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PREDICTION OF $\dot{V}O_{2max}$ IN RUGBY PLAYERS

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This study is dedicated to my Granddad, Peter Mills. He always said I'd be the first one of the family to attend university.

Abstract

This investigation aimed to: (i) assess the reliability of scores from an adapted 20 metre multistage fitness test (MSFT) performed on a dry turf rugby pitch, in which subjects wore studded boots, (ii) develop a calibration model using least squares linear regression which could predict $\dot{V}O_{2max}$ scores (ml kg^{-1} min^{-1}) using scores from the adapted MSFT (cumulative shuttles) and (iii) cross-validate the calibration model by quantifying the agreement between directly measured and predicted $\dot{V}O_{2max}$ scores. A sample of 16 rugby players (12 males and 4 females) took part in the investigation (mean (SD), age 20.8 (±1.2) years, stature 1.81 (±0.08) m and body mass 76.6 (±13.4) kg). Each of the 16 subjects performed two MSFTs in order to establish the reliability of the adapted MSFT (initial test 67 (±21) shuttles, retest 68 (±19) shuttles). The agreement between test and retest scores was quantified using the 95% limits of agreement (LoA) method (bias = -3 (±2) shuttles, t = -0.66, P = 0.517; heteroscedasticity coefficient r = 0.012, P = 0.964; LoA = ±3 shuttles). Eleven subjects were then randomly selected from the group to form a calibration sample. An equation was then formed using average scores from the two MSFTs performed in the reliability stage (66 (±22) shuttles) and $\dot{V}O_{2max}$ scores directly measured using cycle ergometry (44.2 (±8.5) ml kg^{-1} min^{-1}). The equation formed was: $\dot{V}O_{2max}$ (ml kg^{-1} min^{-1}) = 22.3 + (0.327 x MSFT score (shuttles)). The standard error of estimate for the model was calculated as: s_{YX} = ±4.9 ml kg^{-1} min^{-1}.

The remaining five subjects not used in the calibration stage were used to cross-validate the calibration model. MSFT scores, obtained by averaging the two MSFT scores achieved by each subject in the reliability stage (70 (±18) shuttles), were entered into the calibration model and predicted $\dot{V}O_{2max}$ scores were calculated (45.3 (±5.7) ml kg^{-1} min^{-1}). These predicted scores were then compared to $\dot{V}O_{2max}$ scores directly measured using cycle ergometry (44.3 (±7.1) ml kg^{-1} min^{-1}). Their agreement quantified, again using the 95% LoA method (bias = -3.7 (±1.8) ml kg^{-1} min^{-1}, t = -0.99, P = 0.380; heteroscedasticity coefficient r = 0.077, P = 0.902; LoA = ±3.5 ml kg^{-1} min^{-1}). The findings of this study led to the conclusion that an MSFT performed on a dry turf rugby pitch whilst wearing studded boots provides repeatable scores within the sample group of rugby players used in the study. Scores from the adapted MSFT can predict $\dot{V}O_{2max}$ scores using the devised calibration model and the standard error of estimate is lower when compared to the error in the original MSFT study by Léger and Lambert (1982). Despite this, the agreement between predicted and directly measured $\dot{V}O_{2max}$ scores suggested that the calibration model predicted valid $\dot{V}O_{2max}$ scores from adapted MSFT scores for the sample population. Because of the simplicity of the adapted MSFT and its ability to test multiple subjects simultaneously; it was decided that it is a useful test for assessing aerobic fitness of rugby players.

Chapter One - Introduction

1.1 Aerobic requirements of rugby union

Rugby Union is a team game that places large physical demands on players throughout its eighty minute duration. Although the game can be seen to require the ability to perform multiple, intermittent, anaerobic activities; large stresses are predominantly placed upon the aerobic capabilities of the players. Aerobic fitness will account for overall performance throughout a game because of its long duration. Shephard (1994) suggests that activities lasting over one hour, such as a rugby match, are predominantly aerobic activities. It is therefore important, in order to be successful in rugby union, for the coach to be able to assess the aerobic fitness of his players in order to prescribe appropriate training interventions to improve (Luger and Pook, 2004). Shephard (1994) states that maximal oxygen uptake ($\dot{V}O_{2max}$), also known as aerobic power, is the traditional index of aerobic fitness. Aerobic power is a vital component of aerobic function as it defines a subject's upmost tolerance of aerobic exercise (Maud and Foster, 2006). All endurance activities are completed whilst working at a certain percentage of $\dot{V}O_{2max}$; ergo the level of endurance performance can be limited by a low $\dot{V}O_{2max}$ (Wilmore and Costill, 2004). To allow a rugby coach to compare scores among a team fairly, it is likely that the $\dot{V}O_{2max}$ scores for each player will be scaled relative to their individual body mass.

1.2 Measuring $\dot{V}O_{2max}$

The British Association of Sport and Exercise Sciences (BASES; 2007) define $\dot{V}O_{2max}$ as 'the global outcome of the rate at which the body can extract oxygen from the atmosphere via the cardio-pulmonary system, transport it via the cardiovascular system and use it in the skeletal muscle.' The point at which a subject achieves their $\dot{V}O_{2max}$ is defined by the following criteria suggested by BASES: (i) a plateau in oxygen uptake (less than 150 ml min^{-1} oxygen intake in response to increased intensity), (ii) a respiratory exchange ratio above 1.15, (iii) a heart rate close to subject's calculated heart rate max (220-age), (iv) an age-appropriate increase in blood lactate (8-11 mMol L^{-1}) and (v) a rate of perceived exertion above 18 on Borg's scale (The British Association of Sport and Exercise Sciences, 2007).

Direct determination of $\dot{V}O_{2max}$ is the most accurate way of assessing aerobic power; however its use is sometimes considered impractical. This is often because accurate testing requires expensive equipment, laboratory time and trained personnel (Ramsbottom *et al*., 1988). In addition to these factors, the practicality of measuring $\dot{V}O_{2max}$ is also affected by the fact that subjects often have to be tested individually. With rugby union being an example of a team game; it is often multiple subjects (entire teams) that require testing. For analyses of results for multiple players to be most accurate, they must be tested within a small time frame, preferably simultaneously. Due to the limitations of direct $\dot{V}O_{2max}$ testing listed previously, this is often not possible or practical.

