovascular fitness.

Table 2 – RPE, HRmax and VO_{2max} values at each stage during both trials of the CST

(Buckley et al., 2004)

	Stage I		Stage II		Stage III		Stage IV	
	T1	T2	T1	T2	T1	T2	T1	T2
RPE	9.2 (1.5)	8.8 (1.4)	11.0 (1.5)	10.6 (1.6)	12.4 (1.6)	12.2 (1.3)	14.2 (2.0)	13.8 (1.7)
%HRmax	56.8 (8.4)	56.9 (7.6)	63.0 (8.7)	62.2 (8.5)	70.1 (11.3)	70.4 (10.2)	81.1 (11.2)	80.9 (10.3)
% VO_{2max}	38.1 (6.1)	38.2 (5.6)	45.3 (7.7)	45.7 (7.1)	53.7 (8.0)	53.7 (8.2)	65.2 (10.4)	65.6 (9.3)

Table 2 shows the mean values of the three variables during both trials of the CST, with standard deviation values shown in brackets. It is clear that the CST is a reliable test from looking at the values in the table; however its validity is questionable. One of the validity issues was the use of the predicted HRmax value for each participant, which will be discussed further in the risk factors section. The estimated VO_{2max} values against actual VO_{2max} values showed errors between 11% and 19%, where estimated versus actual VO_{2max} for trials one and two were $-2.8 \pm 6.1 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and $-1.9 \pm 7.4 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ respectively. It could be suggested that the error in validity of estimated VO_{2max} lies at each stepping stage, therefore further investigation into its validity as an assessment of cardiovascular fitness is required.

1.2 Risk factors

1.2.1. Using the 220-age equation for the prediction of HRmax

The early theory of predicting HRmax was claimed to arise from 1938, by subtracting an individual's age from 220 (Froelicher & Myers, 2000). Many other authors since the "220-age" equation have used similar methods such as Åstrand, Åstrand, Halback, & Kilbom (1973) who used the equation " $216.6 - 0.84 * \text{age}$ ". One of the reasons why this formula came about was because of the age range in which was used, which found that children under ten years old should use a different equation. In addition, Åstrand et al. (1973) found that the average HRmax for women over 33 years decreased by 19 beats and for men over 21 years, maximum heart rate decreased by nine beats. Although there was a large data set used (225 subjects), the results still showed a large prediction error and this set off a trend for much more research into the prediction of HRmax.

Research from Buckley et al. (2004) as discussed previously used the bias \pm LoA technique to calculate the difference between actual HRmax and estimated HRmax which was found to be -5 ± 12 beats/minute. The actual HRmax was found to be 193 ± 7 beats/minute whereas the estimated HRmax was found to be 198 ± 5 beats/minute. The HRmax worked out to be up to 17 beats/minutes difference between estimated and actual HRmax, which again indicates that the equation has to be used with caution. It is clear since the first use of the 220-age equation that there has been a large prediction error of HRmax and many studies still use the equation due to its simplicity. However it should be made more aware that the equation is not entirely accurate and therefore further research is required.

1.2.2. Use of Borg's RPE 6-20 scale

The RPE 6-20 scale (figure 3) is a widely used and accepted statistical technique used to monitor the rate of fatigue in a participant. It can also be used to prescribe the intensity of an exercise such as when an individual reaches 80% of their HR_{max}, then this equates to 15 on Borg's 6-20 RPE scale (Robertson, 1982; Eston & Williams, 1988). It can be useful when such errors occur as shown in the study by Buckley et al. (2004), where the prediction error of HR_{max} was incorrect by up to 17 beats/minute. The RPE increased by each stage and had a strong relationship with both HR and VO_{2max} throughout each trial. For example by stage four, RPE reached around 14, HR_{max} was 81% and VO_{2max} was approximately 65%.

6	No exertion at all
7	Extremely light
8	Very light
9	Light
10	Somewhat hard
11	Hard (heavy)
12	Very hard
13	Extremely hard
14	Maximal exertion

Figure 3. – Borg's RPE 6-20 Scale. (Borg, 1998).

Significant relationships were found between RPE and HR_{max} at stages three and four in trial one and in all stages in trial two. Similar correlations were found between RPE and VO_{2max} as in trial one there were significant relationships at stages two, three and four and in trial two at stages three and four. Although the study focused mainly on the relationship between HR and VO_{2max}, the validity of RPE and its relationships

with HR_{max} and VO_{2max} became more prominent, however some further investigation specifically on RPE is required.

A study by Lamb, Eston and Corns (1999) studied the reliability of the RPE 6-20 scale using the 95% LoA technique. The study used 16 healthy male athletes aged (mean) 23.6 who volunteered to take part in the study. The subjects were required to attend the laboratory on two separate occasions where two identical running protocols were completed and RPE was

recorded during the last 15 seconds of each three minute stage. Instructions and information on the RPE scale were given to every subject along with familiarisation of the treadmill and test procedures.

Table 3 – r-values and correlation type (Cohen & Holiday, 1996)

Pearson's correlation coefficients (r)	Meaning
0.00 to 0.19	A very low correlation
0.20 to 0.39	A low correlation
0.40 to 0.69	A modest correlation
0.70 to 0.89	A high correlation
0.90 to 1.00	A very high correlation

Following the 95% LoA and clarification that all the assumptions were met, Pearson's correlation coefficient and intra-class correlation (ICC) were used as an extended reliability analysis. Table 3 shows the different correlation types and r-values in which they fall under. The 95% LoA analysis found that there was a degree of uncertainty with the results as an athlete reported an RPE of 12 during stage two of the first trial, but in comparison to the other subject's results, that subject could have reported anything from an RPE of 10 up to 15. Between both trials and all four of the stages, there are no significant differences in the heart rate reserve (HRR), however there were significant differences observed in RPE in both trials at different stages. Both ICC and Pearson's correlation showed decreases from 0.82 and 0.81 from the first stage, to 0.75 and 0.60 in the fourth stage respectively. Even with this high ICC

and Pearson's correlation, the 95% LoA technique is a more appropriate form of statistical analysis and therefore the ICC and Pearson's correlation have to be used with caution (Bland & Altman, 1986).

Noble (1982) found that cardiac patients could not complete anymore than one stage of the Bruce treadmill protocol. The results from Lamb et al. (1999) could suggest that with the lack of reliability, the test could terminate between an RPE of 12 and 18 and therefore show inconsistencies in results. Furthermore, with these results, they cast doubts on the RPE scale, however further investigation into the reliability of the RPE scale with different exercise intensities is required.

1.2.3. Criteria for reaching VO_{2max}

The criterion for reaching VO_{2max} varies in different studies depending on the exercise intensity of the testing. During sub-maximal testing, the criteria for the termination of the test can range from any of the following:-

- When a subject reaches between 80%-90% of their HRmax, using the 220-age equation, the test is stopped (Sykes & Roberts, 2004; Buckley et al., 2004).
- When the subject looks exhausted/stressed then the test must be stopped.
- Using Borg's RPE 6-20 scale, when a participant reaches an RPE of between 14 and 17 (Robertson, 1982; Eston & Williams, 1988).
- The subject could stop to test themselves due to fatigue or sustaining an injury.
- If the subject completes the sub-maximal test to the end then results can be analysed.

During maximal testing, the termination criteria can range from any of the following:-

- When a subject achieves within 10 beats/min of their calculated HR_{max}, however this is more common in those studies using cardiac patients (Astorino et al., 2000).
- When a subject equals or exceeds predicted HR_{max} the test is then stopped (Duncan et al., 1997).
- When the subject achieves volitional exhaustion or if the subject shows signs of distress/fatigue.
- When a plateau between VO₂ and exercise intensity relationship is observed then it indicates that the subject has reached estimated VO_{2max} (Astorino, Robergs, Ghiasvand, Marks & Burns, 2000).
- When a Respiratory Exchange Ratio (RER) of greater than 1.15 is attained (Duncan et al., 1997).
- When a RPE of 19 or 20 is reached (Lamb et al., 1999).
- When blood lactate levels rise above 8 mmol·l⁻¹ (Åstrand et al., 1973).

It is crucial for the researcher who is conducting the test to be fully qualified when conducting a sub-maximal or maximal test. They must know visually when the subject is exhausted and if they show any signs of stress, otherwise the protocol could be a danger to the subject.

A study by Duncan et al. (1997) investigated the validity of VO_{2max} criteria in continuous and discontinuous treadmill protocols. The specific criteria this study used was a plateau in VO_{2max}, a HR equal or greater than estimated HR_{max}, a RER greater than 1.15 and blood

lactate levels exceeding $8 \text{ mmol}\cdot\text{l}^{-1}$. The methodology quality of the study went into great detail, where ten healthy male subjects were used who had experience of maximal tests in the past two to three years. Details of pre-test instructions such as refraining from vigorous exercise on and before the day of testing were given. The study went on to explain the methods of data collection such as the details of the equipment used and how often measurements were taken. Finally the treadmill protocols used were thoroughly described and methods of statistical analysis were explained. One factor that was not described was who took all the measurements and controlled each part of the study, which could affect the accuracy of the results. However, it was only the continuous protocol that was used in this study under these conditions. The discontinuous testing results were obtained from a previous study by Taylor, Buskirk and Henschel (1955). The same criterion was followed in the study by Taylor et al. (1955) however it is questionable whether the procedures were followed stringently.

The overall results showed a greater criteria achievement percentage in the continuous protocols than the discontinuous protocols. The mean HR for the discontinuous protocol was 186.3 ± 7.7 and mean HR for the continuous protocol was 191.7 ± 6.7 . This equated to 40% of the subjects used satisfying the HRmax criteria in the continuous trial and 10% of the subjects used satisfying the HRmax criteria in the discontinuous trial. The mean age of the subjects was 24 ± 2.5 years old which when using the 220-age HRmax equation, shows the mean HRmax would have been 196 beats/min. The results suggest that possibly one subject reached this predicted HRmax, which question the use of the 220-age equation for predicting HRmax and whether the subjects reached $\text{VO}_{2\text{max}}$ (Buckley et al., 2004). This could suggest that the estimation of HRmax was unreliable and other criteria would have to be consulted in order to observe if the subject reached $\text{VO}_{2\text{max}}$.

The results obtained to show a possible plateau in VO_2 produced a greater agreement with the criteria set, with 50% meeting the criteria in the continuous trial and 60% meeting the criteria in the discontinuous trial. Taylor et al. (1955) set a 2.5% elevation of the plateau in VO_2 between each stage where 50% in the continuous trial met this criterion. However as explained previously, it is debatable whether a plateau could show a subject's VO_{2max} and therefore may not produce accurate results (Hawkins et al., 2007).

The RER and lactate level criterion showed very positive results as 90% and 100% of the subjects used satisfied both RER and lactate level criterion in the continuous and discontinuous trials respectively. One possible reason why the RER and lactic acid levels met the criteria could be as the RER value increases; this could be due to the imbalance of acids, particularly lactic acid in the body and therefore as RER increases, so does lactic acid (Wilmore, Costill & Kenney, 2008).

