

A comparison between the cardiorespiratory responses of motorized and non-motorized treadmill protocols

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Dissertation submitted in fulfillment of the requirements for the degree *Master of Science* in Sport Science at the Potchefstroom Campus of the North-West University

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Oct 2017

It all starts here™



FOREWORD

I would like to acknowledge the following people for their support and guidance throughout the completion of this dissertation:

Firstly, to our God, thank you for the many blessings and talents you have given me. Thank you for allowing me to spread my wings!

I sincerely thank my study leaders Dr. Yolandi Willemse, and Dr. Martinique Sparks for your guidance throughout this study.

For Jean Verster and your team of distance runners, I thank you for your willingness to take part in this research study.

To my family and loved ones, I truly appreciate your encouragement, and support!

Lastly, I wish to thank my husband André for your endless support! Your continuous encouragement and unconditional love and care made the completion of this dissertation possible.

“The Lord God is my strength—He makes my feet like those of a deer, equipping me to tread my mountain heights.”

Habakuk 3:19

A motivational quote from my Father that has always served me well:

“Ek is so dankbaar dat God nie die beperkinge op ons plaas wat ons dikwels vir onself stel nie. Gemiddeldheid is nooit Sy visie vir ons nie. Hy roep ons om uitnemend te lewe. Hy maak ons meer as wat ons gedink het ons is.”

George Washington Carver (1884-1943)

DECLARATION

The principle author of this dissertation is Mrs. Jana Storm. The contribution of the author, supervisor and co-supervisor of this study is summarized in the following table:

Author	Contribution
Mrs. J. Storm	Author. Design and planning of manuscripts, compilation and execution of relevant testing procedures, literature review, data extraction, writing of manuscripts, and interpretation of results.
Co-authors	Contribution
Dr. Y. Willemse	Supervisor. Conceptualizing of project. Co-reviewer, assistance in planning and writing of manuscripts as well as interpretation of results. Critical review of contents, including dissertation and Articles 1 and 2.
Dr. M. Sparks	Co-supervisor. Co-reviewer, assistance in planning and writing of manuscripts as well as interpretation of results. Critical review of contents, including dissertation and Articles 1 and 2.

The following is a statement of the co-authors confirming their individual role in each study and giving permission that the manuscripts may form part of this dissertation.

I declare that I have approved the above mentioned manuscripts, and that my role in the study, as indicated above is representative of my actual contribution. I hereby give my consent that the above mentioned manuscripts may be published as part of the Masters dissertation of Mrs. Jana Storm.

Dr. Yolandi Willemse

Supervisor

Dr. Martinique Sparks

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SUMMARY

A comparison between the cardiorespiratory responses of motorized and non-motorized treadmill protocols

Maximal aerobic capacity ($\dot{V}O_{2max}$) can be considered an important performance determinant of distance runners' performance due to endurance events being performed at high percentages of one's $\dot{V}O_{2max}$. The protocol and running modality incorporated into the graded exercise test (GXT) needs to be considered when performing $\dot{V}O_{2max}$ tests on distance runners. The first objective of this study was thus to determine which motorized treadmill (MT) GXT protocol would allow elite male university-level distance runners to attain the highest cardiorespiratory responses ($\dot{V}O_{2max}$, time to exhaustion (T_{lim}), ventilatory threshold (VT), and respiratory compensation point (RCP)). Two GXT protocols were identified for this research study namely, the Adapted Incremental Speed Protocol (AISP) and the Incremental Speed and Incline Protocol (ISIP). The second objective of this research study was to determine which running modality, namely the MT or the Curve non-motorized treadmill (NMT), would elicit the highest cardiorespiratory responses. The AISP was compared to the Adapted Non-Motorized Incremental Speed Protocol (ANMIP). These objectives were achieved through a cross-sectional design by using elite male university-level distance runners.

In order to fulfill these objectives, elite male university-level distance runners were recruited. Twelve runners (age: 21.8 ± 3.0 yrs.; stature: 178.2 ± 6.5 cm; and body weight: 66.7 ± 4.7 kg) from a university of the North West Province in South Africa participated in this research study. For the first objective of this study, results obtained by the two GXT protocols performed on the MT were compared. Maximal cardiorespiratory responses obtained, as well as all cardiorespiratory responses of each corresponding minute, were compared. The $\dot{V}O_{2max}$ values attained by the ISIP (67.6 ± 5.0 vs. 65.0 ± 4.4 ml/kg/min) was statistically significantly higher ($p < 0.05$) than the AISP despite the longer T_{lim} (11.4 ± 1.2 vs. 13.6 ± 1.2 min). Consequently the ISIP is recommended to be used for the determination of elite male university-level distance runners' highest cardiorespiratory responses. Furthermore, GXT protocols with 1 km/h increases cannot be directly compared to GXT protocols with 1% increases in gradient and increments are advised to be adapted to enable more accurate comparison.

For the second objective of this study, results obtained by the AISP and ANMIP, performed on the MT and Curve NMT respectively, were compared. Maximal cardiorespiratory responses, as well as all cardiorespiratory responses of each corresponding speed, were compared. From the results obtained, the ANMIP attained statistically significantly higher ($p < 0.05$) $\dot{V}O_{2max}$ values (66.7 ± 4.0 vs. 65.0 ± 4.4 ml/kg/min) than the AISP. These values were also attained within a significantly shorter time (8.31 ± 0.87 vs. 11.42 ± 1.19 min). Unfortunately, when determining the ANMIP's intensity markers for exercise prescription, unrealistic VT and RCP values were attained. These values are not recommended for exercise prescription owing to the manifestation of the $\dot{V}O_2$ "slow component".

From results obtained by this study, it is clear that the ISIP is considered the more appropriate GXT protocol for elite male university-level distance runners. Use of the ISIP as standardized sport-specific GXT protocol by future coaches, elite male university-level distance runners and athletes' supporting staff will make more accurate determination of $\dot{V}O_{2max}$ values possible.

Keywords: Graded exercise test; oxygen consumption; Curve non-motorized treadmill; running modalities; physical exertion; running performance.

OPSOMMING

'n Vergelyking tussen die kardiorespiratoriese response van gemotoriseerde en ongemotoriseerde trapmeul protokolle

Maksimale aërobiese kapasiteit ($\dot{V}O_{2\text{maks}}$) kan beskou word as 'n belangrike determinant van langafstand-atlete se prestasie aangesien uithouvermoë-items plaasvind teen hoë persentasies van die atleet se $\dot{V}O_{2\text{maks}}$. Die gegradeerde oefeningtoetsprotokol (GOT) en hardloopmodaliteit moet in ag geneem word wanneer 'n $\dot{V}O_{2\text{maks}}$ toets gedoen word op langafstand-atlete. Die eerste doelstelling van hierdie studie was dus om vas te stel watter gemotoriseerde trapmeul- (GT) protokol elite manlike langafstand-atlete op universiteitsvlak sou toelaat om die hoogste kardiorespiratoriese response te bereik naamlik $\dot{V}O_{2\text{maks}}$, tyd tot uitputting (T_{uit}), ventilatoriese drempelwaarde (VD), en respiratoriese kompensaspunt (RKP). Twee GOT is hiervoor geïdentifiseer, naamlik die aangepaste toenemende spoedprotokol (AISP) en die toenemende spoed- en hellingprotokol (ISIP). Die tweede doelstelling van hierdie navorsing was om te bepaal watter hardloopmodaliteit, naamlik die GT of die Curve nie-gemotoriseerde trapmeul (NGT) die hoogste kardiorespiratoriese response tot gevolg sal hê. Die AISP is dus met die aangepaste nie-gemotoriseerde toenemende spoedprotokol (ANMIP) vergelyk. Hierdie doelstellings is bereik deur 'n dwarsnit-ontwerp waarby elite manlike langafstand-atlete op universiteitsvlak betrek is.

Om die doelstellings te bereik, is elite manlike langafstand-atlete op universiteitsvlak genader. Twaalf hardlopers (ouderdom: 21.8 ± 3.0 jr.; lengte: 178.2 ± 6.5 cm; en liggaamsgewig: 66.7 ± 4.7 kg) van 'n universiteit in die Noordwes Provinsie van Suid-Afrika het aan hierdie navorsingstudie deelgeneem.

Om die eerste doelstelling van hierdie studie te bereik, is die resultate van die twee GOT wat op die GT uitgevoer is, vergelyk. Die maksimale kardiorespiratoriese response wat behaal is, sowel as alle kardiorespiratoriese response van elke ooreenstemmende minuut, is met mekaar vergelyk. Die $\dot{V}O_{2\text{maks}}$ -waardes wat op die ISIP behaal is (67.6 ± 5.0 vs. 65.0 ± 4.4 ml/kg/min) was statisties betekenisvol hoër ($p < 0.05$) as dié van die AISP ongeag die langer T_{uit} (11.4 ± 1.2 vs. 13.6 ± 1.2 min). Die ISIP word gevolglik aanbeveel vir gebruik om elite manlike

langafstand-atlete op universiteitsvlak se hoogste kardiorespiratoriese response te bepaal. Verder kan 'n GOT met 1 km/h-toenames nie direk vergelyk word met 'n GOT met 1%-toenames in helling nie. Daar word aanbeveel dat toenames aangepas moet word om meer akkurate vergelyking moontlik te maak.

Om die tweede doelstelling van hierdie studie te bereik, is resultate wat onderskeidelik op die GT en Curve NGT behaal is, vergelyk. Maksimale kardiorespiratoriese response, sowel as alle kardiorespiratoriese response van elke ooreenstemmende spoed, is vergelyk. Volgens die resultate wat behaal is, het die ANMIP statisties betekenisvol hoër ($p < 0.05$) $\dot{V}O_{2\text{maks}}$ -tellings (66.7 ± 4.0 vs. 65.0 ± 4.4 ml/kg/min) as die AISP behaal. Hierdie tellings is ook in 'n statisties betekenisvol ($p < 0.05$) korter T_{uit} (8.31 ± 0.87 vs. 11.42 ± 1.19 min) bereik. Ongelukkig is onrealistiese VD- en RKP-waardes behaal met die bepaling van die ANMIP se intensiteitsmerkers vir oefeningvoorskrifte. Hierdie waardes word nie vir oefeningvoorskrifte aanbeveel nie aangesien die $\dot{V}O_2$ "stadige komponent" teenwoordig is. Die intensiteitsmerkers van die ANMIP wat behaal is, is hoër as die verwagte parameters en mag lei tot ooroefening as dit in 'n oefenprogram toegepas word.

Uit die bevindings van hierdie studie is dit duidelik dat die ISIP meer toepaslik vir elite manlike langafstand-atlete op universiteitsvlak beskou word. Die gebruik van die ISIP as gestandaardiseerde sport-spesifieke GOT word aanbeveel om meer akkurate $\dot{V}O_{2\text{maks}}$ -waardes en oefenvoorskrifte aan toekomstige afrigters, elite manlike langafstand-atlete op universiteitsvlak en atlete se ondersteuningspersoneel te gee.

Sleutelwoorde: Gegradeerde oefeningtoets; suurstofverbruik; Curve nie-gemotoriseerde trapmeul; hardloopmodaliteite; fisieke inspanning; hardloopprestasie.

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LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
%	Percentage
<	Smaller than
>	Greater than
≤	Smaller than and equal to
≥	Greater than and equal to
°	Degree
ASIP	Adapted Speed Incremental Protocol
ANMIP	Adapted Non-Motorized Incremental Speed Protocol
Bla⁻	Blood lactate
BW	Body weight
bpm	Beats per minute
C	Carbon
cm	Centimeters
CO₂	Carbon dioxide
CR10	Category ratio scale
CR 100	Centimax scale
CTP	Continuous test protocol
d	Cohen's d-value

DTP	Discontinuous test protocol
EC	Energy cost
F	Female
GXT	Graded exercise test
HR	Heart rate
ICC	Interclass correlation coefficients
ISIP	Incremental Speed and Incline Protocol
Kg	Kilogram
km	Kilometer
km/h	Kilometer per hour
L/min	Liter per minute
M	Male
HR_{max}	Maximum heart rate
MET's	Metabolic equivalent (Metabolic demand)
min	Minute
ml/kg/min	Milliliter per kilogram per minute
ml/min	Milliliter per minute
mmol/L	Millimol per Liter
MT	Motorized treadmill
n	Number
NMT	Non-motorized treadmill
O₂	Oxygen
O₂S	Oxygen saturation
OGR	Over-ground running

p	Statistical significance
r	Correlation
RCP	Respiratory compensation point
RE	Running economy
RER	Respiratory exchange ratio
RPE	Rating of perceived exertion
sec	Seconds
T_{lim}	Time to exhaustion
$\dot{V}O_{2max}$	Maximal aerobic capacity
$\dot{V}O_{2peak}$	Peak aerobic capacity
\dot{V}_E	Ventilatory equivalent/ minute ventilation
$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}O_2$	Oxygen consumption
vs.	Versus
VT	Ventilatory threshold
yrs.	Years

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The attainment of a high maximal aerobic capacity ($\dot{V}O_{2max}$) value is considered an important performance determinant for distance runners (Basset & Howley, 2000:71; Midgley *et al.*, 2006:117), because endurance activities are performed at high percentages of an athlete's $\dot{V}O_{2max}$ (Davis, 2006:9; Larsen, 2003:168). However for researchers to obtain $\dot{V}O_{2max}$ values that are valid and objective, the testing method should closely simulate the competitive environment of an endurance athlete. Consequently the graded exercise test (GXT), and running modality used for determination of a runner's $\dot{V}O_{2max}$ are of importance.

1.2 PROBLEM STATEMENT

Maximal aerobic capacity is a concept that has received considerable attention in literature in terms of its relevance to aerobic capacity and performance (Basset & Howley, 2000:70). In order to obtain objective and valid $\dot{V}O_{2max}$ values during $\dot{V}O_{2max}$ tests, tests need to simulate the training and competitive environment of an athlete (Davies *et al.*, 1984:78). Specificity in the selection of the test protocol and the use of an appropriate modality are therefore important when assessing athletes' $\dot{V}O_{2max}$ values (Bouchard *et al.*, 1979:85; Davies *et al.*, 1984:77). Most $\dot{V}O_{2max}$ test protocols make use of a motorized treadmill (MT) in a laboratory environment by using a GXT with specific time intervals, and increments in speed and/or gradient as guideline (Billat *et al.*, 1996:314; Davies *et al.*, 1984:75; Haff & Dumke, 2012:211; Hamlin *et al.*, 2012:99). Furthermore, the majority of GXT protocols make use of speed and/or gradient increases and can be categorized as either speed GXT protocols (only speed increases) or incline GXT protocols (set speed or gradient, with speed and/or gradient increases) (Davies *et al.*, 1984:75; Hamlin *et al.*, 2012:97). However, a comparison between these GXT protocols revealed that an incline GXT protocol produced significantly higher ($p < 0.05$) cardiorespiratory responses than a speed GXT protocol (Sloniger *et al.*, 1997:264). The introduction of non-motorized treadmills (NMT), which simulate outdoor running more closely (Davies *et al.*, 1984:74), have also compelled several researchers rather to make use of these running modalities when testing athletes' $\dot{V}O_{2max}$ values (Snyder *et al.*, 2010). Comparatively, the NMT

also seems to produce higher cardiorespiratory responses when compared to the MT (Snyder *et al.*, 2010). Despite these findings, to date researchers have not yet proposed a standardized GXT protocol to determine $\dot{V}O_{2\max}$ specifically for elite male university-level distance runners.

The $\dot{V}O_{2\max}$ test assesses an athlete's maximum endurance ability and is considered an important physiological determinant of aerobic capacity for middle- and long-distance runners (Basset & Howley, 2000:70; Midgley *et al.*, 2006:119). Open-circuit spirometry in a closed laboratory environment is a reliable method to measure $\dot{V}O_{2\max}$ ($r=0.96$) (Davies *et al.*, 1984:76).

Cardiorespiratory responses that are also obtained from a $\dot{V}O_{2\max}$ test include heart rate (HR), maximum heart rate (HR_{\max}), O_2 consumption ($\dot{V}O_2$), CO_2 production ($\dot{V}CO_2$), minute ventilation (ventilatory equivalent (\dot{V}_E)), $\dot{V}O_{2\max}$, respiratory exchange ratio (RER) and time to exhaustion (T_{lim}) (Kang *et al.*, 2001:292; Vai *et al.*, 1988:1860). Two exercise intensity markers can also be determined from the last-mentioned responses, namely the ventilatory threshold (VT) and the respiratory compensation point (RCP) (Chicharro *et al.*, 2000:453). A separate subjective response can also be obtained namely rating of perceived exertion (RPE) (Borg, 1982:377).

Thus far, researchers have agreed that GXT protocols lasting between 8 and 12/15 minutes (Davis, 2006:13; Haff & Dumke, 2012:211) would elicit the highest $\dot{V}O_{2\max}$ values with the lowest perception of discomfort and difficulty experienced by untrained athletes (Kang *et al.*, 2001:291).

However, GXT protocols such as these could underestimate the $\dot{V}O_{2\max}$ values of highly trained athletes because of slow starting speeds, which may be detrimental to running efficiency and cause premature fatigue (Kang *et al.*, 2001:294). On the other hand, GXT protocols that start at faster running speeds (12 km/h for women and 14 km/h for men) may enable trained athletes to reach their $\dot{V}O_{2\max}$ values in a shorter time (Heyward, 1997:47). Then again, GXT protocols with too rapid gradient increases can cause hyperventilation because of greater metabolic demand, causing premature fatigue and early onset of lactate production, which in turn will result in an early rise in $\dot{V}CO_2$ (Davis *et al.*, 1976:548). Hyperventilation may also indicate the appearance of the "slow component" of $\dot{V}O_2$ kinetics (Xu & Rhodes, 1999:324). Furthermore, the manifestation of hyperventilation as a result of extreme, intense exercise occurs because of the body's attempt to attain effective gas exchange in the lungs by increasing ventilatory work, causing a further increase in the "slow component" (Xu & Rhodes, 1999:320).

As mentioned earlier, both speed GXT protocols and incline GXT protocols seem to be overly used for $\dot{V}O_{2\max}$ test protocols (Davies *et al.*, 1984:75; Hamlin *et al.*, 2012:97), though research suggests that incline GXT protocols lead to statistically significant higher ($p < 0.05$) muscle activation percentages ($73.1 \pm 7.4\%$ vs. $67.0 \pm 8.3\%$) and statistically significant higher ($p < 0.05$) peak $\dot{V}O_2$ values (49 ± 6 vs. 41 ± 7 ml/kg/min) in active female runners (Sloniger *et al.*, 1997:262) when compared to speed GXT protocols. These differences in results are attributed to the nature of the incline GXT protocols, which leads to the recruitment of more type 2 muscle fibers, more involvement of the anaerobic energy system and higher RER values compared to speed GXT protocols (Hamlin *et al.*, 2012:102; Sloniger *et al.*, 1997:264).

The type of running modality being used during execution of GXT protocols will also influence the cardiorespiratory responses. The development of the NMT, which forces athletes to use their own power to drive the belt and more closely simulate track running than a MT (Davies *et al.*, 1984:78), has led researchers to use this running modality during GXT protocols. Comparisons between the cardiorespiratory responses of a NMT and MT revealed that active recreational sport participants of both genders who habitually use treadmill running as an exercise modality achieved higher $\dot{V}O_{2\max}$ values on a NMT (NMT: 61.4 ± 11.4 ml/kg/min; MT speed GXT protocol: 59.6 ± 10.3 ml/kg/min; and a MT incline GXT protocol: 61.3 ± 11.6 ml/kg/min), however the measured differences were insignificant (Davies *et al.*, 1984:76). These results were confirmed by Snyder *et al.* (2010) who observed statistically significantly ($p < 0.05$) higher $\dot{V}O_2$ (60.2 ± 11 ml/kg/min), HR (190 ± 10 bpm), and blood lactate values (11.1 ± 2.9 mM) during 6-minute running bouts on the NMT compared to the MT (49.9 ± 9.2 ml/kg/min; 170 ± 11 bpm; 4.5 ± 1.6 mM). Unfortunately, the study did not compare maximal cardiorespiratory responses between the two types of running modalities.

The two gas exchange points mentioned, namely VT and RCP, are influenced by the gas exchange responses of the $\dot{V}O_{2\max}$ test. The reason for this influence is that changes in $\dot{V}O_2$, $\dot{V}CO_2$, and \dot{V}_E will cause a direct increase or decrease in $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ values that are used to calculate VT and RCP (Chicharro *et al.*, 2000:452). However, thus far, researchers have not investigated the possible influence of a GXT protocol on the changes in RCP and VT values.

From the above-mentioned studies it is clear that it is necessary to obtain reliable and valid $\dot{V}O_{2max}$ results by using the most effective GXT protocols and running modality. Considering this need, the following research questions are posed: Firstly, how do elite male university-level distance runners' cardiorespiratory responses (HR_{max} , $\dot{V}O_2$, $\dot{V}CO_2$, \dot{V}_E , $\dot{V}O_{2max}$, RER, T_{lim} , RCP, and VT as well as RPE) compare when performing two different GXT protocols on a MT? Secondly, how do elite male university-level distance runners' cardiorespiratory responses (HR_{max} , $\dot{V}O_2$, $\dot{V}CO_2$, \dot{V}_E , $\dot{V}O_{2max}$, RER, T_{lim} , RCP, and VT as well as RPE) compare when running GXT protocols on a MT and NMT respectively?

Results from this study could enable future coaches, elite male university-level distance runners as well as supporting staff to determine subjects' $\dot{V}O_{2max}$ values accurately through a standardized, sport-specific $\dot{V}O_{2max}$ protocol.

1.3 OBJECTIVES

The objectives of this study are to:

- Compare the cardiorespiratory responses (HR_{max} , $\dot{V}O_2$, $\dot{V}CO_2$, \dot{V}_E , $\dot{V}O_{2max}$, RER, T_{lim} , RCP, and VT as well as RPE) of elite male university-level distance runners when performing a speed GXT protocol and an incline GXT protocol on a MT (); and
- Compare the cardiorespiratory responses (HR_{max} , $\dot{V}O_2$, $\dot{V}CO_2$, \dot{V}_E , $\dot{V}O_{2max}$, RER, T_{lim} , RCP, and VT as well as RPE) of elite male university-level distance runners when performing GXT protocols on a MT and NMT.

1.4 HYPOTHESES

The study is based on the following hypotheses:

- The MT incline GXT protocol will elicit significantly higher ($p < 0.05$) cardiorespiratory responses ($\dot{V}O_{2max}$, RER, RCP, and T_{lim}) in elite male university-level distance runners compared to the MT speed GXT protocol.
- A NMT GXT protocol will elicit significantly higher ($p < 0.05$) cardiorespiratory responses ($\dot{V}O_{2max}$, RER, RCP, and T_{lim}) in elite male university-level distance runners compared to a MT GXT protocol.

1.5 STRUCTURE OF DISSERTATION

Chapter 1: Introduction: Problem statement and purposes of the study.

Chapter 2: Literature review: A review of cardiorespiratory responses attained using different running modalities and treadmill protocols to directly determine aerobic capacity.

Chapter 3: Article 1 - A comparison between the cardiorespiratory responses of a speed versus an incline motorized treadmill protocol. The article will be submitted to the *Journal of Science and Medicine in Sport* for possible publication. Although not according to the guidelines of the journal, the tables will be included within the text to ease the reading of the article. Furthermore the line spacing of the article will be set at 1.5 lines with the exception of table contents which are set at 1.15 instead of the prescribed 2 lines to allow uniformity within the document.