1.3 Field Testing

With $\dot{V}O_{2max}$ scores widely accepted as good indicators of aerobic fitness, more practical methods of attaining reliable values were required. Much research has therefore been documented on the use of simple field tests to predict $\dot{V}O_{2max}$. Calibration modelling is used to predict a criterion test score ($\dot{V}O_{2max}$) from the result of a predictor (field) test. Predictions are calculated through the utilisation of linear relationships between the field test scores and scores obtained from a laboratory-determined $\dot{V}O_{2max}$ test. Research has revealed that the use of field tests, such as the multi-stage fitness test, to predict $\dot{V}O_{2max}$, can be highly reliable and valid (Ramsbottom *et al*., 1988; Paliczka *et al*., 1987; Léger and Lambert, 1982), although some studies have predicted $\dot{V}O_{2max}$ scores significantly lower than the corresponding directly measured values (Cooper *et al*., 2005; St. Clair-Gibson *et al*., 1998). The benefits of field testing are vast, with the ability to perform mass tests on multiple subjects with relative ease. There are no requirements for specialist equipment or trained personnel and the tests are much cheaper and are not restricted to a laboratory environment.

Commercially available field tests claim to be able to accurately predict maximal oxygen uptake values. Perhaps the most well known of these being the twenty metre multi-stage fitness test, popularised by Brewer *et al*., (1988).

Many coaches, of many sports including rugby union, believe that the $\dot{V}O_{2max}$ scores, predicted by cross-referencing scores from the multi-stage fitness test with the booklet provided; give an accurate representation of a subject's aerobic fitness and consequently use them as measures of aerobic fitness in their players (Hazeldine and McNab, 1991; Australian Sports Commission, 2000).

A factor that many coaches fail to consider when administering the test is the recreation of the original study's test parameters. Often, tests are completed on grass pitches, concrete or Astroturf surfaces; which all have varying performance implications when compared to the original wooden gymnasium flooring used Brewer *et al*. (1988). In addition to this, tests are also frequently performed on specific populations, like rugby teams. This again has impacts when making predictions based on the data gathered in the original study, which used a more general population. Because Brewer *et al.* (1988) created a calibration model in order to predict $\dot{V}O_{2max}$ scores, the most accurate predictions can only be applied to the sample population and specific test protocol used. Applying the same calibration model to a different group of subjects or test protocol increases the amount of error that can be expected in prediction (Bryman and Cramer, 1996). When a rugby coach administers a MSFT it is often on the grass pitch that most training is performed on. In this case, players are usually wearing studded boots. Footwear is yet another performance influencing factor that previous studies have failed to address.

1.4 Aims of this investigation

To ensure that accurate $\dot{V}O_{2max}$ scores can be predicted for a sample population of rugby players, adjustments to the original MSFT protocol must be made. The modifications include the performance of the MSFT on a grass rugby pitch and the use of appropriate studded footwear; as players would experience in a rugby match. This study therefore aims to (i) determine the test-retest repeatability of the modified MSFT on rugby players, (ii) create a new calibration model to predict $\dot{V}O_{2max}$ scores from MSFT results and (iii) cross-validate the model with a sample from the same population.

Chapter Three - Methods

3.1 Subjects

The sample group of 16 subjects, used in this investigation, consisted of 12 males and 4 females (mean (SD): age 20.8 (±1.2) years, stature 1.81 (±0.08) m and body mass 76.6 (±13.4) kg), all of whom had played rugby union to at least school first team level. Before participant recruitment began, ethical approval was sought and attained, from the University of Wales Institute, Cardiff (UWIC) Research Ethics Committee (UREC), for the proposed tests involved. Test protocols were then subjected to a risk assessment. Risk factors involved in testing were considered and an overall risk score calculated. A sufficiently low score meant that the test protocols were relatively safe. Before testing, each subject was asked to complete a pre-exercise health questionnaire (Par-Q); in order to assess their physical condition and ability to take part in the investigation. They were then advised of the nature of the tests involved before signing forms of informed consent (Par-Q and informed consent example forms are provided in Appendix A, along with ethics and risk assessment forms). Data collection began by obtaining basic physiological characteristics of each subject, stature and body mass. These were collected by standardized procedures (Lohman, 1988). This was done through use of a Holtain Fixed Stadiometer (Holtain LTD, United Kingdom) and Seca 770 Digital Scales (Vogel and Halke, Germany) respectively. These results were then recorded together with the relevant subject's age.

3.2 Stages of data collection

The aim of this investigation was to validate the use of a predictor test (MSFT) to accurately predict the results of a criterion test ($\dot{V}O_{2max}$ test). The calibration modelling involved had been utilised in a past study by Cooper *et al*. (2004) and this investigation followed the same three part investigation structure. The first stage aimed to indicate the reliability (test-retest repeatability) of the MSFT. Reliability relates to the repeatability or consistency of the test and is an integral part of validity (Thomas *et al*., 2005). A test cannot be considered valid if it is not reliable. In this stage, all sixteen subjects completed two MSFTs within a three week testing period. The MSFT scores (stage:shuttle) were also expressed as the number of cumulative shuttles completed. Cumulative shuttles completed have been used for all analysis involving MSFT scores. Scores from the test and retest were tested for their agreement. This was done using the 95% limits of agreement (LoA) method detailed by Bland and Altman (1986) and explained in more detail in section 3.6.

Stage two gave the basis for the formation of the calibration model. Eleven subjects, randomly selected from the group, performed a $\dot{V}O_{2max}$ test in a laboratory within the three week testing period. An average score of the two MSFTs performed by each subject in stage one, was taken as their MSFT score for use in the second stage. Results collected from the laboratory test were used as criterion data for the calibration model, whilst the average results of the MSFTs were used as predictor data.

The results were analysed to see if a linear relationship between the variables existed before using methods of linear regression to generate the calibration model (Bryman and Cramer, 1996).

The five subjects not used in stage two were used in stage three for the cross-validation of the calibration model. Each of the five subjects performed a laboratory-based $\dot{V}O_{2max}$ test, again within the three week testing period. An average of each of the five subject's two MSFT scores used in stage one, was taken as their MSFT score for stage three. The average results from the MSFTs were then inserted into the calibration model (developed in stage 2) in order to obtain a set of predicted $\dot{V}O_{2max}$ scores. These predicted scores were then tested for their agreement with the lab-determined scores; again the 95% LoA method was used (Bland and Altman, 1986).

3.3 Criterion (laboratory tested $\dot{V}O_{2max}$) test protocol

A strict protocol was followed by all participants throughout the laboratory $\dot{V}O_{2max}$ testing. This was to ensure consistency and reliability of results. The testing had to be consistent in order for the test to be considered valid. Keeping to a strict protocol limits the occurrence of measurement error (Thomas *et al*., 2005). Each subject first sat on the Monark 874 cycle ergometer (Monark Exercise AB, Sweden) to test and adjust the correct height of the seat. This was judged by the knee angle being as close to ninety degrees as possible at the top of a revolution, whilst in a seated position.

Before the test began, each participant was once again made aware of the test protocols. Also at this time, eight 200L Douglas bags (Hans Rudolph Inc., USA) were prepared for collection of expired gas as this was more than any subject was expected to fill. They were emptied using a Harvard dry gas meter (Harvard Apparatus, USA) and the bags were connected to a two-way respiratory valve and mouth piece via 32mm bore respiratory tubing (Hans Rudolph Inc., USA). An unloaded cycle warm-up lasting four minutes was set as the standard warm-up for all participants (Buchfuhrer *et al*., 1983).