Out of the four criteria points, only two agree with the criteria set which were RER and blood lactate levels, resulting in VO_{2max} values. Although HRmax and plateau in VO_2 were not attained, the end result of RER and blood lactate levels suggests that VO_{2max} was reached, as past evidence has shown (Åstrand et al., 1973). However the two criterions on HRmax and a plateau in VO_2 were based on the assumptions that the 220-age equation and a plateau in VO_2 were correct. Further research is required into the accuracy of the theories used for a VO_2 plateau and estimation of HRmax, however with the RER and blood lactate levels increasing over the measures, this could suggest that the VO_2 values obtained show an individual's VO_{2max} .

1.2.4. *Maximal testing*

Maximal testing has been widely used in the assessment of cardiovascular fitness over a long period of time due to its precision (McArdle et al., 2001). Although it can be advantageous to some individuals, it can also act as a disadvantage to others. All maximal testing requires a pre-health screen test before it can take place in order to discover any possible medical conditions or injuries they have. If this does not take place and a participant undergoes a maximal test, this can pose as a potential health risk and medical attention could be required if the subject is pushed as far as possible. More specifically with a uphill treadmill test, the activation of a large amount of muscle mass could be limited by the approaching circulatory failure and therefore the lack of venous return would cause the individual to be forced to stop. This brings up the question of the limitation of oxygen delivery as a smaller muscle mass during a heavy workload has a greater blood flow and VO_2 (Poole and Richardson, 1997; Shepherd, 1984). This feeling of discomfort however is common in individuals during heavy exercise with the majority of discomfort in the thigh muscles and calf muscles.

Maximal testing requires a high level of motivation and some researchers have been reluctant to push their subjects to maximal exhaustion as they believe the stress they endure is too much (Astorino et al., 2000). Depending on if the individual takes up the test, they may not push themselves to a maximal state as they have the authority to stop the test whenever they feel like. More specifically, maximal tests such as the multi-stage shuttle run test that can test large groups of people can make it very difficult to provide much motivation for the participants, therefore those who are determined to push it as far as possible will provide the only accurate results. The motivational skills of the observer are therefore very important to push an individual to reach an oxygen plateau to record as precise results as possible (Shepherd, 2009).

Research from Wagner (2000) argued that a high pain and fatigue tolerance is required for an individual to reach an oxygen plateau, which is usually a trait seen in elite athletes in order to compete at the highest level possible. However for athletes to go into a laboratory to undergo a test to exhaustion is not always treated as an important part of their training programme. The conditions in the laboratory, the running surface of the treadmill and the lack of control of exercise intensity could discourage the athlete and therefore the athlete may not achieve maximal effort (Shepherd, 2009; Grant et al., 1995). In addition, any individual could feel uncomfortable on the treadmill without any practice, any idea of the duration of the test and if there is a steep, progressive increase in the intensity of the exercise. However test details and instructions must be given thoroughly to both encourage and inform the athlete of what to expect during the testing (Noakes, 2008).

Overall the maximal tests are not suitable for those people who are unfit, the elderly and those with any medical contraindications, therefore many sub-maximal tests have been produced in order to accommodate for those individuals. However the precise results obtained by pushing a person to their maximum provide a very good analysis of their cardiovascular fitness and therefore is widely used by researchers and clinicians across the globe (Astorino et al., 2000; Grant et al., 1995).

1.2.5. Age

In an active, healthy adult, there is a general trend for VO_{2max} to decrease over time from an age of approximately 20 years old and upwards (McArdle, Katch & Katch, 2000).

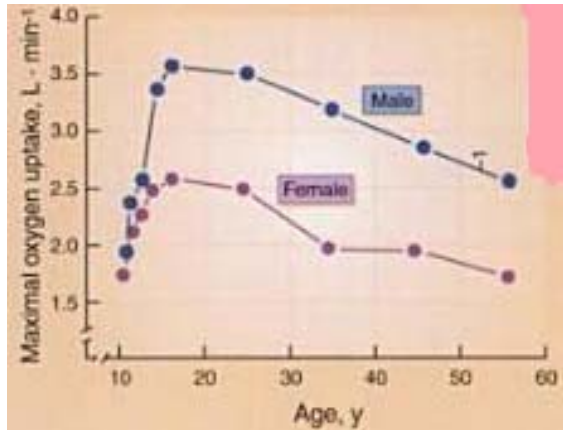


Figure 4 - VO_{2max} values decline once an individual ages. (McArdle et al., 2000).

Figure 4 shows the trend in which VO_{2max} declines when a male or female becomes older. VO_{2max} tends to be at its peak when a person is 20 years old, followed by a decline of approximately 1% after their peak VO_{2max} . After the age of 25 years old, research has found that in males and females, VO_{2max}

declined each year by approximately $0.46 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and $0.54 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ respectively. Over a period of ten years this decline is said to be approximately 10%, however it is not certain that an individual's cardiovascular fitness may change, it could be other factors that influence changes in VO_{2max} (Jackson et al., 1995; Jackson et al., 1996). Factors such as a decrease in HR_{max} , decrease in maximum cardiac output and an increase in body weight could affect VO_{2max} over a period five to ten years even if the individual stays active (McArdle et al., 2000).

The ACSM produced a table of VO_{2max} values to show fitness ratings of different aged individuals, as shown in table 4.

Table 4 – Norms for aerobic capacity measured in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (ACSM, 2005)

Males Fitness rating	Age Group				
	15-19	20-29	30-39	40-49	50+
Excellent	60+	55+	50+	46+	44+
Good	48-59	44-54	39-49	37-45	35-43
Average	39-47	35-43	32-38	30-36	27-34
Below Average	30-38	28-34	22-31	24-29	22-26
Poor	<30	<28	<26	<24	<22
Female Fitness Rating	Age Group				
	15-19	20-29	30-39	40-49	50+
Excellent	55+	50+	46+	43+	41+
Good	44-54	39-49	35-45	34-42	33-40
Average	36-43	32-38	29-34	27-33	26-32
Below Average	29-35	27-31	24-28	22-26	20-25
Poor	<29	<27	<24	<22	<20

As table 4 shows the $\text{VO}_{2\text{max}}$ values each decade decrease by approximately 10% in both males and females. In addition, there is a clear difference between the scale for males and the scale for females shown in table 4 and shown in the trend on the graph in figure 4, due to a number of reasons.

1.2.6. Gender

The difference in VO_{2max} between males and females is apparent in table 4. An example of this difference is under the fitness rating column where an “excellent” fitness rating for males is greater than and equal to $60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and for females it is greater than and equal to $55 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. It has been found that men generally have higher VO_{2max} values by between 15% and 30% than females, due to a number of reasons (McArdle et al., 2001). Men generally have a larger body size, which in turn results in a larger cardiac muscle and therefore a greater blood volume. This is also advantageous to males as they produce greater maximal stroke volume and cardiac output values than females. Furthermore males have a greater $(a-\bar{v}) O_2$ diff when working both sub-maximally and maximally, which is a result of lower haemoglobin content. This haemoglobin content has been found to be an estimated 10% lower than males and past research has found this to be a possible reason for lower VO_{2max} values in females. A study by Freedson (1981) reduced the haemoglobin content of the blood by approximately 19%, which resulted in a 6% reduction in VO_{2max} (Costa & Guthrie, 1994). The differences in body composition are apparent in males and females as females average a 25% body fat percentage whereas males have an average of approximately 15% (McArdle et al., 2001). The larger percentage of body fat results in a lower muscle mass, which could account for the differences in VO_{2max} values between males and females (Costa & Guthrie, 1994).

1.2.7. Estimated VO_{2max} costs using ACSM's equation (ACSM, 2006)

The estimated VO_{2max} cost at each stage of the CST was calculated from the ACSM's stair-stepping equation, as used in the study by Sykes and Roberts (2004). A paper by Latin, Berg, Kissinger, Sinnott and Parks (2001) studied the accuracy of this method in estimating the oxygen cost of a stepping exercise. Latin et al. (2001) used 55 healthy subjects, comprising of

29 males and 26 females who were free from any medical conditions. Testing consisted of six different combinations of step height (m) and step rate (steps.min⁻¹), which were 0.1m, 0.2m and 0.3m at two step rates of 20 steps.min⁻¹ and 25 steps.min⁻¹. After each stage, HR was allowed to return to resting HR or with ten beats of their HR, and it was reported that all subjects completed all stages of the test. The equation used was as follows:-

$$VO_2 (\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = 0.2 (\text{steps}\cdot\text{min}^{-1}) + (\text{step height} \times \text{steps}\cdot\text{min}^{-1} \times 2.4) + 3.5.$$

The statistical analysis combined both male and female VO₂ at each stage as there was found to be no difference in gender, which is debatable as past research has found differences in VO₂ values in males and females (McArdle et al., 2001). Following a Pearson's correlation coefficient between actual and predicted VO₂ means, correlated t-tests were used with a statistical significance level set at p-value 0.05.

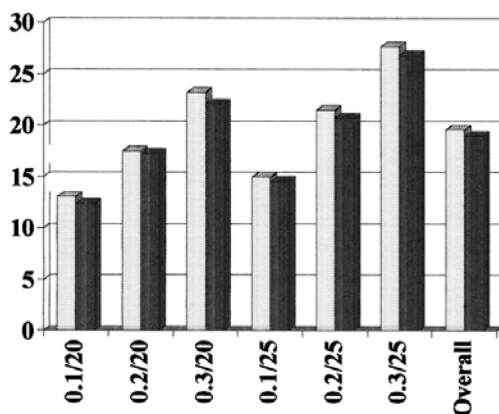


Figure 5 – Mean actual (left bar) versus predicted (right bar) VO₂ values at different step heights and rates in all subjects. (Latin et al., 2001).

As shown in figure 5, the results show very positive correlations between actual and estimated VO₂ values. The difference between actual and predicted VO₂ ranged from -0.2 ml·kg⁻¹·min⁻¹ up to -1.1 ml·kg⁻¹·min⁻¹, showing a less than 5.6% error percentage. The standard total error for all workloads was 1.7 ml·kg⁻¹·min⁻¹, which is possible when compared to previous studies,

stage, as subjects had to maintain the exercise for six minutes in order to attain a steady state value. Since tests such as the CST use two minute stages, results could present a more accurate VO₂ value for each stepping stage. However, overall the study provides valid proof

that the equation produced by the ACSM is an accurate predictor of oxygen cost at different stepping stages.

2. Summary

It is important to obtain an individual's VO_{2max} as it is seen as a valuable indicator for cardiovascular fitness. There are varieties of tests that can be carried out both maximally and sub-maximally to obtain actual and predicted VO_{2max} values, which both types of tests pose many benefits. Athletes and healthy, active individual's who undertake physical activity regularly each week would be able to participate in maximal testing whereas those who are sedentary, inactive or are cardiac patients working on their fitness levels would undertake sub-maximal testing. This is seen as a much safer, inexpensive and a practical method under sub-maximal conditions. The CTWT was then created to provide an alternative to the test created by K. Sykes called the CST which utilises a treadmill rather than a step. There are a number of factors which could affect the data collection including both the methodological quality of the study and the participants used. It is important to consider these factors when testing a new type of sub-maximal test, therefore aims have been stated below to show what this study aims to achieve.

3. Aims of the Study

The main aim of the study is to assess the use of the CTWT for the prediction of VO_{2max} . The first aim is to test the reliability of the CTWT. Participants will carry out the CTWT on two separate days and the outcomes will compare both predicted VO_{2max} values. The second aim is to test the validity of the CTWT. A Bruce treadmill protocol will be used with the addition

of an Oxycon Gas Analyser to measure actual VO_{2max} values against the results from the sub-maximal testing. Finally the study will aim to assess two measurement components which are HR and RPE by assessing the use of the estimated HRmax against actual HRmax and %HR and RPE during each stage of all the tests.

