Bachelor thesis

Comparison of perceptual and physiological responses between track, motorized and non-motorized treadmill running at increasing velocity

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Forfatter: **Veronika Myran Wee**

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Norsk tittel: **Sammenligning av perseptuelle og fysiologiske responser mellom løping på bane, motorisert og non-motorisert tredemølle ved økende hastigheter**

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ABSTRACT

Veronika Myran Wee: Comparison of perceptual and physiological responses between track, motorized and non-motorized treadmill running at increasing velocity. Bachelor thesis in physical education and sport science. North-Trondelag University College, 29.05.2015.

Purpose: The aim of this study was to compare perceptual and physiological responses between running on three different modalities; an indoor athletics track, a motorized treadmill and a non-motorized treadmill when running 1000-meter intervals at three different velocities. **Methods:** Ten male athletes (age 24 ± 3.06 years, body mass 69.8 ± 6.91 kg, height 180.0 ± 6.03 cm, VO_{2peak} 69.0 ± 6.70 mL/kg/min) conducted three 1000-meter laps at 12 km/h, 14 km/h and 16 km/h on three different running modalities. The athletes had a 3-minute recovery between each lap. Rate of perceived exertion (RPE), heart rate and oxygen uptake was registered/measured during the last minute of each 1000-meter lap. Blood lactate concentration was measured during the recovery time right after each running lap. **Results:** RPE, heart rate and oxygen uptake were significantly higher when running on the non-motorized treadmill compared to motorized treadmill and indoor track running. No significant difference was found in blood lactate concentration between running on track and motorized treadmill or between non-motorized treadmill and track, whereas blood lactate concentration was significantly higher on the non-motorized treadmill compared to motorized treadmill. **Conclusions:** The hypothesis that perceptual and physiological responses were higher for running on the non-motorized treadmill compared to track and motorized treadmill running was confirmed. Results from this study also concur with the hypothesis that running economy would be poorer when running on the non-motorized treadmill compared to track and motorized treadmill running. Further investigation should be initiated to determine why such differences occur, and what physiological adaptions the higher energy costs of non-motorized treadmill running leads to.

Key Words: Rating of perceived exertion, blood lactate concentration, heart rate, oxygen uptake, running economy, comparative study

SAMMENDRAG

Veronika Myran Wee: Sammenligning av perseptuelle og fysiologiske responser mellom løping på bane, motorisert og ikke-motorisert tredemølle ved økende hastigheter. Bacheloroppgave i kroppsøving og idrett, Høgskolen i Nord-Trøndelag, 29.05.2015.

Hensikt: Hensikten med dette studiet var å sammenligne perseptuelle og fysiologiske responser mellom løping på tre ulike underlag; innendørs friidrettsbane, motorisert tredemølle og ikke-motorisert tredemølle ved å løpe 1000-metersintervaller på tre ulike hastigheter. **Metode:** Ti mannlige idrettsutøvere (alder 24 ± 3.06 år, kroppsvekt 69.8 ± 6.91 kg, høyde 180.0 ± 6.03 cm, VO_{2peak} 69.0 ± 6.70 mL/kg/min) gjennomførte tre 1000-meter-drag på 12 km/t, 14 km/t og 16 km/t på tre ulike løpsunderlag. Utøverne hadde tre minutters pause mellom hvert drag. Subjektiv anstrengelse (RPE), hjertefrekvens og oksygenopptak ble registrert/målt i det siste minuttet av hvert 1000-meterdrag. Blodlaktatkonsentrasjon ble målt i pausen rett etter hvert løpsdrag. **Resultat:** RPE, hjertefrekvens og oksygenopptak var signifikant høyere ved løping på ikke-motorisert tredemølle sammenlignet med løping på motorisert tredemølle og på innendørs friidrettsbane. Ingen signifikante forskjeller ble funnet i blodlaktatkonsentrasjon mellom løping på bane og motorisert tredemølle eller mellom ikke-motorisert tredemølle og bane, mens blodlaktatkonsentrasjon var signifikant høyere ved løping på ikke-motorisert tredemølle i forhold til motorisert tredemølle. **Konklusjon:** Hypotesen om at perseptuelle og fysiologiske responser var høyere ved løping på ikke-motorisert tredemølle sammenlignet med løping på bane og på motorisert tredemølle ble bekreftet. Også hypotesen om at løpsøkonomi ville være dårligere ved løping på ikke-motorisert tredemølle sammenlignet med løping på bane og motorisert tredemølle ble bekreftet. Videre studier bør gjennomføres for å kartlegge hvorfor slike forskjeller oppstår, og for å finne ut mer om hvilke fysiologiske adaptasjoner de høyere energikostnadene ved løping på ikke-motorisert tredemølle fører med seg.

Nøkkelord: Vurdering av opplevd anstrengelse, konsentrasjon av blodlaktat, hjertefrekvens, oksygenopptak, løpsøkonomi, komparativ studie

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1. INTRODUCTION

When running, the energy cost of the task performed depends upon a number of biomechanical, physiological and environmental factors. Running modality is a significant environmental factor that can affect both biomechanical and physiological factors, and can have great impact on runners' energy costs during a training session or a race. Nowadays, a few new running ergometers have entered the market. In this regard, it would be both interesting and required, to investigate perceptual and physiological responses on these new running modalities compared to the traditional modality types like motorized treadmills and track running. This kind of knowledge will be considered useful for both athletes and coaches regarding the use of new ergometers in their training work.

