Intra-Subject Variability of 5 Km Time Trial Performance Completed by Competitive Trained Runners

by

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Time-trials represent an ecologically valid approach to assessment of endurance performance. Such information is useful in the application of testing protocols and estimation of sample sizes required for research/magnitude based inference methods. The present study aimed to investigate the intra-subject variability of 5 km time-trial running performance in trained runners. Six competitive trained male runners (age = 33.8 ± 10.1 years; stature = 1.78 ± 0.01 m; body mass = 69.0 ± 10.4 kg, VO_{2max} = 62.6 ± 11.0 ml·kg·min^{-1}) completed an incremental exercise test to volitional exhaustion followed by 5 x 5 km time-trials (including a familiarisation trial), individually spaced by 48 hours. The time taken to complete each trial, heart rate, rating of perceived exertion and speed were all assessed. Intra-subject absolute standard error of measurement and the coefficient of variance were calculated for time-trial variables in addition to the intra-class correlation coefficient for time taken to complete the time-trial. For the primary measure time, results showed a coefficient of variation score across all participants of 1.5 ± 0.59% with an intra-class correlation coefficient score of 0.990. Heart rate, rating of perceived exertion and speed data showed a variance range between 0.8 and 3.05%. It was concluded that when compared with related research, there was observed low intra-subject variability in trained runners over a 5 km distance. This supports the use of this protocol for 5 km time-trial performance for assessment of nutritional strategies, ergogenic aids or training interventions on endurance running performance.

Key words: *endurance, running economy, reliability.*

Introduction

Time trials (TTs) in both a sporting and experimental context require athletes to either cover a fixed distance in the shortest possible time or the greatest distance possible in a finite time (Peserico and Machado, 2014). TTs are extensively used in the measurement of performance for running (Paavolainen et al., 1999), cycling (Carter et al., 2004) and rowing (Bruce et al., 2000) based protocols. This physiological testing method is often used to assess the efficacy of supplementation (Ivy et al., 2009), training interventions (Mujika et al., 2012) and physiological response to exercise (Girard et al., 2013).

Establishing reliable and accurate tools for the assessment of performance is vitally important in the area of sport science (Russell et al., 2004). Arguably, intra-subject variance is the most important reliability measure for sports professionals and scientists monitoring performance (Hopkins et al., 2000). Identifying smaller intra-subject variability determines accuracy in detecting a change in performance. An ecologically valid means of TT testing has the potential for wide spread application for future research (Davids, 1988), which has led to studies investigating the intra-subject variation of particular TT distances and disciplines (Alberty et al., 2006). For example, the variability of 20 km and 40 km cycling TT performance (Palmer et al., 1996), 2000 m rowing performance (Schabort et al., 1998) and 10 km running performance (Russel

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et al., 2004) have all been established as having relatively low scores of intra-subject variability (coefficient of variation [CV]; <2%). Such findings have subsequently seen these specific tests justifiably used as a measure of performance, yet despite an obvious need, 5 km-running performance has been used as a performance measure in numerous studies without evidence of establishing intra-subject variance (Girard et al., 2012; Jung, 2003; Paavolainen et al., 1999).

Higher running velocity experienced while running 5 km compared with greater distances increases the spatial and temporal recruitment of motor units (Nummela et al., 2006), representing the ergogenic equivalent of approximately 96% of VO_{2max} (Ramsbottom et al., 1992; Winter et al., 2007). Evidence suggests strong correlations between VO_{2max} and 5 km performance (males, r = -0.85, females, r = -0.80; Ramsbottom et al., 1987). Other performance traits associated with 5 km distance include a high lactate threshold (Noakes et al., 1990) and efficient running economy (Conley and Krahenbuhl, 1980). Subsequently, when compared with greater running distances, 5 km running trials may provide a more maximal physiological measure of running performance, and as such, present a useful outcome measure when considering the potential effect of supplements and training methods.

There is a current dearth of literature addressing the intra-subject variability associated with repeated 5 km running TTs. Such information is useful in the estimation of sample size required for future studies utilising these tests as per statistical significance and magnitude based inference methods (Hopkins, 2000), and is also important in determining the true practical performance benefits associated with any intervention. Furthermore, the 5 km distance would potentially offer less variability between athletes of similar VO_{2max} scores and 5 km performance times, than greater distances. With the above in mind, the primary aim of this study was to investigate the intra-subject variability of 5 km TT running performance in trained runners.

Material and Methods

Utilising a repeated measures design, participants were required to visit the laboratory on six occasions. During the first session,

participants underwent a study briefing, followed by pre-study health checks and an incremental exercise test to volitional exhaustion in order to determine VO_{2max}. Throughout the following five sessions participants were required to complete repeated 5 km TTs (one per session) in order to determine the intra-subject variability. TT sessions were separated by at least 48 hrs (Laursen et al., 2007). The study design was approved by the Health, Exercise and Sport Science (HESS) ethics committee at the Southampton Solent University.

