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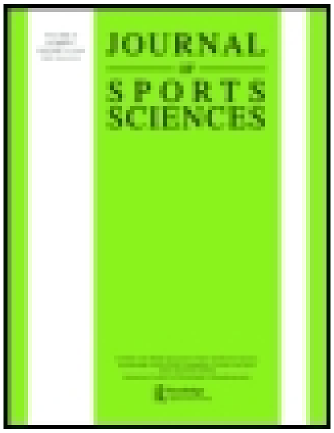

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The validity of endurance running performance on the Curve 3^{TM} non-motorised treadmill

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Abstract

This study aimed to test the validity of a non-motorised treadmill (NMT) for the measurement of self-paced overground endurance running performance. Ten male runners performed randomised 5-km running time trials on a NMT and an outdoor athletics track. A range of physiological and perceptual responses was measured, and foot strike was classified subjectively. Performance time was strongly correlated ($r = 0.82$, ICC = 0.86) between running modes, despite running time being significantly longer on the NMT (1264 ± 124 s vs. 1536 ± 130 s for overground and NMT, respectively; $P < 0.001$). End blood lactate concentration and rating of perceived exertion were significantly higher on the NMT compared to overground. Integrated electromyography was significantly lower on the NMT for three muscles ($P < 0.05$), and mean stride rate was also significantly lower on the NMT ($P = 0.04$). Cardiorespiratory responses of heart rate, oxygen uptake and expired air volume demonstrated strong correlations ($r = 0.68–0.96$, ICC = 0.75–0.97) and no statistical differences ($P > 0.05$). Runners were consistently slower on the NMT, and as such it should not be used to measure performance over a specific distance. However, the strong correlations suggest that superior overground performance was reflected in relative terms on the NMT, and therefore, it is a valid tool for the assessment of endurance running performance in the laboratory.

Keywords: *exercise performance, exercise physiology, endurance training, performance test, pacing strategy*

Introduction

Endurance exercise performance tests are often conducted in a laboratory setting to allow for the use of a wide range of scientific equipment and to control for various environmental and motivational variables. To have important implications, however, performance testing in the laboratory must closely replicate the demands of outdoor competition. For the measurement of running performance in the laboratory, motorised treadmills are widely used and are considered valid measures of outdoor running performance, despite the absence of any direct comparison. Relative oxygen uptake (VO_2) is similar between these running modalities and appears most strongly correlated when running on a treadmill gradient of 1% (Jones & Doust, 1996). A lower oxygen cost for running on a motorised treadmill versus overground may be due to the absence of wind resistance, momentum gained from the moving treadmill belt, or changes in locomotor characteristics on the different surfaces, visual cues of moving surroundings or the extent of familiarity with each modality (Jones & Doust, 1996).

A recent review on performance and fatigue has highlighted the importance of studying self-paced exercise (Tucker, 2008), which accounts for the brain's anticipatory regulation of performance through pacing strategy. The pacing strategy has been described as an algorithm with both conscious and subconscious input incorporating knowledge of the end point, memory of similar events, as well as feedback from external and internal receptors from which running speed may be frequently adjusted (Marcora, 2010; St Clair Gibson et al., 2006). However, when performing a self-paced running

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Correspondence: Christopher J. Stevens, Applied Sports Science and Exercise Testing Laboratory, Faculty of Science and Information Technology, University of Newcastle, 10 Chittaway Rd, Ourimbah, NSW 2258, Australia. E-mail: Christopher.J.Stevens@uon.edu.au task on a motorised treadmill, the speed of the belt remains constant until actively changed by the runner through a computer. Therefore, any change in pacing must be conscious and the motorised belt may motivate the runner to maintain a more consistent running speed across the duration of the task. The use of a non-motorised treadmill (NMT) may eliminate these influences, as the runner dictates the speed of the belt with every step, consistent with overground running. These ergometers have recently become widely available to researchers and the general public. Such treadmills may work by the act of pushing backwards on an inclined treadmill belt (Curve NMT, Woodway, Waukesha, WI, USA), or pushing backwards on a flat treadmill belt with the aid of a cable attached to the runner (Force NMT, Woodway, Waukesha, WI, USA). The Force NMT has demonstrated good reliability and validity for the assessment of sprint (Highton, Lamb, Twist, & Nicholas, 2012; Lakomy, 1987) and repeat sprint (Aldous et al., 2014; Sirotic & Coutts, 2008) intervals in the laboratory, where motorised treadmills are not appropriate due to restrictions on acceleration.