The energy demand for a given velocity of submaximal running is often referred to as running economy (RE). Running economy is proportional to the oxygen cost for a given velocity, and is determined by measuring the steady-state oxygen uptake (VO_2) during submaximal running (Morgan, Martin & Krahenbuhl, 1989). Expressions of RE can be made in several ways, with the most usual one being to interpolate the VO_2 to a common running velocity, most commonly 268 m/min, or in other words 16 km/h. Expressing RE as the VO_2 required to run 1 kilometer is another method used (Foster & Lucia, 2007). Representative VO_2 values for the aerobic cost of running for different types of runners are presented in Table 1 and Table 2 (Saunders, Pyne, Telford & Hawley, 2004). Having good RE implies less use of energy (and therefore less oxygen use) than runners with poor RE when running at the same steady-state speed (Thomas, Fernhall & Granat, 1999). Among runners with a similar VO_{2max} (maximal oxygen uptake), RE can vary as much as 30% (Daniels, 1985). The strong relationship between RE and distance running performance is well documented and clearly indicates that a substantial improvement in RE can improve the performance for distance runners (Anderson, 1996; Conley & Krahenbuhl, 1980; Morgan & Craib, 1992; Costill, 1967).

Table 1. Reference values for running economy at 16 km/h in different populations in terms of the VO_2 required to run 1 minute (Foster & Lucia, 2007)

Population	VO_2 (mL/kg/min)
Reference value (ACSM)	58
Elite Europeans/North Americans	55
Elite East Africans	50

Notes= ACSM= American College of Sports Medicine

Table 2. Reference values for running economy at 16 km/h in different populations in terms of the VO_2 required to run 1 kilometer (Foster & Lucia, 2007)

Population	VO_2 (mL/kg/km)
Reference value (ACSM)	218
Elite Europeans/North Americans	210
Elite East Africans	187

Notes= ACSM= American College of Sports Medicine

While RE and measuring VO_2 represents the aerobic metabolism, the total energy cost when running reflects the sum of both the aerobic and the anaerobic work performed. The aerobic demand to run at a given speed (measured as VO_2 in mL/kg/min or VO_2 in mL/kg/km) may therefore not account for the total energy cost of the running task. By measuring other variables in addition to VO_2 the likelihood of capturing also the anaerobic energy costs, and thereby the total energy costs of the task, increases. Measuring heart rate (HR) is the simplest and most effective way of monitoring intensity. Heart rate oscillates in synchrony with respiration, and provides immediate and consistent feedback about an athlete's intensity level (Keytel, Goedecke, Noakes, Hiiloskorpi, Laukkanen, van der Merwe & Lambert, 2005). Blood lactate concentration (BLa) measures are also used to determine athletes' physiological response to exertion. By measuring BLa at increasing intensities we can determine at which intensity an athlete's production of BLa exceeds the elimination, known as the anaerobic threshold (Brooks, 1985). Measuring rating of perceived exertion (RPE) gives a good picture of an athlete's subjective perception of the tasks energy costs, and is shown to correlate with the athlete's heart rate and lactate levels (Noble, Borg, Jacobs, Ceci & Kaiser, 1983). By using multiple measuring instruments you are also more likely to capture differences between working methods used in training or testing.

Running on a track has generally been found to incur greater energy costs compared to motorized treadmill running (Williams, 1990). This may be due to a number of factors, i.e. air resistance when running on track, visual cues from moving surroundings or athletes' extend of familiarity with the chosen modality (Jones & Doust, 1996). The effect of air resistance becomes more pronounced at high running speeds, and higher differences in energy costs between track running and motorized treadmill running are therefore likely to be observed as speed increases (Daniels, 1985). Other factors that can cause differences in perceptual and physiological responses between track and motorized treadmill running are characteristics in running surface, and thus the momentum runners gain from the moving treadmill belt or a change in locomotion characteristics on the various running surfaces (Jones & Doust, 1996). Amongst others, Saunders et al. (2004) points at changes in technique between motorized treadmill running and track running, where the hamstring are more involved to produce propulsive forces. Yet, motorized treadmills are widely used and considered valid for the measurement of overground running performance. Jones and Doust (1996) emphasize a use of a 1% treadmill gradient to achieve the most strongly correlated VO_2 measures between such running modalities.

While the relationship between energy cost on motorized treadmills and track running to a certain degree has been investigated, fewer studies are conducted on the energy costs on non-motorized treadmills. Non-motorized treadmills, in contrast to motorized treadmills, do not have a motor to create belt motion, but rely on the athlete to drive the belt. In certain areas non-motorized treadmills are said to have greater resemblance to track running compared to motorized treadmills. For instance, opposite to running on a motorized treadmill, the runner dictates the speed of the treadmill belt on the NMT with every step, consistent with track running, whereas on a motorized treadmill the runner follows the speed of the treadmill. The non-motorized treadmill belt can therefore not serve as a motivator for the runner to maintain a high and consistent running speed during the performance of the task (Stevens, Hacene, Wellham, Sculley, Callister, Taylor and Dascombe, 2014). The non-motorized treadmill belt also forces the leg to actively pull through on each step, which is the same as for track locomotion (Franks, Brown, Coburn, Kersey & Bottaro, 2012). The power required to propel the treadmill belt on non-motorized treadmills does on the other hand increase with speed (Lakomy, 1987), and it is also found a high intrinsic resistance of the running belt (Stevens et al., 2014). This differs significantly from both track and motorized treadmill running, along with the need to accelerate the treadmill belt between steps (Highton, Lamb, Twist & Nicholas, 2012).

When it comes to energy costs on non-motorized treadmills, studies utilizing large non-motorized treadmills have consistently shown higher energy costs in comparison with motorized treadmills, even at walking speeds (Otto, Wygand, Flanagan, McPhilliamy & Steward, 1997; De Witt, Lee, Wilson & Hagan, 2009; Hagan, De Witt, Laughlin, Lee & Loehr, 2010). Test subjects have also commented that the exercise was more difficult on non-motorized treadmills, and that locomotion on the non-motorized ergometers felt similar to running up an incline (Lee, De Witt, Smith, Laughlin, Loehr, Norcross & Hagan, 2006).

