Validity and reliability of a modified version of the Chester Treadmill Walking Test (Police) as an alternative to the 15-Metre Multi-Stage Police Fitness Test.

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

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Declaration

I declare that the following assignment is my own work, in which I have correctly acknowledged the work of others.

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Abbreviations

%HRmax – Percentage of predicted heart rate maximum

ATP – Adenosine triphosphate

CO_2 – Carbon dioxide

CTWT – Chester Treadmill Walking Test

CV – Cardiovascular

CVD – Cardiovascular disease

HR – Heart rate

LoA – Limits of agreement

MSFT – Multi-stage Fitness Test

O_2 – Oxygen

OST – Officer Safety Training

RPE – Rating of perceived exertion

SEE – Standard error of estimate

SEM – Standard error of measurement

$\dot{V}CO_2$ – Carbon dioxide production

$\dot{V}O_2$ – Oxygen consumption

$\dot{V}O_2max$ – Maximal oxygen consumption

Tables

Abstract

Police forces in England and Wales require new recruits and serving officers to pass an annual fitness test, reaching level 5:4 on the 15-metre MSFT, a predicted $\dot{V}O_2max$ of 35 mL · min^{-1} · kg^{-1}. This current standard is based on linear regression analysis from directly measured $\dot{V}O_2max$ during a treadmill protocol and number of shuttles achieved during the 15-metre MSFT. The oxygen cost at level 5:4 has not been attained during the 15-metre MSFT, and the reliability of this test has not be investigated, therefore, the present study aims to investigate whether level 5:4 requires an O_2 cost of 35 mL · min^{-1} · kg^{-1}, and whether this is a repeatable measure. Due to police officers unable to complete the 15-metre MSFT due to musculoskeletal impairments, the CTWT, used within the fire service, has been proposed as an alternative occupational fitness test. A modified version of the CTWT (Police) requires a constant treadmill speed of 6 km·h^{-1} with 3% increments in treadmill gradient every 2 minutes up until 10 minutes (12% gradient), when predicted $\dot{V}O_2$ of 35 mL · min^{-1} · kg^{-1} will have been achieved. The validity and reliability of this test has not been examined using direct measurement of $\dot{V}O_2$, therefore, prior to potential inclusion as an alternative fitness test, the validity and reliability of the test require investigation to determine whether 10 minutes is a valid and reliable measure of 35 mL · min^{-1} · kg^{-1}, demonstrating that successful completion requires a $\dot{V}O_2max$ of at least 35 mL · min^{-1} · kg^{-1}.

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1. Literature review

1.1 Occupational health/fitness

Occupational health is concerned with the physical, social and mental well being of workers across various occupations. It is important workers are protected from risks in the workplace and a decline in health is prevented. Occupational health guidelines and standards are in place to ensure workers are physiologically and psychologically capable of performing tasks within their working environment, without causing risk to themselves or others (Serra et al, 2006).

A police officer is expected to successfully respond to various incidents in an effective manner, ensuring public safety. An inability to physically perform such duties may endanger public safety, cause injury or disability and decrease employee productivity (Anderson, Plecas, Segger, 2001). The role of a police officer consists of a large proportion of sedentary work or low-intensity tasks/activities for prolonged periods of time; however, certain tasks (e.g. foot pursuit, resisted arrest) may be physically strenuous, requiring adequate fitness levels (Bonneau & Brown, 1995; Strating, Bakker, Dijkstra, Lemmink, Groothoff, 2010).

Police forces in Canada and the Netherlands utilise occupational fitness tests which aim to replicate specific physical tasks performed during duty in the form of a circuit of exercises, which must be completed within a set period of time (Trottier & Brown, 1994; Strating et al, 2010). Content valid tests based on simulations of the physical tasks of police work do not hold a clear relationship to general health and physical fitness. Occupational fitness testing requires validity and reliability, it must be economical to administer and must impact equally on the entire demographic of the workforce (Trottier & Brown, 1994; Shephard & Bonneau, 2002).

When determining aerobic fitness, a direct measurement of $\dot{V}O_2$ is the gold standard method, however, due to financial expense and length of time required, field tests are more widely used within occupational fitness testing (Aandstad, Holme, Bernsten, Anderssen, 2011).

The UK police force require new recruits and serving police officers to pass an annual fitness test, the 15-metre MSFT, as of September 2013 following the acceptance of a recommendation by the Police Advisory Board for England and Wales (College of Policing, 2014).

Four shuttles on level five (5:4) of the 15-metre MSFT is required, a predicted $\dot{V}O_2max$ of 35 mL · min^{-1} · kg^{-1}, based on research by Brewer, Buckle, Castle (2013) comparing the aerobic demands of the 15-metre MSFT with OST (College of Policing, 2014).

Brewer et al (2013) compared HR responses of 119 police officers (75 male, 44 female; mean age, 31.7 years ± 5.3, range 19 – 56 years) during the 15-metre MSFT and OST, a four hour course involving simulated physical activities (handcuffing, restraint, carrying and lifting weighted objects), to establish whether the physical demands closely resemble one another.

Police officers completed four shuttles on level five of the 15-metre MSFT, followed by a ten to fifteen minute recovery period before OST commenced. Independent samples t-tests were used to compare mean peak HR and four minute mean HR data between OST and the 15-metre MSFT, with a significantly higher peak HR found during the 15-metre MSFT (175 ± 13 bpm) compared with OST (152 ± 12 bpm), and also a significantly higher four minute mean HR (MSFT, 158 ± 11 bpm; OST, 126 ± 10 bpm) during the 15-metre MSFT. (Brewer et al, 2013).

Brewer et al (2013) concluded HR responses during OST did not exceed HR levels attained during the 15-metre MSFT, suggesting completion of four shuttles at level five is an adequate standard measurement of the physiological demands of occupational police duties, and lowering this standard may result in a cardiorespiratory fitness level below that of the normal population.

HR data reported by Brewer et al (2013) has been used as a surrogate indicator of $\dot{V}O_2$, based on a linear relationship between exercise intensity, HR and $\dot{V}O_2$, with no direct measurement of $\dot{V}O_2$. There are limitations with the measurement of HR in predicting $\dot{V}O_2$; hydration levels, ambient temperature, caffeine intake and emotional stress are factors that may affect HR during exercise, with the mode of exercise during OST including isometric contractions (e.g. physical restraint of individuals), which may produce a different CV response to dynamic exercise (Crouter, Albright, Bassett, 2004).

Recovery period between the 15-metre MSFT and OST within the study by Brewer et al (2013) was ten to fifteen minutes. Post exercise $\dot{V}O_2$ remains elevated to restore metabolic processes (lactate, body temperature, catecholamines) to pre-exercise levels, with Tomlin and Wenger (2001) suggesting this process of recovery can take up to several hours, therefore, $\dot{V}O_2$ and HR levels may have been elevated above pre-exercise levels as OST commenced.

Brewer et al (2013) recruited a small sub-group of participants in attempt to validate the HR data, directly measuring $\dot{V}O_2$ during the 15-metre MSFT and OST using the Oxycon Pro analyser. A peak $\dot{V}O_2$ of 36.1 $mL \cdot min^{-1} \cdot kg^{-1}$ was recorded during the 15-metre MSFT and 30.1 $mL \cdot min^{-1} \cdot kg^{-1}$ during OST (batton drill).

A study at Loughborough University of Technology (Hazeldine, Lakomy, Simpson, 1995) designed a modified version of the 20-metre MSFT, over a 15 metre distance, attempting to provide a standard for aerobic fitness among police officers that may be equal to a population they pursue during a foot chase. The standard was set at level 8:1, a predicted $\dot{V}O_2max$ of 42.5 mL · min^{-1} · kg^{-1}, matching the average $\dot{V}O_2max$ of the general population aged between 12 and 54 years. This standard has since changed.

A predicted $\dot{V}O_2$ of 35 mL · min^{-1} · kg^{-1}, upon completion of four shuttles at level five on the 15-metre MSFT, suggested by Brewer et al (2013) is believed to derive from (Roehampton University, 2003 unpublished study) a study aiming to validate the 15-metre MSFT used within the Prison Service. Forty participants (age, 36.28 ± 9.74 years, 19 female) completed a maximal treadmill test and the 15-metre MSFT, three days apart, plotting the correlation between directly measured $\dot{V}O_2$ and number of shuttles completed (MSFT) with linear regression analysis used to correct prison service fitness standards.

The study reported the current standards overestimate $\dot{V}O_2$, and therefore suggested lower standards, with the criterion $\dot{V}O_2max$ of 34.7 mL · min^{-1} · kg^{-1} corrected to the standard of four shuttles on level five of the 15-metre MSFT (Roehampton University, 2003 unpublished study). In relation to the present study, the findings from Roehampton University (2003 unpublished study) permitted Brewer et al (2013) to state a Police officer achieving level 5:4 must have a $\dot{V}O_2max$ of at least 35 mL · min^{-1} · kg^{-1}, and present a table of values for $\dot{V}O_2max$ scores for various police ranks up to level 10:5 on the 15-metre MSFT.

These $\dot{V}O_2max$ scores for different police ranks were acquired some time ago; therefore, future research may be required to investigate the metabolic demands of the different ranks within the police forces in England and Wales via direct measurement of $\dot{V}O_2$, to determine current aerobic demands of police duties and corresponding $\dot{V}O_2max$ scores.