To date, only one investigation has used a NMT for an endurance running time trial, in which participants ran 5 km on a Curve NMT in an average time of 28.4 ± 4.6 min (McCarron, Hodgson, & Smith, 2013). This time would be considered slow for a trained population with an average VO_{2max} of 53 $ml \cdot kg^{-1} \cdot min^{-1}$. Hence, running on the NMT may not accurately represent the demands of overground running. This may be due to a range of NMT characteristics (e.g. the resistance, incline and rubber material of the treadmill belt), which may provide some runners with an advantage over others. Hence, the validity of endurance running on a NMT remains unknown. Therefore, the present study aimed to determine the validity of running performance and physiological responses in a 5-km time trial on a NMT by comparison with running on an overground athletics track.

Methods

Ten moderately trained male runners (age: 33 ± 13 years, height: 175 ± 5 cm, body mass: 70 ± 10 kg, sum of seven skinfolds: 53 ± 20 mm) volunteered for the study. Only participants with a 5-km personal best performance of 18–22 min in the last 6 months were included. The Human Ethics Research Committee at the University of Newcastle granted approval for the project (UoN H-2012-0311) in the spirit of the Helsinki Declaration, and participants provided written informed consent prior to engaging in all procedures.

In a randomised, crossover and counter balanced design, participants performed two 5-km running time trials at the same time of day separated by 5–10 days for observational analysis. One time trial was performed on a Curve 3^{TM} NMT (Woodway, Waukesha, WI, USA; CV = 1.2%; unpublished observations) and the other was performed on an outdoor 400 m tartan athletics track in an anticlockwise direction (CV = 0.95%; Hurst & Board, 2013). The participants were instructed to complete both trials in the fastest time possible. During each time trial, participants were blinded to all measures except for elapsed distance and no feedback was given between trials.

An anthropometric profile was obtained from each participant consisting of height (217 stadiometer, Seca, Birmingham, UK), body mass (DS-530 electronic scales, Wedderburn, Sydney, Australia) and skinfolds (Harpenden Calipers, Baty International, West Sussex, UK) at seven sites. Pre-exercise screening determined that all participants had run on the Curve 3^{TM} NMT on 2–3 occasions in the 2 months before the study and had trained and competed regularly over the 5 km distance overground. A maximal 5-km familiarisation run was performed for both running modalities 5–10 days apart. For 24 h prior to the first experimental trial, caffeine, alcohol and high intensity exercise were not permitted and participants were instructed to undergo their usual pre-race diet (food and drink), which was recorded in checklist format. This diet was repeated in the 24 h before the second trial and assessed by a researcher. If more than 10% of the checklist was not completed as per the first trial, the second trial was cancelled and rescheduled.

The participants performed a self-selected 15-min warm-up for which intensity, time and distance were recorded in the first trial for repetition in the second trial. The time trials commenced 2 min later from a standing start on the command of the tester. Participants took the first stride with their right leg. During the NMT time trial, a 50-cm fan was placed at 1 m distance in front of the participant and provided a wind speed of 4 $m \cdot s^{-1}$ to simulate the convective cooling of outdoor conditions. The treadmill faced a brick wall with no visual stimulus. No music, fluids or food were permitted, and footwear, clothing and instruction were standardised between all trials.

Environmental conditions

Ambient temperature and relative humidity were recorded at the start of each trial with a handheld portable weather meter (971 Thermohygrometre, Fluke Corporation, Everett, Washington, DC, USA). The outdoor trials were not completed in the early morning, middle of the day or late evening to avoid cold and hot temperatures. The outdoor trial was cancelled and rescheduled if the ambient temperature was <15°C or >24°C.

Physiological measures

Heart rate was continuously measured at 1 Hz by a Garmin 910XT monitor (Garmin Ltd., Schaffhausen, Switzerland). Although the participant wore the monitor, no data were shown on the screen in order to blind the participants to the heart rate recordings. Measurements of relative VO_2 and expired air volume were performed breath by breath with a portable gas analyser (Cosmed K4b^2, Rome, Italy). Capillary blood samples were collected from a hyperaemic fingertip for the analysis of [BLa^-] using a Lactate Scout (EKF-Diagnostic, Berlin, Germany) at the end of each trial.

Muscle activation

The electromyography (EMG) signal of four muscles (*gastrocnemius medianus, tibialis anterior, vastus lateralis* and *rectus femoris*) were recorded from the right limb via Trigno^{TM} wireless surface electrodes (Delsys Inc., Boston, MA, USA) as per international standards (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Surface electrodes had a single differential configuration, inter-electrode distance of 10 mm, 4-bar formation, bandwidth of 20–450 Hz and 99.9% silver contact material. The skin was prepared by shaving, light abrasion and cleaning with an alcohol swab.