Non-motorized treadmills in various and improved variants have become readily available to sports scientists and the general public the last few years. The Force Non-motorized treadmill (Woodway, Waukesha, WI, USA) works by the act of pushing backwards on a flat treadmill belt, while the Curve Non-motorized treadmill (NMT) (Woodway, Waukesha, WI, USA) works by actively pushing backwards on an inclined treadmill belt. Both the Force Non-motorised treadmill (Highton et al., 2012; Lakomy, 1987) and the NMT (Gonzalez, Wells, Hoffman, Stout, Fragala, Mangine, McCormack, Townsend, Jajtner, Emerson & Robinson, 2013; Mangine, Hoffman, Gonzalez, Wells, Townsend, Jajtner, McCormack, Robinson, Fragala, Fukuda & Stout, 2014) have demonstrated good validity and reliability for sprint performance assessment in the laboratory, where motorized treadmills due to restrictions in acceleration are not suitable (Stevens et al., 2014).

As of today, two known studies have examined endurance running on an NMT. McCarron, Hodgson & Smith (2013) found average performance time for a 5 km trial on the NMT to be 28.4 ± 4.6 minutes. With the subjects having an average VO_{2max} of 53 ml/kg/min, this performance time would be considered slow. Stevens et al. (2014) performed a study, in which subjects ran a 5 km time trial on both the NMT and on an outdoor athletics track. They compared running performance while running on the two running modalities, and similar to McCarron also found running time to be significantly longer on the NMT (1264 ± 124 s vs. 1536 ± 130 s for track and NMT, respectively; $p<0.001$). Still, measures of physiological and perceptual responses showed cardiorespiratory responses of heart rate and VO_2 to have strong correlations (r = 0.68-0.96, ICC = 0.75-0.97, $p>$ 0.05), while BLa and RPE at the end of the NMT trial were significantly higher compared to the track trial ($p<0.05$).

Stevens et al.'s study (2014) found differences in energy demands for endurance running on the NMT compared to endurance running on a track. Since characteristics in the treadmill belt on the NMT leads to higher power required as speed increases (Lakomy, 1987), investigating energy costs on the NMT for graded exercise intensities, where the intensities are higher than for endurance running, would be necessary. On the basis of this argument it was hypothesized that higher energy costs will occur on the NMT when running 1000 meter at 12 km/h, 14 km/h and 16 km/h, respectively. To compare perceptual and physiological responses on the

NMT both to a motorized treadmill and to track running would be considered vital knowledge, as it would provide a direct comparison between all modalities.

The main purpose of the study was to compare perceptual responses (rate of perceived exertion; RPE) and physiological responses (oxygen uptake, heart rate and blood lactate concentration) when subjects were running 1000-meter intervals on an indoor track, a motorized and a non-motorized treadmill at three increasing intensities (12 km/h, 14 km/h and 16 km/h). It was hypothesized that perceptual and physiological responses on the NMT would be higher compared to the ones for motorized treadmill and track when running 1000 meter-laps at 12 km/h, 14 km/h and 16 km/h.

Running economy is a major factor for determining running performance. Measuring running economy expresses the oxygen demand requirement to run at a given velocity. Running economy is traditionally measured in the laboratory by running at submaximal intensities below anaerobic threshold on a motorized treadmill. Although this is not the same as overground running, RE measured on motorized treadmills under controlled conditions is highly correlated to RE over ground (Saunders et al., 2004). It is necessary to address which modality provides the most economical running to determine RE on non-motorized treadmills versus track and motorized treadmill running. Therefore, the second purpose of this study was to see if there were any differences in running economy when running 1000-meter intervals at increasing intensity (12 km/h, 14 km/h and 16 km/h) on three different running modalities; an indoor athletics track, a motorized treadmill and a non-motorized treadmill. It was hypothesized that RE would be poorer when running on the NMT compared to RE for track and motorized treadmill running.

2. METHODS

2.1. Experimental design

The study during the experimental design compared perceptual and physiological responses between track, motorized and non-motorized treadmill running on well-trained males by using a within-subjects crossover design. Subjects performed three tests each, one on a curved non-motorized treadmill, the other on a motorized treadmill and another on an indoor 200-meter tartan track in a counterclockwise direction. Oxygen uptake, blood lactate concentration, heart rate and RPE were measured and registered both during and after three different submaximal stages of 1000 meter at increasing intensities on each of the different running modality. Tests were performed on separate days with proper rest time in between. In order to reduce intrasubject variability, both the time of day, the shoes worn as well as the testing equipment were all standardized for the three tests. Room temperature was centrally controlled and set to 20-25°C. Both treadmill tests took place in a test laboratory in Trønderhallen, a sports hall located next to the University College in Nord-Trøndelag (HiNT). The track test was recorded on an indoor athletics track affiliated to Steinkjer Upper Secondary School. All testing sessions were completed within seven weeks in January, February and March 2015.

2.2. Subjects

Ten well-trained males were recruited for the current study. The group of subjects consisted of six long distance runners, two middle distance runners, one biathlete and one cross-country skier. Subjects were familiar with running on a motorized treadmill and on an indoor track. All subjects performed one running session on the NMT at least one week prior to their NMT test to familiarize themselves with the running modality. The characteristics of subjects are presented in Table 3. Subjects were informed of experimental procedures before signing a written consent form to participate, and could at any point withdraw from the study.

Table 3. Subject characteristics

	Minimum	Maximum	Mean	SD
Age (years)	18	27	24	3.06
Body height (cm)	171.0	190.0	180.0	6.03
Body mass (kg)	58.9	84.4	69.8	6.91
VO_{2peak} (mL/kg/min)	62.1	83.36	69.0	6.70

Notes: SD = Standard deviation

2.3. Equipment

Participants performed the running tests on a non-motorized Curve NMT (Woodway, Waukesha, WI, USA), a motorized treadmill (h/p/cosmos quasar®, Germany), and on an indoor 200-meter tartan athletics track. For the motorized treadmill incline was set to 1%. To control the intensity of the tests, oxygen uptake (VO_2), blood lactate concentration (BLa) and heart rate (HR) were measured and subjective perception of exertion (RPE) registered for each 1000-meter lap. Oxygen uptake was determined and read from the MetaMax portable metabolic measurement system (MetaMax II Portable CPX Cortex Device). The MetaMax measured oxygen consumption on a breath-by-breath basis and determined the volume of oxygen consumed per minute. Blood samples (0.5 μL whole blood) were drawn from a fingertip for blood lactate analysis, using a Lactate Pro (Arkray Lactate Pro, Shiga, Japan). The fingertip was to be dipped in sterile water and wiped with a piece of paper before getting a needle stick with a sterile lancet (Microlet® 2 Lancing Device). The first blood drop was wiped off before collecting a blood sample with a test strip. To control heart rate a Garmin 910XT (Garmin Ltd., Schaffhausen, Switzerland) with a paired heart rate monitor was used. Heart rate was registered as the mean value from the last minute of each lap. RPE was measured using the Borg 6-20 Rating of Perceived Exertion scale, where 6 is referring to no exertion at all, and 20 allude maximal exertion (Borg, 1982).