Chapter 4: Article 2: - A comparison between the cardiorespiratory responses of a non-motorized and motorized treadmill protocol. The article will be submitted to the *Journal of Science and Medicine in Sport* for possible publication. Although not according to the guidelines of the journal, the tables will be included within the text to ease the reading of the article. Furthermore the line spacing of the article will be set at 1.5 lines with the exception of table contents which are set at 1.15 instead of the prescribed 2 lines to allow uniformity within the document..

Chapter 5: Summary, conclusion, limitations and recommendations.

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CHAPTER 2

LITERATURE REVIEW: A REVIEW OF CARDIORESPIRATORY RESPONSES ATTAINED USING DIFFERENT RUNNING MODALITIES AND TREADMILL PROTOCOLS TO DIRECTLY DETERMINE AEROBIC CAPACITY

2.1 INTRODUCTION

The body's ability to consume oxygen has been investigated by Hill and Lupton from as early as 1923 (Basset & Howley, 2000:71). Although their work in the field of exercise science has been challenged, their classical notion of maximal aerobic capacity ($\dot{V}O_{2max}$) has generally been accepted (Basset & Howley, 2000:72, 80). By using Hill and Lupton's research into aerobic capacity as foundation, endurance performance is better understood and interpreted by sport and exercise scientists (Basset & Howley, 2000:77-79, 82). Aerobic capacity is considered important to endurance performance, because of activities being performed at high percentages of an athlete's $\dot{V}O_{2max}$ (Davis, 2006:9; Larsen, 2003:168). If the $\dot{V}O_{2max}$ value is low, the level of endurance performance is limited (Davis, 2006:9). In order for researchers to obtain objective and valid $\dot{V}O_{2max}$ values during tests, they need to simulate the activity/movement of an endurance athlete's competitive environment closely (Davies *et al.*, 1984:78). Maximal aerobic tests that involve a large group of muscles will ensure exhaustion and higher $\dot{V}O_{2max}$ values can consequently be obtained (Astrand *et al.*, 2003:273, 280; Haff & Dumke, 2012:211).

To determine $\dot{V}O_{2max}$ values, treadmill tests were found to elicit higher values compared to other exercise modalities such as step or bicycle tests (Astrand *et al.*, 2003:275-276; Chatterjee & Chakravarti, 1986:153). Past researchers used motorized treadmills (MT) extensively for the measurement of aerobic capacity (Davies *et al.*, 1984:75; Hamlin *et al.*, 2012:99), but neglected their clear rival, the non-motorized treadmill (NMT). According to Davies *et al.* (1984:74) the NMT is a good alternative to the MT and is proposed to simulate over-ground running (OGR) more closely. Not only is the apparatus used for determining the $\dot{V}O_{2max}$ important, but the

protocol (graded exercise test) used for attainment of $\dot{V}O_{2\max}$ also plays an important role (Bouchard *et al.*, 1979:85-86; Davies *et al.*, 1984:77-78). It is recommended that researchers use graded exercise tests (GXT) with equal increases in workload (speed and gradient) and time intervals to allow participants to achieve steady states (plateau in cardiorespiratory responses) by the end of each test level until exhaustion (Haff & Dumke, 2012:211).

On the basis of the above-mentioned literature overview, the first aim of this study is to provide insight into the importance of aerobic capacity and cardiorespiratory responses, as well as the accurate measurement and determination thereof. The second aim is to investigate and discuss the MT and NMT used by previous researchers to determine which treadmill closer simulates OGR by allowing greater cardiorespiratory responses and aerobic capacity values in trained male runners. Furthermore, environmental factors as well as other measured biomechanical factors that influence the attainment of an athlete's aerobic capacity will be deliberated on briefly. Finally, all literature containing different protocols used to determine the direct aerobic capacity of trained adult male runners for the last two decades on both the MT and NMT will be considered to determine which protocol is most appropriate for the $\dot{V}O_{2\max}$ test. The number of articles relevant to these aims was limited, and older research that is within the previously mentioned scope was also used.

Aerobic capacity and aerobic power are used interchangeably in literature to represent a person's ability to use oxygen when exercising. For the remainder of this literature review only the term aerobic capacity will be used to express this phenomenon.

2.2 AEROBIC CAPACITY

Aerobic capacity can be described as the ability of the pulmonary, vascular and muscular system to consume and utilize oxygen to endure physiological work (Boutcher, 1990:236). This phenomenon can be expressed as an absolute value (milliliter per minute (ml/min)) or as a relative value (milliliter per kilogram per minute (ml/kg/min)) (Morrow & Freedson, 1994:316) and represents the amount of oxygen (O_2) consumed during exercise (Boutcher, 1990:236). A $\dot{V}O_{2\max}$ test as determined by a GXT protocol is terminated when a participant feels he/she cannot continue or when the workload increases without subsequent increases in O_2 consumption (Basset & Howley, 2000:71). In other words, a plateau in O_2 consumption will occur despite increases in workload (Basset & Howley, 2000:71; Wilmore *et al.*, 2008:223). According to Basset and Howley (2000:71), the presence of a plateau in O_2 consumption is evident because of an upper limit in $\dot{V}O_{2\max}$ being reached as well as limited O_2 transport to the working muscles

(Basset & Howley, 2000:71). Attainment of a high $\dot{V}O_{2\max}$ value is considered an important determinant of distance running performance (Basset & Howley, 2000:71; Midgley *et al.*, 2006:117).

Determining $\dot{V}O_{2\max}$ by means of direct measurement, through an automated, open circuit spirometry system (Davis, 2006:18) in a closed laboratory environment is found to be a reliable method to measure $\dot{V}O_{2\max}$ ($r=0.96$) (Davies *et al.*, 1984:76). Furthermore, by measuring the respiratory gas exchange volume of O_2 and carbon dioxide (CO_2) that enter and exit the lungs within a given time, energy expenditure can be determined (Wilmore *et al.*, 2008:100). For O_2 - consumption to reflect energy metabolism, energy production needs to be completely oxidative and aerobic in nature (Wilmore *et al.*, 2008:100). The aerobic capacity test intensity should therefore be low enough to limit anaerobic energy use, but high enough to allow complete exhaustion. Cardiorespiratory responses derived from indirect calorimetry have enabled researchers to determine whether aerobic capacity tests are performed maximally or sub-maximally (Wilmore *et al.*, 2008:104).

2.3 CARDIORESPIRATORY RESPONSES

When working with trained populations, cardiorespiratory responses are used to measure the effect acute exercise has on the body (Wilmore *et al.*, 2008:223). To meet the increasing metabolic demand of exercise, the heart pumps more blood to the exercising muscles, and respiratory ventilation increases in direct proportion (Wilmore *et al.*, 2008:174-6). When performing prolonged bouts of exercise, as in the case of distance running, the body's ability to maintain O_2 delivery is challenged and therefore develops along with the muscles' ability to utilize O_2 (Wilmore *et al.*, 2008:223). Thus, the onset of exercise has an immediate effect on the cardiorespiratory responses of the body and is controlled by neural activation in the respiratory control centers of the brain, as well as the chemical composition of arterial blood (Wilmore *et al.*, 2008:176). These responses are identified by their need to meet the body's demand during dynamic exercise (Wilmore *et al.*, 2008:162,176). Cardiorespiratory responses obtained from $\dot{V}O_{2\max}$ tests include heart rate (HR)/ maximum heart rate (HR_{\max}), O_2 consumption ($\dot{V}O_2$), CO_2 production ($\dot{V}CO_2$), minute ventilation/ ventilatory equivalent (\dot{V}_E), the $\dot{V}O_{2\max}$ value, the respiratory exchange ratio (RER), and time to exhaustion (T_{lim}). From these variables two intensity markers, namely the ventilatory threshold (VT), and the respiratory compensation point (RCP), can be derived (Chicharro *et al.*, 2000:452; Kang *et al.*, 2001:291-292; Vai *et al.*, 1988:1860). Rating of perceived exertion (RPE) is not classified as a cardiorespiratory response, but is a

separate and subjective response to categorize physical strain during tests (Borg, 1982:377). The role of these responses will be discussed in the next section.

2.3.1 Respiratory exchange ratio (RER)

The RER can be determined by expressing the ratio of the measured gases namely, $\dot{V}CO_2$ and $\dot{V}O_2$ during a $\dot{V}O_{2max}$ test (Wilmore *et al.*, 2008:103, 237). The RER value is of importance, as it provides an indication of the food substrate being oxidized to expend energy (Haff & Dumke, 2012:212; McArdle *et al.*, 2010:190-191). Food substrates such as fat (RER=0.7) and carbohydrates (RER=1.00) attain different RER values (Wilmore *et al.*, 2008:103) because of their different chemical composition of carbon (C) and O_2 . The expired air's O_2 and C composition can therefore be analyzed to determine the RER value. The gas exchange between O_2 and CO_2 is directly influenced by the onset of exercise. When the RER reaches 1.00 or exceeds (\geq) 1.00, the food substrate consumed can no longer be accurately reflected owing to the body's attempt to deter lactate by dumping CO_2 into the blood to counteract acidification (Wilmore *et al.*, 2008:104). The body's attempt to purify the blood causes lactate accumulation and a slow decline to fatigue will start. When the RER is above (\geq) 1.00, and continuously increases, athletes are expected to become fatigued shortly thereafter. The highest RER value attained will therefore be used as a $\dot{V}O_{2max}$ criteria point to determine whether the $\dot{V}O_2$ value attained is a $\dot{V}O_{2max}$ or peak aerobic capacity ($\dot{V}O_{2peak}$) value (Davis, 2006:15; Haff & Dumke, 2012:210; McArdle *et al.*, 2010:235). Maximal aerobic capacity criteria will be discussed in section 2.4.1

2.3.2 Minute ventilation (\dot{V}_E)

Minute ventilation can be defined as the amount of air being inhaled ($\dot{V}O_2$) and exhaled ($\dot{V}CO_2$) by the lungs per minute and is dependent on the depth and rate of breathing (Vai *et al.*, 1988:1864). Minute ventilation and HR increase linearly until 60% of the $\dot{V}O_{2max}$ is reached, whereafter \dot{V}_E increases at a higher rate than HR as the exercise intensity continuously increases (Vai *et al.*, 1988:1865). Higher physical demands set by the GXT protocol will lead to a progressive increase in CO_2 production through which the body will attempt to counteract the effect of acidification by increasing \dot{V}_E (Chicharro *et al.*, 2000:450). Unfortunately, with an increasing exercise demand, even more CO_2 will be produced and respiratory compensation will occur in response to metabolic acidosis (Rossi, 1987:455). Furthermore, \dot{V}_E matches the rate of energy

metabolism required and is therefore expressed in terms of the gases being exchanged (e.g. $\dot{V}_E / \dot{V}_{O_2}$) (Wilmore *et al.*, 2008:176).

2.3.3 Oxygen consumption (\dot{V}_{O_2}) and carbon dioxide production (\dot{V}_{CO_2})

Gas exchange of O_2 and CO_2 in the lungs is known as pulmonary diffusion (Wilmore *et al.*, 2008:147). In other words, O_2 is exchanged from the inhaled air to the blood stream and CO_2 is exchanged from the blood stream to the air in the lungs. The presence of O_2 during energy production implies that it is aerobic in nature (Wilmore *et al.*, 2008:53). The oxidative energy system can supply great amounts of energy, but it takes time to activate (Wilmore *et al.*, 2008:53). Aerobic endurance exercises are mainly fueled by the oxidative system and place great demands on the respiratory and cardiovascular system (Wilmore *et al.*, 2008:53). During periods of mild continuous exercise, ventilation matches the rate of energy metabolism by varying the volume of \dot{V}_{O_2} consumed and \dot{V}_{CO_2} produced. Furthermore, the volume of air expired/ventilated and the amount of O_2 consumed ($\dot{V}_E / \dot{V}_{O_2}$) in addition to the amount of CO_2 produced ($\dot{V}_E / \dot{V}_{CO_2}$) is expressed through \dot{V}_E in liter per minute (L/min) (Wilmore *et al.*, 2008:177). Both $\dot{V}_E / \dot{V}_{O_2}$ and $\dot{V}_E / \dot{V}_{CO_2}$ are plotted on a graph for further interpretation and are used to determine the VT and RCP as discussed later in this chapter (2.3.5).

2.3.4 Heart rate (HR) and maximum heart rate (HR_{max}) Heart rate is a useful cardiorespiratory response to determine exercise intensity and can be determined by means of a wireless HR monitor (Achten & Jeukendrup, 2003:518). When using HR as a cardiorespiratory response during a $\dot{V}_{O_{2max}}$ test, a steady state HR is pursued per workload increment (Wilmore *et al.*, 2008:163). As the exercise intensity reaches near maximum effort, HR will deviate from its initial linear increase of steady state per workload increment, and a plateau in HR will form. This plateau is known as HR_{max} and is considered to be the value reached after a maximal exercise effort up to exhaustion (Wilmore *et al.*, 2008:163). This attained value can vary slightly from day to day and will be influenced by an age-related decline of approximately one beat per year from 10 to 15 years of age (Wilmore *et al.*, 2008:163). A theoretical HR_{max} can be determined by using the developed equation to estimate $HR_{max} = 208 - (0.7 \times \text{age})$ (Tanaka *et al.*, 2001:154-155; Wilmore *et al.*, 2008:163).

The HR_{max} of aerobically trained participants is expected to be lower because of higher stroke volumes. Stroke volume can be defined as the amount of blood ejected from the heart's left

ventricle per beat/contraction (Wilmore *et al.*, 2008:531). Heart rate and stroke volume work in unison to meet the metabolic demand of the body by an optimum effort to allow maximal exercise (Wilmore *et al.*, 2008:229). Aerobic training also has a great effect on resting HR, submaximal exercise and the post-exercise HR recovery period (Wilmore *et al.*, 2008:228). Shorter HR recovery periods have been measured after an aerobic exercise regime was followed, and as a result faster recovery periods are expected from trained athletes (Wilmore *et al.*, 2008:229). Consequently, HR recovery is considered an indirect index of cardiorespiratory fitness and should return to resting HR after approximately 5 min of rest once a maximal aerobic test is completed (Wilmore *et al.*, 2008:229).

Test-retest correlation of HR is very high ($r=0.872$), as reported by Brooke and colleagues (cited by Achten & Jeukendrup, 2003:530), although a day-to-day change of two to four beats per minute (bpm) is evident (Achten & Jeukendrup, 2003:530). Numerous factors have been found to influence HR, including environmental factors (cold and heat), physiological factors (cardiovascular drift and hydration status) and altitude (Achten & Jeukendrup, 2003:530-532).

2.3.5 Ventilatory threshold (VT) and respiratory compensation point (RCP)

The VT and RCP are two exercise intensity markers that are identified from the results obtained from gas exchange analysis of a $\dot{V}O_{2\max}$ test. These markers are identified by analyzing the respiration of $\dot{V}O_2$ and $\dot{V}CO_2$ responses to increasing exercise workloads. The first exercise marker VT occurs when there is an increase in $\dot{V}_E / \dot{V}O_2$ values with no change in the $\dot{V}_E / \dot{V}CO_2$ values (Chicharro *et al.*, 2000:452; Meyer *et al.*, 2005:3). The exercise and HR values below VT are considered to be aerobic in nature, and indicate the point at which exercise variables of the low intensity zone are separated from the lowest part of the moderate intensity zone (Lucía *et al.*, 1999:167).

The second exercise intensity marker, RCP, is identified when there is a sudden increase in both the $\dot{V}_E / \dot{V}CO_2$ and $\dot{V}_E / \dot{V}O_2$ values in response to a continuous increase in exercise intensity (Chicharro *et al.*, 2000:452). The RCP separates the moderate intensity zone from the high intensity zone (Lucía *et al.*, 1999:167) and marks the onset of hyperventilation during incremental exercise (Meyer *et al.*, 2004:622) in response to the body's buffering mechanisms failing, causing metabolic acidosis to occur (Wasserman *et al.*, 1973:237). The manifestation of metabolic acidosis only takes place in the absence of adequate O_2 and is affected by an increase in lactic acid production (Wasserman *et al.*, 1973:237). This is followed by increased buffering of lactic

acid, leading to respiratory compensation as a reaction to metabolic acidosis (Wasserman *et al.*, 1973:236-237). From this, one can conclude that RCP is anaerobic in nature.

By applying the VT and RCP intensity markers to cardiorespiratory responses attained, sport scientists can design individualized training programs (Chicharro *et al.*, 2000:451). The measured HR variables are divided into three exercise intensities by applying the VT and RCP markers to prescribe exercise. Heart rate values occurring from the start of the test up to VT are used for low-intensity exercise, between VT and RCP for moderate intensity exercise and above RCP for high intensity exercise (Chicharro *et al.*, 2000:451). When expressing the VT and RCP exercise markers as percentages of $\dot{V}O_{2max}$ between professional (VT: 65% and RCP: 90%) and amateur (VT: 60% and RCP: 80%) cyclists, it demonstrates that these measures are a good performance indicator for endurance events (Chicharro *et al.*, 2000:450) and can therefore be considered to be probably relevant for distance runners.

2.3.6 Time to exhaustion (T_{lim})

Even though endurance runners can tolerate long periods of exercise, T_{lim} as advised by Davis (2006:13) as well as Haff and Dumke (2012:211) research still suggests that a $\dot{V}O_{2max}$ test protocol should be designed to terminate after 8—12/15 minutes. According to Gibson (cited by Davies *et al.*, 1984:77), aerobic capacity tests that yield shorter treadmill endurance times are favored to ensure that a test is not terminated because of premature local muscle fatigue.

Protocols starting at a faster running speed may enable athletes to reach their $\dot{V}O_{2max}$ values in a shorter time (Heyward, 1997:47). However, caution is advised when using protocols with rapid gradient increases in view of their tendency to cause hyperventilation because of a greater metabolic demand, causing premature fatigue and early onset of lactate production (Davis *et al.*, 1976:548). If the time to completion of the protocol is too long, great motivation will be required to complete the test and this could be another reason for lower $\dot{V}O_{2max}$ test values or early test termination (Davis, 2006:13). Consequently, T_{lim} plays an important role in whether the value attained is maximal or submaximal.

2.3.7 Rating of perceived exertion (RPE)

According to Borg (1982:377), perceived exertion is the single best indicator of physical strain during exercise or training. Rating of perceived exertion is categorized into a numerical scale that integrates a diversity of responses elicited through exercise by working muscles, joints, cardiovascular and respiratory function, as well as the central nervous system (Borg, 1982:377). Physical exercise can be divided into both objective and subjective responses (Hardy & Rejeski,

1989:304). Rejeski (cited by Hardy & Rejeski, 1989:304) determined that what people think they are doing (subjectively) may be more important than what they are doing (objectively). Previous research used three RPE scales, namely the Borg RPE scale (6-20), category ratio scale (CR10 scale), and the Borg centiMax scale (CR100) (Borg & Kaijser, 2006:58). The Borg RPE scale (6-20) and the CR10 scale are the two RPE scales well known to researchers (Borg cited by Borg & Kaijser, 2006:57).

Rating of perceived exertion scales require an individual to rate the level of perceived difficulty of the exercise in which he/ she is engaged subjectively (Wilmore *et al.*, 2008:464). The CR10 scale is designed to increase linearly in difficulty as exercise intensity increases (Borg, 1982:378,380). The CR10 scale ranges from 0 (feeling nothing at all) to 10 (maximal) (Borg, 1982:380). The RPE scale (6-20) has been used worldwide and high correlations exist when used alongside HR ($r=0.8-0.9$) (Borg, 1982:378; Hardy & Rejeski, 1989:304). Rating of perceived exertion can assist researchers in the determination of $\dot{V}O_{2max}$ values as well as assessing the quality of a $\dot{V}O_{2max}$ test. Unfortunately a single RPE scale has not yet been specified to use when performing $\dot{V}O_{2max}$ tests (Borg & Kaijser, 2006:68).

2.4 MAXIMAL AEROBIC CAPACITY ($\dot{V}O_{2max}$)

Maximal aerobic capacity is known as the maximal amount of O_2 utilized by the body and is recorded during exercise that continues until voluntary exhaustion (Wilmore *et al.*, 2008:190).

Average $\dot{V}O_{2max}$ values of untrained females and males (18—22 years old) who are normally active, range between 38 and 42 ml/kg/min and 44 and 50 ml/kg/min respectively (Kenney *et al.*, 2012:122). Values closer to and above 80—84 ml/kg/min are expected for trained male endurance runners (Kenney *et al.*, 2012:122). However, $\dot{V}O_{2max}$ values of 70 ml/kg/min can be considered adequate for distance running if the percentages of $\dot{V}O_{2max}$ used during endurance activities are high ($\pm 86\%$) (Kenney *et al.*, 2012:122). Trained endurance runners are therefore expected to achieve values almost twice as high as those achieved by sedentary/less active males and females (McArdle *et al.*, 2010:234), and this is supported by the above-mentioned literature.

Maximal aerobic capacity tests for distance runners are performed on a treadmill for specificity (Astrand *et al.*, 2003:257; McArdle *et al.*, 2010: 235) by performing a GXT protocol. The highest $\dot{V}O_2$ usually occurs in the last minute of a GXT protocol (McArdle *et al.*, 2010:235). Motivational

factors therefore play an immense role, and continuous prodding and urging are required to attain acceptable criteria for either a $\dot{V}O_{2\max}$ or $\dot{V}O_{2\text{peak}}$ (McArdle *et al.*, 2010: 235). Previous researchers have given considerable attention to $\dot{V}O_{2\max}$ criteria; however a single criterion has not been set as the benchmark for $\dot{V}O_{2\max}$ testing. The following section will consequently clarify the criteria points used by researchers, and how to distinguish between a $\dot{V}O_{2\max}$ and a $\dot{V}O_{2\text{peak}}$.

2.4.1 Criteria for the attainment of maximal aerobic capacity or otherwise peak aerobic capacity

The use of $\dot{V}O_{2\max}$ criteria differs across research and therefore poses a great challenge in identifying criteria that remain valid (Midgley *et al.*, 2007a:1019). In past research, aerobic capacity tests were acknowledged as a $\dot{V}O_{2\max}$ test if the results attained demonstrated the achievement of a plateau in $\dot{V}O_2$ (Davis, 2006:9). This was expected during the later stages of a test when the work rate continued to increase and no further increase in $\dot{V}O_2$ occurred (Basset & Howley, 2000:71; Davis, 2006:9). However, the attainment of a plateau in $\dot{V}O_2$ was considered a difficult task, where a participant had to achieve a high level of anaerobic energy output near the end of a $\dot{V}O_{2\max}$ test. This would not be possible for untrained or elderly persons (McArdle *et al.*, 2010:235). Unfortunately, many participants reached their work rate tolerance before a plateau was reached and it was recommended that these results be referred to as a $\dot{V}O_{2\text{peak}}$ (Basset & Howley, 2000:71; Davis, 2006:9). In addition, research showed that a $\dot{V}O_2$ plateau is not a prerequisite for defining a $\dot{V}O_{2\max}$, and that achieving secondary criteria is adequate to attain a $\dot{V}O_{2\max}$ (Duncan *et al.*, 1997:277). Attaining two secondary criteria is considered adequate, and combinations of RER and blood lactate (BLa^-) (Duncan *et al.*, 1997:277), RPE and/or RER, and/or HR_{\max} (Haff & Dumke, 2012:210) are proposed.