4. Hypothesis

The CTWT is a reliable and valid tool for assessing the predicted VO_{2max} of an individual.

5. Identification of Key Variables

a. Independent

The independent variables are the use of the CTWT sub-maximally on two separate occasions and the use of the Bruce treadmill protocol maximally on one occasion.

b. Dependent

The dependent variables for this study are HR, age, VO_{2max} , VO_2 , HRmax, RPE and exercise intensity.

2. Methodology

2.1 Participants

Seven participants (mean age 25.1 ± 3.3 years) volunteered to take part in the study. All participants were apparently active, healthy, and free from any medical contraindications and not currently taking any medications. None of the participants were highly trained or took part in any vigorous training programmes. Participants were asked to refrain from any vigorous exercise 24 hours before each test took place and were told to refrain from consumption of food two hours prior to exercise. Before testing took place, participants were informed of all the procedures for testing and then asked to read and sign an informed consent and pre-test health screen form. Participants were given the opportunity to ask any questions and they were informed of the possible benefits of taking the test (measured VO_{2max} and fitness rating given). All the participants took part in at least 10-30 minutes of physical activity each day and none of the participants had any reason for not being able to take part in physical activity. The study gained Ethical approval by the Faculty Research Ethics Committee before any testing took place. Descriptive statistics of all the participants are shown in table 5.

Table 5 – Physical characteristics of all the participants

Measured Variable	Females	Males	Total
	Mean (SD)		
Age (year)	27.3 \pm 4.0	23.5 \pm 1.7	25.1\pm3.3
Body mass (kg)	61.6 \pm 3.9	78.0 \pm 6.0	71.0\pm10.0
Height (cm)	165.8 \pm 2.6	183.6 \pm 8.0	176.0\pm11.2
Age estimated HRmax (bpm)	192.7 \pm 4.0	196.5 \pm 1.7	194.9\pm3.3
Actual HRmax (bpm)	184.7 \pm 5.0	191.3 \pm 9.5	188.4\pm8.1
Actual VO_{2max} (ml.O ₂ /kg/min)	35.6 \pm 6.5	52.7 \pm 5.9	45.4\pm10.7
Predicted VO_{2max} Day One (ml.O ₂ /kg/min)	44.7 \pm 10.1	53.0 \pm 3.7	49.5\pm7.8
Predicted VO_{2max} Day Two (ml.O ₂ /kg/min)	47.3 \pm 12.7	52.5 \pm 4.3	50.3\pm8.4

2.2 Experimental design

All participants completed two days of sub-maximal exercise on the CTWT and one day of maximal exercise on the Bruce protocol treadmill test. None of the participants completed the CTWT without reaching the criteria set for the sub-maximal protocol. The first and second day of testing and second and third day of testing were separated by no longer than seven days depending on social commitments. All testing was performed in an air-conditioned laboratory at the University of Chester with the same equipment used on each day of testing. It has been reported that the existence of circadian rhythms can affect physiological functions and affect physical performance, therefore testing for all participants on the three days of testing were performed at the same time of day (Reilly, Atkinson & Waterhouse, 2000). All the participants claimed to be familiar with the use of a treadmill however none of the participants were familiar with the use of the gas analyser equipment and RPE scale. Instructions on the RPE scale were briefly given so a familiarisation session with the RPE scale was not given to aim to protect the validity of the study.

2.3 Equipment

To measure HR, a Polar FS1 Heart rate monitor was used, which included a strap for the participant to wear and a watch used to monitor the heart rate by the researcher. Height was measured using a wall-mounted stadiometer and weight was measured using Seca Weight balance scales. A Woodway PPS 55sport-I treadmill was used for carrying out all the tests and an Online Oxycon gas analyser (breath by breath) was used during the maximal test as this would found to be a valid and reliable tool for measuring VO_2 (Carter and Jeukendrup, 2002).

To measure height, a stadiometer was used measuring the participants height in cm. Participants were asked to stand on the centre of the base with their heels touching the bottom of the stadiometer and their feet together. The participant's buttocks and upper back (scapula) were touching the stadiometer and the participants head was in the Frankfort horizontal plane. The researcher asked the participant to breath out, then take a deep breath in whilst the researcher performed the stretch-stature method. Once height was taken, weight was then collected using the weight balance scales after calibration took place. The participant removed their shoes and spread their feet out shoulder width apart so then the measurement could be taken. Both weight and height measurements were taken twice before all tests in order to obtain an average.

The estimated VO_2 at each stage of the CTWT was calculated using the following equation.

$$VO_2 = 3.5 + 0.1(\text{speed}) + 1.8 (\text{speed}) (\text{gradient})$$

Once each estimated VO_2 cost at each stage was calculated, those values were drawn on the data collection sheet to use for each participant (ACSM, 2006).

2.4 Sub-maximal testing

The CTWT was carried on the first two occasions in which the participant attended the laboratory. After signed consent was completed and the participant was informed and given a participant and protocol information sheet, participants were asked to place a HR monitor strap around their chest. Participant weight and height were then taken followed by a three to five minute warm-up on the treadmill at a set speed of 7km/hr with a 0% gradient. The CTWT was programmed into the treadmill before any testing took place, so the speed and gradient was controlled by the computer. However the researcher had complete control of

stopping the test at anytime in case of an emergency. Once the warm-up had been completed and the participant was ready to start the test, the protocol was readied and the test began after a three second count down. As shown in table 6, the CTWT started at a speed of 6.2km/hr, which remained constant throughout. The gradient began at 0% and each stage lasted two minutes, with an automatic increase in gradient by 3% controlled by the computer on the treadmill.

During the last ten seconds of each test, RPE was recorded and HR was recorded using the polar heart rate monitor rather than the computer on the treadmill, with all results written down on a data collection sheet. HR data was kept out of view of the participant during the test and was not shown to them until all the days of testing were complete so RPE could not be influenced by HR. When the test was completed participants were allowed a five minute cool-down period to allow recovery and a return to resting heart rate.

Table 6 – CTWT protocol information

Stage	Time (mins)	Speed (km/hr)	Gradient (%)
1	0	6.2	0
2	2	6.2	3
3	4	6.2	6
4	6	6.2	9
5	8	6.2	12
6	10	6.2	15

Once all results were collected, the HR at each stage of the test was recorded onto separate data collection sheets specifically designed for the CTWT (see Appendix I). This data collection sheet shows a relationship between heart rate, workload and oxygen consumption which enables a statistical line of best fit to be drawn in order to predict an individual's VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$). Before this could be drawn, the 220-age equation was used to estimate participants HRmax and this product was then multiplied by 0.85 to estimate 85% of participants HRmax. A horizontal line was drawn across from calculated HR until this line met the line of best fit drawn, where then a vertical line was drawn downwards to give the researcher an estimated VO_{2max} value.

An important part of the experimental design for the sub-maximal testing was the termination criteria of the test, which was as follows:-

- The test was terminated once a participant reached 85% of their HRmax. However if a participant reached this value during one of the stages, the stage was finished.
- When a participant reached a RPE of 16.
- When the participant showed signs of distress/exhaustion (Sykes & Roberts, 2004).
- When a participant finished all stages of the test without achieving any of the above criteria.

All the same procedures carried out on day one were repeated on the second day of sub-maximal testing within the seven days that followed.

2.5 Maximal testing

Maximal testing was carried out within seven days of the second day of testing and concluded the testing for each participant. Before the testing took place, participants were again informed of the procedures of the test and once weight was recorded, the participants were equipped with a gas analyser mask. Once tightly fitted around their nose and mouth, participants were assisted with placing a HR strap around their chest and then sat down until they were relaxed and ready for testing. A final precaution was taken by measuring the participant's blood pressure to re-examine their current condition.

Before the participants arrived and testing took place, the Oxycon breath-by-breath gas analyser was calibrated to validate the equipment. Ambient conditions in the laboratory were checked and volume and gas analysers were checked automatically. Once the gas analyser was calibrated, patient data was entered into the system which consisted of participant ID, age, height and weight. Participants were ensured that their data was kept completely confidential throughout the testing and only accessible to the researcher. The participant was then connected to the gas analyser via a breathing tube and allowed some time to adjust to the tube connected to the mask. In similar conditions to the sub-maximal testing, the Bruce treadmill protocol was previously setup on the computer of the treadmill to allow the researcher to obtain HR and RPE values without changing the speed and gradient during the testing. In addition of the researcher, a research supervisor was present at all times for the maximal testing in case of a fault with the equipment or in case of an emergency, therefore the participant was ensured that they were in the safest possible environment.

The participant carried out a warm-up for up to five minutes, and then with the help of the research supervisor, the recording of the breath-by-breath gas analyser began when the protocol was started. As shown in table 1, stage one began at a slow pace of 2.7km/hr,

however the gradient began at 10% with a 2% increase at the end of each stage. During the last ten seconds of each stage, RPE and heart rate were taken and participants were kept out of sight of their heart rate throughout the whole test. Participants were able to walk during the first three stages of the test due to the low speed. Although RPE, heart rate and even RER were carefully monitored, participants were motivated throughout to the point where they could not continue running. Motivation was given throughout all the testing to obtain as precise results as possible (Shepherd, 2009).

Once participants completed the test, they were allowed a prolonged period of time to recover and return to near resting heart rate whilst on the treadmill. The mask was removed once the test and recovery period had finished and results were collected for analysis. Participants were informed of their actual VO_{2max} values once the test had finished and kept under supervision until they felt comfortable that they could leave the laboratory.

The maximal testing only comprised of one criteria point to terminate the test, which was for the participant to exercise to volitional exhaustion. Reaching within ten beats of a participants HRmax and reaching a RPE of 19 or 20 was criteria for reaching VO_{2max} , however it was not included in the criteria for terminating the test.

2.6 Statistical Analysis

The Statistical Package for Social Sciences (SPSS) version 16.0 was used to analyse the data, with a statistical significance in all tests set at p-value 0.05. The bias $\pm 95\%$ LoA technique was used to assess the validity of the CTWT (against the actual VO_{2max} measures). This was conducted using a paired t-test between day one and the maximal test, and between day two and the maximal test. Agreement between the age-estimated HRmax and actual HRmax were

assessed using the bias $\pm 95\%$ LoA technique, where a paired sample t-test was used for this analysis. Reliability was assessed using the bias $\pm 95\%$ LoA technique and ICC between the VO_{2max} values measured by the CTWT on day one and day two. The same two techniques were used to assess the reliability of the HR and RPE values produced between day one and day two. The standard deviation of the differences between the repeated measures was multiplied by 1.96 to provide the LoA for 95% of the sample. All tests must pass the assumption that the data is normally distributed by using the Shapiro-Wilk test, as the numbers of participants in the study were less than 100. Once the significance value was below p-value 0.05, then the paired t-tests could be conducted (Bland & Altman, 1986; Coakes & Steed, 2009; Lamb, 1998).

In order to determine to percentage error between the estimated VO_{2max} from trial one and the actual VO_{2max} from the maximal testing, the 95% LoA from trial one was divided by the groups mean VO_{2max} from the maximal testing. This was also repeated for trial two to obtain the percentage error between estimated and actual VO_{2max} values.