1.1.1 Summary

To our knowledge, the 15-metre MSFT has not been examined using direct measurement of $\dot{V}O_2$, therefore the aim of the current study is to investigate the O_2 cost upon completing four shuttles at level five. The reliability of the 15-metre MSFT has also not been examined; therefore the present study aims to determine whether four shuttles at level five produces a repeatable measure of the O_2 cost.

1.2 Cardiovascular health and cardiorespiratory fitness

The cardiovascular system transports O_2 to systemic tissue, where ATP is produced within the mitochondria. $\dot{V}O_2$ determines an individual's energy expenditure, expressed in relative terms ($mL \cdot min^{-1} \cdot kg^{-1}$), accounting for variation in body weight (kg), or absolute terms (L/min) (McArdle, Katch, Katch, 2007).

Aerobic exercise training increases the ability to extract more oxygen from the blood, increasing arteriovenous oxygen ($(a-\bar{v})O_2$ diff) difference, therefore, individuals participating in regular physical exercise typically have greater $\dot{V}O_2max$ levels compared with their untrained counterparts (McArdle et al, 2007).

US normative data from the National Health and Nutrition Examination Surveys suggest an estimated mean $\dot{V}O_2max$ of 42 mL · min^{-1} · kg^{-1} for males, and 35 mL · min^{-1} · kg^{-1} for females aged twenty to forty nine years (Lee et al, 2010). Decreased muscle mass, haemoglobin and stroke volumes attribute to these lower levels compared with males (Lee et al, 2010). Levels of physical activity, a behaviour associated with cardiorespiratory fitness, are consistently lower amongst females reflecting the prevalence of lower cardiorespiratory fitness levels (Carnethon et al, 2005).

A substantial evidence base suggests CVD and CV events are lower in physically active individuals (Talbot et al, 2002; Lee et al, 1999). Many studies have shown cardiorespiratory fitness is a strong independent predictor of CVD mortality, with physical inactivity attributing to 12.2% of all global myocardial infarctions (Carnethon et al, 2005). A prospective study by Blair et al (1995) reported a 52% lower age-adjusted CVD mortality risk (RR, 0.48; 95% CI, 0.31 to 0.74) in males increasing cardiorespiratory fitness from a categorised unfit state (20-39 years, <35 mL · min^{-1} · kg^{-1}; 40-49 years, <32.2 mL · min^{-1} · kg^{-1}; 50-59 years, <29.4 mL · min^{-1} · kg^{-1}; 60+ years, <24.5 mL · min^{-1} · kg^{-1}) to above these levels, compared with males remaining below.

Lee et al (2011) examined the association between change in cardiorespiratory fitness and CVD mortality in males from the Aerobics Centre Longitudinal Study, reporting a 28% and 44% lower risk of CVD mortality in those who maintained cardiorespiratory fitness, and those improving their cardiorespiratory fitness (6.3 year mean interval between physical examinations). A 19% lower risk of CVD mortality was associated with each one MET (3.5 mL · min^{-1} · kg^{-1}) improvement in cardiorespiratory fitness (Lee et al, 2011).

Other studies using similar categorical levels to distinguish cardiorespiratory fitness reported an increased prevalence of cardiovascular risk factors amongst those in the low fitness category (Erez et al, 2015), with Carnethon et al (2005) reporting higher systolic blood pressure in adults with the lowest fitness and a two to four times greater likelihood of obesity than those in moderate or high fitness categories. The cumulative probability, through six years, of a CV event decreased from the low fitness group (4.8%) to moderate (4.2%), and again to the high fitness group (3.4%), with a 30% increased risk of adverse CV outcomes in the low fitness group (Erez et al, 2015).

1.3 Multi-Stage Fitness Test

The MSFT holds practical advantages over other prolonged distance fitness tests; firstly, the MSFT is very quick to administer, requires minimal equipment, is cost efficient and multiple police officers may be tested at once within constant and controlled environmental conditions (Leger & Lambert, 1982). The 15-metre MSFT involves running at an initial speed of 2.2 m·s^{-1} between two visible markers, 15 metres apart, in time with the bleep from a pre-recorded audio CD. Running speed increases to 2.7 m·s^{-1} at level five for the remaining four shuttles, with a total time of 3 minutes 35 seconds to reach level 5:4, covering a total 525 metres. The 15-metre MSFT determines running speed eliminating difficulty with pacing, and requires less space than the more common 20-metre version as police forces have insufficient indoor venues able to accommodate the 20-metre distance (McClain, Welk, Ihmels, Schaben, 2006).

The 20-metre version of the MSFT, developed by Leger & Lambert (1982), has been widely used in the measurement of aerobic fitness in different populations, with various studies examining the validity of the 20-metre MSFT. The 20-metre MSFT begins at a speed of 8.5 $km \cdot h^{-1}$ increasing by 0.5 $km \cdot h^{-1}$ every minute, with a longer duration between levels and increments in speed compared with the 15-metre protocol (Leger, Mercier, Gadoury, Lambert, 1988).

Validity may be separated into relevancy and reliability, two related dimensions of validity (Safrit & Wood, 1989). Relevancy is the ability of the measurement tool and test scores to accurately measure what it has intended to measure and reliability the consistency of repeat measures, or freedom from measurement error. A measurement tool must demonstrate both relevancy and reliability to exhibit validity (Atkinson & Nevill, 1998).

Systematic bias and random error are the two components of variability associated with a measurement error. Total error is the sum of systematic bias and random error. A measurement trend that shows either a positive or negative direction between repeated measures is indicative of systematic bias. Learning effect is an example of systematic bias, where an evident trend of higher scores during re-testing is found. Random error includes errors or inconsistencies within the protocol, and mechanical or biological variances (Atkinson & Nevill, 1998).

Ramsbottom, Brewer & Williams (1988) examined the validity of the 20-metre MSFT in predicting $\dot{V}O_2max$, using a Pearson product-moment correlation coefficient to investigate the relationship between directly measured $\dot{V}O_2max$, during a continuous treadmill protocol, and final level achieved during the 20-metre MSFT ($r = 0.92$, SEE = 3.5 $mL \cdot min^{-1} \cdot kg^{-1}$). Final running speed upon completion of the 20-metre MSFT was used in a regression equation, provided by Leger and Lambert (1982), to predict $\dot{V}O_2max$.

Liu, Plowman & Looney (1992) also used a correlation coefficient to determine the relationship between number of shuttles completed during the 20-metre MSFT and directly measured $\dot{V}O_2max$ during a maximal treadmill test (r = 0.72). Predicted $\dot{V}O_2max$, accounting for age and maximal speed, was calculated using an equation developed by Leger et al (1988) with standard error of estimate (SEE) and a paired t-test used to determine a measurement error of 5.27 $mL \cdot min^{-1} \cdot kg^{-1}$ and no significant differences ($p > .11$) between mean values of predicted $\dot{V}O_2max$ (48.72 ± 5.72 $mL \cdot min^{-1} \cdot kg^{-1}$) and directly measured $\dot{V}O_2max$ (49.97 ± 7.59 $mL \cdot min^{-1} \cdot kg^{-1}$).

Liu et al (1992) found a good level of agreement between predicted and directly measured $\dot{V}O_2max$ with a large proportion of directly measured $\dot{V}O_2max$ values falling within 5.9 $mL \cdot min^{-1} \cdot kg^{-1}$ of the predicted values, concluding the regression equation provides a valid predictor, with an acceptable level of error, among 12 – 15 year olds.

Paradisis et al (2014) investigated the validity of the 20-metre MSFT among forty eight PE college students (male – 25, female – 23, 21.20 ± 1.91 years), comparing with directly measured $\dot{V}O_2$ during a maximal treadmill exercise test. Statistical analysis using a paired t-test and Pearson correlation coefficient show no significant differences between predicted $\dot{V}O_2max$ (49.97 ± 7.17 $mL \cdot min^{-1} \cdot kg^{-1}$) from the 20-metre MSFT and directly measured $\dot{V}O_2max$ (49.98 ± 8.33 $mL \cdot min^{-1} \cdot kg^{-1}$) and a significant correlation between number of completed shuttles during the MSFT and $\dot{V}O_2$max (r = 0.87).

The sole use of correlation coefficients in determining validity and reliability is not recommended (Aandstad et al, 2011) as correlation analysis indicates the relationship between measures, not agreement or the differences between measurement scores, and heterogeneity of the sample may influence the correlation (Atkinson & Nevill, 1998).

A paired t-test compares mean differences and identifies statistically significant bias between repeat tests. The use of a paired t-test on its own is not recommended as random variation is not detected from this statistical method (Atkinson & Nevill, 1998). Repeated measures ANOVA, comparing more than one re-test, with appropriate post hoc comparisons may be used to detect systematic bias between tests, however, like the paired t-test random error affects systematic error which this statistical test is unable to detect (Atkinson & Nevill, 1998).

Cooper et al (2005) notes the reliance upon correlation coefficients, paired t-tests or repeated measures ANOVA in determining reliability and validity in previous studies (Leger & Lambert, 1982; Ramsbottom et al, 1988), with Atkinson & Nevill (1998) suggesting the ±95% LoA as a more favourable method, introduced by Bland & Altman (1986).

