The physiological and perceptual demands of running on a curved non-motorized treadmill compared to running on a motorized treadmill set at different grades

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Abstract

Purpose: To determine which motorized treadmill (MT) grade best replicates the physiological and perceptual demands presented by the concave curved design of the non-motorised Woodway Curve XL treadmill (cNMT).

Method: Ten physically active male students completed, after a familiarization session, a 6 min run at a target velocity of 2.78 $m \cdot s^{-1}$ on the cNMT (cNMTrun). The individual running velocity of cNMTrun was then used as warm-up and experimental running velocity in three subsequent visits, in which participants ran for 6 min on the MT set at different grades (4%, 6% and 8%). In all experimental trials (cNMTrun, 4MTrun, 6MTrun and 8MTrun) and in the warm-up of the participants' third visit (1MTrun), oxygen consumption ($\dot{V}O_2$) and heart rate (HR) were monitored, and ratings of perceived exertion (RPE) obtained.

Results: HR in cNMTrun was significantly higher compared to all MT trials. $\dot{V}O_2$ and RPE were significantly higher in cNMTrun compared to 1MTrun and 4MTrun, but not different to 6MTrun and 8MTrun. The relationship between $\dot{V}O_2$ and MT grade was highly linear, and using this regression equation, the incline of the cNMT was estimated to mimic a 6.9% MT grade.

Conclusion: On matched running velocities, the physiological and perceptual demands of running on the cNMT are similar to a 6-8% MT grade. These findings can be used as reference value by athletes and coaches in the planning of cNMT training sessions, and amend running velocities accordingly. Future studies are needed to determine whether this estimate is similar for lighter and/or female runners.

Introduction:

A variety of non-motorized treadmill (NMT) designs have become widely available to sports scientists and the general public. NMTs are participant driven and allow runners to self-select and change their pace in a subconscious fashion with every treadmill contact. [1] This makes the overall locomotion more consistent with outdoor running, and allows for a more ecologically valid lab assessment of running performance. A recently developed NMT with a concave curved surface ((cNMT); Woodway Curve XL, Woodway Inc, USA) has received considerable scientific interest. When compared to running on matched submaximal velocities on a motorized treadmill (MT; MT grade 1%), the physiological responses and ratings of perceived exertion (RPE) were considerably greater on the cNMT. [1–4] This was accompanied by a less efficient running economy and a larger caloric cost of movement. [1,3,4] When matched for exercise intensities, it was established that on the cNMT a comparable oxygen consumption ($\dot{V}O_2$) and heart rate (HR) are achieved on running velocities up to 25% lower than on a MT. [1,5–7] Despite these differences, the cNMT is thought to be a reliable and valid piece of lab equipment to evaluate self-paced high intensity interval training (HIIT) sessions, endurance and (repeated) sprint performance. [1,5,7,8,9]

The altered energy demands of the cNMT are likely closely linked to its mechanical characteristics and design (belt friction and curvature). Recently, Bruseghini et al., determined the friction of the 29kg heavy treadmill belt, which was found to equal 8.81 N. [4] In an attempt to determine the curvature of the cNMT, observational analysis revealed that participants contact the cNMT belt at an approximated five to ten degree incline above the horizontal, which then decreased throughout the stance phase. [2] Running on the cNMT clearly mimics uphill running, and therefore training adaptations may differ from overground or MT training. Uphill running represents a frequently prescribed form of HIIT in training regimes of distance runners [10,11] , and the cNMT might be a valuable asset when uphill training is geographically challenging. In aid to design appropriate exercise protocols for the cNMT, the current study was designed to determine which MT grade best replicates the physiological and perceptual demands of running on the cNMT.

Methods

Ten physically active male students (age 22±2 y, height 180±6 cm, mass 77±11 kg) visited the sports and exercise science lab on five different occasions over a three-week period. All participants provided voluntary written informed consent. The study received approval from the local ethics committee and was conducted in accordance with the Declaration of Helsinki.