Data recording and analyses were performed as described previously (Billaut, Davis, Smith, Marino, & Noakes, 2010). Twelve seconds of raw data were collected approximately midway through each kilometre of each trial, which aligned with the start of the front straight of the athletics track. The EMG signal was sampled at 3 kHz (EMGworks; Delsys, Boston, MA, USA). During post processing, the raw data were multiplied by 1000 to match the gain settings used by previous researchers (Billaut et al., 2010). A forth-order Butterworth filter of 12–500 Hz was applied to the data before the root mean square and integral were calculated with a 0.050 ms window length and 0.025 ms overlap. The mean EMG integral was calculated for each individual muscle, and further, the integrals of every muscle at each interval were added together to form the parameter of summated integrated-EMG (sum-iEMG; $V{\cdot}s^{-1}$), representing the general behaviour of muscle electrical activity of the lower limb during the time trials (Billaut et al., 2010).

Perceptual

Ratings of perceived exertion were measured using the CR-10 Borg scale where 10 = very, very heavy, for the heaviest running intensity perceived and 0.5 = very, very weak, equal to the weakest running intensity perceived (Borg, 1982). Thermal sensation was measured using Young's Thermal Sensation Scale (Young, Sawka, Epstein, Decristofano, & Pandolf, 1987). Runners were only to choose categories on the scales. Measurements were obtained for every kilometre of the time trials.

Stride characteristics

Stride rate was measured continuously using a telemetric receiver and foot pod (910XT, Garmin Ltd., Schaffhausen, Switzerland) taped to the right shoelaces. Foot strike was classified as either a "rear-foot strike," "mid-foot strike," "fore-foot strike" or a "toe strike" according to descriptions detailed previously (Lieberman, 2012). Each foot strike was filmed with a HDR-CX220 handycam camcorder (Sony Corporation, Tokyo, Japan) at 60 frames · s^{-1} and later analysed in slow motion with Quicktime software (Apple, Los Angeles, CA, USA). Foot strike was classified each kilometre within a 12-s period coinciding with EMG recordings. The foot strike used over the 5-km run was reported as the mode of the 1-km interval observations. Two members of the research team classified each foot strike on two occasions to obtain the intra-rater and inter-rater reliability.

The mean and standard deviation (s) were calculated for all data, with normality assessed using a Kolmogorov–Smirnov test. Differences in data between trials were examined using a two-tailed paired samples t-test for global means and 2 (condition) × 5 (interval) repeated-measures ANOVA for 1-km intervals within SPSS software V21.0 (IBM Corporation, Somers, NY, USA). In regard to the 1-km interval data, where main effects were present, least significant difference *post hoc* analysis identified significant differences between conditions. Alpha (P) was set at <0.05. Change in the mean with 90% confidence intervals, Pearson's product-moment correlation coefficients (r) and intraclass correlation coefficients (ICC) were calculated and interpreted using a custom-made spreadsheet (Hopkins, 2011). A correlation coefficient value of 0.10 or less was considered trivial, 0.11 to 0.30 small, 0.31 to 0.50 moderate and greater than 0.51 strong (Cohen, 1988). A partial correlation was also performed to remove the effect of body mass. Cohen's d effect sizes were evaluated as 0–0.19 trivial, 0.2–0.49 small, 0.5–0.79 medium and greater than 0.8 large (Cohen, 1992). Foot strike data were analysed with Cohen's kappa coefficient (κ) as per previous research (Willson et al., 2014).

Results

All data and residuals were normally distributed ($P > 0.05$). Table I shows the descriptive and validity statistics of all variables measured across the 5-km running time trials. When the effect of body mass was removed with a partial correlation, the correlation was strengthened from 0.82 to 0.85. In the NMT trial, there were significant increases in 5 km performance time ($P < 0.001$), end-exercise [BLa$^-$] ($P = 0.04$) and mean RPE ($P = 0.049$). Significant decreases were observed in the NMT trials for iEMG of the *tibialis anterior* ($P = 0.049$), *vastus lateralis* ($P = 0.012$) and *rectus femoris* ($P = 0.003$), as well as the sum-iEMG ($P = 0.04$). Mean stride rate was also significantly lower in the NMT trial ($P = 0.04$). Figure 1 shows a spaghetti plot of individual performance times, and their pattern of change between trials.