After the warm-up, participants, when ready, began cycling. They accelerated to the correct revolutions per minute in accordance with the standard (70 revolutions per minute (rpm) for males and 50rpm for females) and maintained this. Resistance at the start of the first stage was the 1kg weight of the cycle ergometer's load basket. When the correct speed was reached timing began on a Casio stopwatch. The test consisted of consecutive, three minute stages of increasing intensity until the subject was exhausted and unable to continue (Karpman, 1987). The test was continuous with no rests, but subjects did receive verbal motivation as this encouraged maximal exertion (The British Association of Sport and Exercise Sciences, 2007). Resistance was increased by 0.5kg after every third minute, in conjunction with the timekeeper, whilst rpm remained constant. Expired gas was collected for every third minute of exercise. The timekeeper would give a thirty second warning to the subject to allow them to put the mouth piece in and a nose clip on. This was shortly followed by a five second countdown so that the valve on the Douglas bags could be opened accurately on time.

Another five second countdown towards the end of each stage would result in the valve on the Douglas bag being closed. These processes were repeated for every third minute until either the subject reached their age determined heart rate maximum (220-age) or the subject was unable to continue (volitional exhaustion); at either point testing was ceased (The British Association of Sport and Exercise Sciences, 2007). Heart rate was monitored throughout the test through use of a Polar S610 heart rate monitor (Polar Electro Oy, Finland). Resting heart rate before testing and peak heart rate during the test were recorded for each subject (presented in Appendix B). All subjects exceeded 90% of their heart rate maximum ensuring maximal effort during the test.

The concentrations of expired oxygen and carbon dioxide in the Douglas bags were analysed through use of a dual gas analyser (Servomex Model 1440c). The dual gas analyser was calibrated before use by analysing gases of known oxygen and carbon dioxide concentration and adjusting the machine accordingly. One litre of the expired gases was used to obtain the average values for expired oxygen (FEO_2) and carbon dioxide ($FECO_2$) for each stage of the test completed. The total volume of expired gas within each measured stage was obtained using a Harvard dry gas meter. One litre was then added to this value to replace the litre taken by the dual gas analyser. This process was repeated for each stage and the results recorded.

These results were then entered into a spreadsheet that calculated $\dot{V}O_{2max}$ in ml kg^{-1} min^{-1} and L min^{-1}. This was done using the following equations: (i) $\dot{V}O_{2max}$ (L min^{-1}) = (minute ventilation ($\dot{V}_E$, measured in L) x (20.93 x FEO_2)) / 100; (ii) $\dot{V}O_{2max}$ (ml kg^{-1} min^{-1} = ($\dot{V}O_{2max}$ (L min^{-1}) / body mass of subject (kg)) x 1000.

3.4 Scaling

$\dot{V}O_{2max}$ values, within sports science environments, have often been scaled for individuals into millilitres per kilogram of body mass per minute (Shephard, 1994). This method of scaling is subject to criticism and it is suggested by Tanner (1949) that use of ratio standards such as this are misleading; unless 'Tanner's exceptional circumstance' ((cv_X/cv_Y) = r_{XY}) is satisfied. If this equation is met, then measurements can be accurately adjusted for a subject's body size. Despite this fact, it was decided that ml kg^{-1} min^{-1} was the most appropriate units to use because the MSFT cross-reference table, provided with Brewer *et al.*'s (1988) version of the MSFT, expresses $\dot{V}O_{2max}$ in this form. Therefore, for best comparisons between studies, the same units of $\dot{V}O_{2max}$ measurement are preferable.

3.5 Predictor (multi-stage fitness test) test protocol

After performing a standardized warm-up, consisting of a two lap jog around the rugby pitch and a mixture of relevant static and dynamic stretches, subjects completed a slightly modified version of the MSFT. Despite being pioneered as a fitness test for rugby players originally by Léger and Lambert (1982), the test protocol used was essentially identical to the protocol detailed in Brewer *et al*. (1988). The only difference was the surface on which the test was undertaken. To make this investigation more specific to rugby players, the MSFTs were performed on a dry, turf rugby pitch, as opposed to the sprung wooden flooring, suggested by Brewer *et al*. (1988). Participants were also asked to wear studded boots for the test. This not only allowed for a closer simulation of rugby playing conditions, but also aided safety because of the extra grip given by studded boots.

The test area was set up in the centre of a rugby pitch, using the opposing ten metre lines each side of the half way line as the twenty metre shuttle distance. This distance was confirmed by use of a tape measure prior to testing. Subjects were instructed to follow the audio cues from the investigator's laptop in order to judge the speed to run between the lines. TeamBeep (Bitworks engineering, http://www.rugbycoach.com/fitness/test/20msrt.htm), was the software used to emit the audio cues needed for the test. The software was downloaded to a laptop computer and used to administer the MSFT.

This version of the test was chosen over the versions available on audio cassette or compact disk because the timing of the beeps was extremely accurate and the error could be calculated by the software after each test. The downloaded version of the test suffered limited timing error and required no manual calibration. From a test run of the program, the average timing error incurred on each shuttle was ±0.04s. This compared favourably to the study by Cooper *et al*. (2004) where a timing of error of ±0.25s every 30 seconds was accepted using the cassette version of the test.

The version of the test used had twenty levels; lasting one minute each and beginning at a running speed of 8.5 km h^{-1}. This increased by 0.5 km h^{-1} after every stage. Subjects were encouraged to run to volitional exhaustion, completing as many shuttles as they could, whilst continuing to turn in time with the beeps. Multiple subjects performed the test together, adding a motivational edge. Subjects were disqualified from the test if they failed to complete two consecutive shuttles within the audio defined time scales. At the point of voluntary withdrawal or disqualification, the relevant subject's result was recorded as a stage level and shuttle number, only fully completed shuttles were considered.

3.6 Statistical analysis

Statistical analyses in this investigation were computed by the use of the software program Minitab 14. Before parametric analyses of any of the data used in this investigation could be implemented, normality of the residual errors of scores was quantified through use of Anderson-Darling Normality tests. As mentioned previously, the first stage of the investigation aimed to quantify the agreement between results in both the initial MSFT and retest MSFT. First of all, a paired *t*-test was performed on the test and retest scores in order to quantify any bias between them (mean and standard deviation differences). This also tested the null hypothesis of no difference between the means of the tests (Vincent, 1999). A graph was then plotted of the mean of each subject's test and retest scores; against the residual errors between each subject's test and retest scores. This is known as a *Bland-Altman* plot (Bland and Altman, 1986). The use of regression assumed that the dispersion of results was homoscedastic. If the amount of scatter around the line of best fit varied markedly at different points, the data was said to be heteroscedastic (Bryman and Cramer, 1996). Heteroscedasticity was quantified by obtaining a zero order correlation between absolute differences between test-retest scores and the means of the test-retest scores. A correlation close to zero meant that the 95% LoA, were expressed as ±1.96 x SD_{diff} (obtained from the paired *t*-test). Including the bias, the 95% LoA was written as $\bar{x}_{diff}$ ±(1.96 x SD_{diff}). These upper and lower limits were then superimposed on the *Bland-Altman* plot.