2.4. Procedure

Prior to the first test on each new test day, and thereafter for every second test, the MetaMax was calibrated using a two-point calibration, involving a calibration against ambient air and a commercial gas of known concentration of O_2 (16.00 %) and CO_2 (4.00 %). A volume calibration for the MetaMax II was performed between each new test using a 3 litre high-precision calibration syringe (Calibration syringe D; SensorMedics, Yorba Linda, CA, USA). The Lactate Pro was calibrated prior to each new test, using a Lactate Pro™ calibration strip. After each test the used lancet was removed from the lancing device and replaced with a new one.

Subjects had been instructed not to perform vigorous activity for 24 hours prior to each test. Upon arrival, an anthropometric profile was obtained from each subject, consisting of height (KaWe PERSON-CHECK® height measuring device) and body weight (Soehnle Professional 7730). The subjects then put on the sports watch and paired heart rate monitor, and a backpack with the MetaMax placed inside. The MetaMax was connected to a facemask covering the subjects' nose and mouth. The backpack straps were adjusted and the mask fitted before starting the test.

The subjects performed a 5-minute warm-up at a self-selected speed on the same running modality the following test was to be conducted on. The protocol involved running 1000-meter laps at three pre-set running velocities (12 km/h, 14 km/h and 16 km/h) with a 3-minute recovery between each lap. Heart rate was continuously measured by a Garmin 910XT monitor, and registered along with RPE immediately after finishing each 1000 meter-lap. The blood lactate test was accomplished within the first minute of the 3-minute recovery time between the laps.

Peak VO_2 was measured during a fourth 1000-meter lap on each of the modalities at the highest velocity for the individual capacity to run for this distance. VO_{2peak} was calculated as the average VO_2 value from the last minute of the maximal running bout. To represent the subjects VO_{2peak} for this study the highest average value from the three running modalities was chosen.

2.5. Statistical analysis and calculations

Differences in VO_2, HR and RPE between trials were examined using a repeated 3 (modality: non-motorized treadmill, motorized treadmill, indoor track) x 3 (velocity: 12 km/h, 14 km/h, 16 km/h) analysis of variance (ANOVA) design. Post hoc analysis with Holm-Bonferroni correction of *p*-values was applied for all multiple comparisons. Paired t-tests were used to examine variation in blood lactate concentration, the reason being few BLa measures on one of the running modalities. Statistical analysis was performed using SPSS (version 21.0; SPSS, Inc., Chicago, IL) and Windows Excel (Microsoft Office for Windows, version 14.5.0). The subjective rating scale (RPE) values were treated as continuous variables. Statistical significance was accepted at $p \leq 0.05$. The effect size was evaluated with η^2 (Eta partial squared), where $0.01<\eta^2<0.06$ represents a small effect, $0.06<\eta^2<0.14$ a medium effect and $\eta^2>0.14$ a large effect (Cohen, 1988).

Running economy was calculated as the mean VO_2 during the last minute of each 1000-meter lap. For this study RE is expressed as the oxygen demand for a given time interval (mL/kg/min) and as the oxygen demand for a given distance (mL/kg/km).

3. RESULTS

3.1. Perceptual measures

ANOVA demonstrated a significant increase in RPE at increasing intensities ($F_{2,18}$=262.42, p<0.001, η^2=0.967, fig. 1). There was also significant difference in RPE between the three modalities ($F_{2,18}$=52.09, p<0.001, η^2=0.85, fig. 1). Post hoc comparisons showed that RPE was significantly higher for NMT running compared to the two other running modalities (p<0.001, fig. 1). Total values from all velocities showed the NMT values to be 15.7 ± 3.6 (48.6%) higher than average motorized treadmill and track values.