More recent studies, adopting different statistical methods have also examined the validity and reliability of the 20-metre MSFT. Cooper et al (2005) recruited thirty male sports students (21.8 ± 3.6 years), with twenty one completing the MSFT on two separate occasions, with seven to fourteen days between tests, examining reliability. All thirty completed both the MSFT and an incremental $\dot{V}O_2$max treadmill test, with validity being examined by quantifying agreement between predicted $\dot{V}O_2max$ (MSFT) and directly measured $\dot{V}O_2max$ during the treadmill test, by way of Douglas bag collection.

The ±95% LoA technique was used to assess validity and reliability. 95% LoA is an indicator of absolute reliability, holding the assumption that individual test/re-test differences exist within a population (Atkinson & Nevill, 1998). Providing test/re-test differences (residual errors) are normally distributed and heteroscedasticity (increase in random error with increase in measured values) correlation is close to zero then ±95% LoA analysis may proceed (Cooper et al, 2005; Atkinson & Nevill, 1998).

A dependent t-test found no significant bias between test (52.9 ± 8.8 $mL \cdot min^{-1} \cdot kg^{-1}$) and re-test (53.3 ± 8.9 $mL \cdot min^{-1} \cdot kg^{-1}$) means, differences were normally distributed and the bias was – 0.4 ± 2.7 $mL \cdot min^{-1} \cdot kg^{-1}$ (Cooper et al, 2005).

The validity trial reported normal distribution of residual errors, statistically significant mean bias (1.8 $mL \cdot min^{-1} \cdot kg^{-1}$, p = .004) and ± 6.3 $mL \cdot min^{-1} \cdot kg^{-1}$ ±95% LoA, between predicted $\dot{V}O_2max$ (55.7 ± 5.0 $mL \cdot min^{-1} \cdot kg^{-1}$) from the MSFT and directly determined (57.5 ± 4.5 $mL \cdot min^{-1} \cdot kg^{-1}$) $\dot{V}O_2max$ (Cooper et al, 2005).

Atkinson & Nevill (1998) suggest correct interpretation of ±95% LoA involves stating the differences between two tests (test and re-test), from an individual within the population study, should (95% probability) lie within the limits of agreement.

Aandstad et al (2011) examined the validity and reliability of the 20-metre MSFT in military personnel using ±95% LoA, Pearson correlation coefficient and intraclass correlation coefficient. Male soldiers (n = 38, 34.8 ± 4.0 years, 86.1 ± 12.1 kg) performed the 20-metre MSFT on two separate occasions and an incremental treadmill $\dot{V}O_2max$ test, with direct $\dot{V}O_2$ measurement.

Reliability statistics show a mean difference of – 0.8 ± 3.1 mL · min^{-1} · kg^{-1} between test (49.8 ± 5.0 mL · min^{-1} · kg^{-1}) and re-test (50.6 ± 4.7 mL · min^{-1} · kg^{-1}) predicted $\dot{V}O_2max$ (r = 0.95), similar findings to that of Cooper et al (2005), and a mean difference of 0 ± 7.2 mL · min^{-1} · kg^{-1} between directly measured $\dot{V}O_2max$ (49.6 ± 6.3 mL · min^{-1} · kg^{-1}) and the first 20-metre MSFT run (r = 0.82) (Aandstad et al, 2011). Lamb & Rogers (2007) investigated the reliability of the 20-metre MSFT among thirty five university students (male – 22, 20.9 ± 1.5 years; female – 13, 19.6 ± 1.0 years), with all participants completing three separate trials, one week apart, with $\dot{V}O_2max$ predicted from the equation by Leger et al (1988). Two way repeated measures ANOVA reported significantly higher predicted $\dot{V}O_2max$ from trial two (53.3 ± 8.4 mL · min^{-1} · kg^{-1}) (p = 0.001) and three (52.9 ± 7.6 mL · min^{-1} · kg^{-1}) (p = 0.01), compared with the first trial (52.1 ± 7.8 mL · min^{-1} · kg^{-1}), and ±95% LoA show random error across trials does not vary markedly, -1.1 ± 4.7 mL · min^{-1} · kg^{-1} between trial 1 and 2 (r = 0.96), 0.0 ± 5.0 mL · min^{-1} · kg^{-1} trial 2 to 3 (r = 0.95), and -1.1 ± 5.4 mL · min^{-1} · kg^{-1} trial 1 and 3 (r = 0.94).

Ruiz et al (2009) examined the validity of the 20-metre MSFT, with direct measurement of $\dot{V}O_2$ among youths (n = 48, 26 female, 14.6 ± 1.5 years) running to maximal exhaustion, comparing with predictive $\dot{V}O_2max$ equations derived from studies among youths.

All equations corresponding means (41.5 ± 5.2 mL · min^{-1} · kg^{-1}), except one, significantly underestimated directly measured $\dot{V}O_2max$ (47.1 ± 8.1 mL · min^{-1} · kg^{-1})

($p = 0.001$). Percentage error ranged from 21.24% (Ruiz et al, 2009) to 38.34% (Leger et al, 1988).

Atkinson & Nevill (1998) note that many tables providing predictive $\dot{V}O_2max$ values from directly measured field tests, in order to provide indirect measures may lack validity. The commonly used $\dot{V}O_2max$ table designed by Ramsbottom et al (1988) providing indirect $\dot{V}O_2max$ values from maximum level and shuttle attained derives from linear regression analysis from Ramsbottom et al (1988) data, in which validity was investigated using correlation coefficients and not limits of agreement analysis (Cooper et al, 2005).

1.3.1 Summary

Studies have reported predicted $\dot{V}O_2max$ from the 20-metre MSFT to be a valid predictor of directly determined $\dot{V}O_2max$ in both adults (Ramsbottom et al, 1988; Paradisis et al, 2014) and children (Liu et al, 1992) when using a paired t-test to identify mean differences or correlation coefficients to determine relationship.

Aandstad et al (2011), Cooper et al (2005), Lamb & Rogers (2007) and Ruiz et al (2009) suggest the 20-metre MSFT is neither a valid or reliable predictor of $\dot{V}O_2max$, following different statistical approaches and identifying the measure of agreement between tests. Running economy, test conditions, protocol, biological and technical variations may explain variance in energy expenditure and the inability of the different $\dot{V}O_2max$ predictive equations (Ruiz et al, 2009).

1.4 Shuttle vs. continuous running

The biomechanical differences in running mode between shuttle running, which involves accelerating, decelerating and constant turning, and continuous forward locomotion may explain differences in energy expenditure and $\dot{V}O_2max$ (Aandstad et al, 2011).

The energy cost of shuttle running over ten and twenty metre distances were directly determined by Buglione & Di Prampero (2013) and compared with level treadmill running at constant speed (6 minutes at 10 kph). Two indirect approaches were utilised in the estimation of corresponding energy cost; firstly, from peak velocity estimating energy expenditure due to kinetic energy, and adding to the energy cost of running at constant speed, and secondly, estimating the energy cost of accelerated running by using directly measured energy cost of accelerating forward and an estimation of an equivalent corresponding gradient.

Energy cost was greater over a ten metre distance compared with twenty metres at 2.86 $m \cdot s^{-1}$ (10m – 6.88 ± 0.19 $J \cdot m^{-1} \cdot kg^{-1}$, 20m - 5.32 ± 0.13 $J \cdot m^{-1} \cdot kg^{-1}$), with an energy cost of 4.39 ± 0.43 $J \cdot m^{-1} \cdot kg^{-1}$ for continuous running at 2.77 $m \cdot s^{-1}$. Energy cost increased markedly as speed increased, to a greater extent in shorter distances. At 4.00 $m \cdot s^{-1}$ energy cost increased to 7.52 ± 0.26 $J \cdot m^{-1} \cdot kg^{-1}$ over a twenty metre distance and 14.29 ± 0.75 $J \cdot m^{-1} \cdot kg^{-1}$ over a ten metre distance (Buglione & Di Prampero, 2013).

The two indirect approaches for the estimation of shuttle running energy cost provided similar, statistically non significant differences, estimations to one another, and compared with direct measurement yielded similar results, however, at the speed of 4.00 $m \cdot s^{-1}$ mentioned above, both indirect methods underestimate energy cost (9.52 $J \cdot m^{-1} \cdot kg^{-1}$ and 8.98 $J \cdot m^{-1} \cdot kg^{-1}$) compared with direct measurement (14.29 ± 0.75 $J \cdot m^{-1} \cdot kg^{-1}$) over a ten metre distance (Buglione & Di Prampero, 2013).

Zamparo, Zadro, Lazzer, Beato, Sepulcri (2014) also reported significantly increased energy cost during shuttle running compared with continuous forward running. At an average speed of 4.51 $m \cdot s^{-1}$ the energy cost of shuttle running over a ten metre distance ($\dot{V}O_2$ - 33.9 ± 0.6 $mL \cdot min^{-1} \cdot kg^{-1}$, energy cost - 22.1 ± 0.9 $J \cdot m^{-1} \cdot kg^{-1}$) was significantly higher than continuous forward running (energy cost - 3.97 ± 0.34 $J \cdot m^{-1} \cdot kg^{-1}$), although speed was set at 2.77 $m \cdot s^{-1}$ for continuous forward running. Energy cost decreased as shuttle distance increases (25m: speed - 5.12 ± 0.23 $m \cdot s^{-1}$, $\dot{V}O_2$ - 34.9 ± 4.4 $mL \cdot min^{-1} \cdot kg^{-1}$, energy cost - 10.6 ± 1.2 $J \cdot m^{-1} \cdot kg^{-1}$).