Experimental Design

In their initial visit, participants familiarised with running on the cNMT and were instructed to run as close as possible to a target velocity of 2.78 $m \cdot s^{-1}$ (10 $km.h^{-1}$). During the second visit, participants ran for 6 min on the same target velocity (cNMTrun). Individual running velocities of cNMTrun were sampled at 4 Hz and assessed in the accompanying product software, and then used in the three subsequent visits as warm-up and experimental running velocity. In these remaining visits, participants ran for 6 min on the MT set at different grades (4%, 6% and 8%), in a randomized and counterbalanced order. Participants performed the same warm-up routine prior to all experimental trials, which involved a 6 min run on the MT with the grade set at 1%. [12] In all experimental runs (cNMTrun, 4MTrun, 6MTrun and 8MTrun) and in the warm-up of the participants' third visit (1MTrun), $\dot{V}O_2$ and HR were monitored continuously, and RPE were obtained on completion of the trial.

During the experimental runs, HR was measured using a Garmin HR monitor (910XT, Garmin Ltd., Switzerland), and respiratory parameters were sampled breath-by-breath, using open circuit spirometry (Oxycon Masterscreen CPX, Vyaire Medical, UK). Before each experimental trial, the gas analyser and the turbine flow meter were calibrated following the manufacturer's instructions.

All MT trials were run on a factory calibrated MT (Pulsar 3p, H/P Cosmos, Germany). Accuracy of both the cNMT and MT velocity measures were verified previously in our lab, and found to be within <1.1 % of the described speed. [1]

Statistical Analysis

Data were analysed using SPSS 23.0 (SPSS Inc., USA) and are presented as mean±standard deviation. Attainment of steady state in the last minute of each experimental condition was verified using Pearson correlation comparisons of $\dot{V}O_2$ and HR obtained in the 5th and 6th min, and paired t-tests. Differences in $\dot{V}O_2$, HR and RPE between cNMTrun and the experimental MT runs were compared using one-way repeated measures ANOVA, followed by post hoc Tukey tests. The significance level of all tests was set at $p<0.05$.

Results

Steady state in $\dot{V}O_2$ was confirmed, as no differences were found between the 5th and 6th min in any of the experimental trials (see table 1), however, HR was significantly higher in the 6th min of cNMTrun, 4MTrun, 6MTrun and 8MTrun compared to the 5th min. $\dot{V}O_2$, HR and RPE increased in a linear fashion with the increased MT grade (see table 2). $\dot{V}O_2$ and RPE were significantly higher in cNMTrun compared to 1MTrun and 4MTrun, but not different to 6MTrun and 8MTrun. The HR response in cNMTrun was significantly higher compared to all MT trials (see table 2).

>> table 1 and 2 here <<

The relationship between $\dot{V}O_2$ and MT grade was highly linear (see figure 1), and followed the equation: $\dot{V}O_2 = 1.73 * \% + 34.36$ ($r^2=0.99$). In this, $\dot{V}O_2$ is calculated in $ml.kg^{-1}.min^{-1}$, and % represents the MT grade. Using this equation and the $\dot{V}O_2$ obtained in cNMTrun, the incline of the cNMT was estimated to replicate a 6.9% MT grade.

>> figure 1 here<<

Discussion

The purpose of the current study was to identify which MT grade best replicated the physiological and perceptual demands presented by the concave curved design of the Woodway Curve XL. The main finding was that $\dot{V}O_2$ and RPE were similar in cNMTrun, 6MTrun and 8MTrun. The relationship between $\dot{V}O_2$ and MT grade was highly linear, and using this regression equation, the incline of the cNMT was estimated to mimic a 6.9% MT grade.

For an accurate evaluation of the energy demands of the experimental trials, attainment of a steady state in every condition was required. [12] Running on the cNMT by design is unsteady, as the velocity fluctuates with every treadmill contact. Running velocity of cNMTrun averaged $2.78 \pm 0.11 m \cdot s^{-1}$, and the participants' individual running velocity in cNMTrun was used in subsequent MT trials, however, without any random fluctuations in pace. Steady state of $\dot{V}O_2$ was confirmed, as no differences were found between the 5th and 6th min in any of the experimental trials. HR typically increased throughout the 6 min runs, which may indicate (some) participants where running near or above their lactate threshold, especially in cNMTrun, 6MTrun and 8MTrun. However, despite the potentially elevated blood lactate levels, all participants attained a steady state $\dot{V}O_2$ and were able to complete all experimental conditions.