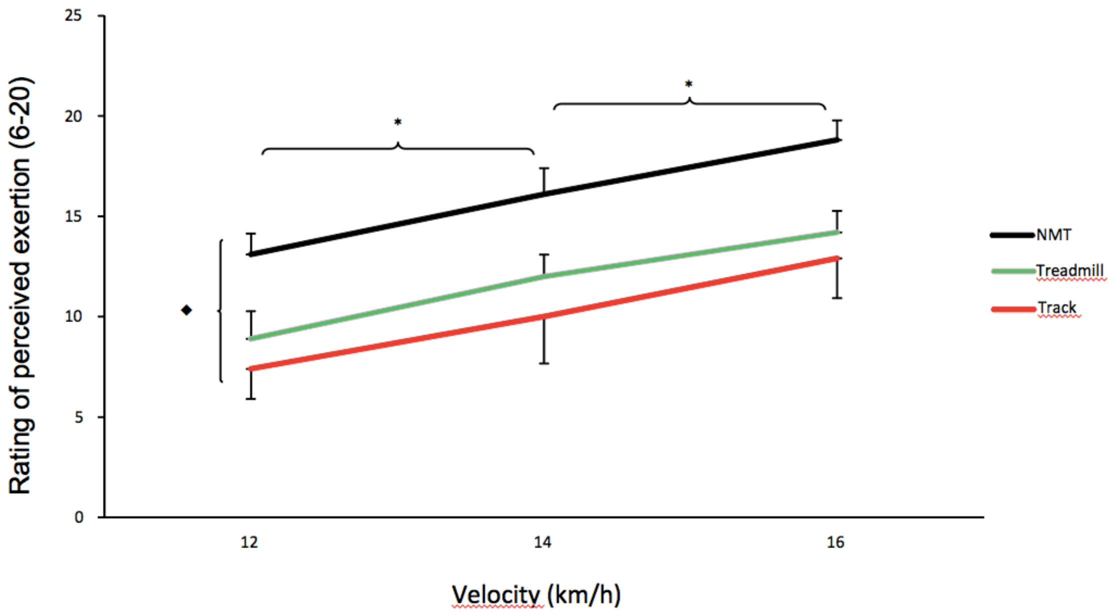

Figure 1. Mean (*SD*) RPE values shown for the 10 subjects at 12 km/h, 14 km/h and 16 km/h on all three modalities.
* = Indicates significant increase in RPE from 12 km/h to 14 km/h and from 14 km/h to 16 km/h
◆ = Indicates significant differences in RPE for NMT compared to track and motorized treadmill running

3.2. Physiological measures

3.2.1. Blood lactate concentration

Blood lactate concentrations from the three velocities on the three different modalities are displayed in Table 4. No significant differences were found in BLa between track and motorized treadmill running or between track running and running on the NMT. However, BLa was significantly higher on the NMT compared to motorized treadmill running on all velocities ($p \leq 0.002$ for 12 km/h, 14 km/h and 16 km/h, Table 4), with the total values for all velocities on the NMT being 12.9 ± 3.4 mmol/L higher than motorized treadmill values. Even though no significant difference was found in BLa between track running and running on the NMT, total BLa values for all velocities on the NMT was 10.3 ± 3.1 mmol/L higher than track values. At 12 km/h and 14 km/h all subjects were below anaerobic threshold corresponding to OBLA (4 mmol/L; Sjødin, Jacobs & Svedenhag, 1982) for track and motorized treadmill running, whereas 8 out of 10 had BLa below 4 mmol/L on the NMT at 12 km/h, and only 1 at 14 km/h. At 16 km/h all subjects had BLa values above anaerobic threshold on the NMT, while this was the case only for 3 of the subjects for both track and motorized treadmill running.

Table 4. Blood lactate concentration (mmol/L) for track, motorized treadmill and non-motorized treadmill 1000-meter running at increasing velocity.

Exercise	Track (*N*=4)	Motorized treadmill (*N*=10)	NMT (*N*=10)
12 km•h^{-1}	2.2 ± 0.7	1.4 ± 0.4	3.3 ± 1.2 *
14 km•h^{-1}	2.3 ± 1.0	1.9 ± 0.8	7.3 ± 3.0 *
16 km•h^{-1}	3.7 ± 1.0	3.3 ± 1.3	9.9 ± 2.6 *

Notes: Values are means ± SD, NMT = Curve Non-motorized treadmill

*Significantly different ($p \leq 0.002$) from motorized treadmill on this velocity

3.2.2. Heart rate

A significant increase in heart rate was found at increasing velocities ($F_{2,18}=141.29$, $p<0.001$, $\eta^2=0.940$, fig. 2). There was also a significant difference in heart rate between the three running modalities ($F_{2,18}=32.72$, $p<0.001$, $\eta^2=0.784$, fig. 2). Post hoc comparison showed that heart rate on the NMT was significantly higher compared to heart rate for track and motorized treadmill running ($p<0.001$, fig. 2). Average heart rate for track running was 140 (± 21) beats/min, for motorized treadmill running 146 (± 20) beats/min and for the NMT 174 (± 18) beats/min.

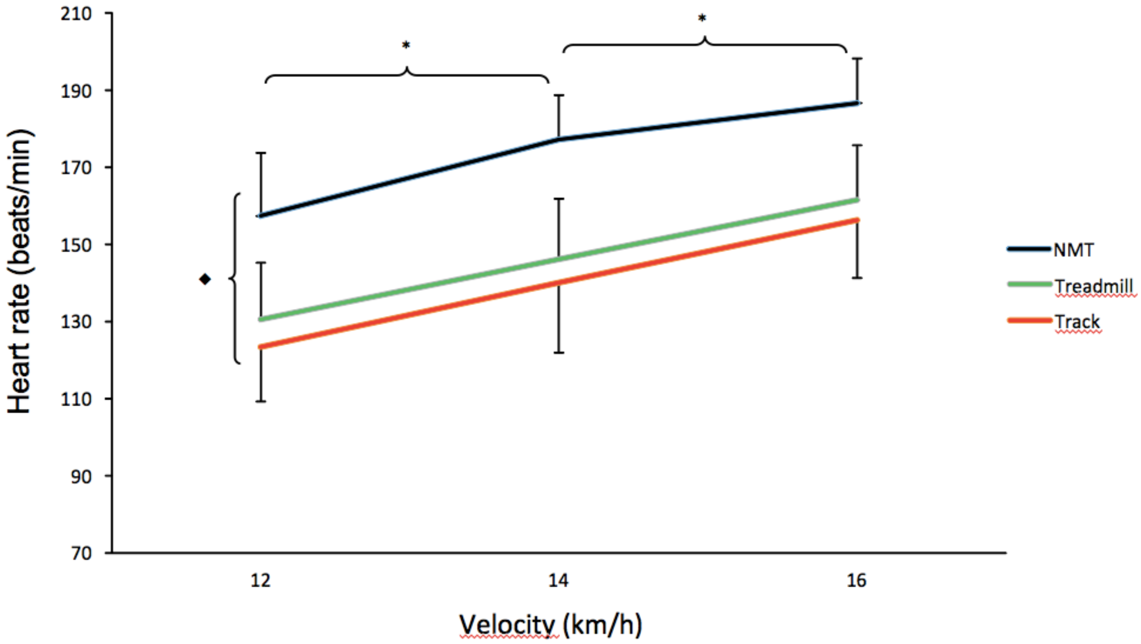

Figure 2. Mean (*SD*) heart rate shown for the 10 subjects at 12 km/h, 14 km/h and 16 km/h on all three modalities.
* = Indicates significant increase in heart rate from 12 km/h to 14 km/h and from 14 km/h to 16 km/h
◆ = Indicates significant differences in heart rate for NMT compared to track and motorized treadmill running