Ramsbottom et al (1988) reported a curvilinear HR response during stages of the 20-metre MSFT, suggesting steady-state conditions were not attained during the one-minute stages. Upon commencing exercise HR, stroke volume, cardiac output, systolic blood pressure and rate pressure product increase to meet metabolic demands of exercise (Porcari, Bryant, Comana, 2015). These variables plateau once energy required and energy expenditure are balanced, indicating steady state exercise has been reached. $\dot{V}O_2$ reaches a plateau between one to four minutes, a time influenced by training state, and extent to intensity increment. Prior to reaching steady state, $\dot{V}O_2$ is lower than the required levels needed in order to produce required energy aerobically, termed oxygen deficit, therefore anaerobic energy systems provide energy to reduce the deficit (Porcari et al, 2015).

1.5 Cardiorespiratory analysis methods

Portable online cardio respiratory systems/analysers may influence results when compared with the “gold standard” Douglas Bag method (Aandstad et al, 2011).

The MetaMax 3B, a portable cardiopulmonary exercise system, measures direct pulmonary gas exchange including the O_2 and CO_2 concentration of inspired/expired air. Macfarlane and Wong (2012) examined the reliability and validity of the MetaMax 3B, with a known CO_2 gas supply attached to a Gas Exchange System Validator (GESV); varying respiratory rates were programmed by the GESV, while connected to the MetaMax 3B turbine measuring minute ventilation (VE), $\dot{V}O_2$ and $\dot{V}CO_2$. To allow for the testing of reliability each trial was repeated twice.

In order to validate the MetaMax 3B, measurements were compared with a Douglas bag method of collection, the primary criterion, and Oxycon Pro system, secondary criterion, whereby expired air was collected sequentially at various workloads on a cycle ergometer (MacFarlane & Wong, 2012).

The reliability trials reported intra-device measurement errors of 0.2% (VE), 1.4% ($\dot{V}O_2$) and 1.1% ($\dot{V}CO_2$) across all respiratory rates, showing measurement errors below the Australian Sports Commission’s recommended reliability limit of 3%. The validity trials found the MetaMax 3B significantly overestimated $\dot{V}O_2$ and $\dot{V}CO_2$ (10-17%) in comparison to the Douglas bag method, however, contrasting studies have reported underestimation of $\dot{V}O_2$ (Brehm et al, 2004; Laurent et al, 2008).

MacFarlane and Wong (2012) concluded the MetaMax 3B was sufficiently reliable, but inadequately valid in the measurement of $\dot{V}O_2$ and $\dot{V}CO_2$.

1.6 Chester Treadmill Walking Test (CTWT)

The CTWT (Sykes, 2007) is a twelve minute graded treadmill test, used in the fire service, to assess fire-fighters aerobic capacity against the minimum recommendation of 42 mL · min^{-1} · kg^{-1} (predicted value at 12 mins). Individuals walk at a constant speed of 6.2 km·h^{-1} increasing the treadmill gradient by 3% every two minutes from a starting gradient of 0% up to 15% at ten minutes for the final two minute stage.

A modified version of the protocol has been proposed for Police Service of England and Wales, CTWT (Police) follows the same protocol as mentioned above, performed at the slightly slower constant speed of 6 km·h^{-1} (1.67 m·s^{-1}), with a predicted $\dot{V}O_2$ of 35 mL · min^{-1} · kg^{-1} at 10 minutes based on ACSM metabolic equations for walking (ACSM, 2013). As a predictive test, the inter-subject $\dot{V}O_2$ variability may have an SEE of 5% (Stevenson, Wilshire, Sykes, 2008).

McGuigan (2009) investigated the validity and reliability of the CTWT among seven participants (25.1 ± 3.3 years), completing two trials of the CTWT protocol and one $\dot{V}O_2$max test (Bruce protocol), with the use of ±95% LoA technique to assess both validity and reliability.

No significant difference was reported between the first trial and maximal testing (p = 0.226), and the second trial and maximal testing (p = 0.252), with a non-significant overestimation of $\dot{V}O_2$max between trial one and maximal testing (4.0 ± 15.4 mL · min^{-1} · kg^{-1}) and also trial two and maximal testing (4.8 ± 19.7 mL · min^{-1} · kg^{-1}). Reliability between trial one and two reported a mean difference of -0.8 ± 5.2 mL · min^{-1} · kg^{-1} and a high correlation between the two (ICC – 0.95). McGuigan (2009) suggested the CTWT is not a valid predictor of $\dot{V}O_2$max, with the small sample size being a possible justification for lacking statistical validity, with an anomalous result profoundly affecting results. However, the CTWT appears to be a reliable measure with an acceptable level of agreement between trials (McGuigan, 2009).

The CTWT (Police) is a more progressive and prolonged test in comparison to the 15-metre MSFT. There are considerable differences in total duration to reach a predicted $\dot{V}O_2$/ $\dot{V}O_2max$ of 35 mL · min^{-1} · kg^{-1} (CTWT (Police) – 10 mins, MSFT – 3 mins 35 secs), therefore steady state conditions may be achieved during the two minutes stages prior to increments in gradient during the CTWT, although steady state conditions are less likely during the 15-metre MSFT as running speed progresses more rapidly over a shorter duration (Porcari et al, 2015).

1.6.1 Summary

Due to the nature of the MSFT, involving frequent stopping and starting through 180° turns, this fitness test may not be suitable for police officers suffering from musculoskeletal impairments (Stevenson et al, 2008). Police forces require an alternative fitness test, the CTWT (Police).

Prior to potential inclusion as an alternative fitness test to the 15-metre MSFT, the validity and reliability of the CTWT (Police) need to be investigated, with the direct measurement of $\dot{V}O_2$, to determine whether 10 minutes equates to a $\dot{V}O_2$ of 35 mL · min^{-1} · kg^{-1} and thereby confirm that the participant will have a $\dot{V}O_2max$ of at least 35 mL · min^{-1} · kg^{-1} and whether this is a reliable measure among police officers.

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Validity and reliability of a modified version of the Chester Treadmill Walking (Police) Test as an alternative to the 15-Metre Multi-Stage Police Fitness Test.

Word Count – 4106

Aerobic, Health, Occupational, Workforce

2.1 Journal Proposal

The following research article is written for inclusion into the Journal of Occupational Health, a journal with an emphasis on current developments within occupational health. Of the six fields covered by the journal, health promotion is the field in which the current research article is contributing, aiming to further knowledge, understanding and development of occupational fitness tests within the police forces in England and Wales to promote health and safety of workers.

2.2 Abstract

Objective: An investigation into the validity and reliability of a modified version of the Chester Treadmill Walking (Police) Test as an alternative to the 15-Metre Multi-Stage Police Fitness Test. **Methods:** Data was gathered using 17 police officers (39.9 ± 6.9 years, 175.5 ± 9.5 cm, 80.5 ± 14.2 kg) using a repeated measures design. Validity of each test was analysed comparing $\dot{V}O_2$ to the criterion $\dot{V}O_2max$ (35 mL · min^{-1} · kg^{-1}) and between trial reliability measured using Bland & Altman's (1986) ±95% LoA. **Results:** Validity analyses for all trials found heteroscedasticity, which required log transformation and ±95% LoA reported as ratio values. MSFT 1: 1.16 ×/÷ 1.11, MSFT 2: 1.17 ×/÷ 1.16, CTWT (Police) 1: 0.98 ×/÷ 1.07, CTWT (Police) 2: 0.96 ×/÷ 1.07. MSFT test-retest reliability: - 0.50 ± 10.85 mL · min^{-1} · kg^{-1}, CTWT (Police) test-retest reliability: 0.51 ± 4.43 mL · min^{-1} · kg^{-1}. **Conclusion:** The 15-metre MSFT and the CTWT (Police) do not require the same O_2 cost. The 15-metre MSFT is not a reliable measure, however, the CTWT (Police) is a valid and reliable measure of 35 mL · min^{-1} · kg^{-1} and can be recommended as an alternative test in the police force.

3. Introduction

Certain tasks police officers encounter (e.g. foot pursuit, resisted arrest) require adequate fitness levels (Bonneau & Brown, 1995; Strating et al, 2010) and an inability to physically perform police duties may endanger public safety, or cause injury (Anderson et al, 2001). Police forces in England and Wales require new recruits and serving police officers to pass an annual fitness test, the 15-metre MSFT, as of September 2013 following the acceptance of a recommendation by the Police Advisory Board for England and Wales (College of Policing, 2014).

The 20-metre version of the MSFT, developed by Leger & Lambert (1982), is the most common field test for the prediction of $\dot{V}O_{2}max$. High correlations have been reported between $\dot{V}O_{2}max$ and 20-metre MSFT performance (Leger & Lambert, 1982; Ramsbottom et al, 1988), however, studies investigating measures of agreement have found the 20-metre MSFT lack validity (Lamb & Rogers, 2007; Ruiz et al, 2009) in predicting $\dot{V}O_{2}max$.