3. Results

3.1 Summary of data collection

During the first and second sub-maximal trials, six of the participants were able to complete all six stages of the CTWT, with the remaining participant completing three of the six stages. During the maximal testing, four of the participants completed four stages of the Bruce treadmill protocol and the remaining three participants completed five stages of the test. Table 5 shows the descriptive statistics of all seven of the participants and all the analysis for the assessment of both predicted VO_{2max} and actual VO_{2max} has been based on the data obtained from all stages of all the trials. No problematic events occurred during the testing and the methods previously stated were all adhered to. Correct calibration of the equipment was conducted and the same researcher and supervisor were used during both the sub-maximal and maximal testing.

3.2 Validity of sub-maximal and maximal testing

To measure the validity of the mean (\pm SD) differences between trial one and the maximal testing, and between trial two and the maximal testing, the 95% LoA technique was used, producing results shown in table 7. There was no significant difference found between trial one and the maximal testing (0.226) and between trial two and the maximal testing (0.252). The results show an over-estimation of VO_{2max} by $4.0 \pm 15.4 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ between trial one and the maximal testing and for trial two and the maximal testing, an over-estimation of VO_{2max} by $4.8 \pm 19.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$.

Table 7 – Validity of the predicted VO_{2max} values produced by the CTWT against actual VO_{2max} using the 95% LoA technique

Trial	95% LoA	
	Mean (SD)	Sig.
Trial 1 v Maximal (ml·kg⁻¹·min⁻¹)	4.0±15.4	0.226
Trial 2 v Max.	4.8±19.7	0.252

Table 8 shows the mean (\pm SD) VO_{2max} values calculated on all three trials of testing. Trial one, trial two and the maximal testing obtained mean (\pm SD) VO_{2max} values of 49.5 \pm 7.8, 50.3 \pm 8.4 and 45.5 \pm 10.7 ml·kg⁻¹·min⁻¹ respectively.

Table 8 – Mean (\pm SD) VO_{2max} (ml·kg⁻¹·min⁻¹) values on all three Trials of testing

	Trial One	Trial Two	Maximal
VO_{2max} (ml·kg⁻¹·min⁻¹)	49.5 \pm 7.8	50.3 \pm 8.4	45.5 \pm 10.7

In addition of the VO_{2max} values obtained during testing, the validity of the age-estimated HRmax and actual HRmax was assessed using the 95% LoA technique (table 9). The age-estimated mean (\pm SD) HRmax was 194.9 \pm 3.3 beats/min and the actual HRmax was 188.4 \pm 8.1 beats/min. There was no significant difference found (0.062) and the LoA found there to be a mean (\pm SD) over-estimation of HRmax by 6.4 \pm 14.6 beats/min. The percentage error between estimated and actual VO_{2max} in trial one and the maximal testing was found to be as high as 34% and the lowest possible percentage error calculated was 9%. The percentage error between estimated and actual VO_{2max} in trial two and the maximal testing was as high as 43% and the lowest possible percentage error calculated was 11%.

Table 9 – Validity of age-estimated HRmax against actual HRmax recorded during sub-maximal and maximal testing

	Age-estimated HRmax (bpm)	Actual HRmax (bpm)	95% LoA	Sig.
Sub-maximal v Maximal	194.9±3.3	188.4±8.1	6.4±14.6	0.062

3.3 Reliability of Trial One versus Trial Two

Table 10 shows the ICC and 95% LoA techniques used to assess the reliability of the VO_{2max} values between trial one and trial two. The ICC shows a very high correlation of 0.95 between trial one and trial two and the 95% LoA technique produced a mean (±SD) difference of -0.8±5.2 ml·kg⁻¹·min⁻¹. The highest possible percentage error between estimated and actual HRmax was 8% and the lowest possible percentage error was 3%.

Table 10 - Reliability of the VO_{2max} values between Trial One and Trial Two using ICC and 95% LoA techniques

Sub-maximal Trial	Method	
	Predicted using HR	
	ICC	95% LoA
Trial 1 – Trial 2	0.95	-0.8±5.2

In reference to table 12, where a significant difference was observed between the HR values in both trials, the LoA in table 10 represents a reliable agreement between the prediction of VO_{2max} between the HR values during each trial.

3.4 Reliability of HR

By using the bias $\pm 95\%$ LoA technique, results in table 12 produced a mean (\pm SD) of 3.0 ± 2.8 bpm and showed a significant difference between HR on trial one and HR and trial two (0.004), with a ICC of 0.99. As the descriptive statistics show in table 11, there is only a small difference visible between HR values and %HR values during each stage of the test.

Table 11 – Mean (\pm SD) HR and %HRmax values during each stage of the CTWT on two separate trials

Stages	Trial One		Trial Two	
	HR (bpm)	HRmax (%)	HR (bpm)	HRmax (%)
1	108.6 \pm 15.8	55.8 \pm 8.9	104.6 \pm 17.0	53.8 \pm 9.6
2	119.1 \pm 19.4	61.2 \pm 10.7	116.4 \pm 16.4	59.9 \pm 9.3
3	132.6 \pm 20.1	68.1 \pm 11.4	127.3 \pm 18.6	65.4 \pm 10.4
4	141.3 \pm 7.2	72.4 \pm 4.9	139.2 \pm 2.7	71.3 \pm 2.5
5	157.2 \pm 5.0	80.4 \pm 3.2	155.2 \pm 5.6	79.5 \pm 3.4
6	170.2 \pm 4.7	87.1 \pm 2.3	168.5 \pm 5.6	86.3 \pm 2.7

During the first three stages during trial one, the HR values were 108 ± 15.8 , 119 ± 19.4 and 132 ± 20.1 and during trial two were 104 ± 17.0 bpm, 116 ± 16.4 bpm and 127 ± 18.6 bpm. For the final three stages, the differences were similar however the variation in values were much less than in the first three stages, which was due to one subject reaching 85% of their HRmax by the end of stage three.

Table 12 – Reliability of overall mean (\pm SD) HR and RPE values between Trial One and Trial Two

Trial 1 -Trial 2	ICC	95% LoA	Sig.
HR1 - HR2	0.99	3.0 \pm 2.8	0.004
RPE1 - RPE2	0.99	-0.2 \pm 0.6	0.296

Figure 6 represents the HR values during each stage of the CTWT on both Trials. It is clear that the CTWT meets the criteria of a sub-maximal test as the HR values progressively increase during each stage to reach 85% of their HRmax.

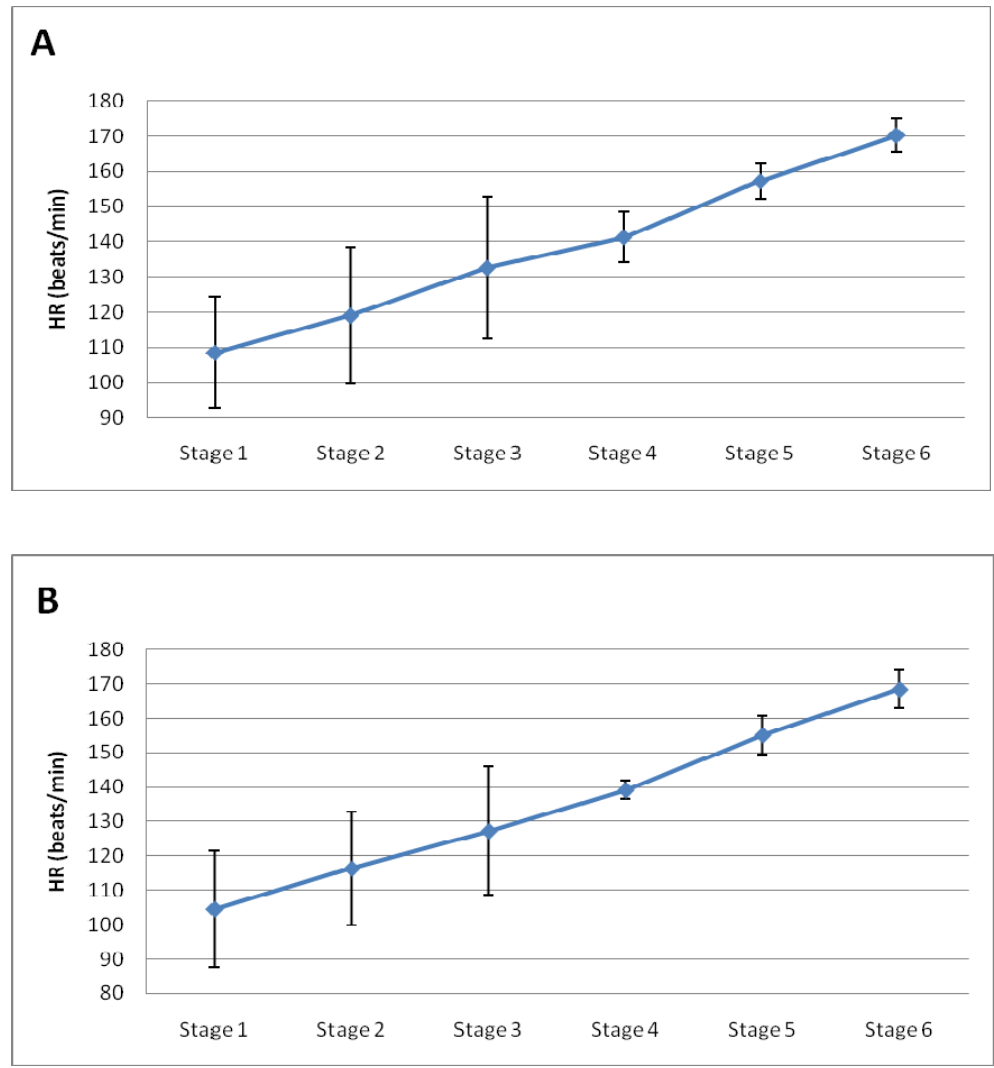


Figure 6 – (A) Trial one mean (\pm SD) HR at each stage of the CTWT. (B) Trial two mean (\pm SD) HR at each stage of the CTWT.

3.5 Reliability of RPE

Table 12 did not show a significant difference between RPE values given on trial one and trial two. The LoA technique showed a mean (\pm SD) of -0.2 ± 0.6 and an ICC of 0.99 showing a very positive correlation between the RPE values.

Table 13 – Mean (\pm SD) RPE values at each stage of the CTWT on two separate Trials

Stages	Trial One	Trial Two
	RPE	RPE
1	7.0 \pm 0.6	7.3 \pm 1.0
2	8.7 \pm 1.0	9.0 \pm 1.5
3	10.7 \pm 0.8	10.9 \pm 1.8
4	12.7 \pm 1.0	12.3 \pm 1.0
5	14.2 \pm 1.0	14.2 \pm 0.8
6	15.2 \pm 1.0	15.7 \pm 0.5

Table 13 shows the means (\pm SD) RPE values for both trials at each stage of the CTWT.

Figure 7 shows a steady increase in RPE during each stage, with a more prominent variation in results shown on trial two. The mean (\pm SD) RPE for example during stage 4 on trial one and trial two was 12.7 \pm 1.0 and 12.3 \pm 1.0 respectively, therefore the variability in results was as high as approximately 14 and as low as 12 on the RPE scale. However during stage 3 on trial one, the mean (\pm SD) RPE was 10.7 \pm 0.8 which was approximately as low as 10 and as high as 12, however on trial two it was 10.9 \pm 1.8, which was approximately as low as 9 and as high as 13 on the RPE scale.