A Pearson's correlation coefficient was also calculated to quantify the relationship between test and retest scores. This was mainly for easy comparison to previous investigations that had used correlation coefficients to assess reliability.

The first statistical method involved in developing the calibration model in stage two of the investigation was determining a zero order correlation between predictor test and criterion test scores. This tested the null hypothesis of no linear relationship between the two test scores. The coefficient of determination (CoD, R^2) was then determined by use of the following equation: CoD % = r^2 x 100. The statistical analysis software also gave an adjusted CoD value. This percentage score indicated the amount of common variance between the criterion and predictor test results and was visually presented by use of a Venn diagram (Bryman and Cramer, 1996; Vincent, 1999). If the correlation was high, then the CoD would be high too. A calibration model was formulated using least squares methods of linear regression (Cooper *et al*., 2004). The end equation was therefore a straight line equation (Y = a + bX). Thus, for accurate prediction of a result from a criterion test (Y) using the result of a predictor test (X), there needed to be a strong linear correlation (a value of r = 1 would have meant that Y could have been exactly predicted from X as there was 100% common variance). From the straight line equation, we wanted to predict Y using X.

To do this, the a and b components of the equation were required. The gradient of the line (b) is the change in the value of *Y* when the *X* value is increased by one unit. The equation for b is therefore as follows: b = $r_{XY}(s_Y/s_X)$, with r_{XY} being the zero-order correlation, s_Y being the standard deviation of the *Y* scores and s_X being the standard deviation of the *X* scores. The b value helped calculate the a value (*Y* intercept) using the equation: a = $\bar{x}_Y$ – (b x $\bar{x}_X$). $\bar{x}_Y$ denoted the mean of all of the *Y* scores and $\bar{x}_X$ was the mean of the *X* scores. With the a and b components calculated, a result from the predictor test (*X*) inserted into the calibration model would give a predicted value for the criterion test (*Y*). Because it is highly unlikely for the CoD to be 100%, calibration models with less than 100% common variance of tests are subject to error.

This error is the standard deviation of the residual scores and is known as the standard error of estimate (s_{YX}). This is calculated with the equation $s_{YX} = \pm s_Y \sqrt{(1 - r_{XY}^2)}$. This gives a range due to error above and below the predicted score, in which the actual score might lie. To be 95% sure of this, s_{YX} is multiplied by ±1.96 to give $\pm s_{YX}$. As calibration models rely on methods of least squares linear regression (parametric analysis) it is of paramount importance that the residual errors derived from the regression are normally distributed (Altman, 1999). Therefore an Anderson-Darling test of normality was performed to confirm that the scores were normally distributed and that parametric analyses could be used on the data.

The final part of the investigation aimed to cross-validate the calibration model. Scores from the MSFT were substituted into the calibration model (developed in stage two) in order to obtain a predicted $\dot{V}O_{2max}$ score. These predicted scores were then compared to actual scores obtained from their laboratory-based $\dot{V}O_{2max}$ test; and tested for their agreement. Like in stage one, the 95% LoA method was applied. A paired *t*-test was performed and the normality of residuals, as well as the heteroscedasticity coefficient were calculated. The results were then summarised in a *Bland-Altman* plot, fully quantifying the 95% LoA. The relationship between predicted and measured $\dot{V}O_{2max}$ was also quantified by a Pearson's correlation coefficient. This type of validity was identified as concurrent criterion validity (Thomas *et al*., 2005).

Chapter Four - Results

All raw data collected and used for statistical analysis during the investigation can be found in Appendix B. Mean and standard deviation values were also calculated for each measured variable used at each stage of the investigation (see Table 1)

Table 1 - Means (± standard deviations) for each variable calculated and used at each stage of this investigation.

		Stage 1 MSFT reliability *n* = 16	Stage 2 Calibration Model *n* = 11	Stage 3 Cross-validation *n* = 5
Age (yrs)		20.8 (1.2)	20.6 (1.4)	21.2 (0.3)
Stature (m)		1.81 (0.08)	1.82 (0.09)	1.79 (0.07)
Mass (kg)		76.6 (13.4)	77.6 (15.1)	74.2 (9.6)
MSFT	Test	67 (21)		
(shuttles)	Retest	68 (19)		
Average of stage 1 MSFTs			67 (22)	70 (18)
$\dot{V}O_{2max}$ (ml kg^{-1} min^{-1})			44.2 (8.5)	44.3 (7.1)
Predicted $\dot{V}O_{2max}$				45.3 (5.7)

4.1 Stage One

In the first stage of the investigation, two MSFTs were completed by each of the sixteen subjects in order to assess its test-retest repeatability (reliability). Results from the initial test and the retest were 67 shuttles (±21 shuttles) and 68 shuttles (±19 shuttles) respectively. A paired *t*-test was then used to assess the null hypothesis (H_0) of no bias between the means of the test and retest MSFT scores (H_0: $\bar{x}_T = \bar{x}_{RT}$). Non-significant bias was evident: $\bar{x}_{diff}$ (SD_{diff}) = -3 (±2) shuttles; $t = -0.66$, $P = 0.517$. An Anderson-Darling normality test found that the residual errors (difference between test and retest scores) were normally distributed ($A^2 = 0.30$, $P = 0.538$). The heteroscedasticity coefficient was sufficiently close to zero ($r = 0.012$, $P = 0.964$), and thus the limits of agreement were expressed as ±1.96 x SD_{diff} (±3 shuttles).

A Pearson's correlation between test and retest MSFT scores showed a strong relationship (r = 0.98; P < 0.05). These results are presented in Figure 1.