Four shuttles at level five of the 15-metre MSFT is required, a predicted $\dot{V}O_{2}max$ of 35 $mL \cdot min^{-1} \cdot kg^{-1}$, based on research by Brewer et al (2013) comparing the aerobic demands of the 15-metre MSFT with officer safety training (OST) (College of Policing, 2014).

A study at Loughborough University of Technology (Hazeldine, Lakomy, Simpson, 1995) designed a modified version of the 20-metre MSFT, over a 15 metre distance, attempting to provide a standard for aerobic fitness that may be equal to a population they pursue during a foot chase. The standard was set at level 8:1, a predicted $\dot{V}$

O_2max of 42.5 mL · min^{-1} · kg^{-1}, matching the average $\dot{V}O_2$max of the general population aged between 12 and 54 years.

This standard has since been lowered to a predicted $\dot{V}O_2$max of 35 mL · min^{-1} · kg^{-1}, at level 5:4, suggested by Brewer et al (2013), derived from (Roehampton University, 2003 unpublished study) a study aiming to validate the 15-metre MSFT, using linear regression analysis from directly determined $\dot{V}O_2$max and number of completed shuttles.

Due to the nature of the MSFT, frequent stopping and 180° turns, the 15-metre MSFT may not be suitable for police officers suffering from musculoskeletal impairments (Stevenson et al, 2008). Therefore, an alternative fitness test is required, the modified CTWT (Police) (College of Policing, 2014). The CTWT (Sykes, 2007), developed by Professor Kevin Sykes at the University of Chester, is a twelve minute graded treadmill test, specifically designed for use within the UK Fire Service to assess whether a fire-fighter reaches the minimum recommended standard of 42 mL · min^{-1} · kg^{-1}. The CTWT (Police) is an adaptation of this protocol designed to assess the appropriate level of aerobic fitness required by police officers.

A previous study (Roehampton University, 2003 unpublished study) has suggested a $\dot{V}O_2$max of at least 35 mL · min^{-1} · kg^{-1} is required to achieve level 5:4. The present study aims to investigate and compare the O_2 cost at level 5:4 with the predicted $\dot{V}O_2$max, and also to determine whether this measure is repeatable. Also, prior to potential inclusion, the validity and reliability of the CTWT (Police) requires investigation, to determine whether 10 minutes equates to a $\dot{V}O_2$ of 35 mL · min^{-1} · kg^{-1} and whether this is a reliable measure among police officers.

4. Method

4.1 Participants

Seventeen police officers (39.9 ± 6.9 years, 175.5 ± 9.5 cm, 80.5 ± 14.2 kg, male: 20, female: 5) volunteered from police forces across north-west England and north Wales. Prior to data collection ethics approval was granted by the Faculty of Life Sciences research committee at the University of Chester. Participants were provided with a written explanation of the study before arriving at the University of Chester. Upon arrival all participants completed a pre-test health status questionnaire and provided written informed consent. Blood pressure (Omron BP710, automated), weight (electronic scale, Seca, Germany) and height (wall stadiometer, Seca, Germany and Tanita, USA) were recorded upon arrival and participants were asked to abstain from caffeine, alcohol, tobacco and heavy exercise 24 hours prior to testing.

4.2 Data collection procedures

The study utilised a repeated measures design, with a minimum 24 hour period between repeated tests. Participants attended the University of Chester on two separate occasions (minimum 24 hours apart), performing both the 15-metre MSFT and the CTWT (Police) once during each visit.

The CTWT (Police) was conducted on a motorised treadmill (Woodway Pro, WI, USA) in the laboratory, and the 15-metre MSFT on a flat non-slip surface. The tests were carried out in a randomised order, with a minimum 3 hour rest period between, and repeat tests were carried out at the same time of day. $\dot{V}O_2$ (MetaMax 3B, Cortex, Germany) and HR (Polar s810i, Finland) were continuously recorded by online breath-by-breath gas analysis and Polar wireless telemetry. Volume and automated gas calibration were performed prior to each session of testing. A 6-20 RPE scale (Borg, 1998) was clearly visible to participants, with a verbal explanation and calibration provided before the start of each test.

4.3 15-metre MSFT

A 15 metre distance was measured using a tape measure and clearly marked using marker cones. A 6-20 RPE scale (Borg, 1998) was clearly visible at either end of the 15 metre distance. A warm-up period (first two stages of the test) and proceeding stretches were carried out, in accordance with routine fitness testing of police officers. Participants were equipped with gas analysis and HR monitoring equipment prior to test commencing. Participants run the 15-metre distance, between the marker cones, in time with the bleep emitted from a pre-recorded audio CD. As time progresses the time interval between bleeps reduces, and therefore running speed increases. The test begins at a speed of 2.2 $m \cdot s^{-1}$, increasing to 2.7 $m \cdot s^{-1}$ during level 5. Participants were encouraged to run until volitional exhaustion, with the test being stopped if an RPE of 18 was reached. Age predicted HRmax calculated using 206 – 0.7 x age (Tanaka et al, 2001).

4.4 CTWT (Police)

Participants were fitted with gas analysis and HR monitoring equipment prior to taking stance on the treadmill. Upon commencing, the treadmill speed was slowly increased to 6 $km \cdot h^{-1}$ (1.67 $m \cdot s^{-1}$), remaining constant for the remainder of the test. A gradient increase of 3% occurs at every 2 minute interval, increasing to a final gradient of 15%, with a total duration of 12 minutes. Data was collected throughout; however, readings at 10 minutes are of particular interest, as this is the point where predicted $\dot{V}O_2$ is 35 mL · min^{-1} · kg^{-1}. Participants continue walking until they either complete the 12 minutes, or until they are unable to continue. RPE was recorded every 2 minutes and in the event of RPE exceeding 18 the test was stopped.

4.5 Statistical analyses

Data was downloaded using 5 (MSFT) and 10 second (CTWT Police) averages. All analyses were performed using SPSS 22 for Windows (IBM Corp, Armonk, NY) with statistical significance set at $p < 0.05$.

4.6 Reliability analyses

$\dot{V}O_2$, HR and RPE reliability of both MSFT and CTWT (Police) test-retests were examined using the Bland & Altman (1986) ±95% LoA technique. A test for normality (Shapiro-Wilk statistic) was performed on test-retest differences. A paired samples t-test identified if significant difference existed between test-retest means and a Pearson correlation coefficient to identify any significant relationship between test-retest differences and test-retest means (Lamb, 1998). SEM, a determination of the amount of variation in measurement error, was calculated using 95% confidence intervals (CI).

4.7 Validity analyses

Agreement between actual $\dot{V}O_2$ values and the predicted $\dot{V}O_2max$/ $\dot{V}O_2$ value of 35 mL · min^{-1} · kg^{-1} were examined using ±95% LoA technique, with the same analyses used to test validity as mentioned above for reliability. A one-sample t-test was used to identify significant difference between actual and predicted $\dot{V}O_2max$/ $\dot{V}O_2$ values. SEE was reported using 95% CI.

5. Results

Table 1: Physiological characteristics

	$\dot{V}O_2$ (mL · min^{-1} · kg^{-1})	HR (beats· min^{-1})	%HRmax	RER	RPE
15-m MSFT 1	41.06 ± 4.19	157 ± 14	88 ± 8	0.99 ± 0.07	11 ± 1
15-m MSFT 2	41.56 ± 6.54	157 ± 14	88 ± 8	0.98 ± 0.06	12 ± 1
CTWT (Police) 1	34.51 ± 2.38	142 ± 21	80 ± 12	0.93 ± 0.06	13 ± 2
CTWT (Police) 2	34.00 ± 2.42	140 ± 21	79 ± 12	0.96 ± 0.07	13 ± 2

Mean ± SD

5.1 Validity

The ±95% LoA between MSFT trial 1 and predicted $\dot{V}O_2$max (35 mL · min^{-1} · kg^{-1}) were 1.16 ×/÷ 1.11 (table 3) and SEE (8.5%), 2.96 mL · min^{-1} · kg^{-1}. A significant relationship (r= 1.00, p= 0.0005) was found, indicating heteroscedasticity, therefore a logarithmic transformation of the data was performed, as suggested by Atkinson & Nevill (1998). A one sample t-test (p=0.0005) found significant bias between MSFT trial 1 $\dot{V}O_2$ and predicted $\dot{V}O_2$max. Antilogs of the values were taken to report limits on the ratio scale. Heteroscedasticity was also found (r= 0.895, p=0.0005) when comparing MSFT trial 2 and predicted $\dot{V}O_2$max (35 mL · min^{-1} · kg^{-1}). Logarithmic transformation of the data was again carried out, with significant bias found (p= 0.0005) and ±95% LoA 1.17 ×/÷ 1.16 on the ratio scale (table 3). SEE calculated at (13.2%) 4.62 mL · min^{-1} · kg^{-1}.