No differences were found in $\dot{V}O_2$ between cNMTrun, 6MTrun and 8MTrun. Additionally, RPE were similar between these experimental trials, indicating a similar perceived effort. These findings confirm the previous observations of Smoliga et al,. [2] The current regression equation for $\dot{V}O_2$ and MT grade was similar to data presented by Jones & Doust [12] and Padulo et al., [10] of trained runners who ran on different velocities at a variety of MT grades. $\dot{V}O_2$ at 1MTrun in the current study (36.2 ± 3.9 $ml.kg^{-1}.min^{-1}$) was considerably higher compared to the findings of Jones & Doust [12] (31.5 ± 1.4 $ml.kg^{-1}.min^{-1}$), despite participants in the current study ran on a slower velocity. These differences can be attributed to the training status of the participants, whereas the trained runners in Jones & Doust [12] can be expected to have a greater running economy than the current participants. Our regression equation may therefore overestimate the $\dot{V}O_2$ for trained runners, and should be used with caution. Additionally, Edwards et al., reported that females perceived running on the cNMT harder than males over a range of velocities, which was accompanied by a higher relative $\dot{V}O_2$ for female runners. [3] These differences are most likely a reflection of the lighter body mass of female runners, which may put them at a disadvantage in overcoming the treadmill belt resistance. [3]

Practical Applications

The cNMT can be used to assess running performance in the lab and to perform 'uphill' HIIT sessions, when uphill training is geographically challenging. [1,5,7,8,9] The findings of the current study can be used as reference value by athletes and coaches in the planning of cNMT training sessions, and amend running velocities accordingly. The physiological and perceptual responses for lighter and/or female runners may be better replicated by a larger MT grade and future research is needed to establish the regression equation for these populations.

Conclusion:

On matched running velocities, the physiological and perceptual demands of running on the cNMT are similar to a 6-8% MT grade. Using the highly linear regression equation for $\dot{V}O_2$ and MT grade, the incline of the cNMT was estimated to mimic a 6.9% MT grade.

Conflict of interest statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Bibliography

1. Schoenmakers PPJM, Reed KE. The physiological and perceptual demands of running on a curved non-motorised treadmill: Implications for self-paced training. *J Sci Med Sport*. 2018. doi:10.1016/j.jsams.2018.05.011
2. Smoliga JM, Hegedus EJ, Ford KR. Increased physiologic intensity during walking and running on a non-motorized, curved treadmill. *Phys Ther Sport*. 2015;16(3):262-267. doi:10.1016/j.ptsp.2014.09.001
3. Edwards RB, Tofari PJ, Cormack SJ, Whyte DG. Non-motorized Treadmill Running Is Associated with Higher Cardiometabolic Demands Compared with Overground and Motorized Treadmill Running. *Front Physiol*. 2017;8:914. doi:10.3389/fphys.2017.00914
4. Bruseghini P, Tam E, Monte A, Capelli C, Zamparo P. Metabolic and kinematic responses while walking and running on a motorised and a curved non-motorised treadmill. *J Sports Sci*. August 2018:1-8. doi:10.1080/02640414.2018.1504605
5. Stevens CJ, Hacene J, Wellham B, et al. The validity of endurance running performance on the Curve 3\n TM\n non-motorised treadmill. *J Sports Sci*. 2015;33(11):1141-1148. doi:10.1080/02640414.2014.986502
6. Morgan AL, Laurent CM, Fullenkamp AM. Comparison of VO2peak Performance on a Motorized vs. a Nonmotorized Treadmill. *J Strength Cond Res*. 2016;30(7):1898-1905. doi:10.1519/JSC.0000000000001273
7. Waldman HS, Heatherly AJ, Waddell AF, Krings BM, O?Neal EK. 5-km Time trial reliability of a non-motorized treadmill and comparison of physiological and perceptual responses versus a motorized treadmill. *J Strength Cond Res*. May 2017:1. doi:10.1519/JSC.0000000000001993
8. Gonzalez AM, Wells AJ, Hoffman JR, et al. Reliability of the Woodway Curve(TM) Non-Motorized Treadmill for Assessing Anaerobic Performance. *J Sports Sci Med*. 2013;12(1):104-108. http://www.ncbi.nlm.nih.gov/pubmed/24149732. Accessed May 23, 2017.
9. Tofari PJ, McLean BD, Kemp J, Cormack S. A self-paced intermittent protocol on a non-motorised treadmill: a reliable alternative to assessing team-sport running performance. *J Sports Sci Med*. 2015;14(1):62-68. http://www.ncbi.nlm.nih.gov/pubmed/25729291. Accessed November 5, 2018.
10. Padulo J, Powell D, Milia R, Ardigò LP, Koralsztein J. A Paradigm of Uphill Running. Seebacher F, ed. *PLoS One*. 2013;8(7):e69006. doi:10.1371/journal.pone.0069006
11. Ferley DD, Osborn RW, Vukovich MD. The effects of uphill vs. level-grade high-intensity interval training on VO2max, Vmax, V(LT), and Tmax in well-trained distance runners. *J Strength Cond Res*. 2013;27(6):1549-1559. doi:10.1519/JSC.0b013e3182736923
12. Jones AM, Doust JH. A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *J Sports Sci*. 1996;14(4):321-327. doi:10.1080/02640419608727717