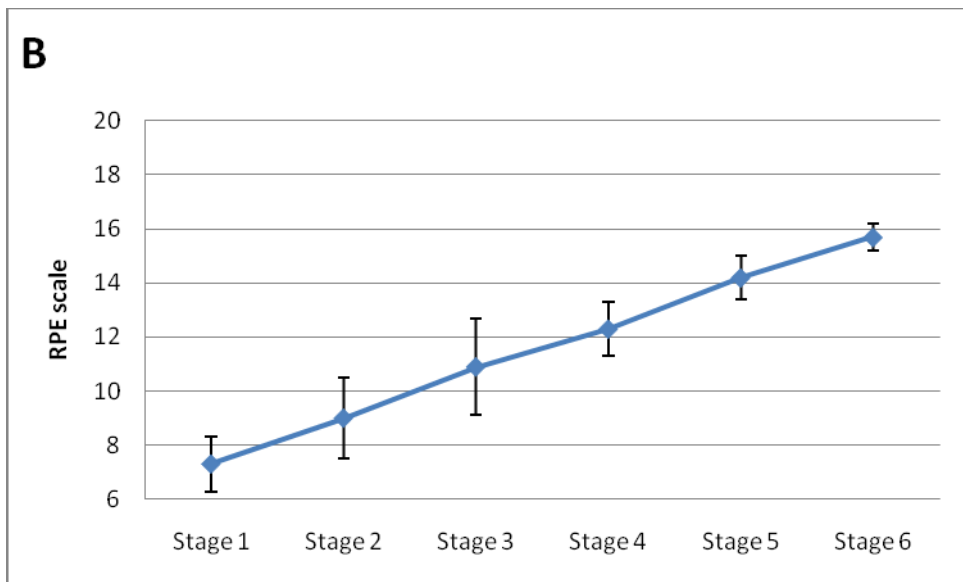
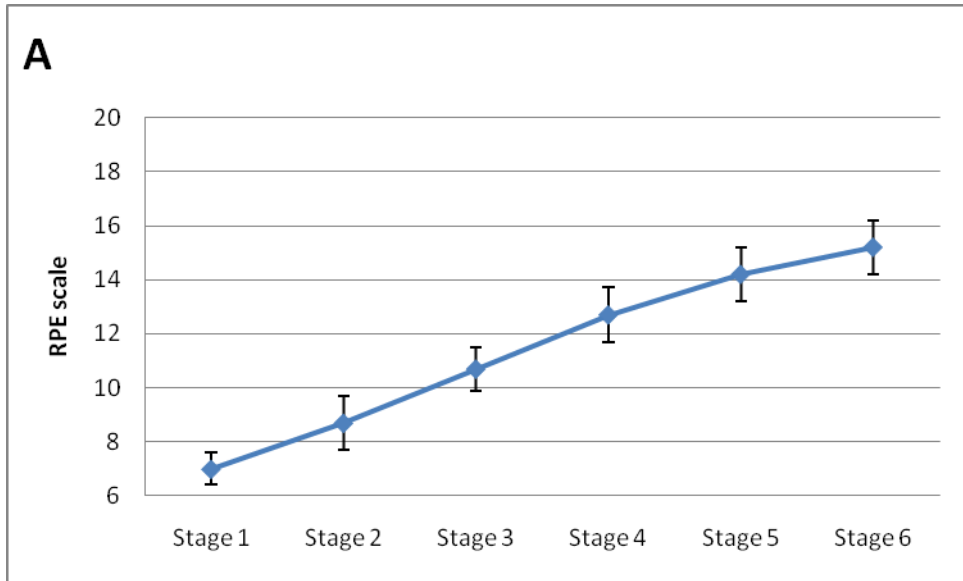


Figure 7 – (A) Trial one mean (\pm SD) RPE during each stage of the CTWT. (B) Trial two mean (\pm SD) RPE at each stage of the CTWT.

3.6 Mean (\pm SD) HR, %HR and RPE scores during maximal testing

Table 14 shows the mean (\pm SD) values of HR, %HR and RPE each each stage of the maximal test. The %HR value $98.3\pm 3.9\%$ in the final stage suggests that participants reached VO_{2max} however only three out of the seven subjects reached this final stage. Table 14 shows a high variability in HR scores, with the highest recorded at stage two of 128.7 ± 15.8 bpm and the lowest recorded at stage four, showing a mean (\pm SD) of 182.9 ± 7.8 bpm. The RPE values show a similar trend to that given in the sub-maximal testing with the highest variability shown in stage one and two of 7.4 ± 1.6 and 9.7 ± 1.6 on the scale respectively. During stage five however the mean (\pm SD) score was 19.0 ± 0.0 on the scale, showing no difference in the results collected between those participants.

Table 14 – Mean (\pm SD) HR, %HR and RPE values during each stage of the Maximal testing

Stages (gradient)	Maximal Testing		
	HR (bpm)	HR (%)	RPE
1 (10%)	107.4 ± 14.7	55.2 ± 7.9	7.4 ± 1.6
2 (12%)	128.7 ± 15.8	66.1 ± 8.7	9.7 ± 1.6
3 (14%)	162.7 ± 11.8	83.5 ± 6.5	13.1 ± 0.7
4 (16%)	182.9 ± 7.8	93.9 ± 3.9	16.6 ± 1.4
5 (18%)	191.3 ± 10.2	98.3 ± 3.9	19.0 ± 0.0

3.7 Relationship of mean (\pm SD) VO_{2max} scores

Figure 8 shows the relationship between all seven participants VO_{2max} scores on all three Trials of testing. It is clear that the predicted VO_{2max} during trial one and trial two was different by exactly $20.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $26.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

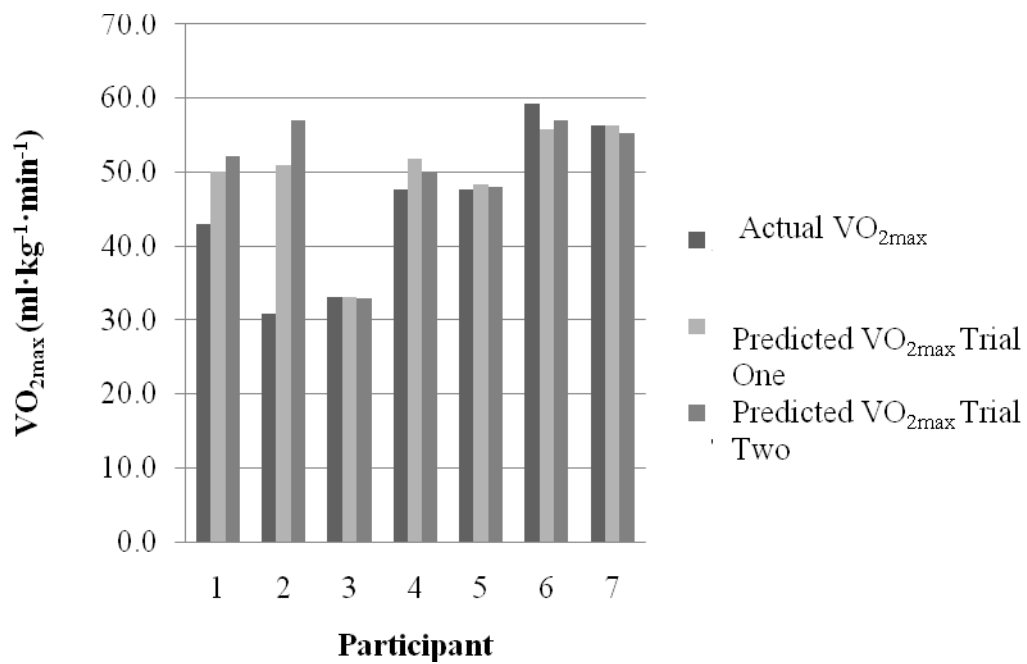


Figure 8 – A histogram showing the relationship between actual VO_{2max} , predicted VO_{2max} during trial one and predicted VO_{2max} during trial two between all the participants.

4. Discussion

This study's main aim was to assess the validity and reliability of the prediction of VO_{2max} by using a sub-maximal treadmill test called the CTWT. The measurement components measured in the whole testing period, which were HR, %HR and RPE were also assessed.

4.1 VALIDITY

4.1.1. VO_{2max}

After using the 95% LoA technique to assess the validity of the CTWT, there were no significant differences found and it was clear that there were overestimations of VO_{2max} by $4.0 \pm 15.4 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in trial one and $4.8 \pm 19.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in trial two. As table 8 shows, the predicted VO_{2max} was overestimated by $4.0 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ between trial one and the maximal testing and $4.8 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ between trial two and the maximal testing. We can see that one error in the validity of the CTWT was the sample size used. Further investigation using the same protocol and similar experimental procedures with more participants could show greater statistical validity. For example, as figure 6 shows, as one participant reached the termination criteria set for sub-maximal testing, the $\pm SD$ were reduced after stage three, however disregarding this participant is not an option.

The results show that the highest possible percentage errors between trial one and the maximal test and trial two and the maximal test by 34% and 43% respectively. The lowest possible percentage error between trial one and the maximal test and trial two and the maximal test was 9% and 11% respectively. When compared to previous results, percentage errors between a similar sub-maximal test was found to be between 5% and 15% (Stevens & Sykes, 1996). The study by Buckley et al. (2004) found an under-estimation percentage of

VO_{2max} by 19% and an over-estimation of VO_{2max} by 11%. It is clear that the range in percentage error in these two studies was much less than this study found, however the results do suggest that the percentage error is not acceptable and therefore the CTWT does not appear to be a valid test.

4.1.2. Estimated HRmax equation

The use of the estimated HRmax equation (220-age) was used as part of the criteria for the termination of the sub-maximal testing. This equation was also used to calculate 85% of an individual's HRmax and therefore played an important part in estimated a participants VO_{2max}. When the maximal testing took place, volitional exhaustion was used as the only termination criteria for stopping the maximal test. As each participants HR was monitored throughout the whole of the maximal testing, HRmax was recorded to compare against estimated HRmax. Table 9 shows a clear difference between the HRmax during the maximal testing and the estimated HRmax. The 95% LoA technique showed a mean (\pm SD) of $6.4\pm 14.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, which questions the use of the 220-age equation. The mean difference in HRmax was approximately 6 bpm and therefore results produced in the sub-maximal testing could be different if actual HRmax was used.

Table 9 shows descriptive statistics of each participant, with actual HRmax and a revised equation using 85% of their actual HRmax. The mean (\pm SD) VO_{2max} for trial one and two using actual HR was $46.8\pm 7.9 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $47.7\pm 8.6 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ respectively. The original equation used (220-age) produced higher estimated VO_{2max} scores of $49.5\pm 7.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ on trial one and $50.3\pm 8.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ on trial two. However the highest and lowest possible percentage error was only found to be 8% and 3% respectively, suggesting that even

with using the estimated HRmax, there is little difference between the values. Similar results were found by Buckley et al. (2004) where there was only a percentage error of 6%. These results suggest that to have such a percentage error as found between estimated and actual VO_{2max} , estimated HRmax difference would be as much as 18 bpm from actual HRmax.