CTWT (Police) trial 1 and trial 2 also required logarithmic transformation, with no significant bias (p=0.22) reported between CTWT (Police) trial 1 and predicted $\dot{V}O_2$

(35 mL · min^{-1} · kg^{-1}) with ±95% LoA reported as 0.98 ×/÷ 1.07 and SEE (4.8%) 1.68 mL · min^{-1} · kg^{-1}. No significant bias (p=0.053) was found between CTWT (Police) trial 2 and predicted $\dot{V}O_2$ (35 mL · min^{-1} · kg^{-1}) with ±95% LoA reported as 0.96 ×/÷ 1.07 and SEE (4.9%) 1.71 mL · min^{-1} · kg^{-1}.

Table 2: CTWT (Police) validity statistics

Predicted $\dot{V}O_2$	35 mL · min^{-1} · kg^{-1}		
	Measured $\dot{V}O_2$	LoA	SEE
CTWT (Police) 1	34.51 ± 2.38	0.98 ×/÷ 1.07	1.68
CTWT (Police) 2	34.01 ± 2.42	0.96 ×/÷ 1.07	1.71

Table 3: 15-metre MSFT validity statistics

Predicted $\dot{V}O_2max$	35 mL · min^{-1} · kg^{-1}		
	Measured $\dot{V}O_2$	LoA	SEE
15-m MSFT 1	*41.06 ± 4.19	1.16 ×/÷ 1.11	2.96
15-m MSFT 2	*41.56 ± 6.54	1.17 ×/÷ 1.16	4.62

*significant difference between MSFT 1 predicted $\dot{V}O_2max$ and actual $\dot{V}O_2$ (p=0.0005) and MSFT 2 predicted $\dot{V}O_2max$ and actual $\dot{V}O_2$ (p=0.0005). ±95% LoA expressed on ratio measurement scale.

5.2 <u>Reliability</u>

The ±95% LoA between MSFT trial 1 and 2 are - 0.50 ± 10.85 mL · min^{-1} · kg^{-1} (table 4), and SEM (9.5%) 3.92 mL · min^{-1} · kg^{-1}. A paired t-test found no significant bias between trial 1 and 2 (p=0.72). The ±95% LoA between CTWT (Police) trial 1 and 2 are 0.51 ± 4.43 mL · min^{-1} · kg^{-1} (SEM- (4.6%) 1.60 mL · min^{-1} · kg^{-1}), with no significant bias found (p=0.37). The limits of agreement for HR and RPE between trials are shown in table 4. Paired t-tests found no significant bias for HR ($p=0.78$) or RPE ($p=0.69$) between MSFT trial 1 and 2. A significant difference in HR ($p=0.03$) was found but not RPE ($p=0.38$) between CTWT (Police) trial 1 and 2.

Table 4: 15-metre MSFT and CTWT (Police) reliability statistics

	$\dot{V}O_2$ (mL · min^{-1} · kg^{-1})		HR (beats· min^{-1})		RPE	
	LoA	SEM	LoA	SEM	LoA	SEM
15-m MSFT	- 0.50 ± 10.85	3.92	0.43 ± 11.25	4.06	0.17 ± 2.75	0.99
CTWT (Police)	0.51 ± 4.43	1.60	*2.67 ± 8.61	3.10	0.20 ± 1.69	0.61

*Significant difference in HR reported between CTWT (Police) 1 and CTWT (Police) 2.

6. Discussion

The aim of the study was to investigate whether 10 minutes on the CTWT (Police) is a reliable and valid measure of 35 mL · min^{-1} · kg^{-1}, indicating that upon successful completion an individual must have a $\dot{V}O_2$max of at least 35 mL · min^{-1} · kg^{-1}. The study also aimed to determine whether the actual O_2 cost at level 5:4 of the 15-metre MSFT was closely related to the predicted $\dot{V}O_2$max of 35 mL · min^{-1} · kg^{-1}, and whether this O_2 cost was a repeatable measure. Reliability shall be discussed first, as a measurement tool requires reliability in order to hold validity (Safrit & Wood, 1989).

6.1 15-metre MSFT reliability

The LoA for $\dot{V}O_2$, -0.50 ± 10.85 mL · min^{-1} · kg^{-1}, suggest -0.50 mL · min^{-1} · kg^{-1} systematic bias between trials, therefore under the assumption this bias is present, 10.85 mL · min^{-1} · kg^{-1} random error is present between two tests for any individual from the study population. A paired t-test found no significant differences between test-retest means ($p=0.72$). These limits suggest, following the first test mean recorded at 41.06 mL · min^{-1} · kg^{-1}, a repeat test from an individual within the study population should lie between 29.71 and 51.41 mL · min^{-1} · kg^{-1}. SEM, reported 3.92 mL · min^{-1} · kg^{-1}, equating to a 9.5% error between trials. Despite no significant bias detected between trials, the LoA and SEM suggest the 15-metre MSFT is not a reliable measure.

Studies (Cooper et al, 2005; Aandstad et al, 2011; Lamb & Rogers, 2007) investigating reliability of the 20-metre MSFT, measuring $\dot{V}O_2$max from predictive methods have reported ±95% LoA of -0.8 ± 3.1 mL · min^{-1} · kg^{-1} (Aandstad et al, 2011), 0.993 ×/÷ 1.05 (Cooper et al, 2005) and -1.1 ± 4.7 mL · min^{-1} · kg^{-1} (Lamb & Rogers, 2007) between trials. The present study is the first to examine the repeatability of directly measured O_2 cost at level 5:4.

The random error found may be attributable to both the nature and duration of the 15-metre MSFT, in comparison to the CTWT (Police). Shuttle running allows for greater variation in efficiency, with a wider running area and differences in turning technique, which a treadmill does not permit (Hatamoto et al, 2014). The duration of levels does not allow steady-state conditions to be achieved, which is methodological criteria for $\dot{V}O_2$max testing (Edvardsen, Hem, Anderssen, 2014).

±95% LoA for RPE suggests a repeat test, following a first test mean of 11, should lie between 8 and 14 on the 6-20 Borg scale.

6.2 CTWT (Police) reliability

The ±95% LoA for $\dot{V}O_2$, 0.51 ± 4.43 mL · min^{-1} · kg^{-1}, suggest 0.51 mL · min^{-1} · kg^{-1} systematic bias between trials, therefore under the assumption this bias is present; 95% of the random error between two tests for any individual from the study population should lie within 4.43 mL · min^{-1} · kg^{-1}. The first test mean recorded at 34.51 mL · min^{-1} · kg^{-1}, suggests the limits of a repeat test should lie between 30.59 and 39.45 mL · min^{-1} · kg^{-1}. SEM was reported as 1.60 mL · min^{-1} · kg^{-1}, or 4.6% error between trials.

The ±95% LoA suggest the CTWT (Police) is a reliable measure, with a level of bias that was not statistically significant and a random error component within the limits (-0.8 ± 5.2 mL · min^{-1} · kg^{-1}) reported by McGuigan (2009) upon measuring reliability of $\dot{V}O_2max$ measurements.

±95% LoA for RPE suggests a repeat test, following the first test mean value of 13, should lie between 12 and 15. These findings concur with those of Lamb, Eston and Corns 1999) noting the reliability of RPE for both the 15-metre MSFT and CTWT (Police) demonstrate LoA which may vary 6 and 3 units on the 6-20 Borg scale, which suggests the 6-20 Borg scale is not a reliable measurement tool.

6.3 15-metre MSFT validity

The ratio LoA for MSFT 1 $\dot{V}O_2$, 1.16 ×/÷1.11, suggest for any individual from the study population, 16% systematic bias and 11% random error represent 95% of differences between measured $\dot{V}O_2$ and the predicted $\dot{V}O_2max$ of 35 mL · min^{-1} · kg^{-1}. To help interpret these LoA, 95% of the ratios should lie between 1.05 (1.16 ÷ 1.11) and 1.29 (1.16 x 1.11). Therefore, from the predicted $\dot{V}O_2max$ of 35

$mL \cdot min^{-1} \cdot kg^{-1}$, $\dot{V}O_2$ at 5:4 may vary between 36.75 (1.05 x 35) and 45.15 $mL \cdot min^{-1} \cdot kg^{-1}$ (1.29 x 35) at level 5:4.

MSFT trial 2 reported 1.17 ×/÷ 1.16 ratio LoA (17% bias, 16% random error). These findings suggest 95% of the ratios should lie between 1.01 and 1.36, therefore $\dot{V}O_2$ may vary between 35.45 (1.01 x 35) and 47.60 $mL \cdot min^{-1} \cdot kg^{-1}$ (1.36 x 35) at level 5:4.