3.2.3. Aerobe energy cost

The oxygen uptake in terms of the VO_2 required to run for 1 minute increased significantly at increasing intensities ($F_{2,18}$=307.22, p<0.001, η^2=0.972, fig. 3). Oxygen uptake was also significantly different between the three modalities ($F_{2,18}$=69.83, p<0.001, η^2=0.886, fig. 3). Post hoc comparisons showed that VO_2 was significantly higher for the NMT compared to the two other modalities (p<0.001, fig. 3). The subjects achieved the highest VO_2 on the NMT (63.76 ± 7.67 mL/kg/min), followed by track running (48.78 ± 7.20 mL/kg/min) and motorized treadmill running (46.30 ± 6.44 mL/kg/min). Interaction between the two main effects, running modality and running velocity, was significant for VO_2 ($F_{4,36}$=4.54, p=0.005, η^2=0.335).

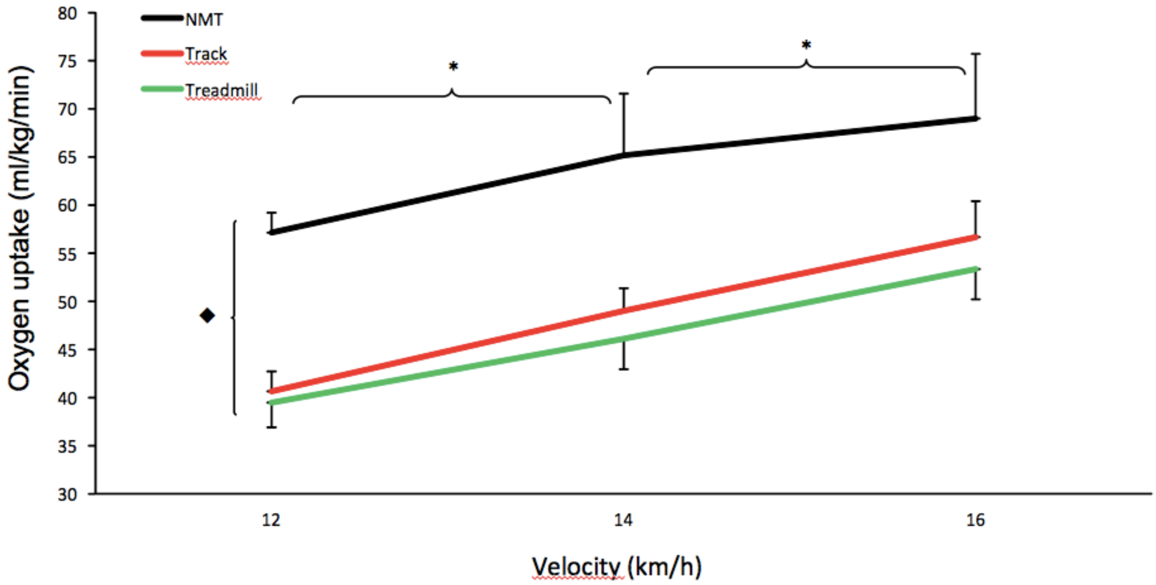

Figure 3. Mean (*SD*) oxygen uptake in terms of the VO_2 required to run 1 minute shown for the 10 subjects at 12 km/h, 14 km/h and 16 km/h on all three modalities.
* = Indicates significant increase in VO_2 between 12 km/h to 14 km/h and from 14 km/h to 16 km/h
◆ = Indicates significant differences in VO_2 for NMT compared to track and motorized treadmill running

3.3 Running economy

The analyses of running economy were conducted only for the 8 subjects with a BLa ≤4 mmol/L for all modalities. For track running only 4 BLa measures were registered. Based upon the low average values of the ones measured, and that two of the ones measured, which did have BLa below 4 mmol/L, were the subjects with the lowest VO_{2peak} values, we can estimate that also the other subjects had BLa beneath 4 mmol/L for track running.

No significant difference was found in running economy in terms of VO_2 required to run 1 minute for track running compared to motorized treadmill running ($p=0.133$, fig. 5), whereas VO_2 on the NMT was significantly higher than on both other modalities ($p<0.001$, fig. 5); 42.47% higher than combined average values from track and motorized treadmill running. Measuring RE in terms of VO_2 required to run 1 kilometer showed NMT values to be highest (285.6 ± 24.52 mL/kg/km), followed by track (203.2 ± 10.38 mL/kg/km) and motorized treadmill (197.3 ± 12.10 mL/kg/km).