Figure 2 shows a comparison of interval measurements between performance time, sum-iEMG, stride rate, VO$_2$, heart rate and RPE. Significant differences between conditions across all 1-km intervals were present for both performance times ($P < 0.001$) and stride rates ($P < 0.05$). For sum-iEMG, a significant difference was present between conditions in the first kilometre only ($P = 0.008$), and for RPE, a significant difference was present between conditions in the fourth kilometre only ($P = 0.023$). No other significant differences between conditions were observed when the data were analysed as 1-km intervals. There was a

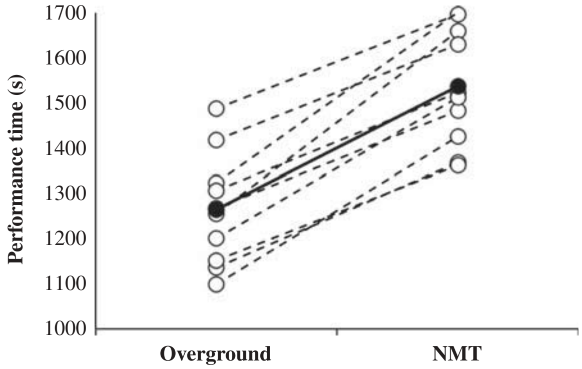

Figure 1. Spaghetti plot of individual 5-km running performance times (empty circles) and mean 5-km running performance times (solid circles) for the overground and non-motorised treadmill (NMT) time trials.

Table I. Descriptive and validity statistics of variables calculated from overground and non-motorised treadmill running time trials.

	Overground Mean ± *s*	NMT Mean ± *s*	Change in Mean Mean ± 90% CI	*r* (90% CI)	ICC (90% CI)	Effect Size (descriptor)
Performance Time (s)	1264 ± 124	1536 ± 130*	272 ± 42	0.82 (0.49–0.92)	0.86 (0.61–0.95)	2.19 (large)
Mean Heart Rate (b · min^{-1})	178 ± 13	178 ± 14	0 ± 2	0.96 (0.86–0.99)	0.97 (0.90–0.99)	<0.01 (no effect)
Mean VO$_2$ (mL · kg^{-1} · min^{-1})	49.2 ± 4.0	51.1 ± 5.0	1.9 ± 2.7	0.70 (0.04–0.93)	0.77 (0.29–0.94)	0.48 (small)
Mean VE (L · min^{-1})	122.4 ± 15.6	122.5 ± 17.3	0.1 ± 8.8	0.68 (0.10–0.92)	0.75 (0.31–0.93)	0.01 (no effect)
End [BLa$^-$] (mmol · L^{-1})	7.8 ± 2.1	9.4 ± 2.3*	1.6 ± 1.1	0.70 (0.14–0.92)	0.77 (0.34–0.93)	0.74 (moderate)
Mean GM iEMG (V · s^{-1})	2.00 ± 0.53	1.78 ± 0.34	−0.22 ± 0.42	−0.33 (−0.75–0.27)	−0.35 (−0.73–0.22)	0.42 (small)
Mean TA iEMG (V · s^{-1})	1.71 ± 0.52	1.38 ± 0.41*	−0.33 ± 0.27	0.53 (−0.03–0.84)	0.57 (0.07–0.84)	0.63 (moderate)
Mean VL iEMG (V · s^{-1})	1.23 ± 0.34	0.93 ± 0.30*	−0.30 ± 0.17	0.58 (0.04–0.86)	0.63 (0.16–0.87)	0.87 (large)
Mean RF iEMG (V · s^{-1})	0.86 ± 0.33	0.55 ± 0.19*	−0.32 ± 0.14	0.69 (0.22–0.90)	0.65 (0.19–0.87)	0.96 (large)
Sum-iEMG (V · s^{-1})	5.62 ± 0.94	4.55 ± 0.93*	−1.07 ± 0.79	0.06 (−0.55–0.62)	0.07 (−0.50–0.59)	1.15 (large)
Mean RPE (AU)	6.1 ± 1.0	6.5 ± 0.9*	0.4 ± 0.3	0.82 (0.49–0.85)	0.86 (0.61–0.95)	0.41 (small)
Mean TS (AU)	5.3 ± 0.9	5.5 ± 0.6	0.2 ± 0.5	0.62 (0.10–0.87)	0.60 (0.11–0.85)	0.33 (small)
Mean Stride Rate (steps·min^{-1})	88 ± 4	86 ± 5*	−2 ± 1	0.92 (0.76–0.98)	0.93 (0.78–0.98)	0.49 (small)

Notes: AU = arbitrary units, b · min^{-1} = beats per minute, CI = confidence Interval, GM = gastrocnemius medianus, iEMG = integrated electromyography, ICC = intraclass correlation coefficient, NMT = non-motorised treadmill, *r* = Pearson's product-moment correlation coefficient, RF = rectus femoris, RPE = rating of perceived exertion, sum-iEMG = summated integrated electromyography, TA = tibialis anterior, TS = thermal sensation, VE = expired air volume, VL = vastus lateralis, VO$_2$ = relative oxygen uptake, [BLa$^-$] = blood lactate concentration, *significantly different to overground ($P < 0.05$).