However, criteria for the attainment of a $\dot{V}O_{2\max}$ have not yet been standardized. Therefore more research is needed to establish a criterion that is independent of exercise modality, test protocol and participants' characteristics (Midgley *et al.*, 2007a:1026). Nonetheless, a variety of criteria has been used by researchers, and can be regarded as adequate secondary criteria for the

attainment of a plateau. The following criteria have been applied in past research to determine if participants had reached a $\dot{V}O_{2\max}$ or otherwise a $\dot{V}O_{2\text{peak}}$:

- Reaching a plateau of < 150 ml/min in $\dot{V}O_2$ despite further increases in work rate (Haff & Dumke, 2012:210; Hamlin *et al.*, 2012; Davis, 2006:15);
- RER of > 1.00 at test termination (Davis, 2006:15), > 1.10 (Haff & Dumke, 2012:210), ≥ 1.10 (Hamlin *et al.*, 2012:99) or > 1.15 (McArdle *et al.*, 2010:235);
- Achievement of age predicted HR_{\max} by using either $HR_{\max} = (220 - \text{age})$, $HR_{\max} = (206.9 - 0.67 \times \text{age})$ (McArdle *et al.*, 2010:235,473), predicted $HR_{\max} = 208 - (0.7 \times \text{age})$ (Tanaka *et al.*, 2001:154-155; Wilmore *et al.*, 2008:163); HR_{\max} at test termination > 90% of age predicted HR_{\max} ($220 - \text{age}$) (Davis, 2006:15; Hamlin *et al.*, 2012:99) or 10 beats/min below age predicted HR_{\max} (Haff & Dumke, 2012:210);
- Reaching an RPE > 17 on the Borg Scale (Haff & Dumke, 2012:210). A value of > 17 is similar to the CR10 score of 10 (Borg & Kaijser, 2006:58).
- A BLa^- concentration in the first 5 minutes of recovery of > 8 mmol/L (Davis, 2006:15; McArdle *et al.*, 2010:290);

According to Davis (2006:15), the attainment of two criteria is sufficient for an aerobic capacity value to be considered a $\dot{V}O_{2\max}$. The combined use of a plateau (< 150 ml/min) in $\dot{V}O_2$, RER (≥ 1.15), HR_{\max} ($208 - (0.7 \times \text{age})$), and the subjective rating of RPE (CR 10 Scale = 10) is considered sufficient $\dot{V}O_{2\max}$ criteria, as mentioned earlier, and will be used in this research study.

Although the achievement of two the above-mentioned responses is considered adequate for the attainment of a $\dot{V}O_{2\max}$, other factors such as the running modality and the protocol used to determine a $\dot{V}O_{2\max}$ also need to be investigated with respect to the role they play in reaching the highest cardiorespiratory responses possible. The subsequent section will discuss the available running modalities and their influence on running performance.

2.5 RUNNING MODALITIES

The running modalities used to evaluate running performance can be considered a significant environmental factor, influencing a runner's biomechanical and physiological aspects (Wee, 2015:1). Even though many running modalities have been used to investigate exercise physiology in the past (McKenna & Riches, 2007:649; Stevens *et al.*, 2015:1141; Cheetham & Williams, 1987:14; Franks *et al.*, 2012:7; Morin & Séve, 2011:1695), the MT and NMT have been used

extensively for aerobic and anaerobic exercise testing respectively. The MT models have improved considerably over the past four decades (Woodway USA, 2013:5), opposed to the NMT. The NMT was only recently improved to a point where a safety harness is no longer required (Snyder *et al.*, 2011).

For $\dot{V}O_{2\max}$ values to be considered valid and objective, the running modality needs to simulate OGR, as this is the environment in which the athlete will compete (Davies *et al.*, 1984:78). To this day, a running modality has not yet been identified to simulate OGR without conflicting results. It is in this light that the above-mentioned running modalities are investigated and compared. To indicate the differences between the MT and NMT, the following section will outline the apparent differences, along with the effect these differences have on the energy cost (energy expenditure (EC)), cardiorespiratory responses, and running effort experienced by the endurance athlete. Finally, other factors possibly influencing measurement will be identified.

2.5.1 Non-motorized treadmill

Earlier research studies made use of a flat NMT that had no set gradient (Cheetham & Williams, 1987:14; Davies *et al.*, 1984:75; Funato *et al.*, 2001:169). The Curve NMT was launched in 2010 and has since then received considerable attention because of its improved “bean” shaped geometric design. The Curve NMT’s surface was upgraded from a flat running surface to a concave shape that exposes an athlete to a set resistance resulting from its built-in gradient (Stevens *et al.*, 2015:1142, 1145). The Curve NMT is relatively new to the research environment and research on it is limited. The athlete is in control of the speed of the Curve NMT’s belt and can accelerate and decelerate the belt with each subsequent step (Snyder *et al.*, 2010). Full velocity is attainable on the Curve NMT (23.4 ± 3.6 km/h) (Gonzalez *et al.*, 2013:104) and therefore the Curve NMT is considered a practical and reliable modality (ICC=0.79—0.97) for testing anaerobic power because it allows unrestricted running motion (Gonzalez *et al.*, 2013:104, 107). Running at a higher velocity allows greater sport specificity and is considered an additional benefit of the Curve NMT (Gonzalez *et al.*, 2013:106-107).

The Curve NMT has recently been presented as a valid tool for assessing endurance running performance when compared to OGR performance. This is suggested through a strong correlation reflected in RPE on the Curve NMT compared to OGR ($r=0.82$; ICC=0.86) (Stevens *et al.*, 2015:1141). According to Stevens *et al.* (2015:1145), the Curve NMT achieved similar cardiorespiratory responses compared to OGR ($\dot{V}O_2$: 51.1 ± 5 vs. 49.2 ± 4 ml/kg/min, respectively; HR: 178 ± 14 vs. 178 ± 13 bpm, respectively; \dot{V}_E : 122.5 ± 17.3 vs. 122.4 ± 15.6 L/min, respectively) with the exception of two responses, namely RPE and BLa^- . These last-mentioned responses were significantly higher on the Curve NMT during a 5 km time trial compared to OGR

(RPE: 6.5 ± 0.9 vs. 6.1 ± 1 , respectively; BLa^- : 9.4 ± 2.3 vs. 7.8 ± 2.1 mmol/L, respectively). The measured RPE and BLa^- responses can be attributed to the natural gradient of the Curve NMT that was perceived to be more difficult (Stevens *et al.*, 2015:1146-1147). These tests results were not performed to complete exhaustion/maximum effort. Even though the Curve NMT is considered a valid tool for measurement of endurance running, these results are obtained from a 5 km time trial and cannot be compared directly to $\dot{V}O_{2max}$ test results.

From investigating the Curve NMT, the differences between the EC of Curve NMT running and OGR have come to light. The EC of running at certain intensity is known as running economy and is determined by assessing the steady state consumption of O_2 as well as the RER (Saunders *et al.*, 2004:465). A runner with good running economy will use less energy at a specific intensity and therefore less O_2 than a runner with poor running economy at the same intensity (Saunders *et al.*, 2004:465). Running economy does not differ much among elite runners because repetitive exercise has made them skilled at running, thus a lower EC is needed to sustain the exercise. According to Saunders *et al.* (2004:465), running economy is a better predictor of performance than $\dot{V}O_{2max}$ when compared. Consequently EC can be used to compare different running modalities.

Incidentally the Curve NMT has been advocated to provide additional training load (Snyder *et al.*, 2010). The higher EC of the Curve NMT can be explained by the nature of the gradient of the belt that requires the athlete to drive the belt with each subsequent step (Franks *et al.*, 2012:72; Stevens *et al.*, 2015:1141). In many respects the Curve NMT resembles OGR more, actively pulling through each step, requiring self-pacing and self-initiation of movement (Stevens *et al.*, 2015:1141-1142).

2.5.2 Motorized treadmill

As an alternative to OGR, MTs are widely used in laboratories and are considered a valid tool/modality to measure endurance performance regardless of the lack of direct comparison to endurance performance (Stevens *et al.*, 2015:1141). In contrast with the Curve NMT, the MT is controlled by a computer through which its speed and gradient can be specified, and is propelled by a motor (Franks *et al.*, 2012:71; Schache *et al.*, 2001:667-668) whose time and distance can be set accurately (Wank *et al.*, 1998:455). Athletes attempt to match the MT's speed and slope by manipulating stride rate and length (Franks *et al.*, 2012:71). Pacing is therefore controlled by a computer and any changes in pacing will be made consciously and will therefore allow a runner to maintain a more consistent pace (Stevens *et al.*, 2015:1142; Stevens & Dascombe, 2015:180).

The nature of the MT makes it easy to mimic a specific exercise (Schache *et al.*, 2001:667), and it has consequently become more popular for endurance training (Wank *et al.*, 1998:455). Although Schache *et al.* (2001:667-668) claim that the MT can be considered a good alternative to OGR, a lot of research contradicts this statement (Fellin *et al.*, 2010; Riley *et al.*, 2008; Schache *et al.*, 2001). Wank *et al.* (1998:455) too found conflicting results regarding step frequency, step length, foot contact time and EC differences between OGR and MT running because of biomechanical influences on the athlete. From a mechanical point of view OGR and MT running should be similar; however, running style and physiological parameters regarding kinetics differ (Wank *et al.*, 1998:455).

Measurement of $\dot{V}O_{2max}$ is independent of the environment in which it is performed, but is rather dependent on the amount of effort spent to complete the task undertaken (Meyer *et al.*, 2003:388). This conclusion was made after a comparative study had been done by Meyer and colleagues (2003:388), who found some similar cardiorespiratory responses for $\dot{V}O_{2max}$ tests performed on a MT and OGR. Even though OGR allowed faster running speeds to be reached, the responses from OGR did not exceed those of MT running (Meyer *et al.*, 2003:388-389). No significant differences were measured between OGR and MT running with regard to $\dot{V}O_{2max}$ values 63.3 ± 7 vs. 63.5 ± 6.6 ml/kg/min, respectively. The RER obtained (1.07 ± 0.04 vs. 1.06 ± 0.04 , respectively) and Bla^- values (10.9 ± 3.1 vs. 11.0 ± 2.5 mmol/L, respectively) were also found to be similar between OGR and MT running. Statistically significant differences ($p < 0.05$) were, however, measured between MT running and OGR, namely T_{lim} ($11:31 \pm 0:39$ vs. $12:07 \pm 0:42$ min, respectively) and HR_{max} (188 ± 6 vs. 189 ± 6 bpm, respectively). The HR_{max} measures differed by less than 2 bpm and were therefore practically negligible (Meyer *et al.*, 2003:388). Nonetheless, the ventilation measurements from the research of Meyer *et al.* (2003:389) found different EC between these modalities.

The EC of running on a MT was found to be significantly higher ($p < 0.05$) than OGR as measured by increased \dot{V}_E and $\dot{V}O_2$ at submaximal running stages (Meyer *et al.*, 2003:389). In this light, Jones and Doust (1996:326) recommended running on a 1% gradient to correct for the lack of air resistance during MT running. Small but significant differences were measured between MT running and OGR concerning air stream, ground surface and movement patterns (Meyer *et al.*, 2003:387). In research conducted by Meyer *et al.* (2003:387), higher \dot{V}_E was measured when running on a MT compared to OGR, and this was attributed to less efficient RE due to a different muscle activation pattern (McMahon & Green cited by Meyer *et al.*, 2003:389). Modified sensory feedback, caused by different running surfaces, has also been mentioned as an explanation for

differences between OGR and MT running (Wank *et al.*, 1998:455). The running technique on OGR and MT running was found to differ, and this was attributed to the hamstring muscle being used more to create propulsive forces on the MT. Differences in EC between OGR and MT running have also become more noticeable as the running speed increased owing to air resistance (Daniels cited by Saunders *et al.*, 2004:467).

2.5.3 Cardiorespiratory responses and energy cost of motorized versus non-motorized treadmills

When comparing the MT and the Curve NMT, cardiorespiratory responses showed significantly higher results on the Curve NMT than on the MT, specifically a higher $\dot{V}O_2$ (60.2 ± 11 vs. 49.9 ± 9.2 ml/kg/min, respectively), HR (190 ± 10 vs. 170 ± 11 bpm, respectively), and BLa⁻ values (11.1 ± 2.9 vs. MT 4.5 ± 1.6 mmol/L, respectively) in a group of experienced distance runners ($n=9$) (Snyder *et al.*, 2010). Even though Snyder *et al.* (2010) made use of a discontinuous test protocol and only performed the Curve NMT evaluation up to the lactate threshold, the Curve NMT values obtained were significantly higher ($p<0.05$) in comparison to results obtained from a MT, except for oxygen saturation (O₂S). Snyder's comparisons were only conducted to a submaximal level and not to complete exhaustion/ maximum effort. According to Snyder *et al.* (2010), these differences can be clarified by the Curve NMT belt's higher friction and greater muscle activation, as shown by lower O₂S in comparison with the MT (22 ± 13 vs. $41 \pm 21\%$, respectively).

Smoliga *et al.* (2015:264,265) compared the Curve NMT to a standard MT at a walking (4.8 km/h) and running speed (8.1 km/h) in a mixed group of healthy active participants ($n=10$), and found the Curve NMT to elicit greater physiological stimulus than that of a MT. The RPE, EC and metabolic rate demand (metabolic equivalent (METs)) of both modalities were investigated among other variables (Smoliga *et al.*, 2015:264). Rating of perceived exertion, EC, and METs were all found to be significantly ($p<0.05$) higher using the Curve NMT in comparison with the MT at a walking and running speed. Other measured cardiorespiratory responses were also found to be significantly higher on the Curve NMT, namely HR ($p=0.002$), $\dot{V}O_2$ ($p=0.012$), and BLa⁻ values ($p=0.013$) (Smoliga *et al.*, 2015:264). The perceived intensity is therefore rated substantially above that of its opponent, the MT (Smoliga *et al.*, 2015:266; Stevens *et al.*, 2015:1145).

In agreement with the above-mentioned findings, the EC of running on a Curve NMT exceeds that of a MT and is caused by higher friction (Stevens *et al.*, 2015:1145) and muscle activation (Snyder *et al.*, 2010). Because of the adaptive nature of the Curve NMT, it is believed that greater neuromuscular control is required to regulate stride rate and length (Smoliga *et al.*, 2015:266). In addition, running on a Curve NMT was found to be similar to OGR uphill (Franks *et al.*, 2012:73;

Smoliga *et al.*, 2015:265). The concave shape of the Curve NMT causes greater muscle activation of the hamstring and quadriceps muscles and in turn causes greater EC when compared to MT running (Franks *et al.*, 2012:74).

From the above-mentioned results one can conclude that running on the Curve NMT is more strenuous regarding its physiological intensity and METs than running on a MT. The higher responses on the Curve NMT in comparison to the MT are partially related to the concave shape of the Curve NMT that has a natural increasing gradient of 5–10° and a MT that has no set gradient. Furthermore, the EC of running on the Curve NMT exceeds that of MT running.

2.6 OTHER FACTORS INFLUENCING MEASUREMENT OF AEROBIC CAPACITY

In the current research study, only cardiorespiratory responses as discussed earlier are of importance. It is, however, important to be aware of factors that may play a role achieving these responses. External factors such as familiarity with the running modality used, visual and auditory surroundings, differences in air resistance (Jones & Doust, 1996:325; Schache *et al.*, 2001:668), mechanical properties of the running surface and energy exchange through inconsistent belt speed may all play a role in differences measured between running modalities (Schache *et al.*, 2001:668).

Other researchers have focused more on kinematic variables (Fellin *et al.*, 2010:407; Riley *et al.*, 2008:1093; Schache *et al.*, 2001:667) such as running technique (McKenna & Riches, 2007:649; Morin & Séve, 2011:1695 ; Sinclair *et al.*, 2013:272), running motion (Fellin *et al.*, 2010:407), running posture (Fellin *et al.*, 2010:407) and foot strike (Snyder *et al.*, 2011) and have measured significant differences on different running modalities. Future studies are advised to investigate the role these variables play in cardiorespiratory responses.

Apparent differences have been pointed out between the running modalities concerning cardiorespiratory responses; however, the running protocol also has an effect on the cardiorespiratory responses during testing. A variety of test protocols exist and a single protocol has not been prescribed to determine the $\dot{V}O_{2\max}$ of endurance runners. In the light of this, the subsequent section will focus on protocols that can be used to determine the highest $\dot{V}O_{2\max}$ for endurance runners.

2.7 TREADMILL PROTOCOLS FOR DETERMINATION OF MAXIMAL AEROBIC CAPACITY

From reviewed research it is clear that a vast number of treadmill protocols exist to determine an athlete's $\dot{V}O_{2max}$. In untrained participants, aerobic capacity is not affected by the protocol used and a test of short duration is prescribed to be time-efficient (Kang *et al.*, 2001:294). However, to determine a trained runner's $\dot{V}O_{2max}$, a few guidelines have been recommended by researchers. According to Davies *et al.* (1984:78), the closer a protocol can simulate a specific population's sporting activity, the more objective and valuable the $\dot{V}O_{2max}$ assessment becomes. The protocol used to determine $\dot{V}O_{2max}$ is vital (Bouchard *et al.*, 1979:85-86; Davies *et al.*, 1984:77-78) and therefore further investigation is required.

A $\dot{V}O_{2max}$ protocol is considered complex and should be put together with the single purpose of gradually increasing exercise intensity to complete exhaustion (Haff & Dumke, 2012: 211). The combination of workload and time intervals used for GXT protocols is, however, regarded to be of great importance (Haff & Dumke, 2012:211). A GXT protocol with large workload increases should be used with longer time intervals (Astrand *et al.*, 2003:291-292), and when using small workload increases shorter time intervals should be used. Graded exercise tests differ vastly concerning workload and time interval increases. A steady state in cardiorespiratory responses is therefore pursued at the end of each incremental level. It is therefore essential to select the extent of a workload carefully, since the use of a too large workload increase can cause premature fatigue and early onset of lactate production (Davis *et al.*, 1976:548). The extent of a workload increase and the length of a time interval are consequently dependent on one another. Furthermore, two GXT protocol methods have been used throughout research, namely continuous test protocols (CTP) and discontinuous test protocols (DTP). Aforementioned protocols will be addressed in the following section.

2.7.1 Continuous and discontinuous graded exercise test protocols

Previous researchers determined aerobic capacity by using either a CTP method or a DTP method. CTP are known as single exercise bouts that aim to finish within 8—15 minutes, whereas DTP are often performed over a few days and consist of multiple exercise intervals that range between 3 and 5 minutes (Duncan *et al.*, 1997:273). DTP exercise intervals are spaced out to allow measured values to return to baseline for each bout (Snyder *et al.*, 2010). Discontinuous test protocols performed by Snyder *et al.* (2010) used interval intensities determined from lactate threshold and were expressed as percentages thereof. The DTP were performed as follows: a 50% interval performed along with a 100% interval on the same day followed by a 65% and 80%

interval on the following day (Snyder *et al.*, 2010). These exercise intervals were 6 minutes in duration and were separated by a 5 minute (increasing speed) or 10 minute (decreasing speed) rest interval. However, DTP differ throughout research and can be performed on a single day as well (Midgley *et al.*, 2007b:935), following the same structure of CTP by using exercise intervals of 2 and 3 minutes (Midgley *et al.*, 2007b:935) with repetitive increases in workload but with 30-second passive rest periods (Midgley *et al.*, 2008:444-445).

Duncan *et al.* (1997:277) found similar $\dot{V}O_{2max}$ values attained by CTP and DTP (55.8 ± 4.2 vs. 56.8 ± 4.7 ml/kg/min, respectively); however, HR_{max} values attained by CTP were found to be higher owing to longer test durations (191.7 ± 6.7 vs. 186.3 ± 7.7 bpm, respectively). Statistically significant higher ($p < 0.05$) RER and BLa^- values were achieved during DTP in comparison with CTP and can be expected in view of the anaerobic energy requirements of these 3—5-minute interval runs (1.28 ± 0.05 vs. 1.22 ± 0.05 , respectively; 14.3 ± 2.7 vs. 11.9 ± 2.7 mmol/L, respectively) (Duncan *et al.*, 1997:277). The greatest difference between the CTP and DTP were the T_{lim} measured for CTPs (12.3 min) and DTPs (67.3 min) (Davis, 2006:14). To determine the T_{lim} , DTP exercise interval times were added up without the applied rest periods (Midgley *et al.*, 2008:445). Because of the DTP time period, these tests are considered time-consuming and athletes and researchers prefer the CTP (Davis, 2006:14).

Continuous test protocols are also known as GXT and are recommended to determine $\dot{V}O_{2max}$. Continuous test protocols are designed to elicit maximal efforts within a specific time frame by gradually increasing workloads until exhaustion (Haff & Dumke, 2012:211). According to Haff and Dumke (2012:211), CTP should aim to increase progressively by using identical increments in workload and time intervals until the athlete reaches a steady state in cardiorespiratory responses before applying a further increase in workload. Furthermore, only CTP will be discussed in the subsequent section because it is preferred by researchers and athletes (Davis, 2006:14). All relevant protocols will be referred to as GXT protocols.

To establish whether there are similarities in current research, all GXT protocols previously used were investigated. Two types of GXT protocols were identified, namely speed GXT protocols with incremental speed increases and incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases. Only research using a similar population of trained male distance runners was used to compare existing GXT protocols. All relevant GXT protocols on both the MT and NMT are summarized in Table 2.1 and Table 2.2. Table 2.1 is comprised of all speed GXT protocols used for male distance runners and Table 2.2 is comprised of incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners. From the last-mentioned tables the basic incremental nature of

GXT protocols, specifically starting speed, time intervals and workloads, will be defined and briefly discussed. Finally, the GXT protocols used in this research study will be discussed.

Table 2.1: Speed GXT protocols used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed; speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Billat <i>et al.</i> , 1993	Horizontal treadmill with speed increases	3 min intervals to 80% of 3 km race pace whereafter; 1 min intervals are used.	12 km/h; 2 km/h and 1 km/h increments.	n = 8 M sub-elite runners Age: 29.3 ± 3 yrs.; Stature: 178 ± 4 cm; BW: 69 ± 5.9 kg.	<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 69.6 ± 4.2 ml/kg/min; T_{lim}: 404 ± 101 sec.
Billat <i>et al.</i> , 1996	Horizontal treadmill with speed increases	2 min.	17 km/h; 1 km/h increments.	n = 15 M endurance trained runners Age: 24 ± 2 yrs.; Stature: 176.4 ± 5.4 cm; BW: 68.2 ± 5.2 kg.	<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 65.98 ml/kg/min; • \dot{V}_E: 139.8 L/min; HR_{max}: 186 bpm; RER: 1.11.
	Horizontal treadmill with speed increases	1 min.	17 km/h; 0.5 km/h increments.		<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 65.98 ml/kg/min; • \dot{V}_E: 133.3 L/min; HR_{max}: 183 bpm; RER: 1.10.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim} : Time to exhaustion.