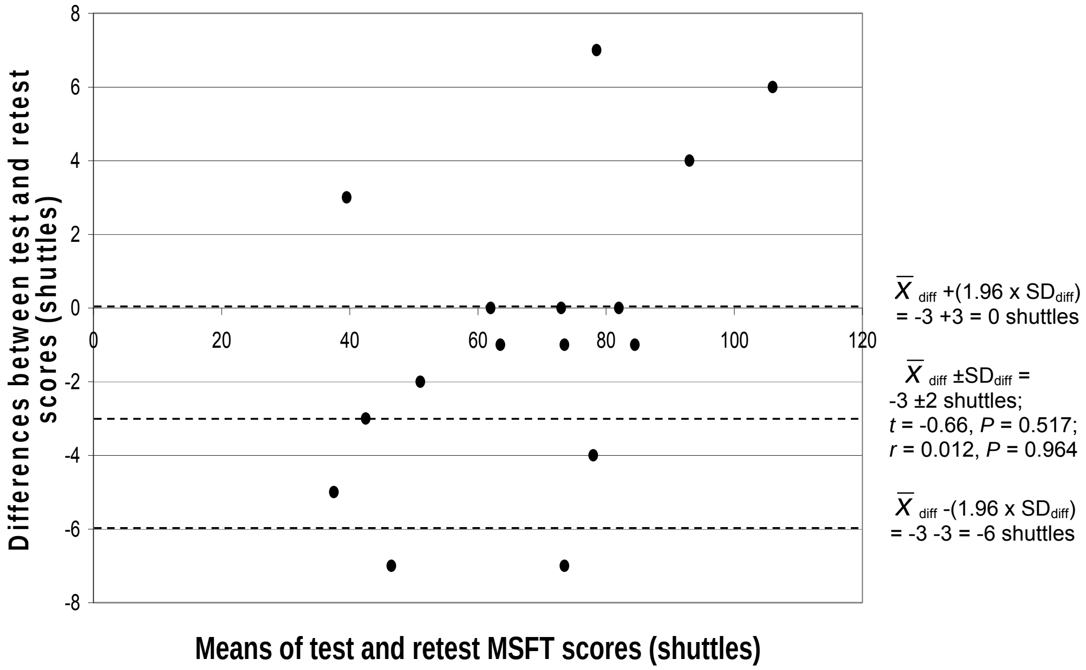

Figure 1 - The reliability of the MSFT was summarised in a Bland-Altman plot. Values for heteroscedasticity and bias are superimposed on the plot.

4.2 Stage Two

Eleven of the sixteen subjects were randomly selected to form a calibration sample. $\dot{V}O_{2max}$ scores determined from the laboratory-based cycle test were then obtained from each subject in the calibration sample. Mean $\dot{V}O_{2max}$ was 44.2 ml kg^{-1} min^{-1} (±8.5 ml kg^{-1} min^{-1}). An average of each subject's two MSFT scores (used in stage one of this investigation) was then calculated and used as their MSFT score in this stage ($\bar{x}$ (SD) = 67 (±22) shuttles).

The null hypothesis of no linear relationship (H_0: $r = 0$), between $\dot{V}O_{2max}$ (ml kg^{-1} min^{-1}) and MSFT (shuttles) scores was tested by obtaining a zero order correlation coefficient. A significant positive correlation was found ($r = 0.835$; $P = 0.001$).

A plot of $\dot{V}O_{2max}$ scores versus MSFT scores confirmed the existence of a linear relationship (seen in figure 3). With a strong linear relationship identified, it was decided that a calibration model could be formed in order to calculate $\dot{V}O_{2max}$ scores in ml kg^{-1} min^{-1} (Y; criterion), from MSFT scores in shuttles (X; predictor). The coefficient of determination (R^2) was calculated at 69.8% (adjusted to 66.4%) and a Venn diagram was drawn to display the common variance (see Figure 2).

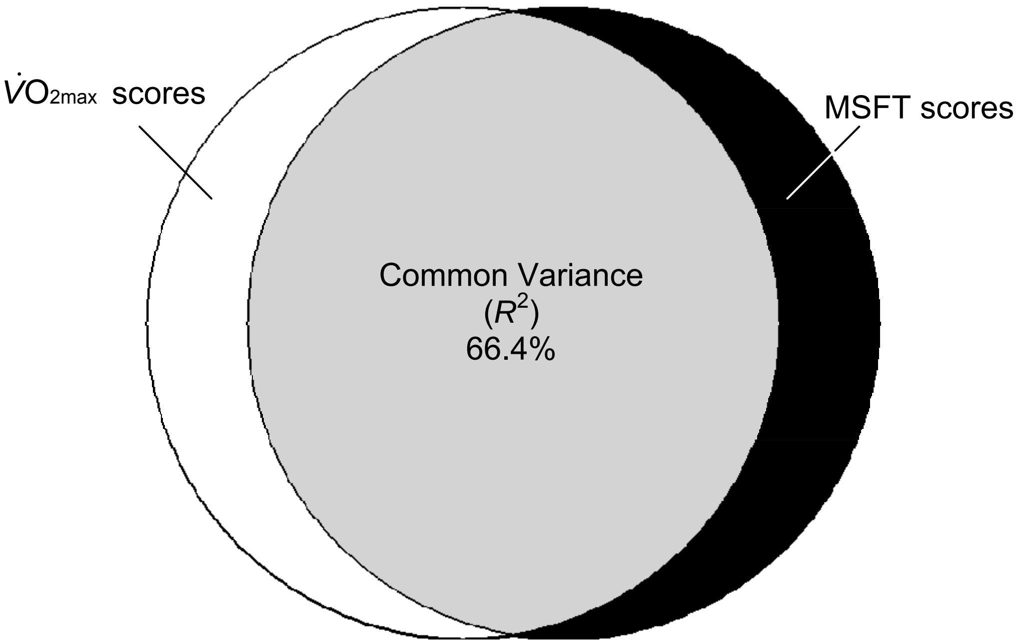

Figure 2 – Common variance (CoD adjusted) between $\dot{V}O_{2max}$ and MSFT scores.

The following equation (calibration model) was then formulated using least squares methods of linear regression in the form $Y = a + bX$: $\dot{V}O_{2max}$ (ml kg^{-1} min^{-1}) = 22.3 + (0.327 x MSFT score (shuttles)). The standard error of estimate was also calculated as: s_{YX} = ±4.9 ml kg^{-1} min^{-1}. These results are presented in Figure 3 and predicted $\dot{V}O_{2max}$ scores for each stage of the MSFT are displayed in Table 2.