figure captions:

Figure 1: The relationship between $\dot{V}O2$ and MT grade (running velocity is 2.78±0.11 $m.s^{-1}$)
* Significant different ($p<0.05$) from: ^{a} 1% grade, ^{b} 4% grade, ^{c} 6% grade, ^{d} 8% grade

Tables:

Table 1: Difference (Δ) in mean $\dot{V}O2$ and HR between 5th and 6th min in all experimental trials

	cNMTrun	1MTrun	4MTrun	6MTrun	8MTrun
Δ $\dot{V}O_2$ ($L \cdot min^{-1}$)	0.14±0.22	0.09±0.10	0.04±0.27	-0.06±0.32	-0.07±0.24
Δ $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	1.94±3.4	1.2±3.0	0.48±3.6	-0.81±4.2	-0.78±3.1
Δ HR (beats/min)	2.3±1.3	0.8±1.8	2.0±2.4	2.5±1.3	1.6±1.1

Note: $\dot{V}O_2$, Oxygen consumption; HR, Heart rate; RPE, Ratings of perceived exertion

Table 2: Physiological and Perceptual responses for all experimental trials

	cNMT	1MTrun	4MTrun	6MTrun	8MTrun
$\dot{V}O_2$ ($L \cdot min^{-1}$)	3.57±0.4 ^{b,c}	2.53±0.3 ^{a,c,d,e}	3.19±0.5 ^{a,b,d,e}	3.42±0.5 ^{b,c,e}	3.73±0.4 ^{b,c,d}
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	46.4±3.7 ^{b,c}	36.2±3.9 ^{a,c,d,e}	41.3±2.8 ^{a,b,d,e}	44.2±2.8 ^{b,c,e}	48.6±4.2 ^{b,c,d}
HR (beats/min)	185±10 ^{b,c,d,e}	139±10 ^{a,c,d,e}	167±12 ^{a,b,d,e}	176±12 ^{a,b,c,e}	181±9 ^{a,b,c,d}
RPE (au)	14.7±3.1 ^{b,c}	9.5±1.4 ^{a,c,d,e}	12.7±2.5 ^{a,b,d,e}	14.0±2.9 ^{b,c,e}	15.4±2.1 ^{b,c,d}

Note: $\dot{V}O_2$, Oxygen consumption; HR, Heart rate; RPE, Ratings of perceived exertion.

Significant different ($p<0.05$) from: ^{a} cNMT, ^{b} 1% grade, ^{c} 4% grade, ^{d} 6% grade, ^{e} 8% grade