Table 2.1 (Continues): Speed GXT protocols used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed; speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Christie & Lock, 2001	Progressive speed protocol	1 min.	12 km/h; 1 km/h increments.	n = 8 M trained participants Age: 22 ± 1.7 yrs.; Stature: 181.1 ± 4.8 cm; BW: 75.3 ± 8.3 kg.	<ul style="list-style-type: none"> $\dot{V}O_{2max}$: 70 ± 7.2 ml/kg/min; HR_{max}: 196 ± 10 bpm; RER: 1.13 ± 0.09; RPE: 20 ± 0.5; T_{lim}: 9.12 ± 1.4 min.
Davies <i>et al.</i> , 1984	Horizontal treadmill with speed increases	1 min.	12 km/h (F); 14 km/h (M); 1 km/h increments.	n = 5 M and 5 F athletes BW: 60.1 ± 4.76 kg.	<ul style="list-style-type: none"> $\dot{V}O_{2max}$: 59.6 ± 10.3 ml/kg/min; T_{lim}: 8.1 ± 3 min.
	NMT horizontal with speed increases	3 min.	10 km/h; 2 km/h increments.		<ul style="list-style-type: none"> $\dot{V}O_{2max}$: 61.4 ± 11.4 ml/kg/min; T_{lim}: 6.0 ± 2.2 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.1 (Continues): Speed GXT protocols used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed; speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Dittrich <i>et al.</i> , 2013	Intermittent treadmill test	3 min.	10 km/h with 1% gradient; 1 km/h increments.	n = 12 M participants Age: 32 ± 6.3 yrs.; Stature: 176.7 ± 5.6 cm; BW: 74.9 ± 5.3 kg.	Lactate steady state % of • $\dot{V}O_{2max}$: 82%; T_{lim} : 66.5 ± 10 min.
Gibson <i>et al.</i> , 1999	Noakes progressive speed protocol	1 min.	12 km/h; 1 km/h increments.	n = 10 M club-level long distance runners Age: 22 ± 3 yrs.; Stature: 181.1 ± 8.1 cm; BW: 69.2 ± 7.8 kg.	• $\dot{V}O_{2peak}$: 68.3 ± 4.0 ml/kg/min; HR_{max} : 196 ± 4 bpm; RER: 1.14 ± 0.05; RPE: 18.6 ± 1.6; T_{lim} : 10.06 ± 1.23 min.
Machado <i>et al.</i> , 2013	Short level speed protocol	1 min.	Warm-up of 6 km/h for 3 min followed by initial speed of 8 km/h; 1 km/h increments.	n = 34 M recreational endurance trained runners Age: 40.1 ± 12.8 yrs.; Stature: 173.3 ± 7 cm; BW: 67.7 ± 7.7.2 kg.	HR_{max} : 181.8 ± 12.1 bpm; RPE: 19.8 ± 0.6; T_{lim} : 11.1 ± 1.6 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max} : Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim} : Time to exhaustion.

Table 2.1 (Continues): Speed GXT protocols used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed; speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Machado <i>et al.</i> , 2013 continues.	Intermediate level speed protocol	2 min.	Warm-up of 6 km/h for 3 min followed by initial speed of 8 km/h; 1 km/h increments.	n = 34 M recreational endurance trained runners Age: 40.1 ± 12.8 yrs.; Stature: 173.3 ± 7 cm; BW: 67.7 ± 7.7.2 kg.	HR _{max} : 184.8 ± 12.7 bpm; RPE: 19.8 ± 0.4; T _{lim} : 19.4 ± 3 min.
	Long level speed protocol	3 min.			HR _{max} : 183.1 ± 12.9 bpm; RPE: 19.9 ± 0.4; T _{lim} : 26.7 ± 4.7 min.
Meyer <i>et al.</i> , 2003	Ramp-like incremental test	30 sec.	Warm-up at 7.2 km/h; speed is increased by 0.54 - 0.72 km/h each increment; with gradient kept at 0.5%.	n = 18 M participants (8 endurance trained athletes, 5 active fit physical education students, and 3 leisure time active students) Age: 28 ± 7 yrs.; Stature: 182 ± 7 cm; BW: 73.0 ± 6 kg.	• VO _{2max} : 63.5 ± 6.6 ml/kg/min; HR _{max} : 188 ± 6 bpm; RER: 1.06 ± 0.04.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity;

$\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.1 (Continues): Speed GXT protocols used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed; speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Midgley, McNaughton, Polman <i>et al.</i> , 2007	Continuous incremental protocol	1 min.	Warm-up for 5 min at 9 km/h; 1 km/h increments for 5 minutes whereafter increments of 0.5 km/h followed.	n = 9 M distance runners Age: 38.2 ± 8.8 yrs.; Stature: 174 ± 4 cm; BW: 74.5 ± 10.8 kg.	• $\dot{V}O_{2max}$: 54.9 ± 7.1 ml/kg/min; HR _{max} : 176 ± 16 bpm; RER: 1.08 ± 0.03; T _{lim} : 10:18 ± 1:42 min.
Sperlich <i>et al.</i> , 2015	Constant speed protocol	30 sec.	Starting speed of 12 km/h; each 30 sec 0.5 km/h speed increments.	n = 14 M well-trained national level participants Age: 26 ± 4 yrs.; Stature: 184 ± 6 cm; BW: 78.5 ± 6.2 kg.	• $\dot{V}O_{2max}$: 61.8 ± 4.3 ml/kg/min; • \dot{V}_E : 156 ± 18 L/min; HR _{max} : 190 ± 9 bpm; RER: 1.19 ± 0.6; RPE: 18 ± 1; T _{lim} : 7:18 ± 1:06 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity;

$\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2: Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed; speed increment (km/h)	Population (n)	Cardiorespiratory values attained
<u>Incline GXT protocols with speed and gradient increases</u>					
Doherty <i>et al.</i> , 2003	Continuous incremental treadmill protocol	1 min.	Test began at 0% gradient and 11.5 km/h for M and F. Treadmill speed was increased by 1.1 km/h each 1 min. until a RER value of 1.00 had been reached (16.9 km/h for F and 19.1 km/h for M). 1% gradient increments.	n = 36 M participants (Great Britain squad members, probable Olympic representatives/international and Olympic representatives) Age: 26.4 ± 4.5 yrs.; Stature: 178.4 ± 6.3 cm; BW: 66.6 ± 5.7 kg.	• $\dot{V}O_{2max}$: 79.1 ± 0.7 ml/kg/min; HR _{max} : 185 ± 1.2 bpm; RER: 1.11 ± 0.1.
Gibson <i>et al.</i> , 1999	Continuous incremental treadmill protocol	2 min.	Walked on treadmill at 4.8 km/h for 2 min. Gradient was increased by 2.5% gradient until 20% was reached. Speed was increased by 0.4 km/h each 2 min until speed could not be maintained.	n = 10 club level M long distance runners Age: 22 ± 3 yrs.; Stature: 181.1 ± 8.1 cm; BW: 69.2 ± 7.8 kg.	• $\dot{V}O_{2peak}$: 69.6 ± 4.2 ml/kg/min; HR _{max} : 190 ± 6 bpm; RER: 1.07 ± 0.04; RPE: 18.9 ± 1; T _{lim} : 33.6 ± 2.7 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Froelicher <i>et al.</i> , 1974	Bruce protocol	1 min.	2.52 km/h starting pace for the 1 st to 3 rd minute along with 10% gradient. During min. 4 to 6, pace is increased to 3.21 km/h and gradient is increased to 12%. Speed and gradient are increased each increment by 1.28 -1.45 km/h and 2% gradient.	n = 15 M volunteers Age: 32 yrs.; Stature: 177.8 cm; BW: 78 kg.	<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 44.3 ml/kg/min; HR_{max}: 185 bpm.
Hamlin <i>et al.</i> , 2012	Novel Athlete LED Protocol	1 min.	Starting speed of 8-10 km/h with no gradient. (8 km/h for more sedentary and 10 km/h for more athletic participants). Speed was increased by 1 km/h until a comfortable running pace was reached whereafter gradient was increased by 1% each increments.	n = 21 M and 9 F participants Age: 29.9 ± 9.7 yrs.; BW: 175.7 ± 8.6 kg.	<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 47.0 ± 9.1 ml/kg/min; • \dot{V}_E : 132 ± 25.7 L/min; HR_{max}: 182.8 ± 10.5 bpm; T_{lim}: 10:18 ± 1:46 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate ; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Hamlin <i>et al.</i> , 2012 continues.	Bruce Protocol	1 min.	2.52 km/h starting pace for the 1 st to 3 rd minute along with 10% gradient. During min. 4 to 6, pace is increased to 3.21 km/h and gradient is increased to 12%. Speed and gradient are increased each increment by 1.28 -1.45 km/h and 2% gradient.	n = 21 M and 9 F participants Age: 29.9 ± 9.7 yrs.; Stature: 175.7 ± 8.6 cm.	<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 46.8 ± 10.1 ml/kg/min; • \dot{V}_E : 131.5 ± 26.7 L/min; HR_{max} : 179.7 ± 8.7 bpm; T_{lim} : 10:41 ± 1:59 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BM: BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate ; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Kang <i>et al.</i> , 2001	Bruce protocol	3 min.	2.52 km/h starting pace for the 1 st to 3 rd minute along with 10% gradient. During min. 4 to 6, pace is increased to 3.21 km/h and gradient is increased to 12%. Speed and gradient are increased each increment by 1.28 -1.45 km/h and 2% gradient.	n = 12 M trained participants Age : 21.3 ± 0.6 yrs.; Stature: 177.9 ± 1.8 cm; BW: 68.4 ± 1.6 kg.	T _{lim} : 17 ± 0.5 min.; • $\dot{V}O_{2max}$ and measured anaerobic threshold were lower when compared to the Astrand and Costill/Fox protocol (Not specified).
Saunders <i>et al.</i> , 2004	Brief Incremental protocol	1 min.	Starting speed 18 km/h; 1 km/h increments until 20 km/h whereafter 1% gradient increases are applied.	n = 11 M elite middle/long distance runners Age: 24.3 ± 3.9 yrs.; BW: 66.6 ± 8.5 kg.	• $\dot{V}O_{2max}$: 70.3 ± 7.3 ml/kg/min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Sperlich <i>et al.</i> , 2015	Incremental protocol	2 min/ 30 sec.	Starting speed of 8.64 km/h for 2 min; each 30 sec 1.44 km/h speed increments until 14.4 km/h whereafter gradient increases each 30 sec by 0.5%.	n = 14 M well-trained national level participants Age: 26 ± 4 yrs.; Stature: 184 ± 6 cm; BW: 78.5 ± 6.2 kg.	<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 62.2 ± 5.2 ml/kg/min; • \dot{V}_E: 158 ± 17; HR_{max}: 189 ± 11 bpm; RER: 1.18 ± 0.6; RPE: 18 ± 1; T_{lim}: 10:54 ± 1:30 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Incline GXT protocols with constant speed and gradient increases					
Davies <i>et al.</i> , 1984	Constant speed with gradient increases	1 min.	12 km/h for F; 14 km/h for M; 1.5% gradient increments 1 min.	n = 5 M and 5 F athletes BW: 60.1 ± 4.76 kg.	$\dot{V}O_{2max}$: 59.6 ± 11.1 ml/kg/min; T_{lim} : 7.4 ± 2.5 min.
	Constant speed with gradient increases	2 min.	12 km/h for F; 14 km/h for M; 1.5% gradient increments 2 min.		$\dot{V}O_{2max}$: 59. ± 11.0 ml/kg/min; T_{lim} : 11.2 ± 3.9 min.
	Constant speed with gradient increases	3 min.	12 km/h for F; 14 km/h for M; 1.5% gradient increments 3 min.		$\dot{V}O_{2max}$: 61.3 ± 11.6 ml/kg/min; T_{lim} : 12.0 ± 4.9 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max} : Maximum heart rate ; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim} : Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Duncan <i>et al.</i> , 1997	Continuous test protocol	3 min/ 1 min.	11.3 km/h with 0% gradient for 3 min, whereafter 2.5% gradient increments follow each min.	n = 10 M active participants Age: 24.1 ± 2.5 yrs.; Stature: 176.6 ± 6.9 cm; BW: 75.7 ± 11.5 kg.	• $\dot{V}O_{2max}$: 55.8 ± 4.2 ml/kg/min; HR _{max} : 191.7 ± 6.7 bpm; RER: 1.22 ± 0.05; RPE: 19.3 ± 0.7.
Froelicher <i>et al.</i> , 1974	Balke protocol	1 min.	5.4 km/h with 0% initial slope for the first 1 min; gradient increased to 2% whereafter 1% increments followed each min.	n = 15 M volunteers Age 32 yrs.; Stature: 177.8 cm; BW: 78 kg.	• $\dot{V}O_{2max}$: 42.8 ml/kg/min; HR _{max} : 184 bpm.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate ; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Kang <i>et al.</i> , 2001	Astrand Protocol	2 min.	Starting speed: 9.7 km/h (speed is kept constant). First increment is 3 min long whereafter increments are 2 min long, with 2% gradient increments each increment.	n = 12 M trained participants Age: 21.3 ± 0.6 yrs.; Stature: 177.9 ± 1.8 cm; BW: 68.4 ± 1.6 kg.	T _{lim} : 14.5 ± 0.5 min; The $\dot{V}O_{2max}$, HR, and measured anaerobic threshold were second to the Costill/Fox protocol in this research study. The Bruce protocol achieved the lowest values among the three testing protocols (Values not specified).

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Kang <i>et al.</i> , 2001 continues.	Costill/Fox Protocol	2 min.	Starting speed: 14.4 km/h; with 2% gradient increments.	n = 12 M trained participants Age: 21.3 ± 0.6 yrs.; Stature: 177.9 ± 1.8 cm; BW: 68.4 ± 1.6 kg.	T _{lim} : 10.4 ± 0.4 min; The $\dot{V}O_{2max}$, HR, and measured anaerobic threshold were higher in the Costill/Fox protocol when compared to the Astrand and Bruce protocol (Values not specified).

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
McConnel & Clark, 1988	Constant speed with gradient increases	1 min.	Starting speed 12.8 km/h; 2.5% gradient increments.	n = 10 well-trained M runners Age: 33.6 ± 8.6 yrs.; BW: 65.2 ± 6.6 kg.	<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 65.0 ± 5.6 ml/kg/min; HR_{max}: 183.6 ± 9.2 bpm; RER: 1.25 ± 0.1; RPE: 18.3 ± 1.1; T_{lim}: 10.1 ± 0.6 min.
	Constant speed with gradient increases	2 min.	Starting speed 12.8 km/h; 2.5% gradient increments.	n = 10 well-trained M runners Age: 33.6 ± 8.6 yrs.; BW: 65.2 ± 6.6 kg.	<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 64.5 ± 5.3 ml/kg/min; HR_{max}: 185.3 ± 9.1 bpm; RER: 1.15 ± 0.10; RPE: 18.9 ± 0.9; T_{lim}: 13.1 ± 1.2 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate ; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
McConnel & Clark, 1988 continues.	Constant speed with gradient increases	2 min.	Starting speed was mean reported training pace for each runner: 14 ± 0.8 km/h; 2.5% gradient increments.	n = 10 M well-trained runners Age: 33.6 ± 8.6 yrs.; BW: 65.2 ± 6.6 kg.	$\dot{V}O_{2max}$: 66.2 ± 3.9 ml/kg/min; HR_{max} : 184.6 ± 8.1 bpm; RER: 1.16 ± 0.07 ; RPE: 19.3 ± 0.7 ; T_{lim} : 11.8 ± 1.1 min.
McLaughlin <i>et al.</i> , 2010	Constant speed with gradient increases	1 min.	Starting speed: 10 km run time; 1% gradient increments.	n = 10 M healthy recreational participants Age: 33.7 ± 5.6 yrs.; Stature: 179 ± 6.5 cm; BW: 73.1 ± 6.9 kg.	$\dot{V}O_{2max}$: 60.2 ± 5.4 ml/kg/min; HR_{max} : 183.5 ± 10.7 bpm; RER: 1.14 ± 0.03 ; RPE: 18.4 ± 2 .

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max} : Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim} : Time to exhaustion.

Table 2.2 (Continues): Incline GXT protocols with a set speed or gradient with a variance of speed and/or gradient increases used for male distance runners.

Author	Protocol name	Interval time (min.)	Starting speed and speed increment (km/h)	Population (n)	Cardiorespiratory values attained
Sperlich <i>et al.</i> , 2015	Constant gradient protocol	2 min.	Starting speed of 14.4 km/h at 0% gradient; each 2 min, 2% gradient increments.	n = 14 M well-trained national level participants Age: 26 ± 4 yrs.; Stature: 184 ± 6 cm; BW: 78.5 ± 6.2 kg.	<ul style="list-style-type: none"> • $\dot{V}O_{2max}$: 63.1 ± 3.3 ml/kg/min; • \dot{V}_E: 161 ± 17 L/min; HR_{max}: 189 ± 9 bpm; RER: 1.24 ± 0.1; RPE: 19 ± 1; T_{lim}: 7:30 ± 1:12 min.

List of abbreviations: n: Number of participants; M: Male; F: Female; yrs.: Years; BW: Body weight; $\dot{V}O_{2max}$: Maximal aerobic capacity; $\dot{V}O_{2peak}$: Peak aerobic capacity; \dot{V}_E : Minute ventilation; HR_{max}: Maximum heart rate; RER: Respiratory exchange ratio; RPE: Rating of perceived exertion; T_{lim}: Time to exhaustion.

2.7.2 Starting speed

The starting speed of a GXT protocol is the speed at which the test is initiated. From research (Table 1 and Table 2), it is clear that the starting speed of a GXT protocol was altered by researchers, depending on the research population. To determine the starting speed of a research population, training background and gender were taken into consideration. Evidently, trained male participants' starting speeds were faster in comparison to female, sedentary or recreational participants (Davies *et al.*, 1984:75; Hamlin *et al.*, 2012:99). This is in line with the findings of Stamford (cited by McConnell & Clark 1988:4) who stipulated that higher running/starting speeds were found to be more appropriate for use with a well-trained population.

When looking at previous research, vast differences in starting speeds have been noticed. Graded exercise tests have used starting speeds ranging from 4.8 km/h up to 18 km/h (Gibson *et al.*, 1999:1227; Saunders *et al.*, 2004:470). From the criteria specified for the attainment of a $\dot{V}O_{2max}$ as specified earlier in section 2.4.1 as a measure for an adequate cardiorespiratory response, most GXT protocols used, achieved one and in some cases two of these responses. In a GXT protocol that achieved at least two of these criteria, the starting speed ranged from 4.4 km/h (Gibson *et al.*, 1999:1227) to 14 km/h (Davies *et al.*, 1984:75); however, starting speeds of 8 km/h and 12 km/h were found to be more common (Christie & Lock, 2001:20; Davies *et al.*, 1984:75; Gibson *et al.*, 1999:1227; Hamlin *et al.*, 2012:99; Machado *et al.*, 2013:578; McConnell & Clark, 1988:3; Sperlich *et al.*, 2015:387). The above stated starting speeds were used on both the speed GXT protocols and the incline GXT protocols. A secondary point is applicable for an incline GXT protocol and is known as the speed at which gradient increases are initiated. The speeds at which gradient increases commence are discussed in the subsequent section.

2.7.3 Speed at which gradient increases commence

An incline GXT protocol with speed increases makes use of a specific speed from where gradient increases are initiated. Gradient increases are often linked to the attainment of a specific cardiorespiratory response, for example an RER value = 1.00 (Doherty *et al.*, 2003:620). The use of a specified RER response has resulted in large speed differences for gradient increases among male and female participants (19.1 vs. 16.9 km/h, respectively) (Doherty *et al.*, 2003:620). From the investigated incline GXT protocols in Table 2, the gradient was increased at speeds ranging from 5.4—14.4 km/h (Froelicher *et al.*, 1974:513; McConnell & Clark, 1988:3; Sperlich *et al.*, 2015:387). The starting speed specified for speed GXT protocols and incline GXT protocols ranges differed vastly across protocols summarized in Table 1 and 2.

2.7.4 Time intervals

As stated earlier, time intervals used in either speed GXT protocols or incline GXT protocols should be controlled to allow a linear increase in exercise demand (Haff & Dumke, 2012:211). Time intervals of one or two minutes are recommended for both speed and incline GXT protocols, since they will allow a steady state to be reached in cardiorespiratory responses (Haff & Dumke, 2012:211) if the workload applied is appropriate. When using larger increases in workload, 3 min time intervals are advised (Astrand *et al.*, 2003:291).

Time intervals of the protocols listed in Table 1 and Table 2 are very different, ranging from 30 seconds to 3 minutes (Machado *et al.*, 2013:578; Meyer *et al.*, 2003:388; Sperlich *et al.*, 2015:387). However, the majority of protocols that attained two of the criteria specified for $\dot{V}O_{2\max}$ made use of 1- minute time intervals (Billat *et al.*, 1993:254; Billat *et al.*, 1996:314; Christie & Lock, 2001:20; Davies *et al.*, 1984:75; Dohery *et al.*, 2003:620; Duncan *et al.*, 1997:274; Gibson *et al.*, 1999:1227; Hamlin *et al.*, 2012:99; Machado *et al.*, 2013:578; McLaughlin *et al.*, 2010:992; Midgley, McNaughton, Polman *et al.*, 2007:1024; Saunders *et al.*, 2004:470; Sperlich *et al.*, 2015:387). This is in agreement with the results of McConnell and Clark (1988:3) who found 1-minute intervals rather than 2-minute intervals allowed athletes to finish within a shorter running time with enhanced athlete comfort.

2.7.5 Workloads

Graded exercise tests are designed to increase workload progressively up to exhaustion. Workload is applied to a treadmill modality by increasing speed and/or gradient to progress linearly. It is recommended that the increases in workload and time intervals used should be identical (Haff & Dumke, 2012:211). It is, however, of great significance to select the extent of a workload carefully, in view of the physiological effect these increases may have. A speed or incline GXT protocol with rapid workload increases can ultimately lead to hyperventilation because of greater metabolic demand, causing premature fatigue and early onset of lactate production (Davis *et al.*, 1976:548).

To discuss workload increases further, the specified GXT protocols, namely the speed GXT protocol and the incline GXT protocol, are discussed in the subsequent section.

2.7.6 Speed graded exercise test protocols

Of the 14 GXT protocols with incremental speed increases identified from past research, eight protocols have attained the cardiorespiratory responses expected from a trained endurance runner. This is based on the findings of Kenney *et al.* (2012:122) who stated that a $\dot{V}O_{2\max}$ of 70 ml/kg/min can be considered adequate, therefore all aerobic capacity measures of

60 ml/kg/min and above were considered suitable for a trained endurance runner (Billat *et al.*, 1993:254; Billat *et al.*, 1996:314; Christie & Lock, 2001:20; Davies *et al.*, 1984:75; Gibson *et al.*, 1999:1227; Meyer *et al.*, 2003:388). From the speed GXT protocols summarized in Table 1, a few tendencies were evident. The use of 1 km/h speed increments (Billat *et al.*, 1993:254; Billat *et al.*, 1996:314; Christie & Lock, 2001:20; Davies *et al.*, 1984:75; Gibson *et al.*, 1999:1227; Meyer *et al.*, 2003:388; Sperlich *et al.*, 2015:387) and the use of a starting speed ranging from 7.2—17 km/h (Billat *et al.*, 1993:254; Billat *et al.*, 1996:314; Meyer *et al.*, 2003:388) were more common. However, higher starting/running speeds were found to be more suitable for a well-trained population (Stamford cited by McConnell and Clark, 1988:3) and therefore a starting speed of 7.2 km/h can be considered too slow. Of the eight GXT incremental speed protocols, an initial speed of 10 km/h (Davies *et al.*, 1984:75; Dittrich *et al.*, 2013) and 12 km/h (Billat *et al.*, 1993:254; Billat *et al.*, 1996:314; Christie & Lock, 2001:20; Gibson *et al.*, 1999:1227; Sperlich *et al.*, 2015:387) were used.

Unfortunately all speed GXT protocols listed in Table 1 could not be used as part of the summary owing to low $\dot{V}O_{2\max}$ values or incomplete cardiorespiratory responses. Research conducted by Dittrich *et al.* (2013) and Machado *et al.* (2013) did not report any aerobic capacity values. These speed GXT protocols were consequently not discussed in this section.