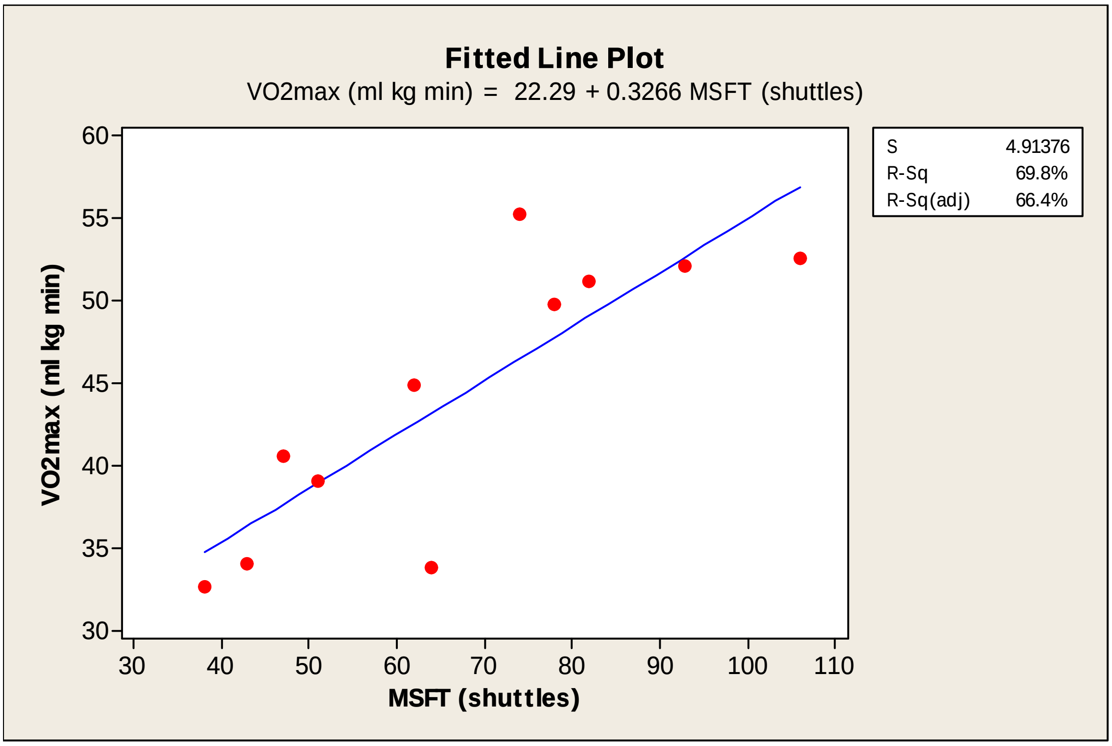

Figure 3 - Fitted line plot representing the calibration model developed in stage two of this investigation.

4.3 Stage Three

The five participants that were not included in the calibration sample were used for the purpose of cross-validation. Average scores (shuttles) of the two MSFTs completed by the subjects in stage one were calculated and used as their MSFT score for stage three ($\bar{x}$ (SD) = 70(±18) shuttles). These scores were then entered into the calibration model developed in stage two and predicted $\dot{V}O_{2max}$ scores (ml kg^{-1} min^{-1}) were calculated. Participants in the cross-validation group also performed a laboratory-based cycle $\dot{V}O_{2max}$ test ($\bar{x}$ (SD) = 44.3(±7.1) ml kg^{-1} min^{-1}. A paired *t*-test provided evidence of no significant bias between predicted and directly measured $\dot{V}O_{2max}$ scores ($\bar{x}_{diff}$ (±SD_{diff}) = -3.7 (±1.8) ml kg^{-1} min^{-1}, t = -0.99, P = 0.38). The residual errors were found to be normally distributed (A^2 = 0.53, P = 0.084) and the heteroscedasticity coefficient was close to zero (r = 0.077, P = 0.902). The bias ± the 95% LoA was therefore calculated as: -3.7 ±3.5 ml kg^{-1} min^{-1}. A Pearson's correlation between predicted and measured $\dot{V}O_{2max}$ scores showed a strong relationship (r = 0.96; P < 0.05). Figure 4 highlights the results of this stage of the investigation.

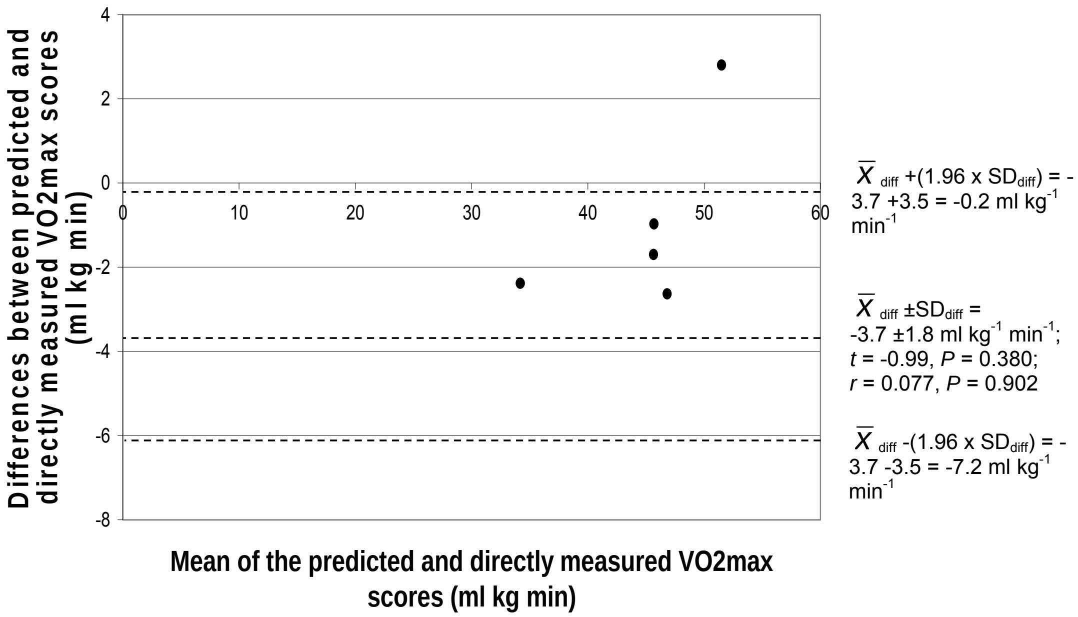

Figure 4 - Bland-Altman plot highlighting the results of the cross-validation stage of this investigation. LoA, bias and heteroscedasticity data have also been superimposed on the plot.

Table 2 - Predicted VO_{2max} (ml kg^{-1} min^{-1}) scores for each stage of the MSFT

Stage	Cumulative Shuttles	Predicted VO_{2max}
1	7	24.6
2	15	27.2
3	23	29.8
4	31	32.4
5	40	35.4
6	49	38.3
7	59	41.6
8	69	44.9
9	79	48.1
10	90	51.7
11	101	55.3
12	113	59.3
13	125	63.2
14	138	67.4
15	151	71.7
16	165	76.3
17	179	80.8
18	194	85.7
19	205	89.3
20	220	94.2

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Appendix A

UWIC
School of Sport

Participant Consent Form

UWIC Ethics Protocol Number:
Participant Name:
Study: The 20m multistage fitness test as a predictor of VO_{2max} in rugby players.
Researcher: Carl Corcoran

Participants to complete the following section by putting their initials in each box.