Although the mean VO_{2max} values were less than first predicted and after using the LoA technique the mean difference was less, the use of actual HRmax would not be possible as this is only a sub-maximal test. When used in the public, it may not be possible to obtain actual HRmax therefore the 220-age equation must be used. The actual HRmax was used to assess the validity of the 220-age equation which found that it would be more useful to use actual HRmax. However as the percentage error shows, the difference between the estimated HRmax and actual HRmax is not significant and the 220-age equation is a useful calculation for the CTWT.

4.2 RELIABILITY

4.2.1. VO_{2max}

Although the CTWT has questions regarding its validity in predicting VO_{2max} , the reliability results of the CTWT were far more encouraging. The reliability of the VO_{2max} values found between trial one and trial two were assessed using the 95% LoA technique, which produced a mean (\pm SD) of $-0.8 \pm 5.2 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. There was little inter-trial bias and the LoA was acceptable, which suggests that the CTWT is a reliable test to use. Similar results were found in the study by Buckley et al. (2004), where the CST was assessed and analysed using similar statistical analysis. Buckley et al. (2004) found the test-retest reliability of the CST was $-0.8 \pm 3.7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and a study by Sykes and Roberts (2004) also assessed the use of the

CST, showing a test-retest reliability of $-0.7 \pm 4.5 \text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. In addition of the LoA technique, the $\text{VO}_{2\text{max}}$ values were assessed using ICC, which showed a correlation of 0.95. According to Cohen and Holiday (1996), r-values of between 0.90 and 1.00 represent a very high correlation between measured variables. Although the 95% LoA technique is a more appropriate form of statistical analysis, ICC provides an extended reliability analysis and therefore the results in this case represent a very high correlation between trial one and trial two (Bland & Altman, 1996).

4.2.2. HR reliability

A significant difference (0.004) was found between the HR values obtained from trial one and those obtained from trial 2. The LoA technique was acceptable ($\pm 2.8 \text{bpm}$) and there was little inter-trial bias (3.0bpm) suggesting that the CTWT is a reliable test when measuring HR. The HR increased at each stage of the CTWT (as shown in figure 6) and due to the small sample size, one participant finished the CTWT at stage three. This was obvious as the $\pm \text{SD}$ decreased dramatically from stage four until the last stage. In table 11, the mean ($\pm \text{SD}$) HR values at the final stage were $170 \pm 4.7 \text{bpm}$ in trial one and $169 \pm 5.6 \text{bpm}$ in trial two, showing very similar results between all the participants apart from one participant. The largest difference in mean ($\pm \text{SD}$) HR is only at stage three by 6bpm, as trial one showed a mean ($\pm \text{SD}$) of $133 \pm 20.1 \text{bpm}$ and trial two showed a mean ($\pm \text{SD}$) of $127 \pm 18.6 \text{bpm}$. Additional data was calculated to show %HRmax values, showing only a small difference during each stage of the test. More importantly as the criteria for termination of the test was 85% of estimated HRmax, trial one showed a mean ($\pm \text{SD}$) of $87.1 \pm 2.3\%$ and trial two showed a mean ($\pm \text{SD}$) of $86.3 \pm 2.7\%$. This shows that none of the six participants did not reach 85% of

their HRmax and the termination criteria was correctly adhered to, producing an accurate set of results.

All participants correctly completed the CTWT with no stopping until criteria were met and HR was accurately recorded within the last five seconds of each stage. In addition of the LoA technique, ICC was used showing a correlation of 0.99. This provides an additional assessment to the reliability of HR and shows a very high correlation between the HR values recorded in trials one and two. The relationship between the two trials can be seen on figure 6 where there is a steady increase in HR throughout each stage.

4.2.3. RPE Reliability

The RPE reliability showed no significant difference between trial one and trial two; however the LoA technique showed positive results. As with HR, there was very little inter-trial bias (-0.2) and the LoA was found to be good (± 0.6) as shown in table 12. Figure 7 shows the relationship between RPE values during trial one and trial two, where if they were overlapped there would be very little difference between them. As will be discussed, one participant did not understand the RPE scale as on all occasions that participant gave an RPE of 6 during the first stage of the test, which is inaccurate as work was being done at stage one of the CTWT. The one participant who completed the test at stage three did not exceed a RPE of 13, which could suggest other factors such as anxiety, body temperature and hydration state could have affected HR levels, causing the participant to have a high HR and not continue the test (Mier & Gibson, 2004). However even with these minor errors, RPE mean difference was less than 0.5 therefore even with the upper limit, the participants could exercise until the final stage

using the RPE scale. Similar results were found with the study by Buckley et al. (2004) as they concluded that RPE could be used safely as termination criteria for the CST.

As used for HR, ICC was used to assess overall reliability of the RPE values obtained from both trials. The r-value was 0.99, showing a very high correlation between RPE values and further showing the reliability between trial one and trial two of the CTWT.

4.3. Sample size

A clear observation made after the results had been collected and then analysed was the small sample size obtained. It was clear that with a larger sample size, the results were heavily affected by one of the participants when comparing a sub-maximal test to the maximal test. As shown in figure 8, number 2 predicted $\text{VO}_{2\text{max}}$ of $20.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in trial one and $26.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in trial two, which was much higher than actual $\text{VO}_{2\text{max}}$.

There are a number of reasons which could have affected the results collected on this one participant. It was clear before any testing took place that the participant had verbally agreed to the familiarisation of a treadmill. However this was not apparent in this specific individual as only after the maximal testing was conducted was it clear that the participant had a poor running economy. Although the participant claimed to do 10-30 minutes of exercise per trial on the health screen form, it was not clear what type of exercise was conducted and therefore running could not be part of their exercise they claim to carry out each trial. Their running technique was not clear during sub-maximal testing as it only required the participant to brisk walk in order to complete the test.

When each participant reached stage four of the maximal test, rather than walking they began to run. However this particular participant carried on walking for the duration of this stage. It

was clear that the participant looked uncomfortable walking at this pace and they were advised to start running. The treadmill dictates the stride length of the participant and it was clear that this became too difficult to handle once the speed increased. Furthermore research from Romanov (2002) who concentrated on an enhanced running technique called the “Pose method” found that a number of errors in technique could affect running economy. Some of these errors were obvious in the participant such as the landing of the feet and cadence. The participant did not follow a vertical line when placing their foot back on the treadmill, causing an increase in stride length and further reducing velocity on the treadmill. This was made even clearer once the test progressed to a steeper gradient and a higher speed, as the participant kept holding onto the treadmill railings although they were clearly instructed that you were not allowed. This allowed the participant to use their arms to help pull themselves up the treadmill as the speed and gradient increases and therefore a further stage was completed over four of the participants.

Another observation made with this particular individual was during the sub-maximal tests, as the participant did not reach any of the criteria points set before testing took place. The participant did not exceed a RPE of 16, nor did they look physically stressed or exceed 85% of their estimated HR_{max}. A number of reasons could be connected to this outcome including incorrect use of the RPE scale, estimated VO₂ plateau on the data collection sheet or difficulty in completing the test. There was clear misuse of the RPE scale during all the testing as the participant claimed that the intensity represented “no exertion at all” of 6 on the RPE scale, which is usually declared when a person is at rest (Borg, 1998).

On the data collection sheets (appendix I) for the sub-maximal testing, the increase in HR was much lower than in the other participants, suggesting a plateau in estimated VO₂ for that participant. The maximal testing showed that the participant had an actual VO_{2max} value of

30.8 ml·kg⁻¹·min⁻¹. However with the estimated VO_{2max} as high as 56 ml·kg⁻¹·min⁻¹, the calculated VO₂ values would suggest the participant would have stopped at stage four. This could suggest that the test was too difficult for the participant and therefore further investigation could involve the use of the Oxycon gas analyser during the sub-maximal testing to obtain actual VO_{2max} values.

A possible factor that could have affected the results was the level of anxiety of each participant. Although the warm-up on the treadmill before any of the testing took place would have raised HR levels, the mean (±SD) HR levels after stage one were 109±15.8bpm, 105±17.0bpm and 107±14.7bpm in trial one, trial two and the maximal testing respectively. Not only could the anxiety levels effect a participants HR level, the visual line of best fit drawn onto the data collection sheet could have been affected, therefore changing the predicted VO_{2max} value (ACSM, 2005).

4.4. Potential errors in measurement

There was potential for errors in measurement throughout all the testing, however the data collection was correctly adhered to such as collecting height, weight, HR and RPE. The possible errors with the CTWT however were the use of the 220-age equation as previously described, the relationship between HR, VO₂ and workload, and the use of the line of best fit. The relationship between HR, VO₂ and workload was analysed using the ACSM walking equation, similar to the equation used by Sykes and Roberts (2004) to estimate the VO₂ cost at each stage of the CST (ACSM, 2006). This relationship was then analysed using the HR values obtained from every participant at each stage of the CTWT, as these values were drawn onto the line which meets the estimated VO₂ cost at each stage. The equation is only

an estimated of VO_2 cost at each stage and therefore may not be an accurate measure of VO_2 cost for each participant. Furthermore, the use of the 220-age equation could affect where the line of best fit meets the estimated HRmax and in turn the line of best fit has to be accurately drawn over the HR values at each stage on the data collection sheet. As the HR values increased at each stage of the CTWT for every participant, it was not difficult to draw the line of best fit as no uncharacteristic HR values were reported. With any slight abnormality in HR, the statistical line of best fit can remove any variability and therefore is an accurate method to use to estimate VO_{2max} (Sykes & Roberts, 2004).

It is clear that the CTWT was prone to some errors when using the data collection sheet; however these potential errors were kept to a minimum. Although there has been much research into the 220-age equation to estimate HRmax, it was used in previous studies when investigating the use of a sub-maximal test (Sykes & Roberts, 2004; Buckley et al., 2004; Mier & Gibson, 2004). In addition, previous research has found that HRmax can change over a period of 21 years by 9bpm and for females over 33 years by 19bpm and the variability in HRmax can be up to 12bpm (Åstrand et al., 1973; ACSM, 2000). However with the age range and amount of physical activity reported in this study, the estimated HRmax equation provides a reliable estimation. The additional research found no significant differences between actual and estimated HRmax (table 9) therefore it provides an easy and practical method for an individual to calculate their HRmax.

4.5. Additional criteria for maximal exertion

All the participants appeared to meet the one criteria point set before any of the maximal testing took place, which was to exercise to volitional exhaustion. However the estimated

HRmax when using the 220-age equation was not achieved in the case of most of the participants, as one participant achieved 5bpm over their estimated HRmax.

Table 15 – Additional termination criteria of the maximal testing in each participant

Participant I.D	Maximal values		
	HRmax (bpm)	RPE	RER
1	197	17	1.36
2	189	19	1.27
3	192	19	1.59
4	194	16	1.24
5	197	17	1.46
6	198	19	1.34
7	197	19	1.24

Table 15 shows the HRmax, RPE and RER values that were achieved by each participant.

Only four of the seven participants reached an RPE of 19, which is commonly used as termination criteria in maximal testing (Borg, 1998; Sykes & Roberts, 2004). The remaining three participants did not report a RPE higher than 17 as RPE was only taken at the end of each stage. The next stage started after the RPE was recorded and as they were not able to complete it, RPE was not recorded again as it was assumed that participants reached maximal exertion.