2.7.7 Incline graded exercise test protocols with a set speed or gradient with a variance of speed and/or gradient

A similar comparison as the previous discussion of speed was made regarding incline GXT protocols as summarized in Table 2. By using the same $\dot{V}O_{2\max}$ value of 60 ml/kg/min and above as measure for an adequate GXT protocol, 10 of the 21 protocols thought relevant to this research study attained aerobic capacity values that exceeded 60 ml/kg/min (Davies *et al.*, 1984; Doherty *et al.*, 2003; Gibson *et al.*, 1999; McConnell & Clark, 1988; McLaughlin *et al.*, 2010; Saunders *et al.*, 2004; Sperlich *et al.*, 2015). Even though these incline GXT protocols differed vastly concerning starting speed and the speed where gradient increases occurred, a small increment in speed (0.4—1.44 km/h) was evident for incline GXT protocols (Doherty *et al.*, 2003:620; Gibson *et al.*, 1999:1227; Saunders *et al.*, 2004:470; Sperlich *et al.*, 2015:387). The gradient increases (0.5%, 1%, and 2.5%) used in these protocols differed greatly but were in accordance with the time intervals used (30 sec, 1 min and 2 min) (Doherty *et al.*, 2003:620; Gibson *et al.*, 1999:1227; McConnell & Clark, 1988:3; McLaughlin *et al.*, 2010:992; Saunders *et al.*, 2004:470; Sperlich *et al.*, 2015:387).

Furthermore, incline GXT protocols differed regarding the manner in which workload increases were applied. Some incline GXT protocols increased in speed and gradient interchangeably

(Gibson *et al.*, 1999:1227), others increased speed to a specific point, whereafter only gradient was increased (Doherty *et al.*, 2003:620; Sperlich *et al.*, 2015:387) and others increased gradient from a constant speed (Davies *et al.*, 1984:75; McConnell & Clark, 1988:3; McLaughlin *et al.*, 2010:992). All incline GXT protocols had attained adequate $\dot{V}O_{2max}$ values and were therefore considered adequate incline GXT protocols.

2.8 GRADED EXERCISE TEST PROTOCOLS AND TRAINING REGIME

According to Davies *et al.* (1984:78), the GXT protocol used should simulate the activity or movement of an athlete's competitive environment to obtain objective values. Athletes taking part in both track and cross-country running impose a significant challenge on the GXT protocols used. The training regimes used during both track and cross-country season are therefore important to take note of, for simulation purposes.

Due to limited research regarding training regimes and graded exercise test protocols, Svedenhag (1985) and Vanhoy's (2012) research were used. Svedenhag (1985:128) conducted a longitudinal research study over a period of one year on middle (800 m to 1 500 m) and long (5 000 m to 10 000 m) distance runners, during which these runners were documented with regard to their weekly training load concerning the total kilometers run, as well as the intensity of these workouts. Svedenhag (1985:128) found that cross-country competitions were preceded by predominantly long, slow distance running along with faster distance running, or long interval workouts. The intensity of these exercises was increased by adding uphill training to the training regime, as well as more intense interval training (Svedenhag, 1985:128) as the competitive cross-country season approached. Training was, however, further intensified as runners neared the track competition season (Svedenhag, 1985:128). From the above-mentioned findings it is clear that the intensity of training during track and cross-country season differs. It is interesting to note that Vanhoy (2012:46) stated that a specific training regime may support better performance results on a specific GXT protocol because of physiological adaptations that manifest in response to following a focused training regime. However, for these adaptations to occur, a single training regime was recommended for a long period of time (Vanhoy, 2012:46). The training regime used to prepare for track and cross-country season should therefore be kept in mind to simulate the GXT protocol used.

2.9 CONCLUSION

Maximal aerobic capacity can be regarded as one of the most researched topics in exercise science. For determination of an objective and sport-specific $\dot{V}O_{2max}$, the protocol and running modality used are required to simulate an athlete's sporting activity closely. However, a single method of determining both the running modality as well as GXT protocol used has not yet been

benchmarked for trained distance runners. In the light of these findings, the first aim of this literature review was to describe aerobic capacity as well as the cardiorespiratory responses necessary to enable researchers to determine $\dot{V}O_{2max}$ and consequently aid in the identification of a $\dot{V}O_{2max}$ criterion. The second aim was to investigate running modalities, namely the Curve NMT and the MT, to determine the effect the possible differences in modality may have on trained distance runners. Both the Curve NMT and the MT were investigated with respect to OGR simulation, EC of running, the effort experienced as well as measured cardiorespiratory responses on the respective running modalities. The last aim of this literature review was to investigate all GXT protocols previously used to test male distance runners to identify the basic incremental building blocks required for a successful GXT protocol for the determination of $\dot{V}O_{2max}$.

Maximal aerobic capacity determined by means of direct measurement through an automated system in a closed laboratory environment was considered a reliable method. Cardiorespiratory responses were investigated that were considered to be important for aerobic capacity testing to identify a set of criteria to determine $\dot{V}O_{2max}$. From numerous criteria set by earlier researchers, a set of criteria was identified that was considered adequate, namely a plateau in $\dot{V}O_2$ (<150 ml/min), RER (>1.15), HR_{max} (208- (0.7x age)), as well as RPE (CR10=10). The attainment of any two of these responses was considered adequate for the attained value to be a $\dot{V}O_{2max}$, otherwise the attained value was graded to be a $\dot{V}O_{2peak}$ and the results were excluded from the research study.

In an investigation of the running modalities, namely the MT and the Curve NMT, as alternative running modalities to OGR, the Curve NMT was found to resemble OGR closely. The Curve NMT was found to mimic OGR by requiring power to drive the belt with each subsequent step. Because of the non-motorized nature of the belt, running on the Curve NMT requires self-initiation of movement and therefore self-pacing. Measured cardiorespiratory responses on the Curve NMT exceed those of MT and OGR. The Curve NMT was found to be more strenuous regarding physiological intensity and metabolic demand. These findings are partially due to the Curve NMT's natural increasing gradient of 5—10 degrees. Finally, the Curve NMT is thought to expend more energy than both the MT and OGR. Although the Curve NMT is thought to mimic OGR more closely, it is still important to use the appropriate GXT protocol to obtain valid and reliable $\dot{V}O_{2max}$ results.

A vast number of GXT protocols have been used throughout the years, but only GXT protocols performed on trained male distance runners were used for this research study. Speed GXT (speed increases) protocols and incline GXT protocols (with a set speed or gradient with a variance of speed and/or gradient increases) were found to be prominent throughout the literature and were consequently investigated. According to reviewed research, GXT protocols had to be continuous in nature and increase progressively in identical workloads and time intervals for the entire GXT protocol. The relationship between the duration of a workload and size of a time interval was found to be important.

Motorized treadmills were habitually used in past research for the execution of GXT protocols. Reviewed GXT protocols indicate that numerous MT GXT protocols exist; it was, however, clear that limited research into NMT running and GXT protocols had been undertaken previously. Nonetheless, a single GXT protocol was performed on a NMT and was identified for use in this research study. The GXT protocol identified was a speed GXT protocol and was performed on a NMT. Two GXT protocols performed on a MT were also identified from reviewed research. The first GXT was a speed GXT protocol and the second an incline GXT protocol. Of the 14 speed GXT protocols identified from past research, only eight (Billat *et al.*, 1993; Billat *et al.*, 1996; Christie & Lock. 2001; Davies *et al.*, 1984; Gibson *et al.*, 1999; Meyer *et al.*, 2003; Sperlich *et al.*, 2015) attained $\dot{V}O_{2max}$ values high enough to be considered successful. These speed GXT protocols still differed with regard to their basic incremental nature. It was, however, evident that 1 km/h speed increments and starting speeds of 10 km/h and 12 km/h were more common among these speed GXT protocols.

Of 21 incline GXT protocols identified from earlier research, ten (Davies *et al.*, 1984; Doherty *et al.*, 2003; Gibson *et al.*, 1999; McConnel & Clark. 1988; McLaughlin *et al.*, 2010; Saunders *et al.*, 2004; Sperlich *et al.*, 2015) were found relevant to this research study by attaining a $\dot{V}O_{2max}$ value of 60 ml/kg/min or above. All basic incremental components of the GXT protocols differed vastly concerning incline GXT protocols. In the investigated components, small increments in speed (0.4—1.44 km/h) were found to be favored. Furthermore, a clear relationship between the time interval and workload used was evident, with incline GXT protocols using 30 seconds, 1-minute and 2-minute time intervals alongside 0.5%, 1% and 2.5% gradient increases respectively.

From these MT GXT protocols investigated, guidelines on the incremental nature were identified, namely workload increases of 1 km/h or 1% gradient, and 1-minute time intervals. The starting speeds (10 km/h) of these protocols were limited by the single NMT GXT protocol identified. The following GXT protocols were selected from Table 1 and Table 2 and were adapted slightly to allow comparability in this study:

Adapted Incremental Speed Protocol on a MT (AISP) – The AISP was adapted from the speed GXT protocol of Davies *et al.* (1984:75). The test started at a starting speed of 10 km/h with increases of 1 km/h each minute until voluntary exhaustion. The starting speed of this GXT protocol was adapted from 14 km/h to 10 km/h to allow comparability between results obtained from the MT and the Curve NMT.

Incremental Speed and Incline Protocol on a MT (ISIP) – The ISIP was adapted from the incline GXT protocol of Hamlin *et al.* (2012:99). The ISIP started with no gradient and a starting speed of 10 km/h with increases of 1 km/h each minute until a comfortable running pace was attained, whereafter the speed was kept constant. Thereafter the gradient was increased each minute by 1% until voluntary exhaustion (Hamlin *et al.*, 2012:99). The comfortable running pace was set at 15 km/h, which was similar to speeds used in Table 2.

Adapted Non-Motorized Incremental Speed Protocol (ANMIP) – The ANMIP was adapted from the speed GXT protocol on the NMT of Davies *et al.* (1984:75). The test started at a starting speed of 10 km/h with a 2 km/h increase every 2 minutes until voluntary exhaustion. The time intervals used by Davies *et al.* (1984:75) have been adapted from 3 minutes to 2 minutes, to compare the attained cardiorespiratory responses of the Curve NMT to the corresponding responses of the MT at similar speeds. Longer time intervals (2 min) were selected because the non-motorized nature of the belt required athletes to self-pace the required speed of each increment and consequently allowed athletes to achieve a steady state in cardiorespiratory responses.

In conclusion, current literature contains numerous research studies on $\dot{V}O_{2max}$ testing; however, a gold standard for determination of $\dot{V}O_{2max}$ has not been set for distance runners. From reviewed research it is clear that the NMT simulates OGR more closely than the MT and can therefore be considered a better running modality for $\dot{V}O_{2max}$ testing. Unfortunately, limited research has been done on $\dot{V}O_{2max}$ testing on the Curve NMT. Furthermore, the GXT protocol used for determination of $\dot{V}O_{2max}$ is considered important, even though several GXT protocols have been used in past research on trained male distance runners. A single GXT protocol has not yet been standardized for $\dot{V}O_{2max}$ testing. As result, a need for the standardization of both the running modality and GXT protocol used for determination of the highest $\dot{V}O_{2max}$ for distance runners exist.

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CHAPTER 3

**A COMPARISON BETWEEN THE
CARDIORESPIRATORY RESPONSES OF A
SPEED VERSUS AN INCLINE MOTORIZED
TREADMILL PROTOCOL**

Title page**Title:**

A comparison between the cardiorespiratory responses of a speed versus an incline motorized treadmill protocol.

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Word Count

Excluding abstract and references: 2928

Abstract: 245

Number of Tables: 2

Number of Figures: 0

Prepared for submission to: *Journal of Science and Medicine in Sport.*

Abstract

Objectives: To compare the cardiorespiratory responses attained by elite male university-level distance runners of two maximal aerobic capacity ($\dot{V}O_{2max}$) graded exercise test (GXT) protocols on a motorized treadmill.

Design: A once-off cross-sectional design using elite male university-level distance runners.

Methods: Two GXT protocols were used, namely the Adapted Incremental Speed Protocol (AISP) and the Incremental Speed and Incline Protocol (ISIP). Both protocols commenced from a starting speed of 10 km/h, whereafter the AISP continuously increased by 1 km/h speed increments and the ISIP increased by 1 km/h speed increments up to 15 km/h, after which 1% gradient increases were applied. Both treadmill GXT protocols were performed to complete exhaustion. Cardiorespiratory responses (oxygen consumed, carbon dioxide produced, oxygen utilized, minute ventilation, heart rate, time to exhaustion and respiratory exchange ratio) were used to determine exercise intensity markers, namely ventilatory threshold and respiratory compensation point (RCP). Rating of perceived exertion was measured after completion of each test level.

Results: The $\dot{V}O_{2max}$ value (67.6 vs. 65.0 ml/kg/min), as well as the relative RCP value (64.1 vs. 60.7 ml/kg/min) attained by the ISIP, was statistically and practically higher ($p < 0.05$; $d > 0.8$; $r < 0.5$) than those of the AISP despite the longer time to exhaustion (11.4 vs. 13.6 min) and the longer time to the attainment of RCP (11.1 vs. 8.8 min).

Conclusion: The ISIP $\dot{V}O_{2max}$ result exceeded that of the AISP and it is consequently considered the more appropriate GXT protocol to attain the highest cardiorespiratory responses in an elite male university-level distance running population.

Keywords

Oxygen consumption; Exercise tolerance; Exercise test; Physical exertion; Running performance.

Introduction

The attainment of a high maximal aerobic capacity ($\dot{V}O_{2\max}$) value is considered an important determinant of endurance running performance¹, due to endurance events being performed at high percentages of $\dot{V}O_{2\max}$ ^{2,3}. Several graded exercise test (GXT) protocols have been developed in the past to determine runners' $\dot{V}O_{2\max}$ ⁴. Regardless of the various existing GXT protocols developed in the past, a single GXT protocol has not yet been standardized for the sport-specific measurement of a distance runner's cardiorespiratory responses. It should, however, be noted that previously used GXT protocols, such as the standardized Bruce protocol, were put together for a population of participants with coronary heart disease in mind⁵. Although this GXT protocol has been used by researchers on healthy trained and untrained participants⁶, other GXT protocols have been more specifically designed for trained participants.

Maximal aerobic capacity values are considered more objective and valuable if the GXT protocol used closely simulates the population's specific activity⁷, therefore the GXT protocol used to determine the $\dot{V}O_{2\max}$ is considered vital⁷. Treadmill GXT protocols differ with regard to the basic incremental nature, namely starting speed, time intervals and workload increases (speed and gradient) used to reach the point of exhaustion progressively⁴. The use of a continuous GXT protocol² with equal increases in workload and time intervals has been prescribed by research⁸. The continuous nature of the GXT protocol will allow adequate time for a steady state in cardiorespiratory responses before increasing the workload to the next level of the test⁸.

Generally, two GXT protocols were of interest to determine distance runners' $\dot{V}O_{2\max}$, firstly a speed GXT protocol with speed increases^{7,9,10}, and secondly an incline GXT protocol with a set speed with a variance of speed and/or gradient increases^{6,7,11,12}.

Speed GXT protocols differed greatly among research studies, with starting speeds varying between 8 and 12 km/h^{10,12}, speed increases ranging from 0.5—1 km/h^{9,13,14}, and time intervals from 30 seconds to 180 seconds^{10,14,15}. Incline GXT protocols differed even more, with starting speeds from 2.5—18 km/h^{16,17}, increases in speed ranging from 0.4—1.4 km/h^{4,12}, and gradient increases from 0.5—10%^{17,18}. Time interval changes were also large, ranging from 30 seconds up to 120 seconds^{12,17}.

According to reviewed research, a specific GXT protocol has not been prescribed to determine distance runners' $\dot{V}O_{2\max}$ values. Even more significantly, a GXT protocol has not been prescribed for elite male university-level distance runners who take part in both track and cross-

country running. The previously mentioned background emphasizes the vast differences in past $\dot{V}O_{2\max}$ GXT protocols and consequently this study was designed to compare two motorized treadmill GXT protocols to determine which GXT protocol would depict the highest values when working with elite male university-level distance runners. The aim of this study is to propose a sport-specific GXT protocol to simplify measurement of $\dot{V}O_{2\max}$ in elite male university level distance runners.

Methods

Twelve elite male university-level distance runners (age: 21.8 ± 3.0 yrs.; stature: 178.2 ± 6.5 cm; and body weight: 66.7 ± 4.7 kg) from a university in the North West Province of South Africa participated in this research study. All participants were training for track and/or cross-country running and competing for the university team during the 2016 season. All tests were performed during the track season. After being fully informed of the nature of the study as well as possible risks and benefits, each participant gave written consent for participation. The testing procedures were approved by the Health Research Ethics Committee (HREC) of the Faculty of Health Sciences, North-West University (NWU - 00201- 15 - A1). Furthermore, participants had to be injury-free and complete all tests involved in this research study. A once-off cross-sectional design was used.

The following GXT protocols were conducted:

- *Incremental Speed and Incline Protocol (ISIP)* – The ISIP was adapted from Hamlin and colleagues' athlete-led protocol⁶. Hamlin *et al.*'s⁶ GXT began at a starting speed of 10 km/h with increases of 1 km/h each minute until a comfortable running pace had been reached. The ISIP's comfortable running pace was set at 15 km/h. Thereafter the gradient was increased each minute by 1% gradient until voluntary exhaustion⁶.
- *Adapted Incremental Speed Protocol (AISP)* – The AISP was adapted from the speed GXT protocol of Davies *et al.*⁷. Davies *et al.*'s⁷ GXT began at a starting speed of 14 km/h with increases of 1 km/h each minute until voluntary exhaustion. The starting speed of the AISP was adapted from 14 km/h to 10 km/h to enable comparability to the ISIP.

Two familiarization sessions on the motorized treadmill were completed two weeks prior to the tests. The AISP's familiarization sessions started at 10 km/h and increased each 1-minute interval by 1 km/h until a comfortable running pace was reached. The athlete kept running until 10 minutes had passed. The ISIP's familiarization sessions started at a running speed of 10 km/h and increased by each 1-minute interval by 1 km/h until 13 km/h was reached. Gradient was thereafter

applied for 2 minutes (1% gradient increase each 1-minute interval). Athletes kept running for 10 minutes. These familiarization sessions were considered adequate¹⁹.

Participants were required to take part in two GXT protocols to determine their $\dot{V}O_{2max}$ on the Woodway Pro XL motorized treadmill (Woodway, W229 N591, Foster Ct, Waukesha, WI). Both GXT protocols were performed within a time frame of five days at exactly the same time of day. All participants were healthy (Physical Activity Readiness Questionnaire) and well-hydrated (hydration status and recovery questionnaire). They were tested in a temperature-controlled laboratory with temperature ranging between 19 and 21°C. A normal diet throughout the study was required and participants were requested to abstain from food for two hours, alcohol and coffee for 12 hours and vigorous training for 48 hours prior to testing. Stature and body weight were measured on each test day on arrival at the laboratory. The GXT protocols were preceded by a 10-minute warm-up, consisting of treadmill running at 10 km/h for a distance of 1 km, followed by a set of dynamic stretches. After the warm-up, participants were fitted with a heart rate (HR) monitor belt (Polar Electro, Kempele, Finland: T34) for HR measurement and a face mask for breath analysis. The Oxycon Pro static ergo spirometry system (Jaeger Oxycon Pro, Viasys, 22745, Savi Ranch Parkway, Yorba Linda, CA, USA) was used to measure cardiorespiratory responses ((maximum HR (HR_{max}), oxygen consumed ($\dot{V}O_2$), carbon dioxide produced ($\dot{V}CO_2$), minute ventilation (\dot{V}_E), $\dot{V}O_{2max}$, oxygen utilized ($\dot{V}O_2$) respiratory exchange ratio (RER), and time to exhaustion (T_{lim})) every 15 seconds during each GXT. Participants were motivated to continue until voluntary exhaustion. The difficulty of the GXT was rated by the participant in the last 10 seconds of each test level according to the Borg Scale (CR-10 Scale)²⁰ and was visually indicated by a show of fingers to match the perceived difficulty. Communication during the GXT protocol was limited to basic signaling: thumbs up (continue) and thumbs down (stop). HR recovery was taken after completion of the test at 1, 3, and 5 minutes of passive rest.

Other cardiorespiratory responses, namely the ventilatory threshold (VT) and respiratory compensation point (RCP), were determined by two experienced sport scientists using a plotted graph on which the increases and decreases of $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ values were displayed.

The VT was identified as the point where the $\dot{V}_E/\dot{V}O_2$ increased without a corresponding change in the $\dot{V}_E/\dot{V}CO_2$ or departure in the linearity of the \dot{V}_E line. The RCP was identified as the point where both the $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ increased dramatically²¹. If the two sport scientists did not agree, a third sport scientist was consulted. Time to exhaustion was measured from the initiation of the GXT protocol's starting speed of 10 km/h and ended when exhaustion set in and

the $\dot{V}O_{2max}$ test was terminated. Participants had to attain two of the responses described below for the value to be accepted as a $\dot{V}O_{2max}$. The criteria points used to determine the achievement of a $\dot{V}O_{2max}$ was an RER value of ≥ 1.15 ²², the attainment of a plateau in $\dot{V}O_2$ (<150 ml/min)^{6,8}, RPE score of 10 (CR 10 Scale)²⁰ and the attainment of HR_{max} as determined by using the formula of $208 - (0.7 \times \text{age})$ ²³. In cases where only one criterion was attained, the test was deemed to be a peak aerobic capacity ($\dot{V}O_{2peak}$) value and participants were excluded from this research study.

The statistical data processing package SPSS Statistics (version 21.0.0.0) was used to process the data. A hierarchical linear model was used to determine differences between the AISP and ISIP over time (per minute) to model the dependency of repeated measures for each participant²⁴. Variance per person (VPP) was taken into account, as well as unexplained variances (Mean square error (MSE)). Statistical significance (p-values) was set at $p < 0.05$ and the effect size values (Cohen's d-value) were reported with guideline values of 0.2 for small, 0.5 for medium, and 0.8 for large²⁵. A paired sample t-test was used to determine the statistical significance between the maximal values attained of all repeated measures of the AISP and ISIP ($p < 0.05$). Cohen's d-value was used for the standardized differences in averages²⁵. Because of the small sample size, the results were confirmed with the Wilcoxon rank test (p-value) set at $p < 0.05$ and non-parametric effect size (r-value) with guideline values of 0.1 for small, 0.3 for medium, and 0.5 for large effect size²⁶.

Results

The cardiorespiratory responses recorded during both GXT protocols are shown in Table I. Although a small sample size was used for this study, both statistical and practical significant results were obtained. Results of the differences in maximum cardiorespiratory responses for the two protocols in Table I were found to be in agreement with measures of dependent t-test and Wilcoxon's rank test (p-value) results. Therefore, attention will be paid to the interpretation of parametric and non-parametric effect size (d-value; r-value), and Wilcoxon's rank test (p-value). Large effect sizes were evident between the AISP and ISIP for both d-values and r-values. Time to exhaustion was statistically ($p = 0.002$) and practically ($d = 1.87$; $r = 0.89$) lower during the AISP compared to the ISIP (11.4 ± 1.2 vs. 13.6 ± 1.2 min). The practically measured RER values for the AISP significantly exceeded ($d = 0.63$; $r = 0.51$) those of the ISIP (1.16 ± 0.05 vs. 1.13 ± 0.05). Furthermore, the time in which the RCP was attained (11.1 ± 1.3 vs. 8.8 ± 1.8 min), as well as the RCP's relative values (64.1 ± 4.2 vs. 60.7 ± 5.3 ml/kg/min) differed, with both statistical ($p = 0.015$) and practical ($d = 0.64$; $r = 0.7$) significantly higher values attained by the ISIP in comparison to the AISP. The $\dot{V}O_{2max}$ responses (67.6 ± 5.0 vs. 65.0 ± 4.4 ml/kg/min) showed statistically significant

measures through the Wilcoxon rank test ($p=0.038$) in favor of the ISIP compared to the AISP, as well as practical significant ($d=0.51$; $r=0.60$) results. The results of the Wilcoxon's rank test are regarded as more appropriate than the dependent t-test that was found statistically insignificant ($p=0.390$) because of the small sample size used.