Participants

Eight trained competitive male runners were recruited from the Southampton Solent University athletics team using a convenience sampling method (age, 33.8 ± 10.1 years; stature, 1.78 ± 0.01 m; body mass, 69.0 ± 10.4 kg, $VO_{2max,}$ 62.6 ± 11.0 ml·kg·min^{-1} [range = 45.4 to 78.3 ml·kg·min^{-1}]). Inclusion criteria required that participants were non-smokers with a sub-25 min 5 km run time in the past 12 months, and that all participants were free from orthopaedic injuries and any medical conditions for which running is contraindicated. All participants provided written informed consent prior to any testing.

Procedures

Session 1; Pre-checks/VO_{2max}

Twenty-four hours prior to the first session participants received a standardised text asking them to avoid any participation in strenuous exercise and to refrain from any consumption of alcohol and caffeine. Participants were also encouraged to maintain regular eating habits and drink *ad-lib* in order to keep well hydrated. The following morning, participants reported to the sport science labs with their usual exercise clothing. Participants then underwent various health checks and anthropometric measures including body mass via balance scales (Seca Flat Scales 710, Seca, UK), stature via a stadiometer (Harpenden stadiometer, Holtain Ltd, UK), blood pressure via an automated sphygmomanometer (Boso Medicus Automated Sphygmomanometer, Bosch and Sochn, Jungingen, Germany), hydration status via a portable osmometer (Osmocheck Pocket, Vitech Scientific Limited, UK), blood glucose via fingertip capillary sampling (Biosen C Line, EKF Diagnostic, Germany), and finally a 12 lead ECG (Oxycon Mobile, Jaeger, Germany). In order to participate in testing, participants were required

to present euhydration (<700 mOsm), a stable blood glucose value (within 4.4 to 6.1 mmol·l⁻¹), a stable resting blood pressure (<160/90 mm·Hg systolic/diastolic), and finally a regular ECG trace.

Following pre-checks, participants were asked to undertake an incremental exercise test to volitional exhaustion on a motorised treadmill (ELG 70/200, Woodway, USA). A self-paced warm up was conducted for 5 min prior to exercise. Following this, the protocol began at 4 km·h⁻¹ for a period of 2 min allowing participants to stabilise breathing. At the 2nd min, the speed of the treadmill was increased to 10 km·h⁻¹, and then it was subsequently increased by 1 km·h⁻¹ every minute until volitional exhaustion was reached (Winter et al., 2007). Throughout the protocol, the gradient was maintained at 1% in order to better represent the physiological requirements of outdoor running (Jones and Doust, 1996). Oxygen uptake (VO₂) and the respiratory exchange ratio (RER) were continually assessed during the test via breath-by-breath on-line gas analysis (Oxycon Pro, Jaeger, Germany). In addition, the heart rate (HR) via a remote transmitter (RCX5, Polar Electro, Finland) and the rating of perceived exertion (RPE) via Borg 6-20 scale were recorded on the 50th s of every minute. Standardised verbal encouragement was provided once the RPE exceeded a score of 17. At exhaustion blood lactate (BLa) via fingertip capillary blood sampling was assessed. To conclude the test, participants completed a self-paced 5 min cool down. In order to determine whether a maximal effort had occurred within the test, a set of criteria was used in which participants were required to present at least three of the following: a plateau in VO₂, RER >1.15, HR within 10 beats of the maximal (age predicted) HR, RPE > 19, and a BLa value of >8 mmol·l⁻¹.

Session 2-6; 5 km Time Trial

For each participant, sessions 2-6 were completed at the same time of day to exclude any influence of circadian rhythms upon results (Comfort, 2013). Participants were provided the same pre-testing guidance with regard to nutrition and hydration, and pre-checks were again carried out prior to exercise in each session, with the exception of the ECG. To initiate exercise, participants completed a standardised 5 min warm-up at a speed equivalent to 50% of the maximal speed achieved during the VO₂max test.

Following the warm up, participants were instructed to complete the subsequent 5 km TT as quickly as possible as though it was a competitive race. A standardised starting speed was set for 1 min, equalling the average pace of the participants suggested 5 km personal best time of the previous six months. Following this initial minute, participants were then free to self-select their pace for the remainder of the TT. The gradient remained at 1% throughout the test and participants were blinded to both the speed of the treadmill and the elapsed time with no verbal encouragement. Notification of the completion of each km was provided to mimic 1 km markers as seen in competitive races. RPE and HR data were recorded at the end of each km. Finally, upon completion of the TT, a 5 min self-paced cool down was conducted at the preferred speed of the participant.