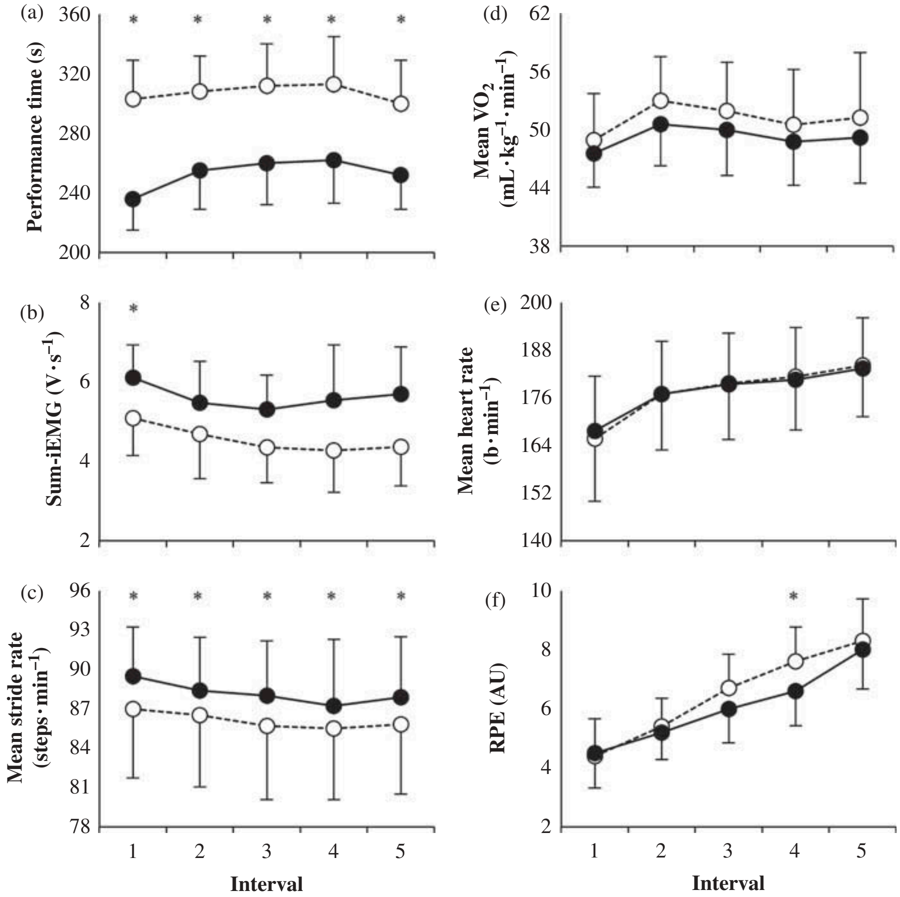

Figure 2. Interval measurements of (a) performance time, (b) sum-iEMG, (c) mean stride rate, (d) mean VO_2, (e) mean heart rate and (f) RPE, for the overground (solid circles) and non-motorised treadmill (empty circles) time trials. AU = arbitrary units, $b \cdot min^{-1}$ = beats per minute, $mL \cdot kg^{-1} \cdot min^{-1}$ = millilitres per kilogram per minute, RPE = rating of perceived exertion, $steps \cdot min^{-1}$ = steps per minute, sum-iEMG = summated integrated electromyography, $V \cdot s^{-1}$ = volts per second, VO_2 = relative oxygen uptake, * denotes significant difference between conditions ($P < 0.05$).

significant interaction between condition and interval for both performance time ($F_{(4,36)} = 3.211$, $P = 0.024$) and RPE ($F_{(4,36)} = 3.158$, $P = 0.025$).

For foot-strike classification, the intra-rater agreement was “almost perfect” ($\kappa = 0.877$) and inter-rater agreement was “substantial” ($\kappa = 0.795$). In the overground trial, nine runners used a “rear-foot strike” and one runner used a “mid-foot strike” most often. In the NMT trial, two runners used a “rear-foot strike” and eight runners used a “mid-foot strike” most often. The likelihood of runners to convert from a “rear-foot strike” to a “mid-foot strike” between overground and NMT was greater than that expected from chance alone, as there was no agreement between trials ($\kappa = 0.54$).

There were no significant differences between ambient temperatures (19.4 ± 2.5°C vs. 19.7 ± 1.0°C for overground and NMT, respectively; $P = 0.76$) or relative humidity’s between conditions (53.5 ± 16.6% vs. 56.9 ± 10.0% for overground and NMT, respectively; $P = 0.63$).