Table I: Mean cardiorespiratory responses from maximum values attained by AISP and ISIP (n=12)

Cardiorespiratory Response	Protocol	Mean±SD	Dependent t-test (p-value)	Effect size (d-value)	Wilcoxon rank test (p-value)	Non-parametric effect size (r-value)
T _{lim} (min)	AISP	11.4±1.2	0.001 ^c	1.87 ^a	0.002 ^c	0.89 ^a
	ISIP	13.6±1.2				
HR _{max} (bpm)	AISP	192.3±9.0	0.505	0.14	0.350	0.27
	ISIP	193.8±10.1				
HR 1 min R (bpm)	AISP	145.7±22.1	0.844	0.05	0.875	0.05
	ISIP	144.6±23.0				
HR 3 min R (bpm)	AISP	107.3±16.7	0.515	0.12	0.505	0.19
	ISIP	109.6±19.3				
HR 5 min R (bpm)	AISP	98.4±12.8	0.142	0.26	0.142	0.42
	ISIP	103.4±19.2				
RER	AISP	1.16±0.05	0.670	0.63 ^b	0.075	0.51 ^a
	ISIP	1.13±0.05				
• VO _{2max} (ml/kg/min)	AISP	65.0±4.4	0.390	0.51 ^b	0.038 ^c	0.60 ^a
	ISIP	67.6±5.0				
RPE	AISP	9.4±1.2	0.210	0.34	0.197	0.37
	ISIP	9.8±0.4				
VT (ml/kg/min)	AISP	49.3±6.3	0.373	0.32	0.239	0.34
	ISIP	51.5±6.9				
VT (min)	AISP	4.9±1.7	0.282	0.35	0.196	0.37
	ISIP	5.8±2.4				
RCP (ml/kg/min)	AISP	60.7±5.3	0.007 ^c	0.64 ^b	0.015 ^c	0.7 ^a
	ISIP	64.1±4.2				
RCP (min)	AISP	8.8±1.8	0.001 ^c	1.32 ^a	0.002 ^c	0.88 ^a
	ISIP	11.1±1.3				
• VT% of VO _{2max} (%)	AISP	75.7±7.8	0.859	0.07	0.48	0.2
	ISIP	76.5±10.3				
• RCP% of VO _{2max} (%)	AISP	93.3±3.9	0.207	0.42	0.209	0.36
	ISIP	94.9±3.2				

AISP – Adapted Incremental Speed Protocol; ISIP – Incremental Speed and Incline Protocol; HR – Heart rate; HR_{max} – Maximum heart rate; RER – Respiratory exchange rate; RPE – Rating of perceived exertion; R – Recovery; RCP – Respiratory compensation point; (T_{lim}) – Time to exhaustion; •
VO_{2max} – Maximal aerobic capacity; VT – Ventilatory threshold.

n – Number of participants; SD – Standard deviation; a: Large effect (practical significance); b: Medium effect (practical significance); c: Statistical significance.

Cardiorespiratory responses obtained from each time point of the AISP and ISIP GXT protocols were compared using hierarchical linear models. All responses were statistically significant ($p < 0.05$) over time. Furthermore, Cohen's d-values were used to test for differences between the protocols at each time point. Time points 1 to 7 showed no practical significant results and protocols were therefore considered similar and were not reported in Table II. Furthermore, it should be noted that the ISIP lasted significantly longer than the AISP and therefore per minute comparisons could only be made up to minute 14. Both \dot{V}_E and RER values were higher for AISP compared to ISIP and showed large effect sizes ($d > 0.8$) for all time points. The measured responses for \dot{V}_{O_2} of the AISP surpassed all time points of the ISIP and showed medium effect size ($d > 0.5$) for the majority of time points (8, 9, 10, 11, 12, and 13 min) except for the 14th minute, which showed a large effect size ($d > 0.8$). The measured responses for HR were higher for all measures of the AISP compared to the ISIP and presented medium practical significant values ($d > 0.5$) for the 11th and 12th minutes of the test, of which the 13th and 14th minutes showed a large effect ($d > 0.8$). Furthermore, the measured RPE differences in the early stages of the test presented medium effect sizes ($d > 0.5$) for the 9th minute and large effect sizes ($d > 0.8$) for the 10th, 11th and 12th minutes, with values of the AISP exceeding the ISIP. Rating of perceived exertion showed no further effect size values above $d > 0.5$.

Table II: Cardiorespiratory response values per minute of the AISP and ISIP

CR	8 min		9 min		10 min		11 min		12 min		13 min		14 min		MSE	VPP	P-value
	AISP	ISIP	AISP	ISIP	AISP	ISIP	AISP	ISIP	AISP	ISIP	AISP	ISIP	AISP	ISIP			
Per P per min	n=(12)	n=(12)	n=(12)	n=(12)	n=(12)	n=(12)	n=(9)	n=(12)	n=(5)	n=(12)	n=(1)	n=(10)	n=(1)	n=(6)			
\dot{V}_E	126.8 ^a	112.0	144.1 ^a	123.4	158.8 ^a	129.2	169.8 ^a	139.9	166.1 ^a	150.7	176.6 ^a	162.6	192.1 ^a	174.6	92.4	166.3	<0.001 ^c
RER	0.99 ^a	0.93	1.04 ^a	0.96	1.08 ^a	0.97	1.12 ^a	1.01	1.13 ^a	1.04	1.14 ^a	1.06	1.19 ^a	1.11	0.001	0.003	<0.001 ^c
$\dot{V}O_2$	58.8 ^b	57.2	61.2 ^b	59.4	63.5 ^b	61.4	65.3 ^b	63.4	66.8 ^b	64.7	69.7 ^b	67.5	74.4 ^a	69.1	5.1	7.2	<0.001 ^c
HR	176.5	172.2	180.2	175.6	184.1	180.8	189.3 ^b	182.8	194.6 ^b	185.7	200.9 ^a	188.6	205.4 ^a	193.3	17.5	171.3	<0.001 ^c
RPE	6.0	6.0	7.2 ^b	6.5	8.3 ^a	7.0	9.2 ^a	7.8	9.8 ^a	8.6	10.0	9.6	9.8	10.1	0.96	1.57	<0.002 ^c

AISP – Adapted Incremental Speed Protocol; ISIP – Incremental Speed and Incline Protocol; CR – Cardiorespiratory responses; HR – Heart rate (bpm); RER – Respiratory exchange rate; RPE – Rating of perceived exertion; \dot{V}_E – Minute ventilation (L/min); $\dot{V}O_2$ – Amount of oxygen utilized (ml/kg/min).

MSE – Mean square error; n – Number of participants; P – Protocol; P-value: Time x Method; VPP – Variance per person; a: Large effect (practical significance); b: Medium effect (practical significance); c: Statistical significance.

Discussion

The aim of this research study was to compare two motorized treadmill GXT protocols to determine which protocol would elicit the highest cardiorespiratory responses during the evaluation of elite male university-level distance runners. The main finding of this study was that the ISIP achieved higher cardiorespiratory responses with regard to the $\dot{V}O_{2\max}$ values obtained compared to the AISP.

According to the above-mentioned findings, responses for the AISP were significantly lower compared to those of the ISIP for measures of T_{\lim} (11.4 ± 1.2 vs. 13.6 ± 1.2 min), $\dot{V}O_{2\max}$ (65.0 ± 4.4 vs. 67.6 ± 5.0 ml/kg/min), RCP expressed as relative value (60.7 ± 5.3 vs. 64.1 ± 4.2 ml/kg/min), and the RCP time point (8.8 ± 1.8 vs. 11.1 ± 1.3 min). Despite these differences both the AISP and ISIP attained $\dot{V}O_{2\max}$ values within the prescribed time frame of 8–15 min as suggested by researchers^{2,8}. The RCP marks the onset of metabolic acidosis, which takes place in the absence of oxygen^{27,28} and is therefore considered the anaerobic threshold. In this regard the athletes seemed to convert quicker from the aerobic energy system to the anaerobic energy system during the AISP compared to the ISIP. This is supported by the data showing that the RCP time point (8.8 ± 1.8 vs. 11.1 ± 1.3 min) as well as relative RCP (60.7 ± 5.3 vs. 64.1 ± 4.2 ml/kg/min) is attained earlier in the AISP compared to the ISIP. Even though the AISP is considered more anaerobic than the ISIP, the percentage of $\dot{V}O_{2\max}$ where RCP was attained does not differ significantly (93.3 ± 3.9 vs. $94.9 \pm 3.2\%$). Researchers interested in exercise prescription can therefore use either of the investigated GXTs for exercise prescription since there were no significant differences between the percentages of $\dot{V}O_{2\max}$ where RCP was attained²⁹.

The $\dot{V}O_{2\max}$ value (67.6 ± 5.0 vs. 65.0 ± 4.4 ml/kg/min) attained by the ISIP was measured statistically significantly higher ($p < 0.05$) than the values obtained by the AISP. This finding is in agreement with research previously conducted by Sperlich *et al.*⁴ (62.2 ± 5.2 vs. 61.8 ± 4.3 ml/kg/min) and Gibson and colleagues¹² (69.6 ± 4.2 vs. 68.3 ± 4 ml/kg/min), where incline GXT protocols also attained higher $\dot{V}O_{2\max}$ values than their speed GXT protocols. From previous investigations the higher responses of the ISIP may be due to higher muscle activation from running uphill^{29,30}. According to Sloniger *et al.*³⁰ higher muscle recruitment and running efficiency are indirectly responsible for higher $\dot{V}O_2$ during GXTs. Although these researchers did

not stipulate the time or season when these tests were conducted, the belief that the competitive environment should dictate the GXT protocol used⁷ still exists.

Based on the above-mentioned statement, further investigation is required into which GXT protocol to use when participating in a specific competitive environment, running season or following a specific training regime. According to Vanhoy²⁹, physiological adaptations as a result of following a specific training regime may support better performance results on a GXT protocol that is similar to the training regime followed. However, these physiological adaptations are only expected to occur in athletes who have followed a specific training regime for a long time²⁹, whereas the current research population takes part in both the track and cross-country running seasons. Differences between training regimes preparing them for both track and cross-country running might cause physiological adaptations to occur, but may perhaps not be specific to either track or cross-country running, rather to a combination of both. The required physiological adaptations that have manifested in each athlete might therefore be rather limiting concerning the GXT protocols that are useable. Therefore, we would not expect the athletes in this study to attain different cardiorespiratory results if the testing protocol should be duplicated during the cross-country season.

Most cardiorespiratory responses measured per minute during the AISP compared to the ISIP were found to be higher, as presented in Table II. From these responses clear evidence exists that when the workload increases above 15 km/h, a 1 km/h speed increase is measured to be more intense than a 1% gradient increase. It can therefore be concluded that GXT protocols with 1 km/h speed increases cannot be compared to GXT protocols with 1% gradient increases. Furthermore, it is interesting to note that the RPE responses attained during testing differed practically significantly between the 9th and 12th minute of the performed protocols, but no practical significant differences were found during the final exhausting stages of the test, implying that the AISP and ISIP were perceived to be similar regarding exhaustion.

Conclusion

The results of this study prove that the ISIP elicits $\dot{V}O_{2max}$ values exceeding those of the AISP and is therefore prescribed for the attainment of the highest cardiorespiratory responses. However, for the prescription of exercise intensity markers, both the ISIP and AISP are considered adequate GXT protocols in view of similar RCP percentages of $\dot{V}O_{2max}$ values. Furthermore, the effect a training regime can have on athletes' physiological adaptations is of importance, but by following a single training regimen the physiological adaptations pursued will be more specific. In addition, GXT protocols that are compared by researchers should elicit similar intensity

increments in the workload to enable accurate comparison. Accordingly, GXT protocols with 1 km/h increases in speed are not comparable to GXT protocols with increases of 1% in gradient.

Practical implications

- The use of the ISIP is proposed for athletes taking part in both track and cross-country running.
- Graded exercise test protocols with 1 km/h speed increases are not comparable to 1% gradient increases owing to higher cardiorespiratory responses measured for speed increases. A higher workload in gradient is advised for comparability to a GXT protocol using 1 km/h speed increases.
- The training regime of an athlete can influence the cardiorespiratory responses of a $\dot{V}O_{2\max}$ test attained and should therefore be taken into consideration when selecting an appropriate $\dot{V}O_{2\max}$ GXT protocol.
- Both the AISP and ISIP are prescribed for determination of exercise intensity prescription.

Acknowledgements

The authors wish to thank the coach and participating distance runners for their time and willingness to participate in this research study.

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CHAPTER 4

**A COMPARSION BETWEEN THE
CARDIORESPIRATORY RESPONSES OF A NON-
MOTORIZED AND MOTORIZED TREADMILL
PROTOCOL**

Title page**Title:**

A comparison between the cardiorespiratory responses of a non-motorized and motorized treadmill protocol.

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Word Count

Excluding abstract and references: 3279

Abstract: 249

Number of Tables: 2

Number of Figures: 0

Prepared for submission to: *Journal of Science and Medicine in Sport.*

Abstract

Objectives: To determine which running modality, the motorized treadmill (MT) or the Curve non-motorized treadmill (NMT), will allow elite male university-level distance runners to attain the highest cardiorespiratory responses.

Design: A once-off cross-sectional design using elite male university-level distance runners.

Methods: Two GXT protocols were used to compare the above-mentioned running modalities - the Adapted Incremental Speed Protocol (AISP), performed on a MT, and the Adapted Non-Motorized Incremental Speed Protocol (ANMIP), performed on a Curve NMT. Both protocols started at a speed of 10 km/h, whereafter the AISP continuously increased by 1 km/h speed increments each 1 minute, and the ANMIP increased by 2 km/h speed increments every 2 minutes until exhaustion. Cardiorespiratory responses were recorded throughout the test from which the intensity markers, the ventilatory threshold (VT) and the respiratory compensation point (RCP)

were determined. *Results:* The maximal aerobic capacity ($\dot{V}O_{2max}$) value of the ANMIP exceeded that of the AISP significantly ($p < 0.05$; $d = 2.61$; $r = 0.89$) and attained these values within a significantly ($p < 0.05$; $r > 0.5$) shorter time frame (8.31 ± 0.87 vs. 11.42 ± 1.19 min). The percentage of $\dot{V}O_{2max}$ where VT and RCP were attained, was significantly higher ($p < 0.05$; $r > 0.5$) on the ANMIP (84.1 ± 4.3 vs. $97.2 \pm 2.4\%$) compared to the AISP (75.7 ± 7.8 vs. $93.3 \pm 3.9\%$).

Conclusion: The ANMIP is perceived as substantially more difficult, both physiologically and psychologically, compared to the AISP. The VT and RCP intensity markers attained by the ANMIP, are not practical for exercise prescription.

Keywords

Oxygen consumption; Physical exertion; Exercise test; Running; Running modalities; Maximal aerobic capacity.

Introduction

Maximal aerobic capacity ($\dot{V}O_{2\max}$) is considered one of the fundamental factors for distance running performance¹. However, for a $\dot{V}O_{2\max}$ value to be considered objective and sport-specific, the running modality needs to simulate over-ground running (OGR) closely, as this is the environment in which the distance runner trains and competes². The motorized treadmill (MT) and non-motorized treadmill (NMT) running modalities were used to investigate aerobic and anaerobic exercise testing. Motorized treadmills were extensively used in laboratories as a valid tool for measuring endurance running performance despite the lack of any direct comparison to over-ground endurance performance³. The Curve, a newly designed NMT, has recently been presented as a valid tool for assessing endurance running performance compared to OGR³ but comparative research between the Curve NMT and MT is fairly limited.

Motorized treadmills are controlled by a computer, through which speed and gradient are dictated, and then propelled by a motor⁴. An athlete attempts to adapt to the set running speed of the MT by manipulating stride rate and length⁴. Therefore, any changes in running pace are made consciously, with the MT belt enabling a runner to maintain a more consistent running speed³. The MT has consequently become popular among endurance runners⁵. In contrast with the MT, the Curve NMT's new "bean" shaped geometric design³ dictates an increasing gradient of 6—10° that is perceived as similar to uphill running⁶. When running on the Curve NMT, the athlete is in control of the speed of the belt by driving through each subsequent step⁷. An additional benefit of the Curve NMT is that it allows unrestricted running motion⁸ and therefore greater sport specificity⁸. The self-pacing nature of the Curve NMT is in agreement with OGR and is therefore regarded as more consistent with OGR³ than MT running. Based on these mechanical differences, cardiorespiratory responses measured on the MT and Curve NMT were expected to differ.

Cardiorespiratory responses obtained from MT and OGR during a continuous graded exercise test (GXT) protocol were found to be similar, even though OGR allowed athletes to attain higher running speeds⁹. No significant differences in MT running and OGR $\dot{V}O_{2\max}$ values (63.5 ± 6.6 vs. 63.3 ± 7 ml/kg/min) were measured, although statistically significant differences ($p < 0.001$) were measured for time to exhaustion (T_{im}) ($11:31 \pm 0:39$ vs. $12:07 \pm 0:42$ min) and maximum heart rate (HR_{\max}) (188 ± 6 vs. 189 ± 6 bpm). Furthermore, there were significant differences ($p < 0.001$) in measures of minute ventilation (\dot{V}_E)⁹, and as a result energy cost consequently differed, with the MT energy cost exceeding that of OGR.

During a 5 km time trial, both the Curve NMT and OGR attained similar cardiorespiratory responses with respect to the attained submaximal values, namely, oxygen utilized ($\dot{V}O_2$) (51.1 ± 3 vs. 49.2 ± 4 ml/kg/min), HR (178 ± 14 vs. 178 ± 13 bpm), and \dot{V}_E (122 ± 17.3 vs. 122.4 ± 15.6 L/min). However rating of perceived exertion (RPE) (6.5 ± 0.9 vs. 6.1 ± 1) and blood lactate values (9.4 ± 2.3 vs. 7.8 ± 2.1 mmol/L) were significantly ($p < 0.05$) higher on the Curve NMT than for OGR. These responses were attributed to the natural gradient of the Curve NMT that was perceived to be more difficult than OGR³. These results led Stevens *et al.*³ to regard the Curve NMT as a valid tool for assessing endurance running performance; however, values attained by a 5 km time trail cannot be compared directly to $\dot{V}O_{2max}$ results.

Early research of Davies *et al.*² compared MT running to NMT running and found similar results for $\dot{V}O_{2max}$ values attained (59.6 ± 10.3 vs. 61.4 ± 11.4 ml/kg/min). The $\dot{V}O_{2max}$ value of the NMT exceeded that of all MT tests conducted, but was not statistically significantly higher.

Furthermore, the NMT attained $\dot{V}O_{2max}$ within a shorter running time than all other MT tests (6.0 ± 2.2 vs. 8.1 ± 3.0 min). However, the NMT used in this research study was flat and results obtained by this NMT are therefore not comparable to the Curve NMT. More recently, Snyder *et al.*⁷ compared submaximal cardiorespiratory responses measured on a MT to a Curve NMT by using a discontinuous test protocol. All responses measured, $\dot{V}O_2$ (49.9 ± 9.2 vs. 60.2 ± 11 ml/kg/min), HR (170 ± 11 vs. 190 ± 10 bpm), RPE (4.1 ± 1.6 vs. 8.2 ± 1.1), and blood lactate (4.5 ± 1.6 vs. 11.1 ± 2.9 mmol/L) were significantly higher ($p < 0.05$) on the Curve NMT than on the MT. However, the use of discontinuous test protocols have been found to be time-consuming and the use of continuous GXT protocols was preferred¹⁰.

From these findings it is clear that a single running modality has not yet been prescribed as the gold standard for $\dot{V}O_{2max}$ testing, specifically with the use of a continuous GXT protocol. The aim of this research study is therefore to determine which treadmill running modality will enable elite male university-level distance runners to attain the highest cardiorespiratory responses.

Methods

Twelve elite male distance runners (age: 21.8 ± 3.0 yrs.; stature: 178.2 ± 6.5 cm; body weight: 66.7 ± 4.7 kg) from a university in the North West Province of South Africa participated in this research study. All participants competed and trained for the university during the 2016 season and had to participate in both university cross-country and track running. All tests of this research study were performed during the track season. Participants consented to participate in writing

after being fully informed of the nature of this research study. The Health Research Ethics Committee (HREC) of the Faculty of Health Sciences, North-West University (NWU - 00201- 15-A1) approved the testing procedure. Participating distance runners had to be injury-free during the testing period and had to complete all tests involved in the research study. A once-off cross-sectional design was used.

The following GXT protocols were conducted:

- *Adapted Incremental Speed Protocol (AISP)* – The AISP performed on the MT was adapted from the speed GXT protocol of Davies *et al.*². The AISP started at a speed of 14 km/h with increases of 1 km/h each minute until exhaustion. The starting speed of the AISP was adapted from 14 km/h to 10 km/h to allow comparability to the NMT GXT protocol following.
- *Adapted Non-motorized Incremental Speed Protocol (ANMIP)* – The ANMIP performed on the Curve NMT was adapted from the NMT GXT protocol of Davies *et al.*². The ANMIP started at a speed of 10 km/h with a 2 km/h increase every 3 minutes until exhaustion. The time intervals of the ANMIP were adapted from 3 minutes to 2 minutes to allow comparability each 2 minutes with the AISP. Because of pacing difficulty on the NMT, 2-minute rather than 1-minute time intervals were selected.

Two familiarization sessions were completed two weeks prior to the tests on both the MT and NMT. All sessions started at 10 km/h and increased by 1 km/h each 1-minute time interval for the MT and 2 km/h each 2-minute time interval on the NMT for approximately 4 minutes, whereafter a comfortable pace was reached and running continued for 10 minutes. These familiarization sessions were considered adequate¹¹.

Participants were required to participate in two GXT protocols, of which the earlier AISP mentioned was performed on the Woodway Pro XL MT (Woodway, W229 N591, Foster Ct, Waukesha, WI) and the ANMIP on the Woodway Curve 1 NMT (Woodway, W229 N591, Foster Ct, Waukesha, WI). Both test protocols were performed at exactly the same time of day within a time frame of five days. Participants were healthy (Physical Activity Readiness Questionnaire) and well-hydrated (hydration status and recovery questionnaire) at the time of participation. The laboratory's temperature was controlled to stay within 19 to 21°C. Participants were requested to follow a normal diet throughout the research period and abstain from food (2 hours), alcohol and coffee (12 hours), and vigorous training (48 hours) before the tests. A profile was created for each participant by measuring his stature and body weight the day of the test on arrival at the laboratory. Each GXT protocol was preceded by a 10-minute warm-up consisting of a treadmill running at 10km/h for 1 km, followed by a set of dynamic stretches. After completing the warm-up, participants were fitted with a heart rate (HR) monitor belt (Polar Electro, Kempele, Finland: T34) for HR measurement and a face mask for breath analysis. Once the GXT protocol started,

the cardiorespiratory responses HR_{max} , oxygen consumed ($\dot{V}O_2$), carbon dioxide produced ($\dot{V}CO_2$), \dot{V}_E , $\dot{V}O_{2max}$, oxygen utilized ($\dot{V}O_2$), \dot{V}_E , respiratory exchange ratio (RER), and T_{lim} , were recorded every 15 seconds during the tests by the Oxycon Pro static ergo spirometry system (Jaeger Oxycon Pro, Viasys, 22745, Savi Ranch Parkway, Yorba Linda, CA, USA). Each participant was motivated to continue the GXT protocol for as long as possible until exhaustion. Rating of perceived exertion was obtained from the participant in the last 10 seconds of each level according to the Borg Scale (CR-10 Scale)¹². Participants communicated through a basic signaling system of thumbs up – continue, and thumbs down - stop at the end of the level. The GXT protocols were terminated on reaching complete exhaustion, after which HR recovery was taken at 1, 3, and 5 minutes' rest.