Statistical Analysis

The primary outcome measure was the time taken to complete the 5 km treadmill TT. Expected intra-subject variability of the 5 km TT was determined through performance data drawn from sessions 3-6, following a familiarisation TT in session two. As a measure of typical error of individuals' mean score as per Hopkins (2000), intra-subject absolute standard error of measurement (SEM) was calculated in addition to the coefficient of variance (CV) to provide a relative measure of variance of TT variables (time as well as mean and peak speed, HR and RPE). The CV, suggested when considering performance testing, was used in order to provide comparative data to previous studies, with an analytical goal of the data being 10% or below (Atkinson and Nevill, 1999). SEM was used to reflect the absolute variation of the measures upon repeated testing in order to understand the minimal difference required to ascertain a 'real change' in performance between tests (Hopkins, 2000). First, the standard deviation across trials for all participants was determined, this was then squared and the absolute SEM was calculated using the following equation (Perini et al., 2005):

$$\text{Absolute SEM} = \sqrt{\frac{\sum \sigma_i^2}{2n}}$$

Where:

$\sum \sigma^2$, summation of standard deviations squared
n, number of participants measured
i, number of standard deviations

As a secondary outcome measure, an intra-class correlation coefficient (ICC) of each subject's time taken to complete the TT was calculated, with a score close to 1 showing excellent reliability (>0.9 high reliability; Vincent, 1994). As a Pearson's correlation coefficient is suggested to overestimate true correlation with sample sizes similar to that of the present study (Hopkins, 2000), the ICC was deemed more appropriate to detect the relative degree of reliability and retest correlation (Atkinson and Nevill, 1998). Calculations were performed using Microsoft Office Excel 2013 (Microsoft Corporation, Redmond, WA, USA) and statistical analysis was conducted using IBM SPSS Statistics for Windows (version 20; IBM Corp, Portsmouth, Hampshire, UK). A limit for statistical significance was set at $p \leq 0.05$.

Results

Eight participants were initially enrolled in the study with two failing to complete all trials, leaving a total of six trained competitive male runners that completed the study. Table 1 shows the time taken to complete each of the 5 km TTs, as well as the Mean, SD and CV scores of each subject. Mean CV of the participants' four trials was 1.5 ± 0.64% over an average time of 1227 seconds (20 min 27 s). Intra-subject absolute SEM for time taken to complete the TT was 14.2 s. The ICC for time necessary to complete the TT was 0.990 (95% CI, 0.966 - 0.998). Table 2 shows the CV scores for both mean and peak HR, RPE and speed during the TTs, in addition to intra-subject absolute SEMs.

Table 1

Observed time assessed across repeated 5 km time trials completed by competitive trained male runners

| | Time (s) | | | | | | |
	Trial 1	Trial 2	Trial 3	Trial 4	Mean	SD	CV (%)
Subject 1	1123	1121	1163	1113	**1130**	**22.4**	**2.0**
Subject 2	1123	1100	1100	1132	**1114**	**16.3**	**1.5**
Subject 3	1410	1388	1403	1336	**1384**	**33.5**	**2.4**
Subject 4	1248	1271	1248	1247	**1254**	**11.7**	**0.9**
Subject 5	1211	1191	1179	1216	**1199**	**17.3**	**1.5**
Subject 6	1294	1280	1273	1282	**1282**	**8.7**	**0.7**
Mean	**1235**	**1225**	**1228**	**1221**	**1227**	**18**	**1.5**
SD	**109.5**	**109.5**	**105.9**	**86.3**	**101.5**	**8.8**	**0.6**

Table 2

Physiological and performance measures assessed across repeated 5 km time trials completed by trained competitive runners

	CV (%)	SEM
Mean HR (b·p·m⁻¹)	1.4 ± 0.4	1.7
Peak HR (b·p·m⁻¹)	2.0 ± 0.7	2.7
Mean RPE	2.6 ± 1.6	0.3
Peak RPE	2.5 ± 2.0	0.4
Mean Speed (km·h⁻¹)	1.1 ± 0.4	0.1
Peak Speed (km·h⁻¹)	1.5 ± 2.2	0.3

Repeated measures design; n = 6; Number of trials, 4; CV data are mean ± SD

Discussion

This investigation aimed to assess the intra-subject variability of 5 km TT running performance in trained runners. The first key finding from the present study suggests that a laboratory based 5 km running TT is a highly reproducible test of performance, with an intra-subject variance score of 1.5 ± 0.6% (CV), falling well below the 10% level suggested by Atkinson and Nevill (1999). Of note, this suggested acceptable value by Atkinson and Nevill, (1999) does not provide much clarity as all treadmill based studies reviewed by Russell et al. (2004) and Alberty et al. (2006) indicate range from 0.95 to 7.82%. As such, the inclusion of the absolute SEM in the present study provides an absolute indicator of the error typically seen in the test, which can be used when drawing inferences regarding the impact of interventions upon TT performance. The SEM reported in the present study was 14.2 s suggesting that any change in TT performance should exceed this for investigators to be confident that a real change has occurred.