20-metre MSFT validity studies utilising ±95% LoA analysis have reported -0.4 ± 6.2 $mL \cdot min^{-1} \cdot kg^{-1}$ (Aandstad et al, 2011) and ratio limits of 1.034 ×/÷1.116 (Cooper et al, 2005), assessing agreement between directly measured $\dot{V}O_2$max and predicted $\dot{V}O_2$max. Previous studies (Paradisis et al, 2014; Ramsbottom et al, 1988; Cooper et al, 2005; Aandstad et al, 2011) have been concerned with maximal performance. The validity findings from the present study suggest predicted $\dot{V}O_2$max does not match the O_2 cost at level 5:4. A previous study (Roehampton University, 2003 unpublished study) suggested a participant with a $\dot{V}O_2$max of 35 $mL \cdot min^{-1} \cdot kg^{-1}$ should reach level 5:4, however the O_2 cost at 5:4 has shown to be significantly higher. A participant with a $\dot{V}O_2$max of 35 $mL \cdot min^{-1} \cdot kg^{-1}$ may reach level 5:4 reliant on anaerobic metabolism to produce energy required to achieve level 5:4, creating an O_2 deficit. To demonstrate this point, a sub-group of 3 participants from the study all recorded an RER of 1.09 at 5:4, 1.1 is a criterion value for achieving $\dot{V}O_2$max (Edvardsen et al, 2014). Recorded $\dot{V}O_2$ (37.1 ± 2.3 $mL \cdot min^{-1} \cdot kg^{-1}$) for these participants nearing maximal effort, suggested by RER and HR data (mean HR: 176 ± 4 beats$\cdot$ min^{-1}, 99 ± 1.4 %HRmax), is below the O_2 cost required to achieve level 5:4, suggesting anaerobic metabolism is producing the required energy to meet the O_2 demand at 5:4, and we may expect a participant with a higher $\dot{V}O_2max$ to record a higher O_2 cost as they may be less reliant on anaerobic energy systems. Interestingly, a mean RPE of 12 ± 1.7 was recorded at 5:4 from this sub-group.

Ruiz et al (2009) suggested predictive $\dot{V}O_2max$ equations derive from treadmill based protocols, explaining the equations underestimation of directly measured $\dot{V}O_2max$ from the 20-metre MSFT. The 15-metre MSFT requires more frequent decelerating and accelerating through 180° turns, which requires a greater O_2 cost than continuous linear running (Buglione & Di Prampero, 2013; Zamparo et al, 2014). The predicted $\dot{V}O_2max$ of 35 mL · min^{-1} · kg^{-1} (Roehampton University, 2003 unpublished study) derived from measured $\dot{V}O_2max$ during a treadmill protocol, which may explain the variance (continuous vs. shuttle) in predicted $\dot{V}O_2max$ and the O_2 cost at 5:4.

Despite the limited reporting on the methodology of $\dot{V}O_2$ measurements, Brewer et al (2013) found a peak $\dot{V}O_2$ of 36.1 mL · min^{-1} · kg^{-1}, during the 15-metre MSFT amongst a sub-group from the study. Macfarlane & Wong (2012) found the MetaMax 3B significantly overestimated $\dot{V}O_2$ compared with the DB method and the Jaeger Oxycon Pro, used by Brewer et al (2013), however these overestimations are not consistent with our CTWT (Police) findings.

Brewer et al (2013) presented peak $\dot{V}O_2$ and HR data and also mean $\dot{V}O_2$ and HR values over 4 minute periods during the 15-metre MSFT and OST. However the 15-metre MSFT is 3 minutes 35 seconds in duration, with no indication of the representative data for the preceding or following 25 second period.

6.4 CTWT (Police) validity

The ratio ±95% LoA for CTWT (Police) 1 are 0.98 ×/÷ 1.07 (2% bias, 7% random error). 95% of the ratios are expected to lie between 0.92 and 1.05, therefore, the $\dot{V}O_2$ of an individual may vary from 32.2 (0.92 x 35) to 36.75 mL · min^{-1} · kg^{-1} (1.05 x 35). CTWT (Police) 2 reported 0.96 ×/÷ 1.07 (4% bias, 7% random error) ratio limits, with 95% of the ratios between 0.90 and 1.03, with variation in $\dot{V}O_2$ expected between 31.50 (0.90 x 35) and 36.05 mL · min^{-1} · kg^{-1} (1.03 x 35).

The SEE reported 1.68 mL · min^{-1} · kg^{-1} (CTWT Police 1) and 1.71 mL · min^{-1} · kg^{-1} (CTWT Police 2), equating to 4.8% and 4.9% measurement error from the estimated 35 mL · min^{-1} · kg^{-1}, therefore completing 10 minutes on the CTWT (Police) indicates a participant has a minimum $\dot{V}O_2max$ of 35 mL · min^{-1} · kg^{-1} to within 4.8 – 4.9% accuracy.

The ACSM (2013) metabolic equation for walking accounts for resting metabolic rate (1 MET=3.5 mL · min^{-1} · kg^{-1}). Biological variation in resting metabolic rate may account for the random error present, with Gunn et al (2002) suggesting resting $\dot{V}O_2$ to be widely varied among individuals.

The sub-group previously mentioned recorded lower RER (1.00 ± 0.07), $\dot{V}O_2$ (33.27 ± 1.19 mL · min^{-1} · kg^{-1}) and HR (161 ± 14 beats· min^{-1}, 91.7 ± 8.7 %HRmax) values at 10 minutes during the CTWT (Police), suggesting, physiologically, level 5:4 at the 15-metre MSFT is more strenuous than the CTWT (Police), however mean RPE was 13 ± 1.2.

An interesting finding shows that participants perceive the 10 minute point during the CTWT (Police) to be physically more strenuous than level 5:4 of the 15-metre MSFT, based on mean values between tests (table.1).

A potential limitation to the present study is the sample size (n =17). Outliers within a limited data set have a greater effect on LoA, which are extrapolated to a particular population (police officers). Atkinson and Nevill (1998) recommend a minimum sample size of 40 participants.

7. Conclusion

The present study has shown that the 15-metre MSFT and the CTWT (Police) require a different O_2 cost, when the 15-metre MSFT is performed totally aerobically. The 15-metre MSFT has shown that the O_2 cost at level 5:4 is significantly higher than the predicted $\dot{V}O_2max$ of 35 mL · min^{-1} · kg^{-1}, however it is important to distinguish the difference between the measures of O_2 cost and $\dot{V}O_2max$ at level 5:4.

The 15-metre MSFT provides an economical and efficient means of fitness testing amongst police officers, however, the reliability is unconvincing.

The CTWT (Police) can be recommended for use within the police service of England and Wales as a valid and reliable measure of 35 mL · min^{-1} · kg^{-1}.

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9. Appendices

Appendix A

University of Chester

PARTICIPANT INFORMATION SHEET

Validity and reliability of the 15m Multi-Stage Fitness Test, Chester Treadmill Walk Test (Police) and Chester Treadmill Test (Firearms) in predicting fitness levels ($\dot{V}O_2$) required for specific Police Force Units

You are being invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully. If you would like further information, please do not hesitate to ask our research team.

What is the purpose of the study?

The aim of the study is to investigate the validity and reliability of the 15 metre multi-stage fitness test (15m MSFT) currently used in Police fitness testing and two proposed alternatives, Chester treadmill walking test (CTWT) and Chester Treadmill Test (CTT), as job-related fitness tests for police officers

Why have I been chosen?

You have been chosen due to you being the appropriate age, being apparently healthy and being a serving Police officer.

Do I have to take part?

No, all potential participants are volunteers and you should not feel obliged or prejudiced in any way either by the researchers, your employer, or your work colleagues to participate. If you do agree to participate you are free to withdraw at any time without reason and without prejudice to your work. Your employer will not be made aware of reason for withdrawal

What will be required of me if I take part?

If you wish to participate, you will be asked to attend the Exercise Physiology laboratory and the Small Hall at the University of Chester, Parkgate Road, Chester on two occassions. You will be asked to abstain from heavy exercise, alcohol, tobacco and caffeine for 24 hours prior to testing.

On each visit you will be asked to participate in one 15m MSFT and one treadmill test, which will be performed wearing a face mask (to measure the air you breathe) and chest strap heart rate monitor. You will repeat the same exercise tests on your second visit to the laboratory. Measures including blood pressure, body mass and height will be taken prior to testing. A health screening questionnaire must be completed along with an informed consent form prior to beginning the study.

During the exercise testing we will be measuring the following:

1. Oxygen consumption and carbon dioxide production (for which you will be required to wear a face mask).
2. Heart rate (for which you will be required to wear a belt around your chest).
3. Rating of perceived exertion (a measurement of how hard it feels while you are exercising).

What are the possible disadvantages and risks of taking part?

Risk assessments are carried out by researchers prior to carrying out research to help manage risks associated with this study. You may feel slight discomfort during exercise testing due to exercise intensity and/or online gas analysis face mask or vest worn during testing. As with any exercise or shuttle running there is a risk of injury due to slips, trips or falls but these will be minimised by ensuring that the flooring is suitable for shuttle running and there are no electrical leads etc., which may cause trips.

What are the possible benefits of taking part?

By taking part, you will be contributing to the development and understanding of the current fitness testing procedure used by the Police. You will be contributing to the development of an alternative walking treadmill tests which may be used in place of the 15m MSFT. Participating will also allow you valuable practice of the exercise testing used within the Police force.

What will happen to the results of the research study?

The results will be written up in a report as part an MSc thesis and also possibly used for research publication. A report of sample data and relevant findings will also be given to the College of Policing. Individuals who participate will not be identified in any subsequent report or publication.

What if something goes wrong?

If you wish to complain or have any concerns about any aspect of the way you have been approached or treated during the course of this study, please contact Dean of the Faculty of Life Sciences, University of Chester, Parkgate Road, Chester, CH1 4BJ, 01244 513055.

Will my taking part in the study be kept confidential?

All information which is collected during the course of the research will be kept strictly confidential so that only the researcher/s carrying out the data collection will have access to such information.

Who may I contact for further information?