RER was not used as termination criteria however the Oxycon gas analyser monitored RER values throughout the whole of the maximal testing, calculating the ratio between the amount of oxygen inhaled and the carbon dioxide exhaled. The RER commonly used for termination criteria is greater than or equal to 1.15 and as table 15 shows, all the participants reached a

RER of over 1.15. This suggests that VO_{2max} was achieved regardless of six of the seven participants not attaining their estimated HRmax.

4.6. Mental stress

It was clear that every participant reached volitional exhaustion during the maximal test, however four of the participants complained firstly of the pain they endured in their legs and felt like they could go on. The Bruce protocol has abrupt increases in exercise intensity between each stage more than some of the other treadmill tests such as the Balke treadmill test. For those individuals with lower fitness levels this test could be too difficult for them therefore modifications can be made (McArdle et al., 2001).

In regards to the mental stress of the test, a review by Noakes, St Clair-Gibson and Lambert (2005) hypothesised the fact that exercise is discontinued by the brain before actual VO_{2max} is attained, protecting excessive effort during exercise. They concluded that fatigue is not only an expression of the physical event, but a sensation that results from conscious perception and subconscious processes in the brain. However a study by Hawkins et al. (2007) suggests that they found evidence against these findings by Noakes et al. (2005) and that the subjects were able to carry out heavy physical activity beyond their maximal oxygen transport capacity. The feedback from four of the participants however suggest that the cause for them to finish the test was due to the mental stress of the test, therefore linking to the premise stated by Noakes et al. (2005). It is not clear whether this has sufficient evidence to the termination of the test as results show typical criteria such as HRmax and RER was met, therefore further investigation is required.

4.7 Further investigation

Further investigation could assess the use of the CTWT by using an Oxycon gas analyser during either one or both days of sub-maximal testing to obtain actual VO_2 cost at each stage of the test. This could be used against HR and workload to estimate $\text{VO}_{2\text{max}}$ of that individual. These values could then be compared to the actual $\text{VO}_{2\text{max}}$ which would be obtained from the maximal day of testing to provide a more thorough statistical analysis for the validity of the CTWT.

It was clear that the sample size used was small in comparison to other studies assessing the use of a sub-maximal test (Buckley et al., 2004; Mier & Gibson, 2004). With a larger sample size this would provide greater statistical reliability and could prevent any anomalous results from affecting the results. This was evident with one of the participants as explained before as their predicted $\text{VO}_{2\text{max}}$ was over estimated by $20.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in trial one and $26.1 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in trial two. Table 16 shows how the results would have been without this one participant. The mean ($\pm\text{SD}$) difference was $1.8 \pm 4.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ between trial one and the maximal testing and the mean ($\pm\text{SD}$) difference between trial two and the maximal testing was $1.8 \pm 4.3 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$.

Table 16 – Validity of the predicted $\text{VO}_{2\text{max}}$ values produced by the CTWT against actual $\text{VO}_{2\text{max}}$ using six participants

Trial	95% LoA	
	Mean (SD)	Sig.
Trial One v Max.	1.8±4.2	0.339
Trial Two v Max.	1.8±4.3	0.357

Although no significant differences were found between the two trials and the maximal testing, it shows the extent to which one participant changed the outcome of the results when assessing the validity of the CTWT. The lowest percentage error for both trials was 4% and the highest was 9%, agreeing with the percentage error results found by Stevens and Sykes (1996). It is clear that all participants would be used for analysis following testing however this table suggests that with an increased number of participants used, the CTWT could appear to be a valid test as well as a reliable one.

Further investigation could also involve measuring blood lactate levels at the end of each stage for both the sub-maximal and maximal testing. A typical blood lactate level where the test is terminated is when blood lactate levels rise above $8 \text{ mmol}\cdot\text{l}^{-1}$ (Åstrand et al., 1973). Since both the CTWT and Bruce treadmill protocol are continuous tests, the incidence of reaching the blood lactate criteria would almost equal the time at which RER criteria is met. Duncan et al. (1997) found that 90% of the subjects reached the termination criteria for both RER and lactate levels therefore both criteria would be useful for determining maximal effort.

5. Conclusion

The validity of the CTWT to predict actual $\text{VO}_{2\text{max}}$ is questionable however its role for cardiovascular fitness should be used as a reliable measuring tool. The percentage error found between trials one and two against the maximal testing was very high and therefore requires further investigation. The reliability of the predicted $\text{VO}_{2\text{max}}$, HR and RPE values found during the CTWT show positive results with little inter-trial bias and an acceptable LoA. The use of the 220-age HRmax equation was assessed however the results showed a small error

percentage; therefore the potential error lies with the estimated VO_2 values at each stage of the CTWT. It is clear that when recruiting the participants, their current physical activity level must be thoroughly assessed and a larger sample size is required when assessing the validity of the CTWT. Further investigation could involve the use of the Oxycon gas analyser during the sub-maximal days of testing to obtain actual VO_2 levels at each stage and lactate levels could be obtained throughout the testing.

6. References

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University of
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Consent Form

Project Title:

Reliability and Validity of the Chester Treadmill Walk Test for the prediction of Aerobic Capacity

Name of Researcher:

Ross Alexander McGuigan

1. I confirm that I have read the information sheet regarding the details of the Chester Treadmill Walk test and I have had the opportunity to ask any questions.
2. My participation is voluntary and therefore I understand that I have the ability to withdraw from the study at anytime without giving a reason.
3. I have been told that my responses will be kept strictly confidential and my details will not be identified in any report produced by the researcher.

Name of Participant

Signature

Date

Name of Researcher

Signature

Date



University of
Chester

Pre-test Health Screen

Reliability and Validity of the Chester Treadmill Walk Test for the prediction of Aerobic Capacity

Researcher – Ross Alexander McGuigan

Name: _____ Test Date: _____

Home Address: _____

Contact number: _____ Date of birth: _____

YOU MUST READ THIS FORM CAREFULLY

This form is required to be completed by the participant in order to declare any possibly health issues that could influence the study. If this is the case, you will not be able to participate in the study. Please circle either YES or NO.

- | | |
|--|----------|
| 1. Do you suffer from a heart condition and therefore have been given a recommended amount of physical activity to carry out by your doctor? | YES / NO |
| 2. When performing physical activity have you experienced any chest pain? | YES / NO |
| 3. Do you have a history of dizziness, epilepsy, blackouts or loss of consciousness? | YES / NO |
| 4. Do you have any joint or bone problems that could be affected by physical activity? | YES / NO |
| 5. Have you sustained any injuries in the past 6 months to your hip, ankle or knee? | YES / NO |
| 6. Are you currently being prescribed any drugs for a heart condition, blood pressure or any other illnesses? | YES / NO |
| 7. Are you currently pregnant or have been in the past 6 months? | YES / NO |

8. Do you know of any other reasons why you should participate in physical activity? If so please state below.

YES / NO

For the final question please circle ONE correct answer for the following question.

9. How much exercise on average do you do each day?

None. Less than 10 minutes. 10-30 minutes. 30-60 minutes. Over an hour.



Participant Information Sheet

Researcher – Ross Alexander McGuigan

Project Title: Reliability and Validity of the Chester Treadmill Walk Test for the prediction of Aerobic Capacity

You have been invited to take part in this research study. It is important for you to know all the information regarding why the test is being done and the correct procedures. If you have any questions to ask about the information sheet please do not hesitate to contact the researcher.

What is the purpose of the study?

The aim of the study is to assess the use of a new method to predict a person's fitness level which is also known as VO_{2max} . This method will exercise a person to 85% without having to take them to exhaustion and therefore estimate a person's fitness level. Each participant will only be required to attend three days with the final day taking the participant to exhaustion.

Why have I been chosen?

You are aged between 18 and 45 years old and you are reasonably active.

Do I have to take part?

Your participation is entirely voluntarily and you can withdraw from the study at anytime. If you decide to take part you will be required to sign a consent form and you will be given this participant information sheet to keep.

What will happen to me if I take part?

You will be given this participant information sheet and you will be asked to sign a consent form before testing takes place.

For the first two days you will be taken to 85% of your maximum on a running treadmill in a research laboratory in the University of Chester. The final day you will be taken to exhaustion and you will wear a mask that will cover your mouth and nose. Your oxygen and carbon dioxide production will be recorded along with your heart rate (a belt will be placed round your chest) and rating of perceived exertion (how you feel during the test).

Each test will take approximately 45 minutes and there will be a break of no more than a week between each of the testing days.

What are the possible risks of taking part?

You could experience respiratory distress during the maximal testing period. The gas analyser and/or the heart rate monitor could be uncomfortable to wear. The testing could be inconvenient as testing requires you to come into the university within a week between day one and day two and within a week between day two and day three. You could be uncomfortable giving out certain information such as weight although your information will be kept completely confidential.

What are the possible benefits of taking part?

VO₂max is an indicator of your cardiovascular fitness level and can provide you with a fitness rating. In addition you could be encouraged (if unfit) to take up exercise more regularly and improve fitness levels.

What if something goes wrong?

If you have any complaints to make, any concerns of the testing, obtain any injuries or illness during testing, contact Professor Sarah Andrew, Dean of the School of Applied and Health Sciences, University of Chester, Parkgate Road, Chester, CH1 4BJ, 01244 513055 for further information.

Will my taking part in the study be kept confidential?

All information collected about you will be kept strictly confidential and the only access to the data produced will be available to the researcher and research supervisor.

What will happen to the results of the research study?

Results will be reported in a write up for the researcher and it is hoped that the test can be used as a predictor for cardiovascular fitness levels. All participants will not be identified in the report or in any possible publication.

Who should I contact for further information?

If you would like further information regarding the project, please contact the following:-

Name: Ross McGuigan

Tel: 01244 513 402

Email: 0816955@chester.ac.uk

Thank you for your interest in this research project.



Protocol Information Sheet

Researcher – Ross Alexander McGuigan

Project Title: Reliability and Validity of the Chester Treadmill Walk Test for the prediction of Aerobic Capacity

Chester Treadmill Walk Test:-

- Speed is set at a pace of 6.2 km/hr for the whole test.
- Gradient increases by 3% every two minutes.
- Subjects start with a 0% gradient.
- Heart rate monitor worn throughout the test.

Bruce Treadmill Protocol:-

- Speed varies at each stage of the test.
- Gradient begins at 10% and increases by 2% every three minutes.
- Gas analyser worn throughout the test which will cover the mouth and nose.
- Heart rate monitor worn throughout the test.

Stage	Time (mins)	Speed (km/hr)	Gradient (%)
1	0	2.7	10
2	3	4.0	12
3	6	5.5	14
4	9	6.8	16
5	12	8.1	18
6	15	8.9	20



University of
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Data Collection Sheet – Sub-maximal (Trial ONE)

Researcher: **Ross Alexander McGuigan**

Project Title: Reliability and Validity of the Chester Treadmill Walk Test for the prediction of Aerobic Capacity

Participant ID: _____ Date: _____

Age: _____ Height (cm): _____ Weight (kg): _____

VO_{2max} : _____

PREDICTED VO₂ values during sub-maximal testing.

	STAGE 1	STAGE 2	STAGE 3	STAGE 4	STAGE 5	STAGE 6
Heart rate recorded at each level						
RPE						



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Data Collection Sheet – Sub-maximal (Trial TWO)

Researcher: **Ross Alexander McGuigan**

Project Title: Reliability and Validity of the Chester Treadmill Walk Test for the prediction of Aerobic Capacity

Participant ID: _____ Date: _____

Age: _____ Height (cm): _____ Weight (kg): _____

VO_{2max} : _____

PREDICTED VO₂ values during sub-maximal testing.