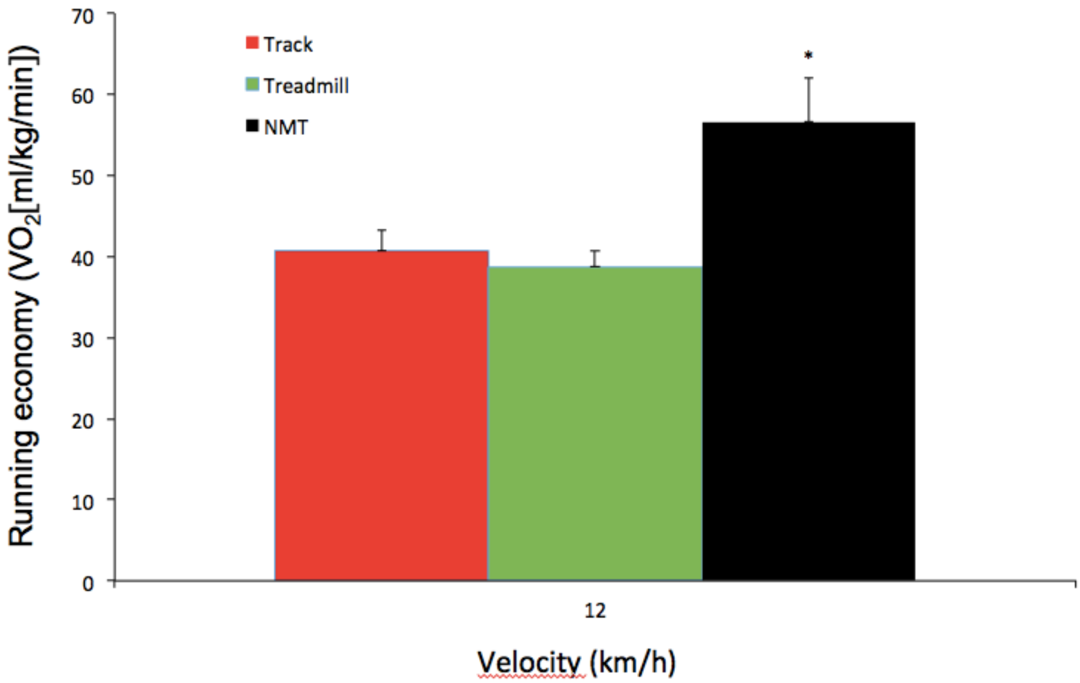

Figure 5. Mean (*SD*) oxygen uptake in terms of the VO_2 required to run 1 minute shown for the 8 subjects at 12 km/h on all three modalities.
* = Indicates a significant difference compared to track and motorized treadmill running

4. DISCUSSION

The main purpose of this study was to compare perceptual and physiological responses when running on an indoor track, a motorized treadmill and a non-motorized treadmill. It was hypothesized that perceptual and physiological responses on the NMT would be higher compared to similar responses on a motorized treadmill and on track when running 1000-meter laps at increasing intensities of 12 km/h, 14 km/h and 16 km/h. The second purpose was to investigate possible differences in running economy between track, motorized and non-motorized treadmill running. It was hypothesized that running economy would be poorer when running on the NMT compared to running economy for track and motorized treadmill when running 1000-meter intervals at increasing velocity.

4.1 Perceptual and physiological responses

The main findings were that running on the NMT requires greater energy costs than both track and motorized treadmill running, which concurs with the hypothesis. Subjectively, running on the NMT was physically more demanding than running on the track or the motorized treadmill, as judged by the RPE values for NMT being 48.6% higher than track and motorized treadmill values. RPE values increased linearly from 12 km/h to 14 km/h and from 14 km/h to 16 km/h for all modalities. This is logical considering the stepwise increase in running velocity.

Also physiological measures of the task performed were higher for the NMT compared to the two other modalities. Blood lactate concentration was significantly higher on the NMT compared to motorized treadmill values. No significant difference was found in blood lactate concentration between NMT and track running, but NMT values were still 10.3 ± 3.1 mmol/L higher compared to those on track. Not finding significant differences between NMT and track blood lactate concentration may be due to fewer measures for track running, and therefore wrong statistical analysis.

While this is, as known today, the first study to compare NMT running to both track and motorized treadmill running, others who compared NMT to outdoor track running also found RPE and blood lactate concentration to be significantly higher for the NMT (Stevens et al., 2014). That study suggests the NMT's curved incline to be the reason for higher RPE and blood lactate concentration values on the NMT compared to track running, since it might have increased the load of the subjects. Accordingly, the high intrinsic resistance of the running belt and the treadmill belts need to be accelerated between steps (Highton et al., 2012), may also have increased the load of the subjects, and may therefore have lead to higher RPE and blood lactate concentration values on the NMT compared to the two other running modalities.

High values for blood lactate concentration on the NMT indicate that subjects were close to or above anaerobic threshold corresponding to OBLA already at 12 km/h. Subjects were for certain above threshold at 14 km/h and 16 km/h on the NMT, as judged by average values of 7.3 ± 3.0 and 9.9 ± 2.6 for 14 km/h and 16 km/h, respectively. This was not the case for track and motorized treadmill running, where subjects were close to or above blood lactate concentrations corresponding to OBLA only for the 16-km/h laps. Anaerobic processes involved because of high workload may be one of the main reasons to fatigue. The anaerobic capacity of a runner may therefore be of importance when running 1000-meter intervals on the NMT, even at relative slow running speed.

A significant difference on the NMT compared to track and motorized treadmill running was also found for heart rate and VO_2. Heart rate and VO_2 increased linearly for track and motorized treadmill running as a consequence of increased intensity. However, for NMT running, heart rate and VO_2 values almost flatten out between 14 km/h and 16 km/h. This indicates that for NMT running, the aerobe metabolism persists without increasing significantly as speed increases, and that a significant increase in anaerobe metabolism is covering for the rest of the energy demand. This is verified by the high and increasing BLa values for NMT running at 14 km/h and 16 km/h, and may be explained by the increase in power required to propel the belt as speed increases (Lakomy, 1987). The lack of significant difference between heart rate and VO_2 for track and motorized treadmill running may originate from the treadmill gradient of 1% set to replicate demands for track-running (Jones & Doust, 1996).

The findings of higher heart rate and VO_2 on the NMT compared to track and motorized treadmill running is consistent with other studies that conducted tests on larger, flat non-motorized treadmills in comparison with motorized treadmills (Otto et al., 1997; De Witt et al., 2009; Hagan et al., 2010). Newer studies utilizing the Curve NMT did however found cardio-respiratory responses to be similar for NMT and outdoor track (Stevens et al., 2014). They did however conduct an endurance running test, and achieving similar heart rate and

VO_2 responses on the two running modalities could be due to increased energy costs caused by the need to overcome wind resistance when running on track outdoors. The fact that the power required to propel the treadmill belt increases with speed (Lakomy, 1987) can also explain why heart rate and VO_2 for endurance running at slower speeds is similar between NMT and track running, but not when running at higher velocities, like our running test.

By extrapolating VO_2 from 12 km/h on the NMT (Figure 3) with an imaginary horizontal line we can se that the aerobic energy demands for the NMT at 12 km/h are higher for track and motorized treadmill running at both 14 km/h and 16 km/h, but that it is approaching at 16 km/h. In order to run at the NMT with the same aerobe energy demands as for track and motorized treadmill running, one will need to adjust with a decrease in speed with at least 4 km/h.