Although the values within the present study show high correlation and low intra-subject variability as per Atkinson and Nevill (1999), at a glance they are not vastly different to studies focusing on distances greater than 5 km. Russell et al. (2004) investigated the reliability of a 10 km TT using a similar sample size reporting CV scores of 1 ± 0.25% with an even lower CV when considering only male participants (0.54 ± 0.19%), which would suggest that the CV does not increase over time and duration. However, Russell et al. (2004) considered the reliability of 10 km running performance after a 90 min pre-loaded run. The pre-loaded run consisted of high intensity sprints to achieve a "steady state" running technique, thus limiting the participants sprint capabilities (Doyle and Martinez, 1998). Such a protocol may be less representative of other research implementing 10 km TTs as a performance measure (e.g. Mitchell et al., 2000). Furthermore, the study noted issues with their treadmill which reached maximum velocity too early for some of the more experienced runners; this meant they had to complete the run on a 3% incline as opposed to 1%. Research by Jones and Doust (1996) suggests that working at a 1% incline on a treadmill replicates the ergogenic cost of

outdoor running; another study indicates that running at a greater incline will increase the variability of factors associated with running economy (Saunders et al., 2004).

Studies that implemented more comparable testing protocols but with greater distances potentially provide a better comparison. Schabort et al. (1998) considered repeated trials, replicating a similar protocol to that of the present study and found CV scores of 2.7% and an ICC of 0.90 over a 1 hour trial. Conversely, Hopkins and Hewson (2001) examined the intra-subject variance of running TT distances ranging from 2500 m to a half marathon with CV scores ranging from 1.2 to 4.7%. These results are difficult to draw comparisons from, yet Hopkins and Hewson (2001) found only 0.3% less intra-subject variation in a TT half the length of the present study.

Associations and comparisons may also be drawn through physiological and performance traits that participants present over the different distances. The heart rate averaged 172 ± 1.42 b.p.m-1 across all participants and trials in the present study, compared with 173 ± 6 b.p.m-1 and 175 ± 6 b.p.m-1 for both trials at 10 km (Russell et al., 2004). Furthermore, speed averaged 14.91 ± 0.18 km.h-1 within the present study. Lima-Silva et al. (2010) discussed how when running a 10 km TT, pacing strategies differed regardless of performance levels, but the more experienced and superior performers were able to be consistent with their approach. With this in mind, Russell et al. (2004) did not report CVs for their HR data and as such direct comparison cannot be made with the present study. A heart rate is considered to be a key physiological component of running economy (Morgan and Craib, 1992) which influences running speed (Kyröläinen et al., 2001) and the CVs and SEMs reported in the present study (Table 2) would suggest that the 5 km TT used was reproducible in terms of these variables.

A potential limitation of the present study regards the range of ability levels of participants which might have increased the variability marginally. Research by Girard et al. (2013) and O'Rourke et al. (2008) used a 5 km TT as a measure of performance reporting average times of 17 min 30 s and 17 min 38 s compared to 20 min 27 s (range = 18 min 36 s to 23 min 04 s) for the present study. Therefore, if experience and ability

prove to be a factor (Lima-Silva et al., 2010), this suggests that a faster sample and narrower range in the population could potentially provide less variability (Numella et al., 2006). However, we should also consider that this range of values might also be perceived a strength of the present study, since it represents a more heterogeneous sample. Future studies can be confident to utilise a 5 km TT for a non-elite population sample since the present data support high correlation and low variability even across a moderate range of values.

The authors believe that the present study offers a strong methodological approach that supports previous publications having already implemented a 5 km TT as a performance measure. However, comparisons between the intra-subject variability of other running based TTs are difficult due to a lack of studies considering the true variance between individuals in a controlled environment and a lack of absolute measures of variances (i.e. SEM). Future research should utilise this established protocol to consider the intra-subject variability of distances other than 5 km.

Conclusion

In conclusion, the 5 km TT displays low intra-subject variability based on the suggestions of Atkinson and Nevill (1998) and Vincent (1994), with the 5 km TT test itself also showing to be accurate and reliable (Atkinson and Nevill, 1998). Relative to other running TT research, the use of pre-loaded protocols across a selection of studies makes it difficult to draw comparisons regarding the intra-subject variability. Furthermore, the results from the most relevant study by Russell et al. (2004) do not seem comparable due to the lack of repeated trials used. Despite such differences, data from the present study in the context of other related publications suggest that intra-subject variance of running TTs does increase over time and duration.

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