Discussion

Running performance over 5 km on the NMT was significantly slower than overground by 272 ± 42 s (22 ± 3%) as shown in Figure 1. A large effect size statistic (*ES* = 2.19) for performance times between the running modalities also highlights the disparity. However, strong correlations ($r = 0.82$, ICC = 0.86) depict that performances were similar in relative terms. The *r*-value presented is comparable to past data reporting on physiological parameters that are used to predict endurance running performance such as running economy ($r = 0.79$–0.83) (Conley & Krahenbuhl, 1980) and VO_{2max} ($r = 0.82$) (Farrell, Wilmore, Coyle, Billing, & Costill, 1993). However, the correlation in the present study is weaker than the correlation for onset of plasma lactate accumulation ($r = 0.91$) (Farrell et al., 1993), but this type of testing is limited for intervention-based research. It is likely that these physiological factors underpin performance both during overground and NMT running. Hence, the NMT is a useful tool for the measurement of endurance running performance, but should not be used to replicate the demands of a specific running distance.

While this is the first study to report slower endurance running times on the NMT compared to overground conditions, others who investigated the difference in short distance (10–30 m) sprint performances also reported slower times on the NMT, but the change was twice that of the present study (0.7–1.9 s; 41–44%) (Highton et al., 2012). Such a difference most likely occurs as the power required to propel the treadmill belt increases with speed (Lakomy, 1987), and therefore, NMT performance times in longer duration endurance exercise, where runners travel at slower speeds, may be more similar to overground performances. The slower times reported in all studies on the NMT may be attributed to the high intrinsic resistance of the running belt. Also, the NMT does not provide the inertial characteristics of overground sprint running when the maximal speed is reached, as the treadmill belt must still be accelerated between steps (Highton et al., 2012). Finally, the NMT used in the present study has a steep incline, which may have increased the load on the participants. As such, RPE and end-exercise [BLa^-] were significantly higher in the NMT trial, despite similar cardio-respiratory responses as per Figure 2.

In contrast to the present study, a 40-km cycling time trial was completed significantly faster in a laboratory setting than in outdoor, overground conditions (Smith, Davison, Balmer, & Bird, 2001). The slower outdoor performance was attributed to the wind resistance experienced in this environment. Wind resistance has a greater negative effect on cycling compared to running, since it increases with exercise velocity (Davies, 1980). Further, the terrain, road surface and corners of the course may have slowed the cyclists. These variables were minimised in the present study by the use of a 400-m athletics track, which was flat and tartan-surfaced and had gentle corners. Therefore, fewer potentially slowing factors were present in the outdoor condition of present study, which highlights the great difference in performance times.

The correlation coefficient between overground and NMT running time trials was strong, and therefore, the best runners overground were generally the best runners on the NMT. In Figure 1, most participants who ran faster than the mean time overground also ran faster than the mean time on the NMT. However, three runners ran slower than expected on the NMT as demonstrated by their lower rank order in the NMT condition. These participants ran on average 140 s slower than the rest of the group, while the three participants with the greatest body mass ran on average 76 s faster than the rest of the group. This may be explained by their lower body mass (64 ± 4 kg), which was 6 kg below the group average. A partial correlation revealed that increasing body mass did have a positive influence on NMT running performance. Lower body mass has previously been identified as a disadvantage for NMT running performance, since greater force is required (per kg body mass) to overcome the resistance of the NMT belt (Lakomy, 1987). Therefore, performance time on the NMT is somewhat negatively influenced by the variation in body mass between participants in the present study ($s = 10$ kg).

The correlation may be negatively affected by alterations in pacing strategy between the NMT and overground running modalities. In the overground trial, the first kilometre was run at the fastest speed, whereas the last kilometre was run at the fastest speed in the NMT trial (see Figure 2a). Since the participants were very experienced at running the 5 km distance overground, this may be explained by a lack of familiarity with the NMT, where the runners began the time trial at a cautious lower speed. Such a difference may have been eluded with additional familiarisation trials. Differences in pacing strategy may have also been influenced by an expected longer time trial duration in the NMT condition. Further, speed differences in the early stages of the run may result from an unmatched perception of speed between treadmill and overground running (Kong, Koh, Tan, & Wang, 2012), where the static external surroundings make treadmill runners perceive themselves to be running faster than they really are. However, during the middle three intervals (i.e. between 2–4 km), when runners might be more likely to pace themselves from internal feedback, performance times followed a very similar pattern between running modalities, where time was increased slightly over each kilometre in a linear fashion. Therefore, the NMT could produce very similar pacing strategies to overground running if the participants are educated to focus on internal feedback at the beginning of the time trial.