Two experienced sport scientist determined the ventilatory threshold (VT) and respiratory compensation point (RCP) by using a plotted graph on which the increases and decreases in $\dot{V}_E / \dot{V}O_2$ and $\dot{V}_E / \dot{V}CO_2$ values were presented. The VT was identified as the point where the $\dot{V}_E / \dot{V}O_2$ increased without a corresponding change in the $\dot{V}_E / \dot{V}CO_2$, or departure in the linearity of the \dot{V}_E line. The RCP was identified as the point where both the $\dot{V}_E / \dot{V}O_2$ and $\dot{V}_E / \dot{V}CO_2$ increased dramatically¹³. In cases where the two sport scientists did not agree, a third sport scientist was consulted. Time to exhaustion was measured from the starting speed of 10 km/h to the point where the GXT protocol was terminated owing to exhaustion. The criterion used to determine the achievement of a $\dot{V}O_{2max}$ was an RER value of ≥ 1.15 ¹⁴, the attainment of a plateau in $\dot{V}O_2$ (<150 ml/min)^{10,15,16}, RPE (CR 10-Scale) of 10¹⁷, and the attainment of HR_{max} as determined by using the formula of $208 - (0.7 \times \text{age})$ ^{18,19}. Participants were required to attain at least two of the specified criteria to be accepted as a $\dot{V}O_{2max}$. If only one criterion was attained, it was graded a peak aerobic capacity ($\dot{V}O_{2peak}$) value and participants' results were excluded from this study.

The statistical data processing package SPSS Statistics (version 21.0.0.0) was used to process the data. To model the dependency of repeated measures for each participant, a hierarchical linear model was used to determine differences between the AISP and ANMIP for comparative speeds (km/h)²⁰. For statistical significance, the p-value was set at $p < 0.05$ and effect size values (Cohen's d-value) were reported with guideline values of 0.2 for small, 0.5 for medium, and 0.8 for large²¹. Variance per person (VPP) was taken into account, as well as unexplained variances

(Mean square error (MSE)). A single measure of statistical significance was determined for all corresponding speeds used per measured variable (HR, $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}O_{2max}$, $\dot{V}E$, $\dot{V}O_2$ utilized, RER, and T_{lim}). To determine statistical significance between the maximal values attained of all repeated measures of the AISP and ANMIP ($p < 0.05$), a paired sample t- test was used. Cohen's d-value was used for the standardized differences in averages²¹. Because of the small research population, results were confirmed with the Wilcoxon rank test (p-value) set at $p < 0.05$ and non-parametric effect size (r-value) with guideline values of 0.1 for small, 0.3 for medium, and 0.5 for large effect size²².

Results

The maximal cardiorespiratory responses documented during this research study are shown in Table I. Even though a small sample size ($n=12$) was used, statistical and practical significant results were obtained by a dependent t-test (p-value) and Wilcoxon's rank test (p-value) respectively, and are in agreement. Furthermore, attention will be paid to parametric (d-value) and non-parametric (r-value) effect size as well as Wilcoxon's rank test (p-value). The $\dot{V}O_{2max}$ measures of Table I attained varying effect size values ($d=0.38$; $r=0.61$) because the Cohen's d-value does not take outliers into account; however, non-parametric effect size takes outliers into account and these were consequently corrected for. Large effect sizes were marked between the AISP and ANMIP for parametric effect size (d-value) and non-parametric effect size (r-value). The NMT's T_{lim} was shorter than the AISP's T_{lim} and both statistically ($p < 0.05$) and practically significant ($d=2.61$; $r=0.89$). The ANMIP $\dot{V}O_{2max}$ values attained, exceeded those of the AISP, both statistically ($p < 0.05$) and practically, with a large effect size ($r=0.61$). All measures of VT and RCP measures were statistically ($p < 0.05$) and practically ($d=0.77-1.34$; $r=0.56-0.86$) significant.

Table I: Mean cardiorespiratory responses from maximum values attained on the AISP and the ANMIP (n=12)

Cardiorespiratory Response	Protocol	Mean±SD	Dependent t-test (p-value)	Effect size (d-value)	Wilcoxon (p-value)	Non-Parametric effect size (r-value)
T _{lim} (min)	AISP	11.42±1.19	0.00 ^c	2.61 ^a	0.002 ^c	0.89 ^a
	ANMIP	8.31±0.87				
HR _{max} (bpm)	AISP	192.3±9.1	0.84	0.05	0.754	0.09
	ANMIP	191.8±10.3				
HR 1 min R (bpm)	AISP	145.7±22.1	0.32	0.19	0.479	0.20
	ANMIP	140.4±27.5				
HR 3 min R (bpm)	AISP	107.3±16.7	0.72	0.06	0.844	0.06
	ANMIP	108.5±20.2				
HR 5 min R (bpm)	AISP	98.4±12.8	0.73	0.06	0.894	0.04
	ANMIP	99.5±17.9				
RER	AISP	1.16±0.05	0.38	0.26	0.398	0.24
	ANMIP	1.17±0.04				
• VO _{2max} (ml/kg/min)	AISP	65.0±4.4	0.04 ^c	0.38	0.034 ^c	0.61 ^a
	ANMIP	66.7±4.0				
RPE	AISP	9.4±1.2	0.39	0.2	0.334	0.28
	ANMIP	9.7±0.7				
VT (ml/kg/min)	AISP	49.3±6.3	0.001 ^c	1.09 ^a	0.005 ^c	0.82 ^a
	ANMIP	56.19±4.0				
VT (min)	AISP	4.92±1.73	0.01 ^c	0.92 ^a	0.011 ^c	0.73 ^a
	ANMIP	3.33±0.98				
RCP (ml/kg/min)	AISP	60.7±5.3	0.001 ^c	0.77 ^a	0.003 ^c	0.85 ^a
	ANMIP	64.8±3.3				
RCP (min)	AISP	8.75±1.76	0.00 ^c	1.34 ^a	0.003 ^c	0.86 ^a
	ANMIP	5.92±2.11				
• VT% of VO _{2max} (%)	AISP	75.7±7.8	0.003 ^c	1.07 ^a	0.006 ^c	0.56 ^a
	ANMIP	84.1±4.3				
• RCP% of VO _{2max} (%)	AISP	93.3±3.9	0.01 ^c	1.00 ^a	0.015 ^c	0.70 ^a
	ANMIP	97.2±2.4				

AISP – Adapted Incremental Speed Protocol; ANMIP – Adapted Non-motorized Incremental Speed Protocol; HR – Heart rate; HR_{max} – Maximum heart rate; R - Recovery; RER - Respiratory exchange ratio; RPE - Rating of perceived exertion; • VO_{2max} - Maximal aerobic capacity; RCP - Respiratory compensation point; VT - Ventilatory threshold.

n – Number of participants; SD – Standard deviation; a: Large effect (practical significance); b: Medium effect (practical significance); c: Statistical significance

A single measure of statistical significance was determined between the AISP and ANMIP's corresponding speeds by using the measured cardiorespiratory responses (HR, $\dot{V}O_2$, $\dot{V}CO_2$, \dot{V}_E , $\dot{V}O_2$ utilized, RER, T_{lim}). Cardiorespiratory responses obtained were compared by using hierarchical linear models as well as Cohen's d-values to test for differences between each corresponding speed (presented in Table II). However, it should be noted that the AISP lasted significantly longer than the ANMIP, consequently speed comparisons could only be made up until 18 km/h. All measures of HR, $\dot{V}O_2$, $\dot{V}CO_2$, \dot{V}_E , $\dot{V}O_2$ utilized, RER, and HR obtained large effect ($d > 0.8$) for all speeds used (10, 12, 14, 16, and 18 km/h) between the two running modalities, with the ANMIP exceeding those of the AISP. Moreover, the measured RPE responses of the ANMIP predominantly exceeded those of the AISP with large effect ($d > 0.8$) for all speeds used (12, 14, 16, 18 km/h) except for 10 km/h ($d = 0.61$).

Table II: Cardiorespiratory response values per speed of the AISP and the ANMIP

Cardiorespiratory response per speed (km/h) of each protocol conducted:	10 km/h		12 km/h		14 km/h		16 km/h		18 km/h		MSE	VPP	P-value (Speed x Method)
	AISP	ANMIP	AISP	ANMIP	AISP	ANMIP	AISP	ANMIP	AISP	ANMIP			
	n=(12)	n=(12)	n=(12)	n=(12)	n=(12)	n=(12)	n=(12)	n=(11)	n=(12)	n=(4)			
\dot{V}_E (L/min)	59.6	96.9 ^a	74.7	120.7 ^a	91.0	145.2 ^a	111.3	166.3 ^a	144.7	188.2 ^a	134	203.5	0.06
RER	0.79	0.87 ^a	0.86	0.95 ^a	0.89	1.05 ^a	0.95	1.12 ^a	1.04	1.15 ^a	0.002	0.003	0.00 ^c
$\dot{V}O_2$ (ml/min)	2398	3412 ^a	2834	3868 ^a	3302	4243 ^a	3696	4433 ^a	4094	4568 ^a	25125.3	74418.6	0.00 ^c
$\dot{V}CO_2$ (ml/min)	1890	2984 ^a	2431	3701 ^a	2959	4437 ^a	3530	4948 ^a	4272	5249 ^a	53316.1	155465.9	0.00 ^c
$\dot{V}O_2$ (ml/kg/min)	36.0	51.1 ^a	42.4	57.9 ^a	49.3	63.6 ^a	55.1	66.4 ^a	61.1	68.2 ^a	4.66	5.02	0.00 ^c
HR (bpm)	134.1	155.6 ^a	147.2	168.8 ^a	158.6	179.8 ^a	170.4	186.3 ^a	181.4	198.9 ^a	25.0	118.8	0.189
RPE	1.4	2.3 ^b	2.1	4.1 ^a	3.3	6.9 ^a	5.1	8.9 ^a	7.0	10.7 ^a	0.9	1.3	0.00 ^c

AISP – Adapted Incremental Speed Protocol; ANMIP – Adapted Non-motorized Incremental Speed Protocol; HR - Heart rate; RER - Respiratory exchange ratio; RPE - Rating of perceived exertion; \dot{V}_E - Minute ventilation; $\dot{V}O_2$ - Oxygen consumed; $\dot{V}CO_2$ - Carbon dioxide produced; $\dot{V}O_2$ - Amount of oxygen utilized.

MSE – Mean square error; n – Number of participants; P-value: Speed x Method; VPP – Variance per person; a: Large effect (practical significance); b: Medium effect (practical significance); c: Statistical significance.

Discussion

The objective of this research study was to compare two running modalities to establish which modality elicits higher cardiorespiratory responses in elite male university-level distance runners. The main finding of this study was that the Curve NMT's cardiorespiratory responses predominantly exceeded the MT responses within a shorter running time.

According to cardiorespiratory responses in Table I, the $\dot{V}O_{2max}$ values of the ANMIP exceeded those of the AISP significantly ($p < 0.05$; $d = 2.61$; $r = 0.89$). It is, however, remarkable that the AISP values were attained within a statistically significantly ($p < 0.05$; $d = 2.61$; $r = 0.89$) shorter time frame (8.31 ± 0.87 vs. 11.42 ± 1.19 min) compared to the AISP. These findings are comparable to the results of Davies *et al.*² who used a NMT and MT along with similar GXT protocols as used in this study. In the above-mentioned study, the NMT attained higher $\dot{V}O_{2max}$ values (61.4 ± 11.4 vs. $59. \pm 10.3$ ml/kg/min) within a shorter running time (6.0 ± 2.2 vs. 8.1 ± 3.0 min) compared to the MT, even though a NMT with a flat running surface was used². These results indicate higher exercise intensity on the Curve NMT compared to the MT.

Results reported in Table II indicate that the ANMIP's cardiorespiratory responses exceed those of the AISP for each speed compared over the course of the two GXT protocols. All responses of the ANMIP, namely HR, $\dot{V}O_2$, $\dot{V}CO_2$, \dot{V}_E , $\dot{V}O_2$ utilized and RER, significantly ($d > 0.8$) exceeded responses of the AISP. Consequently it is clear that the physical demands set by the Curve NMT, owing to its mechanical differences, exceed those of the MT, as running on the Curve NMT has been described as similar to running uphill^{4,6}. Furthermore, the energy cost of running on the Curve NMT surpasses that of the MT owing to higher friction of the belt and higher muscle activation⁴. It thus seems that the Curve NMT is thought to be physically more challenging and exhausting compared to the MT and consequently these modalities should rather not be compared in this manner.

An interesting finding of this study was that the percentage of $\dot{V}O_{2max}$, where VT and RCP were attained, was significantly higher ($p < 0.05$; $r > 0.5$) on the ANMIP compared to the AISP (Table I). The reason for this finding is not clear, but the results from Table II might suggest a possible explanation. All measures of the ANMIP exceed those of the AISP and the exercise intensity on the Curve NMT is therefore considered to be higher than that of the MT, probably caused by additional recruitment of type II muscle fibers²³. The recruitment of type II muscle fibers and increased ventilation are considered contributing factors to the manifestation of the "slow component" of $\dot{V}O_2$ kinetics and can cause an increase in the oxygen cost of exercise. This component is characterized by a slow increase in $\dot{V}O_2$ during incremental exercises^{23,24,25}.

Furthermore, extremely intense exercises are considered to be so severe that exhaustion intervenes before the kinetics of $\dot{V}O_2$ allows the attainment of a higher $\dot{V}O_{2max}$ ²⁶. Intense exercise is also associated with the occurrence of hyperventilation due to the body's attempt to attain effective gas exchange in the lungs by increasing ventilatory work, causing a further increase in the "slow component"²³. These findings are regarded as relevant to this research study in view of the high percentages of VT and RCP (Table I) expressed through $\dot{V}O_{2max}$ and might have occurred in response to hyperventilation.

For researchers interested in the results of $\dot{V}O_{2max}$ tests for exercise prescription, the values attained by the ANMIP are unsuitable. From past research, the VT and RCP for endurance trained sportsmen are expected to occur close to 65 and 90% respectively¹³. The exceptionally high intensity markers attained by the ANMIP are not recommended because of the intense effect these high percentage exercises will have on muscle recruitment and ventilatory work. Training at these extreme intensity markers is bound to have a destructive effect on performance. Nevertheless, training on the Curve NMT might be beneficial to intensify exercise with its added training load.

In accordance with the above-mentioned findings, the perceived exertion measured by the RPE of the ANMIP predominantly exceeded that of the AISP ($d > 0.8$). These findings are similar to the findings of Smoliga *et al.*⁶ who compared the Curve NMT to a MT where measured RPE responses were significantly higher ($p < 0.05$) on the Curve NMT at a walking and running speed⁶. Therefore the Curve NMT was rated to be perceived as substantially more strenuous than the MT^{3,6}. Even though the speeds of the two GXT protocols (ANMIP and AISP) running modalities correspond, the physical demands required from the athlete for the same speed on the respective modalities are not equivalent (see Table II). Furthermore, the measured HR (104.4 vs. 82.7 bpm; 151.6 vs. 120.6 bpm) and $\dot{V}O_2$ (1.39 vs. 0.8 L/min; 2.53 vs. 1.76 L/min) were found to be significantly higher on the Curve NMT⁶ compared to a MT at walking and running speeds. These findings are also in line with the results from this study.

Even though adequate familiarization sessions were performed on the Curve NMT, more training-oriented exercises on the Curve NMT might be beneficial for minimizing the significant measured differences recorded through cardiorespiratory responses. Further investigation is advised to determine equivalent exercises on the Curve NMT and MT.

Conclusion

The results of this study suggest that the Curve NMT (ANMIP) is perceived as substantially more difficult than MT running (AISP), both physiologically and psychologically. Even though higher cardiorespiratory responses were attained using the Curve NMT (ANMIP), the intensity markers obtained, namely VT and RCP, were not practical for exercise prescription. Nevertheless, the Curve NMT can be considered more time-efficient for $\dot{V}O_{2max}$ testing. It is of importance to familiarize athletes prior to testing to ensure comfort; however, more sessions on the Curve NMT might be advantageous to lessen the effect of the mechanical differences on the cardiorespiratory responses.

Practical implications

- The cardiorespiratory responses of a $\dot{V}O_{2max}$ test performed on a Curve NMT exceed those of a MT.
- Performing $\dot{V}O_{2max}$ tests on the Curve NMT is found to be time-efficient for a distance running population; however, the VT and RCP values obtained are not recommended for exercise prescription.
- Training-oriented exercises on the Curve NMT might be beneficial to minimize recorded differences measured between the two running modalities' cardiorespiratory responses.
- The Curve NMT can be considered an ideal training tool to intensify the exercise load.

Acknowledgements

The authors wish to thank the coach and participating distance runners for their time and willingness to participate in this study.

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CHAPTER 5

SUMMARY, CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

5.1 SUMMARY

The attainment of a high maximal aerobic capacity ($\dot{V}O_{2max}$) can be considered an important performance determinant for distance runners, since endurance events are performed at high percentages of one's $\dot{V}O_{2max}$. However, to determine distance runners' $\dot{V}O_{2max}$, the running modality and graded exercise test (GXT) used should simulate the demand set by the distance runners' event closely. Unfortunately a single running modality and GXT have not yet been standardized specifically for the determination of distance runners' $\dot{V}O_{2max}$. Consequently a running modality and GXT protocol need to be standardized to enable researchers to obtain valid and reliable $\dot{V}O_{2max}$ results for elite male university-level distance runners.

Consequently, the purpose of this research study was firstly to determine which GXT protocol would allow elite male university-level distance runners to attain the highest cardiorespiratory responses (maximum heart rate (HR_{max}), oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation (ventilatory equivalent(\dot{V}_E)), $\dot{V}O_{2max}$, respiratory exchange ratio (RER), time to exhaustion (T_{im}), respiratory compensation point (RCP), ventilatory threshold (VT), and rate of perceived exertion (RPE)) when performed on a motorized treadmill (MT). Secondly, it was to determine which running modality, MT or non-motorized treadmill (NMT) is most effective in eliciting the highest cardiorespiratory responses.

Chapter 1 provided a brief overview of the problem that was identified in the research questions, objectives and hypotheses, as well as the structure of the dissertation.

Chapter 2 consisted of a literature overview titled: "A review of cardiorespiratory responses attained using different running modalities and treadmill protocols to directly determine aerobic capacity ." The purpose of this chapter was threefold – firstly to define aerobic capacity and the relevant cardiorespiratory responses to identify an appropriate $\dot{V}O_{2max}$ criterion for the determination of a $\dot{V}O_{2max}$. Secondly to investigate the running modalities, namely the MT and the Curve NMT, to determine what effect the identified differences may have on the attainment of cardiorespiratory responses. Lastly, to investigate all GXT protocols previously used on male distance runners for the attainment of cardiorespiratory responses, specifically $\dot{V}O_{2max}$.

To determine which $\dot{V}O_{2\max}$ criterion to use, all cardiorespiratory responses thought important for aerobic capacity were investigated. The various collective $\dot{V}O_{2\max}$ criteria points used by earlier researchers differed considerably. Even though similar $\dot{V}O_{2\max}$ criterion's existed, the specified values differed from one researcher to the next. From these findings a $\dot{V}O_{2\max}$ criterion, namely a RER value of ≥ 1.15 , the attainment of a plateau in $\dot{V}O_2$ (<150 ml/min), and the attainment of HR_{\max} as determined by $208 - (0.7 \times \text{age})$, was identified and deemed to be an adequate cardiorespiratory response for the attainment of a $\dot{V}O_{2\max}$. Rating of perceived exertion was also used as a $\dot{V}O_{2\max}$ criterion; even though it is not a cardiorespiratory response it is considered a separate yet subjective response to categorize physical strain. The attainment of any two of these criteria were considered sufficient for a $\dot{V}O_{2\max}$.

Over-ground running (OGR) is considered the golden standard for distance runners, therefore any running modality used should simulate the running environment and physical demands. Consequently the MT and Curve NMT were investigated. The Curve NMT was found to be a closer simulation to OGR than the MT because of self-initiation of movement, self-pacing, and driving the belt with each consecutive step. This is further supported by several cardiorespiratory responses of the Curve NMT exceeding those of the MT. Because of the Curve NMTs increasing gradient of approximately 5—10 degrees, the Curve NMT is also perceived to be physiologically more strenuous and requires a greater metabolic demand than the MT. The apparent mechanical differences of the running modalities used, consequently play an important role in the cardiorespiratory responses obtained. Apart from specifying a running modality for distance runners, a GXT protocol must also be selected to determine a runner's $\dot{V}O_{2\max}$.

Even though a vast number of GXT protocols exist, two GXT protocols were prominent among the GXT protocols used for male distance runners, namely an incline GXT protocol (with variances in speed and/or gradient) and a speed GXT protocol. The basic incremental components (starting speed, time intervals and workloads (speed and gradient)) used in GXT protocols were compared to identify any tendencies/similarities among them. Starting speed, time intervals and workloads were used to ultimately exhaust the athletes by increasing the physiological demand required for each level. These GXT protocols were mostly performed on MTs, with a single GXT protocol performed on a NMT with a flat running surface. From the investigated GXT protocols, firstly, two GXT protocols were identified to compare on the MT, namely the Incremental Speed and Incline

Protocol (ISIP) and the Adapted Incremental Speed Protocol (AISP), to determine which protocol would elicit the highest cardiorespiratory responses. Secondly, to compare the MT to the new “bean”-shaped Curve NMT, a NMT protocol was identified, namely, the Adapted Non-Motorized Incremental Speed Protocol (ANMIP). The ANMIP was compared to the AISP to determine which running modality would elicit the highest cardiorespiratory responses.

Chapter 3 consisted of the first article that was prepared according to the guidelines of *The Journal of Science and Medicine in Sport* and was titled: “A comparison between the cardiorespiratory responses of a speed versus an incline motorized treadmill protocol”. The purpose of this article was to prescribe a GXT protocol performed on a MT for elite male university-level distance runners who take part in both track and cross-country running. The GXT protocols, namely the ISIP and AISP, were compared to determine the most effective protocol in eliciting the highest cardiorespiratory responses. Because the experimental period fell in the track season, the AISP was expected to attain higher cardiorespiratory responses owing to the training regime followed in the track season; however, this was not the case. The ISIP attained significantly ($p < 0.05$) higher $\dot{V}O_{2max}$ values (67.6 ± 5.0 vs. 65.0 ± 4.4 ml/kg/min) than the AISP. This might be due to the effect of following two training regimes instead of one, consequently the physiological adaptations required for the specific time of the season are not met because the athlete is participating in two seasons. Furthermore, the VT % (76.5 ± 10.3 vs. $75.7 \pm 7.8\%$) and RCP% (94.9 ± 3.2 vs. $93.3 \pm 3.9\%$) of $\dot{V}O_{2max}$ did not differ significantly between the ISIP and AISP, consequently both GXT protocols were considered adequate for exercise prescription. Finally, by comparing the ISIP and AISP on the per minute values, it was clear that cardiorespiratory responses obtained from a GXT protocol using 1 km/h increases in speed were not comparable to a GXT protocol with 1% increases in gradient. Finally, for runners taking part in both track and cross-country season, the ISIP is considered more appropriate for the determination of $\dot{V}O_{2max}$, and is therefore prescribed.