1. I have been informed of the nature and procedures involved in the testing and understand the requirements of the study. I have had the opportunity to consider the information and ask questions about the tests. Any questions raised have been answered to my satisfaction. ☐
2. I understand that my participation is voluntary and that I am free to withdraw from testing at any point, without need for reason and without compromising any professional relationship or my legal rights. ☐
3. I understand that sections of any research notes and data collected during the study may be reviewed by responsible individuals from UWIC for monitoring purposes, where it is relevant to my taking part in this study. I give permission for these people to have access to my records. ☐
4. Having considered all previous information, I agree to take part in this study. ☐

____________________________ _______________
Signature of Participant Date

____
Name of Person Taking Consent

____________________________ _______________
Signature of person taking consent Date

UWIC
School of Sport

Physical Activity Readiness Questionnaire (PAR-Q)

Please circle appropriate responses to the following questions:

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

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

3. In the past month have you had any chest pain whilst not performing physical activity?
Yes / No

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

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

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

7. Do you know of any other reason why you should not participate in the required physical activity?
Yes / No

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

______________________________ __________________

Signed Date

UWIC RISK ASSESSMENT (RA99) (V3/07)		*Page 1 - (Hazards)*	
School / Unit and Area:		**Assessment Number:**	
Risk Assessment undertaken by: Recommended to be 2 or more people			
Description of the work activity being assessed:			
Persons Affected:	Staff ☐	Students ☐	Others ☐
Details of Others:			

HAZARD IDENTIFICATION Please provide details of the hazards associated with the area or task. **EXAMPLES INCLUDE:** Working at height, Manual Handling, Electricity, Fire, Noise, Contact with moving parts of machinery, Dust etc		**RISK RATING - without Controls** The Risk Rating **(RR)** and Degree of Risk are determined by multiplying the Severity **(S)** of injury by the Likelihood **(L)** of occurrence. Please see UWIC Risk Rating Matrix for details			
		S	**L**	**RR**	**Degree of Risk**
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
Example - 1. Electric Shock (office)		4	3	12	Unacceptable

Once all potential hazards have been identified and a Risk Rating has been applied, please go to page 2 and provide details of the control measures required to reduce the risk to an acceptable level.

UWIC **RISK ASSESSMENT (RA99)** *Page 2 – (Controls)*

CONTROLS TO BE APPLIED Examples Include: Elimination, Substitution for something less hazardous, Barriers or fixed guards, standard operating procedures and personnel protective equipment		Date Applied	RISK RATING - with Controls			
			S	L	RR	Degree of Risk
1						
2						
3						
4						
5						
6						
1.	**Examples of possible controls:** All appliances are to be PAT tested. Any new items are to be reported to estates. Users to undertake visual checks prior to use. Damaged equipment to be removed from use.	07/06/07	4	1	4	**Moderate**

Date of First Assessment:		Review Date of overall Assessment:	

Appendix B

This table gives the age and physical characteristics of each subject, along with test scores and heart rate data

Subject	Age	Par-Q	Informed Consent	Stature	Body Mass	Resting HR	HRmax	Test max HR	% of HRmax achieved
1	21.3	x	x	188.5	112.8	56	199	200	100.7
2	18.4	x	x	192.1	81.9	73	202	202	100.2
3	18.7	x	x	184.7	69.8	80	201	189	93.9
4	18.6	x	x	182.6	73.6	74	201	187	92.9
5	21.5	x	x	189.3	64.5	83	199	201	101.3
6	22.3	x	x	176.5	79.5	67	198	185	93.6
7	21.8	x	x	176.5	65.2	79	198	183	92.3
8	21.0	x	x	181.4	74.2	67	199	196	98.5
9	20.4	x	x	188.0	91.7	56	200	184	92.2
10	21.3	x	x	159.1	58.1	69	199	202	101.7
11	21.1	x	x	181.9	82.7	50	199	194	97.5
12	21.2	x	x	183.8	79.0	62	199	187	94.1
13	21.2	x	x	187.1	84.6	62	199	189	95.1
14	21.7	x	x	179.6	74.4	74	198	200	100.9
15	20.8	x	x	174.2	74.4	72	199	188	94.4
16	21.0	x	x	170.3	58.7	85	199	182	91.5
Mean	**20.8**			**181.0**	**76.6**	**69.3**	**199.2**	**191.8**	**96.3**
St Dev	**1.2**			**8.3**	**13.4**	**10.2**	**1.2**	**7.3**	**3.7**
Calibration - mean	**20.6**			**181.9**	**77.6**				
St Dev	**1.4**			**9.1**	**15.1**				
Cross Validation - mean	**21.2**			**179.0**	**74.2**				
St Dev	**0.3**			**6.9**	**9.6**				

MSFT 1	Shuttles	MSFT 2	Shuttles	Average shuttles	VO2max	Date of VO2max test
6.1	50	6.3	52	51	39.1	12/02/2008
7.3	62	7.3	62	62	44.9	06/02/2008
8.1	70	8.8	77	74	55.3	06/02/2008
5.3	43	6.1	50	47	40.6	06/02/2008
8.6	76	9.1	80	78	49.8	12/02/2008
5.1	41	5.4	44	43	34.1	11/02/2008
4.3	35	5.0	40	38	32.7	11/02/2008
9.3	82	9.3	82	82	51.2	12/02/2008
10.1	95	10.5	91	93	52.1	12/02/2008
7.4	63	7.5	64	64	33.8	05/02/2008
11.8	109	11.2	103	106	52.6	05/02/2008
9.3	82	8.6	75	79	45.5	05/02/2008
9.5	84	9.6	85	85	52.9	05/02/2008
8.3	73	8.4	74	74	44.8	06/02/2008
8.3	73	8.3	73	73	45.2	06/02/2008
5.1	41	4.6	38	40	33.0	11/02/2008
	67.4		**68.1**	**67.8**	**44.2**	
	21.2		**19.1**	**20.1**	**7.8**	

Calibration Group	**Mean**	**66.9**	**44.2**
	St Dev	**21.8**	**8.5**
CV Group	**Mean**	**69.8**	**44.3**
	StDev	**17.6**	**7.1**

Minitab worksheet used in stage one of this investigation

MSFT 1	MSFT 2	Means	Residuals	Absolute Differences
50	52	51	-2	2
62	62	62	0	0
70	77	73.5	-7	7
43	50	46.5	-7	7
76	80	78	-4	4
41	44	42.5	-3	3
35	40	37.5	-5	5
82	82	82	0	0
95	91	93	4	4
63	64	63.5	-1	1
109	103	106	6	6
82	75	78.5	7	7
84	85	84.5	-1	1
73	74	73.5	-1	1
73	73	73	0	0
41	38	39.5	3	3

Minitab worksheet used for stages two and three of the investigation

Calibration group VO_{2max} (ml kg min)	Calibration group MSFT (shuttles)	Cross-Validation VO_{2max} (ml kg min)	Cross-Validation MSFT (shuttles)
39.1	51	45.5	79
44.9	62	52.9	85
55.3	74	44.8	74
40.6	47	45.2	73
49.8	78	33	40
34.1	43		
32.7	38		
51.2	82		
52.1	93		
33.8	64		
52.6	106		