Mean iEMG activity over the 5-km run was significantly lower in the NMT condition compared to overground for *tibialis anterior, vastus lateralis* and *rectus femoris*, which may be attributed to changes in stride characteristics between modalities. A large effect was present for both *vastus lateralis* and *rectus femoris*, suggesting that the quadricep muscles experienced the greatest change. On the NMT, running occurred on an incline and with a “mid-foot strike,” compared to a flat surface with a “rear-foot strike” in overground. Indeed, *tibialis anterior* EMG activity is known to decrease across the entire stride cycle when changing from a “rear-foot strike” to a “mid-foot strike” due to decreased foot-ground impact shock (Giandolini et al., 2013). Adding to this, the rubber material of the NMT belt is designed to reduce the shock of impact. Another possible explanation is that running on an incline increases the EMG activity of the *gluteus maximus* and *bicep femoris* (Wall-Scheffler, Chumanov, Steudel-Numbers, & Heiderscheit, 2010), which may have reduced the recruitment of the muscles measured in the present study. Finally, the participants adopted a significantly lower stride rate on the NMT, which may have reduced the neural load. While one research group has reported no changes in running root mean square EMG activity with increased stride rate (Giandolini et al., 2013), others have demonstrated increased iEMG activity of the vastus lateralis with higher cycling cadence (Bieuzen, Lepers, Vercruyssen, Hausswirth, & Brisswalter, 2007). Since iEMG activity was lower for all muscles measured on the NMT, the sum-iEMG measure accurately reflects the changes in recruitment of the lower limb, which was significantly lower and had a large effect size statistic. Regarding the interval measurements of sum-iEMG, significant decreases were observed across the first and last kilometre (Figure 2b), which were the fastest intervals in both trials, suggesting the differences in EMG activity may be greatest at higher speeds.

The present study was limited by the small sample size used. Further, different convective loads due to wind resistance and greater heat stress outdoors from radiation may have altered core and skin temperatures, which could not be measured in this investigation. Higher body temperatures may have slowed runners; however, thermal comfort was not significantly different between trials and is highly related to skin temperature (Schlader, Simmons, Stannard, & Mündel, 2011). Further, there were no significant differences in ambient temperatures or relative humidity between trials. Therefore, a difference in heat stress does not appear to have played a large role in the disparity in performance times between running modalities. Future research should undertake a more comprehensive biomechanical study on the NMT in comparison with overground endurance running, including the use of force plate and 2D video analysis systems. The validity of motorised treadmill running should also be assessed in cohort with NMT running, in order to determine which is most appropriate for laboratory performance analysis.

Conclusions

Running performance time over 5 km is 22% longer on the Curve 3^{TM} NMT when compared to overground. The best overground runners are generally the best NMT runners, but those with a low body mass may be at a disadvantage on this type of treadmill. Cardio-respiratory responses are similar between running modalities, but a higher blood lactate concentration was measured following the NMT run and participants perceived it to be harder. The iEMG activity of most muscles measured was significantly reduced on the NMT, possibly due to the tendency to use a “mid-foot strike,” a lower stride rate and the incline of the treadmill belt. Overall, the NMT is not a valid representation of track running and should not be used to measure performance over a specific distance. However, strong correlations reveal that running on the NMT is a useful measure of endurance running performance and can be used for intervention-based research, especially when pacing is of importance.

References

Aldous, J. W., Akubat, I., Chrismas, B. C., Watkins, S. L., Mauger, A. R., Midgley, A. W., … Taylor, L. (2014). The reliability and validity of a soccer-specific nonmotorised treadmill simulation (intermittent soccer performance test). *Journal of Strength and Conditioning Research*, *28*(7), 1971–1980.

Bieuzen, F., Lepers, R., Vercruyssen, F., Hausswirth, C., & Brisswalter, J. (2007). Muscle activation during cycling at different cadences: effect of maximal strength capacity. *Journal of Electromyography and Kinesiology*, *17*(6), 731–738.

Billaut, F., Davis, J. M., Smith, K. J., Marino, F. E., & Noakes, T. D. (2010). Cerebral oxygenation decreases but does not impair performance during self-paced, strenuous exercise. *Acta Physiologica (Oxford)*, *198*(4), 477–486.

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and Science in Sports and Exercise*, *14*(5), 377–381.

Cohen, J. (1988). *Statistical power analysis for the behavioural sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.

Cohen, J. (1992). Quantitative methods in psychology: A power primer. *Psychological Bulletin*, *112*(1), 155–159.