4.2 Running economy

Running on track and motorized treadmill required less VO_2 than the NMT for submaximal running, and thus required less energy to carry out the specific task. Running economy expressed as the VO2 required to run 1 minute was 40.7 mL/kg/min, 39.5 mL/kg/min and 57.1 mL/kg/min when running at 12 km/h for track, motorized treadmill and non-motorized treadmill, respectively. Expressed in terms of the VO_2 required to run 1 kilometer running economy was 203.2 mL/kg/km, 197.3 mL/kg/km and 285.6 mL/kg/km for track, motorized and non-motorized treadmill, respectively. The submaximal VO_2 for NMT was 42.5% higher than track and motorized treadmill values, indicating a significantly poorer running economy when running on the NMT. Track and motorized treadmill running thus appeared to encourage a more economical running than the NMT, with motorized treadmill having a slight, but not significant, lower VO_2 compared to track running. No significant difference in VO_2 between track and motorized treadmill running is in accordance with the literature when running at a 1% treadmill gradient (Jones & Doust, 1996).

Running economy on the NMT has upon today not been investigated. Running economy in terms of the VO_2 required to run 1 minute on 12 km/h on the NMT was 57 mL/kg/min compared to reference values from 16 km/h for elite Europeans or North Americans or for elite East African being 55 mL/kg/min and 50 mL/kg/min, respectively. Reference values measured as the VO_2 required to run 1 kilometer was 210 mL/kg/km and 187 mL/kg/km for elite Europeans or North Americans or for elite East African, respectively. For NMT running at 12 km/h running economy values were 285 mL/kg/km. Subjects conducting this study were well-trained athletes with a lot of running experience, but not elite runners. This may account for the differences between running economy on the NMT and reference values to a certain degree, but considering the difference of 4 km/h in running speed, the difference in running economy between reference values and NMT can be considered massive.

Differences in running economy between the NMT and track and motorized treadmill running may be due to characteristics with the modality, such as the belt inclination, belt resistance and the need to accelerate between steps (Highton et al., 2012). The curved incline may lead to the subjects running in a more forward leaning position (Franks et al., 2012). Hausswirth, Bigard and Guezennec (1997) found that running economy impaired during the last 45 minutes of a marathon treadmill run, partly explained by a greater forward lean. The NMT's curved belt may also lead to a greater vertical oscillation, since the subjects have to place their lead foot a little higher than the rear one in order to keep the belt moving. Cavanagh & Williams (1982) reported a better running economy connected to a slightly less vertical oscillation in elite runners. Differences in stride length and stride frequency may also occur because of treadmill characteristics. While some studies (Cavanagh & Williams, 1982; Bailey & Messier, 1991) found no differences in VO_2 when running on different stride lengths, decrease in stride length has also shown to impair running economy in elite runners (Hausswith et al., 1997). Even though Stevens et al. (2014) found mean stride rate on the NMT to be significantly lower compared to track running we cannot be certain that this also occurred on our NMT tests, which were conducted with shorter running laps and at higher, increasing intensities. Such questions are important and requires further investigation.

When measuring running economy, factors such as subjects' footwear, time of day of testing and prior training activity as well as air temperature may affect intra-individual variation in running economy (Morgan, 1988). Such factors were all standardized for our study and should therefore not play a large role in the disparity in running economy between the running modalities. For this study, it is not known why running on the NMT was less economical than track and motorized treadmill running, but NMT belt characteristics may be used as an explanation. This requires further investigation.

4.3. Methodical consideration

This study was limited by its small sample size as only 10 subjects restrict the degree to which meaningful conclusions can be drawn (Morgan, Baldini, Martin & Kohrt, 1989). Furthermore, the subjects were all experienced in running graden intensity exercises on both track and motorized treadmill, but had only run one familiarization test on the NMT. It has been suggested that a minimum of two familiarization trials, separated by at least 48 hours, should be required prior to experimental testing on the NMT to improve reliability (Gonzales et al., 2013; Hopker, Coleman, Wiles & Galbraith, 2009). Lack of familiarity with the running modality has shown to affect VO_2 (Morgan, 1988). Even though great differences in both perceptual and physiological responses between running on the NMT compared to track and motorized treadmill running most likely would occur even if the subjects were fully familiarized with the modality, it might be that some effect could have been eluded with additional familiarization tests prior to test start. Furthermore, in order to determine running economy on the NMT, running speed should be lower then the ones conducted in this study. It was not forecasted that the NMT would require such great energy costs that the athletes would approach or even cross the lactate threshold already when running at 12 km/h, thereof the chosen running velocities for this test. Additionally, in this study no EMG (electromyography), stride rate or positional measurements were performed. This could have given more detailed information about the muscle behavior and locomotion during running on the three running modalities.

5. CONCLUSION

Subjectively, running on the NMT was more demanding than track and motorized treadmill running. NMT running was also conducted with significantly higher cardio-respiratory responses. Additionally, running on the NMT requires a significant anaerobic component when compared to track and motorized treadmill running at the same speed. The hypothesis that perceptual and physiological responses were higher for running on the non-motorized treadmill compared to motorized treadmill and track running was therefore confirmed. Considering running economy, the submaximal VO_2 values for NMT was 42.5% higher than track and motorized treadmill values, indicating a significantly poorer running economy when running on the NMT. This concurs with the hypothesis.

Conducting training on modalities that require higher energy demands than those encountered in competition when running at the same speeds can be beneficial to achieve training efficacy. Exercising on the NMT may therefore prove to be useful. Alternatively, when using the NMT in training, one can run at lower velocities in order to replicate VO_2 demands. It should however be further investigated why differences in perceptual and physiological responses occur between the three running modalities. Further investigation should also be initiated to determine what physiological adaptions the higher energy costs of non-motorized treadmill running leads to, i.e. to avoid altered running techniques caused by the use of the NMT.

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