Predicted VO_{2max}	Residuals	Means	Absolute Differences
48.1	-2.6	46.8	2.6
50.1	2.8	51.5	2.8
46.5	-1.7	45.6	1.7
46.2	-1.0	45.7	1.0
35.4	-2.4	34.2	2.4

This table shows the calculated VO_{2max} scores for each subject

along with their body weight and expired gas during each stage of the lab test

		Stage	FEO_2	$FECO_2$	*V*E (L)	Adjusted	VO_{2max} L min^{-1}	VO_{2max} ml kg^{-1} min^{-1}
Subject	13	1	18.2	2.9	36	37	1.01	11.9
Mass	84.6	2	17.2	3.5	42.9	43.9	1.64	19.4
		3	17	4	57.8	58.8	2.31	27.3
		4	17.8	3.2	82.2	83.2	2.60	30.8
		5	17.8	3.5	110	111	3.47	41.1
		6	17.9	3.5	146.8	147.8	4.48	52.9
	12	1	16.2	4.3	17.9	18.9	0.89	11.3
	79	2	16	4.9	28.9	29.9	1.47	18.7
		3	16	5	34.7	35.7	1.76	22.3
		4	16.6	4.5	57.8	58.8	2.55	32.2
		5	17	4.4	91.1	92.1	3.62	45.8
		6	18.1	3.4	126.1	127.1	3.60	45.5
	10	1	18.9	1.8	28	29	0.59	10.1
	58.1	2	18.3	2.5	31.8	32.8	0.86	14.8
		3	18.2	2.6	34.8	35.8	0.98	16.8
		4	18.2	2.7	37.7	38.7	1.06	18.2
		5	17.5	3.6	41.1	42.1	1.44	24.9
		6	17.4	4	54.6	55.6	1.96	33.8

11	1	16.6	4.4	35.4	36.4	1.58	19.1
82.7	2	15.8	4.9	38.8	39.8	2.04	24.7
	3	15.8	5	47.5	48.5	2.49	30.1
	4	16	4.8	56.9	57.9	2.85	34.5
	5	16.4	4.6	71.4	72.4	3.28	39.7
	6	16.5	4.1	85.8	86.8	3.85	46.5
	7	17	4.3	109.6	110.6	4.35	52.6
2	1	17.9	3.7	60.1	61.1	1.85	22.6
81.9	2	18.3	3.4	78.2	79.2	2.08	25.4
	3	17.6	3.8	68.6	69.6	2.32	28.3
	4	17.9	3.7	104.6	105.6	3.20	39.1
	5	18.3	3.3	138.9	139.9	3.68	44.9
3	1	17.5	3.8	39.1	40.1	1.38	20.0
68.8	2	17.1	4.2	42.1	43.1	1.65	24.0
	3	16.7	4.5	49.7	50.7	2.14	31.2
	4	17	4.3	69.2	70.2	2.76	40.1
	5	17.3	4.2	91.3	92.3	3.35	48.7
	6	17.7	3.8	116.8	117.8	3.80	55.3
4	1	17.6	3.4	36.9	37.9	1.26	17.1
73.6	2	17.3	3.8	45.1	46.1	1.67	22.7
	3	17.3	4	60.1	61.1	2.22	30.1
	4	17.7	3.6	78.9	79.9	2.58	35.1
	5	17.9	3.6	97.6	98.6	2.99	40.6
15	1	16.3	5.2	31.9	32.9	1.52	20.5
74.4	2	17.4	4.2	51.2	52.2	1.84	24.8
	3	17.6	3.9	59.2	60.2	2.00	26.9
	4	17.5	4	83.4	84.4	2.89	38.9
	5	17.8	3.8	106.4	107.4	3.36	45.2

14	1	17.4	3.6	42.3	43.3	1.53	20.5
74.4	2	16.9	4.1	47.4	48.4	1.95	26.2
	3	16.5	4.4	52	53	2.35	31.6
	4	17.1	4.1	68.3	69.3	2.65	35.7
	5	17.1	4.2	85.6	86.6	3.32	44.6
	6	17.3	4.3	90.9	91.9	3.34	44.8
16	1	17.8	3.5	29.5	30.5	0.95	16.3
58.7	2	18	3.4	39.4	40.4	1.18	20.2
	3	17.9	3.6	52.7	53.7	1.63	27.7
	4	17.9	3.5	62.9	63.9	1.94	33.0
6	1	16.4	4.1	21.3	22.3	1.01	12.7
79.5	2	16.2	4.4	27.8	28.8	1.36	17.1
	3	16.4	4.5	36.5	37.5	1.70	21.4
	4	16.8	4.3	48.4	49.4	2.04	25.7
	5	17	4.2	59.1	60.1	2.36	29.7
	6	17.6	3.8	80.5	81.5	2.71	34.1
7	1	17	4	22.7	23.7	0.93	14.3
65.2	2	17.3	4	34.6	35.6	1.29	19.8
	3	17.4	4	44.7	45.7	1.61	24.7
	4	17.5	3.9	61.2	62.2	2.13	32.7
9	1	17.2	3.9	38.7	39.7	1.48	16.1
91.7	2	16.9	4.1	46	47	1.89	20.7
	3	16.7	4.3	53.3	54.3	2.30	25.0
	4	16.7	4.3	62.5	63.5	2.69	29.3
	5	16.4	4.5	69.5	70.5	3.19	34.8
	6	17	4.2	91.9	92.9	3.65	39.8
	7	17.1	4	106.1	107.1	4.10	44.7

	8	17.4	3.9	134.3	135.3	4.78	52.1
8	1	16.3	4.4	28.8	29.8	1.38	18.6
74.2	2	16	4.8	35.3	36.3	1.79	24.1
	3	16.3	4.7	49.5	50.5	2.34	31.5
	4	16.8	4.4	63.7	64.7	2.67	36.0
	5	17.1	4.3	80.9	81.9	3.14	42.3
	6	17.8	3.7	120.3	121.3	3.80	51.2
5	1	17	4.1	41.1	42.1	1.65	25.7
64.5	2	17.5	4	59.3	60.3	2.07	32.1
	3	17.3	4.1	70.4	71.4	2.59	40.2
	4	17.8	3.7	101.7	102.7	3.21	49.8
1	1	17.7	3.8	61.9	62.9	2.03	18.0
112.8	2	17.4	4	60.3	61.3	2.16	19.2
	3	17.5	4	73.3	74.3	2.55	22.6
	4	17.4	3.9	89.3	90.3	3.19	28.3
	5	17.6	3.8	124.5	125.5	4.18	37.0
	6	18.3	3.2	166.9	167.9	4.42	39.1