Many thanks for your due consideration, if there is anything that is not clear or if you would like more information, please do not hesitate to ask our research team.

- Dr Mike Morris (University of Chester) m.morris@chester.ac.uk 01244513363
- Miss Elizabeth Parker (University of Chester) e.parker@chester.ac.uk 01244513959

Mr Andrew Birks (University of Chester) 1417230@chester.ac.uk

Appendix B

Informed Consent

Validity and reliability of the 15m Multi-Stage Fitness Test, Chester Treadmill Walk Test (Police) and Chester Treadmill Test (Firearms) in predicting fitness levels ($\dot{V}O_2$) required for specific Police Force Units

Please initial box

I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions. ☐

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason and without my legal rights being affected. ☐

I agree to take part in the above study. ☐

Name of Participant	Date	Signature
____________________	____________________	______________
Researcher	Date	Signature
____________________	____________________	______________

Appendix C

University of Chester

Pre-exercise test questionnaire

Participant Name: ______________ **Date of birth:** ______________________

BP:_____________ **Height**: ______________ **Weight**:______

In order to ensure that this study is as safe and accurate as possible, it is important that each potential participant is screened for any factors that may influence the study.

Please circle your answer 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 pain in the chest when you perform physical activity? YES / NO

3. In the past month, have you had chest pain when you were 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 bone or joint problems (e.g. back, knee or hip) that could be made worse by a change in your physical activity? YES / NO

6. Is your doctor currently prescribing drugs for your blood pressure or heart condition? YES / NO

7. Are you pregnant, or have you been pregnant in the last six months? YES / NO

8. Have you injured your hip, knee or ankle joint in the last six months? YES / NO

9. Do you know of any other reason why you should not participate in physical activity? YES / NO

Thank you for taking your time to fill in this form. If you have answered 'yes' to any of the above questions, please speak to a member of our research team.

Signed (Participant): ____ Date_____________

Signed (Researcher):____

Appendix D

University of Chester

Inclusion/exclusion criteria

Inclusion Criteria

- Police officers currently signed off by Occupational Health as fit for service within one of the following units: Marine Police Unit, CBRN, Method of Entry, Dog Handler, Mounted Branch, Police Cyclist, Police Support Unit, Air Support, Police Divers, Marine Police (Tactical Skills), Authorised Firearms Officer, Armed Response Vehicle, Dynamic Intervention AFO
- Males and females aged 18-65
- Able to attend the exercise physiology laboratory to carry out 15m MSFT and relevant treadmill test on two occasions
- Satisfied health screening questionnaire

Exclusion Criteria

- Those not fulfilling the above inclusion criteria
- Anyone with a current acute or chronic neuromusculoskeletal or circulatory condition, which may be worsened by included exercise tests
- Anyone who has chronic obstructive pulmonary disease
- Anyone who at the time of the study has or develops an acute bout of bronchitis or asthma, fever/flu, infection, or viral condition causing mild muscle fatigue, or any acute lung disorder where breathing responses to mild to moderate levels of exertion result in abnormal breathing
- Anyone having suffered an acute cardiac event within the last 6 months, who has not yet been fully stabilised and discharged from the care of a cardiologist or specialist physician and unable to easily perform mild to moderate physical activities
- Anyone who knows she is pregnant
- Anyone who has any other health condition (mental or physical) in which they feel would be exacerbated by the stated exercise tests

Appendix E

CTWT (Police) protocol

Equipment: Woodway Pro treadmill, RPE scale, Cortex Metamax 3B, heart rate monitor chest strap and watch.

- Participant shall be equipped with the Cortex Metamax 3B gas analysis equipment and a heart rate monitor.
- An RPE chart shall be placed in front of the treadmill in a clearly visible position.
- Researchers shall calibrate/anchor the RPE scale with participants prior to the start of the test and also verbally explain the procedure.
- Participant shall step onto the treadmill and hold onto handrails in preparation for gradual increase in treadmill belt speed.
- Researchers shall ensure there are no leads/cables that may be in danger of causing the participant to trip during the test.
- The treadmill speed increases to a speed of 6km/h (walking speed) at the start of the test and will remain at this speed for the duration of the test.
- The protocol begins with a 0% incline (no gradient) and every 2 minutes the incline of the treadmill will increase by 3% and on 10 minutes the incline will increase for the last time to 15% for the final 2 minutes of the test (total time- 12 minutes).
- RPE and HR shall be recorded every 2 minutes, at the end of each stage.
- Participants shall continue walking until they either complete the test or are unable to continue, in which case they are instructed to take hold of the hand rails to either side of the treadmill and place their feet to either side. Researchers shall explain this prior to test.
- Researchers shall stop the test if RPE is recorded at 18 or above at any point during the test.

CTWT Protocol			
Stage	Time (minutes)	Incline (%)	Speed
1	0-2	0	6km/h (3.7mph)
2	2-4	3	
3	4-6	6	
4	6-8	9	
5	8-10	12	
6	10-12	15	

Appendix F

15m MSFT protocol

Equipment: flat, non-slip surface of more than 15 meters, RPE scale, marker cones, 15 meter tape measure, beep test audio CD and CD player, Cortex Metamax 3B, heart rate monitor.

- A 15 meter distance will be measured using a tape measure, with marker cones placed at each end to indicate running distance.
- Participant shall be equipped with the Cortex Metamax 3B gas analysis equipment and a heart rate monitor.
- Participant is required to continuously run between the two cones, 15 meter distance, in time with the beeps from the audio recording. Upon failing to reach the distance within the beep, the participant is required to speed up to reach the cone in time with the beep. Three consecutive fails shall result in the test being stopped.
- The test begins at a steady speed and gradually increases (time between beeps decreases) as the participant progresses through each level of the test.
- Researchers shall calibrate the RPE scale with participants prior to the start of the test and also verbally explain the procedure and provide them with a chance to listen to the audio recording.
- The number of completed shuttles shall be recorded; RPE and HR shall be recorded at the end of each stage of the test and at each level specified in Appendix 13.
- Participants shall run until either they reach volitional exhaustion/wish to stop the test. The test will be stopped by researchers if RPE is recorded at 18 or above.

Appendix G

Fitness requirements for each Police Force Unit

UNIT	15M SHUTTLE (LEVEL:SHUTTLE)	Predicted $\dot{V}O_2$ / Aerobic Capacity ($mL \cdot kg^{-1} \cdot min^{-1}$)
Marine Police Unit	5:4	35
CBRN	5:4	35
Method of Entry	5:4	35
Dog Handler	5:7	35.8
Mounted Branch	5:7	36.1
Police Cyclist	5:8	36.1
Police Support Unit	6:3	37.2
Air Support	6:4	37.3
Police Divers	6:8	39
Marine Police (Tactical Skills)	7:2	40
Authorised Firearms Officer	7:6	41
Armed Response Vehicle	9:4	46
Dynamic Intervention AFO	10:5	50.8

Appendix H

Anthropometric measurements

Stature (Height) Measurement

- The participant's height will be measured to the nearest 0.1cm using a wall stadiometer (Seca, Germany and Tanita, USA).
- The participant is instructed to stand underneath the stadiometer facing away from the wall, with heels, scapulae and buttocks in contact with the wall.
- Participant will be asked to stand as tall as possible with heels together and feet evenly balanced at approximately 60.
- The participant will be asked to inhale deeply and maintain the position, one edge of the sliding scale will be lowered onto the participants head and the participant then asked to step away.
- The height to the nearest tenth of a centimeter (0.1cm) will then be recorded.

Mass Measurement

Participants body mass will be measured to the nearest 0.1kg using an electronic scale (Seca, Germany). The results from the measurement of stature and mass will be used to determine the participants body mass index (BMI) using the formula BW(kg)/Ht^2(M).

Appendix I

University of Chester

Blood Pressure measurement

Equipment: Omron (BP710) automated blood pressure device

1. Participant is asked to remove tight-fitting clothing from the upper arm.
2. The cuff is applied to the left upper arm so the arrow is centered on the inside of the arm and aligned with the middle finger. The air tube runs down the inside of the participants arm. The bottom of the cuff should be approximately ½" above the elbow.
3. Participant is asked to sit on a chair with their feet flat on the floor.
4. The arm is placed on a table so the cuff is level with their heart.
5. Participant is asked to keep still and not to talk during measurement.
6. Press the START/STOP button.
7. The cuff starts to inflate automatically. As the cuff inflates, the monitor automatically determines the ideal inflation level.
8. Participant is asked to remain still and not move their arm until the entire measurement process is completed.
9. Inflation stops automatically and the measurement is started. As the cuff deflates, decreasing numbers appear on the display and the Heartbeat Symbol will flash.
10. When the measurement is complete, the arm cuff completely deflates. The blood pressure and pulse rate are displayed.

Appendix J

Gas analysis and HR telemetry equipment

Cortex Metamax 3B will be used to measure oxygen uptake ($\dot{V}O_2$) during CTWT, CTT and 15m MSFT. The device weighs <1kg and can be carried on the front or back using the carrying system.

http://www.cortex-medical.de/METAMAX-3B-en.htm

Polar HR monitor will be used to transmit HR data directly to the Cortex Metamax 3B during exercise testing. This strap is worn around the chest of the participant during exercise.

http://www.polar.com/uk-en/products