Conley, D. L., & Krahenbuhl, G. S. (1980). Running economy and distance running performance of highly trained athletes. *Medicine and Science in Sports and Exercise*, *12*(5), 357–360.

Davies, C. T. (1980). Effects of wind assistance and resistance on the forward motion of a runner. *Journal of Applied Physiology: Respiratory, Environmental and Exercise Physiology*, *48*(4), 702–709.

Farrell, P. A., Wilmore, J. H., Coyle, E. F., Billing, J. E., & Costill, D. L. (1993). Plasma lactate accumulation and distance running performance. 1979. *Medicine and Science in Sports and Exercise*, *25*(10), 1091–1097; discussion 1089–1090.

Giandolini, M., Arnal, P. J., Millet, G. Y., Peyrot, N., Samozino, P., Dubois, B., & Morin, J.-B. (2013). Impact reduction during running: Efficiency of simple acute interventions in recreational runners. *European Journal of Applied Physiology*, *113*(3), 599–609.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology*, *10*(5), 361–374.

Highton, J. M., Lamb, K. L., Twist, C., & Nicholas, C. (2012). The reliability and validity of short-distance sprint performance assessed on a nonmotorized treadmill. *Journal of Strength and Conditioning Research*, *26*(2), 458–465.

Hopkins, W. G. (2011). Precision of measurement. *A New View of Statistics*. Retrieved from http://www.newstats.org/precision.html

Hurst, P., & Board, L. (2013). Reproducibility of outdoor 5 km running time-trial in a competitive environment. *British Journal of Sports Medicine*, *47*(17), e4.

Jones, A. M., & Doust, J. H. (1996). A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *Journal of Sports Sciences*, *14*(4), 321–327.

Kong, P. W., Koh, T. M., Tan, W. C., & Wang, Y. S. (2012). Unmatched perception of speed when running overground and on a treadmill. *Gait Posture*, *36*(1), 46–48.

Lakomy, H. K. A. (1987). The use of a non-motorized treadmill for analysing sprint performance. *Ergonomics*, *30*(4), 627–637.

Lieberman, D. E. (2012). What we can learn about running from barefoot running: An evolutionary medical perspective. *Exercise and Sport Sciences Reviews*, *40*(2), 63–72.

Marcora, S. (2010). Counterpoint: Afferent feedback from fatigued locomotor muscles is not an important determinant of endurance exercise performance. *Journal of Applied Physiology (1985)*, *108*(2), 454–456; discussion 456–457.

McCarron, J., Hodgson, T., & Smith, M. (2013). Brain drain: Evaluating the impact of increased cognitive load during self-paced running performance. *British Journal of Sports Medicine*, *47*(17), e4.

Schlader, Z. J., Simmons, S. E., Stannard, S. R., & Mündel, T. (2011). Skin temperature as a thermal controller of exercise intensity. *European Journal of Applied Physiology*, *111*(8), 1631–1639. doi:10.1007/s00421-010-1791-1

Sirotic, A. C., & Coutts, A. J. (2008). The reliability of physiological and performance measures during simulated team-sport running on a non-motorised treadmill. *Journal of Science and Medicine in Sport*, *11*(5), 500–509.

Smith, M. F., Davison, R. C., Balmer, J., & Bird, S. R. (2001). Reliability of mean power recorded during indoor and outdoor self-paced 40 km cycling time-trials. *International Journal of Sports Medicine*, *22*(4), 270–274.

St Clair Gibson, A., Lambert, E. V., Rauch, L. H., Tucker, R., Baden, D. A., Foster, C., & Noakes, T. D. (2006). The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Medicine*, *36*(8), 705–722.

Tucker, R. (2008). Thermoregulation, fatigue and exercise modality. *Thermoregulation and Human Performance*, *53*(1), 26–38.

Wall-Scheffler, C. M., Chumanov, E., Steudel-Numbers, K., & Heiderscheit, B. (2010). Electromyography activity across gait and incline: The impact of muscular activity on human morphology. *American Journal of Physical Anthropology*, *143*(4), 601–611.

Willson, J. D., Bjorhus, J. S., Williams 3rd, D. S., Butler, R. J., Porcari, J. P., & Kernozek, T. W. (2014). Short-term changes in running mechanics and foot strike pattern after introduction to minimalistic footwear. *Physical Medicine and Rehabilitation*, *6*(1), 34–43.

Young, A. J., Sawka, M. N., Epstein, Y., Decristofano, B., & Pandolf, K. B. (1987). Cooling different body surfaces during upper and lower body exercise. *Journal of Applied Physiology*, *63*(3), 1218–1223.