	STAGE 1	STAGE 2	STAGE 3	STAGE 4	STAGE 5	STAGE 6
Heart rate recorded at each level						
RPE						



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Chester

Data Collection Sheet – Maximal test

Researcher: **Ross Alexander McGuigan**

Project Title: Reliability and Validity of the Chester Treadmill Walk Test for the prediction of Aerobic Capacity

Participant ID: _____ Date: _____

Age: _____ Height (cm): _____ Weight (kg): _____

Heart rate max (bpm): _____ VO_{2max} : _____

ACTUAL VO_2 values during maximal testing.

	10% gradient	12% gradient	14% gradient	16% gradient	18% gradient	20% gradient
Heart rate recorded at each level						
RPE						

Appendix H – SPSS tables

Example Test for Normality (using Shapiro-Wilk)

Tests of Normality

	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
DayOnediff	.252	7	.199	.846	7	.112

a. Lilliefors Significance Correction

Paired T-tests to test Validity

Paired Samples Statistics

	Mean	N	Std. Deviation	Std. Error Mean
Pair 1 Day one of testing (ml. o2/kg/min)	49.457	7	7.8057	2.9503
Maximal testing (ml. o2/kg/min)	45.457	7	10.7103	4.0481
Pair 2 Day two of testing (ml. o2/kg/min)	50.271	7	8.4146	3.1804
Maximal testing (ml. o2/kg/min)	45.457	7	10.7103	4.0481

Paired Samples Test

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	Day one of testing (ml. o2/kg/min) - Maximal testing (ml.o2/kg/min)	4.0000	7.8494	2.9668	-3.2595	11.2595	1.348	6	.226
Pair 2	Day two of testing (ml. o2/kg/min) - Maximal testing (ml.o2/kg/min)	4.8143	10.0577	3.8015	-4.4876	14.1161	1.266	6	.252

Reliability between Trial 1 and Trial 2 using ICC

Intraclass Correlation Coefficient

	Intraclass Correlation ^a	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig.
Single Measures	.950 ^b	.764	.991	37.232	6	6	.000
Average Measures	.974 ^c	.866	.996	37.232	6	6	.000

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. Type A intraclass correlation coefficients using an absolute agreement definition.

b. The estimator is the same, whether the interaction effect is present or not.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Paired T-test between Trial 1 and Trial 2

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Day one of testing (ml. o2/kg/min)	49.457	7	7.8057	2.9503
	Day two of testing (ml. o2/kg/min)	50.271	7	8.4146	3.1804

Paired Samples Test

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	Day one of testing (ml. o2/kg/min) - Day two of testing (ml.o2/kg/min)	-.8143	2.6252	.9922	-3.2421	1.6136	-.821	6	.443

Paired T-test between HR values and RPE values during both trials of the CTWT

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	HR Day 1	138.167	6	23.0952	9.4286
	HR Day 2	135.200	6	23.9879	9.7930
Pair 2	RPE Day 1	11.417	6	3.1971	1.3052
	RPE Day 2	11.567	6	3.1557	1.2883

Paired Samples Test

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	HR Day 1 - HR Day 2	2.9667	1.4052	.5737	1.4920	4.4414	5.171	5	.004
Pair 2	RPE Day 1 - RPE Day 2	-.1500	.3146	.1285	-.4802	.1802	-1.168	5	.296

Chester Treadmill Walk Test for the prediction of Aerobic Capacity (Sykes 2008)

Name: _____ data collection and results sheet

Age: _____ M/min: _____ 80% MaxHR: _____ 80% MaxHR: _____
 Tick when checked

Readiness to exercise check

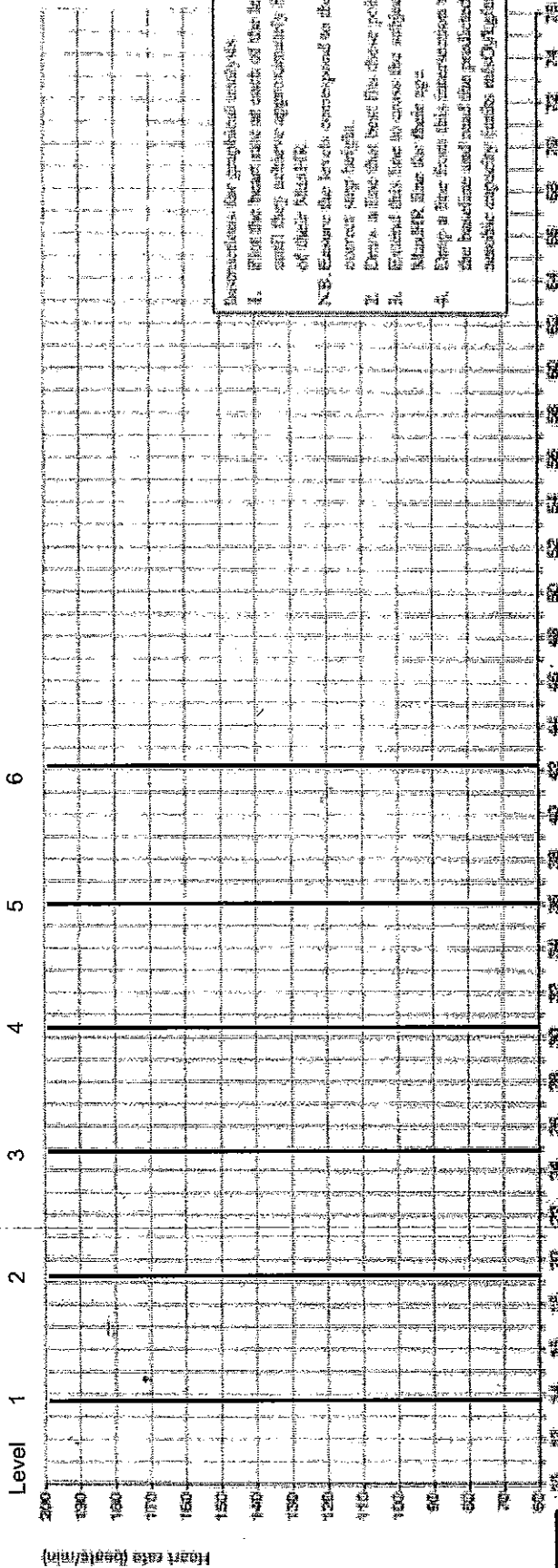
Contra-indications to exercise

Lifestyle activity level check

Tester's initials

Stop level	II	III	IV	V	VI
Heart rate reached at stop level					
Exhaustion level from RPE scale					

Date of test:	
Aerobic capacity (mls/kg/min)	
Fitness rating:	
Remarks:	



Procedures:

1. Check there are no medical contraindications to vigorous exercise
2. Subject walks at 6.2km/hr at 0% for 2mins
3. Every 2mins increase gradient by 3%
4. Test is completed when HR reaches 85% or RPE=15
5. Test should be stopped if subject is showing overt signs of distress and exhaustion
6. Plot the HRs, draw a line of best fit to HRMax, drop a perpendicular to predict Aerobic Capacity.

15% MaxHR

Age	15-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90+
Male	195	190	185	180	175	170	165	160	155
Female	185	180	175	170	165	160	155	150	145

15% MaxHR

Age	15-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90+
Male	185	180	175	170	165	160	155	150	145
Female	175	170	165	160	155	150	145	140	135

WANTED

HOW FIT ARE YOU?



- **VOLUNTEERS REQUIRED TO FIND OUT CARDIOVASCULAR FITNESS LEVELS.**
- **ALL LEVELS OF FITNESS, MALE OR FEMALE AGED BETWEEN 18-45 YEARS OLD WELCOME**
- **A SERIES OF TESTS WILL TAKE PLACE OVER A COURSE OF THREE DAYS (NON CONSECUTIVE) WHICH WILL TEST YOUR VO₂ MAX**
- **LOCATION: RESEARCH LAB NEAR SWIMMING POOL**

FOR FURTHER INFORMATION CONTACT

ROSS MCGUIGAN ON

0816955@CHESTER.AC.UK

OR ON 01244 513 402



University of
Chester

VERSION 1

University of Chester
Faculty of Applied and Health Sciences
Research Ethics Committee

370 413

2nd July 2009

Dear Ross,

Study title: Reliability and Validity of the Chester Treadmill Walk test for the prediction of aerobic capacity.

FREC reference: 326/09/RM/CENS

Version number: 1

Thank you for sending the above-named application to the Faculty of Applied and Health Sciences Research Ethics Committee for review.

The application has been considered by the Faculty Research Ethics Committee.

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form and supporting documentation.

The favourable opinion is given provided that you comply with the conditions set out in the attached document. You are advised to study the conditions carefully.

The Participant Information Sheet 'What is the purpose of the study' should clearly indicate that the test might continue even if the subject reaches 85% of their maximum heart rate to make it consistent with the answer given for bullet point 2 on the Committee's feedback.

The final list of documents reviewed and approved by the Committee is as follows:

Document	Version	Date
Response to the Committee	1	June 2009
Participant Information Sheet	2	June 2009
Protocol Information Sheet	1	June 2009
Pre-test Health Screen	2	June 2009

With the Committee's best wishes for the success of this project.

Yours sincerely,

Mohammed Saeed
Chair, Faculty Research Ethics Committee

Enclosures Standard conditions of approval.
c.c. Supervisor FREC Representative

Human Performance / Exercise Physiology Research Laboratories Support for MSc Student Research Project

To whom it may concern,

I can confirm that the student named below has the support of the technical staff in carrying out their research testing.

Student name

Programme

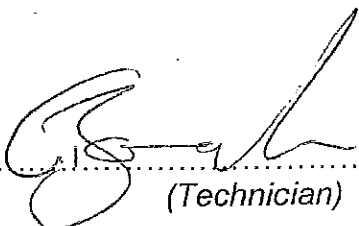
Study title

Equipment

Laboratory

delete as appropriate

- The equipment required is currently available and working.
- The consumables are available, or will be ordered as required.
- Sufficient laboratory time should be available to complete the testing required.
- The student is proficient with the equipment he/she wishes to use.
- A risk assessment has been completed. Copy attached.


Signed  Date 30.4.09
(Technician)

n.b. technician to photocopy completed form for laboratory records

Risk Assessment Form

Please consult a technician for advice before completing this form

HAZARD (e.g. equipment / procedure)	PERSONS AT RISK	RISK OF	CONTROLS TO BE FOLLOWED
MAXIMAL AEROBIC CAPACITY TESTS	EXPERIMENTAL SUBJECTS	breathlessness, dizziness, nausea, lulls, cardiac arrest.	Pre-test health questionnaire, test not suitable for untrained subjects ensure subject familiarised with test apparatus, test to be supervised by technician/doctor.
SUB-MAXIMAL AEROBIC EXERCISE TEST	EXPERIMENTAL SUBJECTS	breathlessness, dizziness, nausea, lulls in some subjects	Pre-test health questionnaire, advise subject familiarised with test apparatus, close supervision of vulnerable subjects (obese/ untrained), ensure cessation criteria adhered to.

Student Signature 

Technician Signature 

Date 