Chapter 4 consisted of the second article that was prepared according to the guidelines of *The Journal of Science and Medicine in Sport* and was titled: “A comparison between the cardiorespiratory responses of a non-motorized and motorized treadmill protocol”. The purpose of this article was to compare the two running modalities, namely the MT and the Curve NMT, by means of two GXT protocols: the AISP performed on a MT and the ANMIP, which was performed on the Curve NMT. From the results obtained, the ANMIP was perceived as substantially more difficult than the AISP both physiologically and psychologically (RPE). The ANMIP attained significantly ($p < 0.05$) higher $\dot{V}O_{2max}$ values (66.7 ± 4.0 vs. 65.0 ± 4.4 ml/kg/min) in a significantly

($p < 0.05$) shorter time frame (8.31 ± 0.87 vs. 11.42 ± 1.19 min) than the AISP. Despite these last-mentioned differences in favor of the ANMIP, the VT% (84.1 ± 4.3 vs. $75.7 \pm 1.76\%$) and RCP% (97.2 ± 2.4 vs. $93.3 \pm 3.9\%$) of $\dot{V}O_{2\max}$ attained by the ANMIP were not practical for exercise prescription and rather suggested the manifestation of the $\dot{V}O_2$ “slow component”. The higher exercise demand of the ANMIP inherently increases both recruitment of type II muscle fibers as well as ventilation and therefore the oxygen cost of exercise is higher. Nonetheless, the GXT protocol conducted on the Curve NMT can be considered adequate in eliciting the highest cardiorespiratory response if results are not used for exercise prescription.

5.2 CONCLUSION

The conclusions drawn from this research study are presented in accordance with the set hypotheses from Chapter 1:

Hypothesis 1

The MT incline GXT protocol will elicit statistically significantly higher ($p < 0.05$) cardiorespiratory responses ($\dot{V}O_{2\max}$, RER, RCP, and T_{lim}) in elite male university-level distance runners compared to the MT speed GXT protocol.

(Incline GXT protocol – ISIP; Speed GXT protocol – AISP)

Hypothesis 1 is partially accepted, since the results obtained for the ISIP is statistical significantly ($p < 0.05$) higher for the majority responses of RCP, $\dot{V}O_{2\max}$ and T_{lim} compared to the AISP, but is not statistical significantly higher for the RER value. Also, all values of the intensity markers, namely the VT and RCP attained from the ISIP and the AISP, do not differ statistically significantly.

Hypothesis 2

A NMT GXT protocol will elicit statistically significantly higher ($p < 0.05$) cardiorespiratory responses ($\dot{V}O_{2\max}$, RER, RCP, and T_{lim}) in elite male university-level distance runners compared to a MT GXT protocol.

(NMT GXT protocol – ANMIP; MT GXT protocol – AISP)

Hypothesis 2 is partially accepted owing to significantly higher ($p < 0.05$) values obtained by the ANMIP concerning responses of $\dot{V}O_{2\max}$ and RCP as well as a statistically significantly shorter

($p < 0.05$) T_{lim} than the AISP. No significant ($p < 0.05$) differences were, however, measured between the RER values of the ANMIP and the AISP. Even though the ANMIP performed on the Curve NMT attained significantly higher ($p < 0.05$) $\dot{V}O_{2max}$, VT, and RCP responses, the ANMIP's attained intensity markers were too high, and therefore not practical for exercise prescription. Ventilatory threshold and RCP values are expected to occur at approximately 65% and 90% respectively. Training at the attained VT and RCP responses of the ANMIP might cause overtraining.

All GXT protocols performed are considered adequate GXT protocols in attaining high cardiorespiratory responses. More specifically, the highest $\dot{V}O_{2max}$ value was attained by the ISIP, followed by the ANMIP and the AISP. In addition, the cardiorespiratory responses obtained by each GXT protocol were unique to the specific GXT protocol with regard to HR_{max} , $\dot{V}O_{2max}$, RER, T_{lim} , VT, RCP and RPE attained. However, for determination of the highest cardiorespiratory responses on a MT, the ISIP is recommended. For the determination of intensity markers for use in exercise prescription, both the ISIP and AISP attained VT and RCP values within acceptable parameters. Furthermore, when comparing the cardiorespiratory responses obtained by the ANMIP and AISP, the ANMIP's values exceeded those of the AISP and were therefore considered superior. However, the ANMIP is not recommended for exercise prescription owing to the attainment of impractically high intensity markers that when used might lead to overtraining.

The Curve NMT ANMIP's workload and time intervals need to be reconsidered because of the occurrence of extreme exhaustion among participants. All measures of the ANMIP exceed those of the AISP, and therefore the exercise intensity on the Curve NMT is considered to be higher than on the MT, probably caused by additional recruitment of type II muscle fibers as well as increased ventilation, resulting in the manifestation of the $\dot{V}O_2$ "slow component". Extremely intense exercise such as the ANMIP is considered so intense that exhaustion intervenes before higher $\dot{V}O_{2max}$ values are attained. The ANMIP is therefore considered too intense and consequently not suitable for $\dot{V}O_{2max}$ testing of this specific population.

5.3 LIMITATIONS AND RECOMMENDATIONS

To the researchers' knowledge, this is the first study to investigate GXT protocols on a MT and Curve NMT to determine which running modality and matching GXT protocol to use when evaluating elite male university-level distance runners. Although this research study contributed

valuable information on the use of running modalities as well as the use of GXT protocols, several limitations should be considered, along with recommendations relevant to this area of research:

- The ANMIP's VT and RCP intensity markers were found impractical for exercise prescription. The attainment of these extremely high values was unexpected. To limit the effect familiarization sessions may have on performance, more familiarization sessions are therefore advised on the Curve NMT.
- The occurrence of the $\dot{V}O_2$ "slow component" could not be confirmed from results because of the lack of blood lactate sampling. The use of blood lactate sampling as part of the $\dot{V}O_{2max}$ criterion should consequently be considered strongly for future studies.
- From the MT GXT protocol results obtained, it was clear that 1 km/h and 1% gradient increases per time interval could not be compared, as 1 km/h increases were more intense, as indicated by the cardiorespiratory responses obtained. Future researchers are therefore advised to compare GXT protocols with 1km/h increases to GXT protocols with gradient increases greater than 1% increases for a closer comparison.
- The results of this research study were in favor of the ISIP; however, the population used in this research study participated in both track and cross-country season and therefore followed two training regimens. Future researchers are advised to make use of a population that specifically focuses on a single season to determine the effect of a single training regime on the GXT protocol considered specific to the population.

APPENDICES

APPENDIX A: RESEARCH METHOD AND PROCEDURE

RESEARCH METHOD AND PROCEDURE

1. RESEARCH METHOD

1.1. LITERATURE SEARCH

The following databases and search engines were used to compile chapter one: Google Scholar, Science Direct, EBSCOhost, Sabinet References, SAEpublications. These electronic databases were used to search for the following key words: Motorized treadmill; non-motorized treadmill; maximum oxygen consumption; protocols; running intensity; incremental incline protocol; incremental speed protocol; graded exercise test.

1.2. EMPIRICAL DESIGN

1.2.1. RESEARCH DESIGN

The research design was a once-off cross-sectional design using convenience sampling.

2. PARTICIPANTS

Twelve elite male university-level distance runners (age: 21.8 ± 3.0 yrs.; stature: 178.2 ± 6.5 cm, body weight: 66.7 ± 4.7 kg) from a university in the North-West Province of South Africa were recruited to participate in this study by using the inclusion criteria to identify eligible participants. The North-West University's (NWU) middle- and long-distance runners' coach was approached and he was given a detailed explanation of the study design. The coach indicated his willingness to co-operate and gave permission for his athletes to be used as participants in the study. The study design and purpose of the investigation were explained to all potential participants. Participation in this study was entirely voluntary. Informed consent (Appendix C) was sought from all participants one week before the onset of the familiarization sessions.

The following inclusion criteria were applied for participation in the study:

- Participants had to be male and involved in middle- and long-distance running at senior university level;
- Participants had to participate in track and cross-country competitions at university level;
- Participants had to be free of any injuries at the time of testing;
- Only participants who had completed the proposed familiarization sessions were considered eligible to participate in this study;
- Only participants who provided voluntary consent were allowed to participate in this study;
- Only participants who completed the Physical Activity Readiness Questionnaire (PAR-Q) (Appendix D) and hydration status and recovery questionnaire (Appendix E) (Howley & Franks, 2007:23) on all occasions were allowed to participate in this study; and
- Participants had to indicate their Borg Scale (Borg, 1982:377) level when carrying out the treadmill tests.

Athletes who adhered to the following guidelines were allowed to participate in this study:

- Participants who did not eat for two hours prior to the testing sessions (Haff & Dumke, 2012:211);
- Participants who did not drink alcohol or coffee for 12 hours prior to the testing sessions (Wilmore *et al.*, 2008:360;363); and
- Participants who did not train hard for 48 hours prior to each testing session (Broeder *et al.*, 1992:803) and were well rested (Haff & Dumke, 2012:211).

The following exclusion criteria were applied for study participation:

- All participants who did not adhere to the above-mentioned criteria were excluded from the study.
- Participants were also excluded from the study if they were injured or became ill at any time during the testing period.
- Participants were excluded from the study if they voluntarily withdrew from the study at any time.

To ensure that the participants did not participate in any strenuous training 48 hours prior to the scheduled tests, the coach was requested to provide information on prior training sessions to the research team. The participants had to maintain the same diet during the week of testing and had to arrive at the testing sessions in a rested and fully hydrated state.

3. MEASURING INSTRUMENTS AND EQUIPMENT

3.1. OXYCON PRO STATIC ERGO SPIROMETRY SYSTEM

The Oxycon Pro static ergo spirometry system (OP) (Jaeger Oxycon Pro, Viasys, 22745, Savi Ranch Parkway, Yorba Linda, CA, USA) produces similar respiratory results to those of the Douglas bag (DB) (Carter & Jeukendrup, 2002:438). The OP was a valid system for measuring cardiorespiratory responses such as $\dot{V}O_2$, $\dot{V}CO_2$ and respiratory exchange ratio (RER) (OP = coefficient of variation (CV): 2.7-4.8%; DB = CV: 1.8-2.3%) (Carter & Jeukendrup, 2002:440). The OP static ergospirometry system was calibrated once on each test day at the beginning of the day. The system was calibrated as instructed by the Viasys Oxcon Pro Manual (Viasys Healthcare, 2004:24-32). A spirometry test was completed before the test according to the Oxycon Pro Static Unit Manual as part of the calibration procedures (Viasys Healthcare, 2004:39-41).

3.2. POLAR HEART RATE MONITOR BELT

A Polar heart rate monitor belt (T34) was used along with the above-mentioned system to record heart rate (HR) data of participants.

3.3. TREADMILLS

During this study two different treadmills were used – the motorized Woodway Pro XL treadmill (Woodway, W229 N591, Foster Ct, Waukesha, WI) and the non-motorized Curve 1 treadmill (Woodway, W229 N591, Foster Ct, Waukesha, WI).

3.4. STATURE AND BODY WEIGHT

Stature (Stadiometer- AHP001) and body weight (scale - TSCALE RW/BBQ-3040 GYM scale) were determined on the day of the test on arrival at the laboratory at the beginning of each session to create a profile for each participant.

4. MEASURING PROTOCOLS:

- **Incremental Speed and Incline Protocol (ISIP)** – The ISIP was adapted from Hamlin and colleagues' athlete-led protocol (2012). Hamlin *et al.*'s (2012:99) GXT began at a starting speed of 10 km/h, with increases of 1 km/h each minute until a comfortable running pace was reached. The ISIP's comfortable running pace was set at 15 km/h. Thereafter the gradient was increased each minute by 1% gradient until voluntary exhaustion (Hamlin *et al.*, 2012:99).
- **Adapted Incremental Speed Protocol (AISP)** – The AISP was adapted from the speed GXT protocol of Davies *et al.* (1984:75). Davies *et al.*'s (1984:75) GXT began at a starting speed of 14 km/h, with increases of 1 km/h each minute until voluntary exhaustion. The starting speed of the AISP was adapted from 14 km/h to 10 km/h to allow comparability between results obtained from the MT and the Curve NMT.
- **Adapted Non-Motorized Incremental Speed Protocol (ANMIP)** - The ANMIP performed on the Curve NMT was adapted from the NMT GXT protocol of Davies *et al.* (1984:75). The ANMIP started at a starting speed of 10 km/h with a 2 km/h increase every 3 minutes until voluntary exhaustion. The time intervals of the ANMIP had been adapted from 3 minutes to 2 minutes to allow comparability each 2 minutes with the AISP. Because of pacing difficulty on the NMT, 2-minute rather than 1-minute time intervals were selected, consequently allowing athletes to achieve a steady state in cardiorespiratory responses.
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The ANMIP and AISP were adapted according to the guidelines of Hamlin *et al.* (2012:99). These GXT protocols had to be adapted to enable the researcher to compare the different GXT protocol responses.

5. FAMILIARIZATION SESSIONS

Before the commencement of the study each participant was introduced to the MT, NMT, three different treadmill running GXT protocols, Polar heart rate belt as well as the spirometry system and apparatuses. Two familiarization sessions on both the MT and NMT were completed two

weeks prior to the tests before the study commenced. Only part of each GXT protocol was completed during the familiarization sessions because of the physical strain of each of the GXT protocols. The familiarization session demanded nothing more than a comfortable running pace to which participants were used in regular training. This pace could therefore differ from one participant to the next. The familiarization GXT protocols were completed in the following manner:

- Each session started with a 10 minute warm-up that included a 1 km run on the specified treadmill at 10 km/h, along with specified stretches. After completing the 1 km run, the prescribed stretching exercises were done. The treadmill familiarization GXT protocols were carried out as follow:
1. ISIP simulation - The ISIP's familiarization sessions started at a running speed of 10 km/h and increased by 1 km/h until 13 km/h was reached. Gradient was applied thereafter until a comfortable running pace was reached. Athletes kept running until 10 minutes had passed.
 2. AISP simulation - The AISP's familiarization sessions started at 10 km/h and increased each 1 minute by 1 km/h until a comfortable running pace had been reached. The athlete kept running for 10 minutes.
 3. ANMIP simulation – The ANMIP's familiarization sessions started at 10 km/h and increased by 2 km/h each 2 minutes until a comfortable running pace had been reached. The athlete kept running for 10 minutes.

During the familiarization sessions, participants were also taught how to self-terminate treadmill tests voluntarily when exhaustion set in. In this regard participants were shown how to jump off the MT and how to decelerate the NMT to a stop.

6. PROCEDURE

At the start of the experimental period (familiarization sessions and tests) each participant completed an informed consent form that was handed to him one week before commencement of the familiarization sessions by the researcher. The informed consent forms were collected by the researcher when the familiarization sessions started. Every day before the start of testing, participants completed the PAR-Q (Appendix D) and hydration status and recovery questionnaire (Appendix E). The three GXT protocols were conducted in a time frame of five days (day 1, 3 and 5) starting with the incline GXT protocol (ISIP) and Speed GXT protocol (AISP), followed by the speed GXT NMT protocol (ANMIP). Each participant performed each test at exactly the same time of day. The temperature of the laboratory was monitored to stay within 19 to 21°C throughout the testing period.

Stature and body weight were determined before commencement of the test, with minimum clothing and without shoes. This was done in a private room. These measurements were used to

describe participants' anthropometric profiles. A Polar heart rate monitor was also fitted to each participant's chest.

The participants completed a warm-up of 10 minutes that included a 1 km run at 10 km/h on the specified treadmill on which the test was conducted on that day (Davies *et al.*, 1984:75). One set of dynamic stretches of 10 repetitions was performed for the upper and lower body (McMillian *et al.*, 2006:494), with the focus placed on muscles that were primarily involved during running: hip, knee and ankle flexors and extensors (Faccioni, 2002:8), as well as shoulder extensors and flexors.

After a complete warm-up the following steps were followed:

Before completion of the GXT protocols: The specific GXT protocol was explained in depth with regard to the speed, gradient and specific time intervals, as well as the means of communication (hand signals to indicate participant fatigue and condition). A basic signaling system was used: thumbs up - continue; thumbs down - stop at the end of the running level or "I am exhausted". Participants were reminded of the way in which the test could be ended when they could no longer continue. Participants were requested to sit down to fit the mask over their nose and mouth. The mask had to fit comfortably but had to be tight enough to ensure that there were no gaps where expired air could escape. The mask was then fitted to the air-flow meter, after which a spirometry test was performed.

While the test loaded, the participant stepped onto the treadmill for test commencement. As soon as the treadmill reached a speed of 10 km/h, the breath-by-breath analysis was activated and data was recorded from the beginning of the test.

During the GXT protocol: Participants were motivated to achieve the highest possible test level. Updates of progress were provided throughout the test. Before a new test level started, the participant was informed and was motivated to continue. At the end of each test level, before progressing to the next level, participants indicated their rate of perceived exertion (RPE) by using Borg's RPE scale (Borg, 1982:377): This scale ranged from 0 (feeling nothing at all) to 10 (very, very hard). Participants were requested to grade the perceived difficulty of each level. At the end of the test, the final RPE level was also documented.

If participants could not proceed to the next level, the test was terminated manually. The system and MT were stopped. The mask was removed immediately. When the protocol on the NMT was performed, the athlete had to stop the belt by running more slowly and then stopping it themselves.

After the GXT protocol: After completion of the test the participants were asked to sit down and to rest passively on a chair for 5 minutes to record resting heart rate values at 1, 3 and 5 minutes.

7. DETERMINATION OF GAS EXCHANGE POINTS AND $\dot{V}O_{2max}$

Two members of the research team determined the RCP and VT by using the set guidelines for identification. The VT and RCP were determined by using a plotted graph on which the increases and decreases of $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ values for the different incremental levels were displayed. The VT was identified as the point where the $\dot{V}_E/\dot{V}O_2$ increased without a corresponding change in the $\dot{V}_E/\dot{V}CO_2$ or departure in the linearity of the \dot{V}_E line. The RCP was identified as the point where both the $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}CO_2$ increased dramatically (Chicharro *et al.*, 2000:451). A third sport scientist was consulted if the members of the research team disagreed (Chicharro *et al.*, 2000:453).

The criterion that was applied to determine if participants had reached their $\dot{V}O_{2max}$ values were the following (Christie & Lock, 2001:19; Hamlin *et al.*, 2012:99):

- The attainment of a plateau where a <150 ml/min increase was observed despite increases in treadmill gradient or speed (Haff & Dumke, 2012:210; Hamlin *et al.*, 2012; Davis, 2006:15);
- The attainment of a RER equal to or greater than 1.15 (Astrand *et al.*, 2003:235);
- The attainment of a maximum heart rate: $208 - (0.7 \times \text{age})$ (Tanaka *et al.*, 2001:154-155; Wilmore *et al.*, 2008:163);
- The attainment of the subjective rating of RPE on the category ratio scale10 (CR10) of 10 (Borg & Kaijser, 2006:58).

The attainment of two of the above-mentioned responses were considered adequate for the attainment of a $\dot{V}O_{2max}$. In cases where only one criterion was attained, the test was deemed to be a peak aerobic capacity (Christie & Lock, 2001:19) and participants were excluded from this research study.

8. ETHICAL CONSIDERATIONS

Before commencement of the research project ethical approval was obtained from the Health Research Ethics Committee of the Faculty of Health Science of the NWU. All athletes who participated in this study were required to sign an informed consent form that was handed to them by the researcher prior to the familiarization sessions (Appendix A). The researcher collected the consent forms before the familiarization sessions. The risks, precautions and benefits of participation were thoroughly explained in the informed consent form. Participants would benefit by receiving a personal report by e-mail that could help individualize training programs and improve performance. The participants' coach benefitted by receiving a complete report on all participants' results. All reports were distributed two weeks after completion of the experimental

period. Other researchers can benefit from broadened knowledge of middle- and long-distance runners' aerobic ability, including the effect different protocols and different testing apparatus would have on cardiorespiratory responses. This knowledge can be used in other testing facilities to achieve optimal values from middle- and long-distance runners. The study design and purpose of this investigation were explained to potential participants four weeks prior to the testing period and one week later the familiarization sessions started. Anonymity and confidentiality of each participant's results were ensured by assigning a code to each participant that was only known to the researcher. It would not be possible to identify a participant in the final data set. The potential participants' coach was informed and permission was granted to use the athletes as participants in the study. Study procedures were explained to the coach and athletes in depth. Participation in this study was completely voluntary. The participants were under no obligation to participate in the study and were free to withdraw if they saw fit to do so.

No other physical, psychological or social stressors than those normally encountered by the athletes when participating in middle- and long-distance events were experienced by the athletes during study participation. Our team of researchers and assisting sport scientists took responsibility for the athlete's warm-up. Even though the athletes were active and healthy, an accredited level 2 first-aid consultant was present throughout the duration of the study and a medical practitioner was on standby at all times. An automated external defibrillator was also available in case of emergency. Participants might feel nauseous, fatigued, exhausted, light-headed or short of breath or develop a headache during participation in the study. All password-protected electronic data and hard copies of the results will be kept locked in a research office at the NWU Potchefstroom campus for a minimum of seven years and then destroyed.

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APPENDIX B: ETHICAL APPROVAL



NORTH-WEST UNIVERSITY
YUNIBESITHI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

Private Bag X6001, Potchefstroom
South Africa 2520

Tel: (018) 299-4900
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Web: <http://www.nwu.ac.za>

**Institutional Research Ethics Regulatory
Committee**

Tel +27 18 299 4849
Email Ethics@nwu.ac.za

ETHICS APPROVAL CERTIFICATE OF PROJECT

Based on approval by **Health Research Ethics Committee (HREC)**, the North-West University Institutional Research Ethics Regulatory Committee (NWU-IRERC) hereby approves your project as indicated below. This implies that the NWU-IRERC grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the project may be initiated, using the ethics number below.

Project title: A comparison between the cardiorespiratory responses of motorized and non-motorized treadmill protocols.			
Project Leader: Dr Y Willemse			
Ethics number:	N	W	U
	-	0	0
		2	0
		1	-
		1	5
		-	A
			1
	<small>Institution</small>		<small>Project Number</small>
	<small>Year</small>		<small>Status</small>
<small>Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation</small>			
Approval date: 2015-10-28	Expiry date: 2016-11-30	Risk	Minimal

Special conditions of the approval (if any): None

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, please note the following:

- The project leader (principle investigator) must report in the prescribed format to the NWU-IRERC:
 - annually (or as otherwise requested) on the progress of the project,
 - without any delay in case of any adverse event (or any matter that interrupts sound ethical principles) during the course of the project.
- The approval applies strictly to the protocol as stipulated in the application form. Would any changes to the protocol be deemed necessary during the course of the project, the project leader must apply for approval of these changes at the NWU-IRERC. Would there be deviations from the project protocol without the necessary approval of such changes, the ethics approval is immediately and automatically forfeited.
- The date of approval indicates the first date that the project may be started. Would the project have to continue after the expiry date, a new application must be made to the NWU-IRERC and new approval received before or on the expiry date.
- In the interest of ethical responsibility the NWU-IRERC retains the right to:
 - request access to any information or data at any time during the course or after completion of the project;
 - withdraw or postpone approval if:
 - any unethical principles or practices of the project are revealed or suspected,
 - it becomes apparent that any relevant information was withheld from the NWU-IRERC or that information has been false or misrepresented,
 - the required annual report and reporting of adverse events was not done timely and accurately,
 - new institutional rules, national legislation or international conventions deem it necessary.

The IRERC would like to remain at your service as scientist and researcher, and wishes you well with your project. Please do not hesitate to contact the IRERC for any further enquiries or requests for assistance.

Yours sincerely

**Linda du
Plessis**

Digitally signed by Linda du Plessis
DN: cn=Linda du Plessis, o=NWU,
ou=Vaal Triangle Campus,
email=linda.duplessis@nwu.ac.za,
c=ZA
Date: 2015.11.09 09:09:29 +02'00'

Prof Linda du Plessis

Chair NWU Institutional Research Ethics Regulatory Committee (IRERC)

APPENDIX C: INFORMED CONSENT

**PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM FOR ELITE MALE
UNIVERSITY LEVEL MIDDLE AND LONG DISTANCE ATHLETES**

TITLE OF THE RESEARCH PROJECT:

A COMPARISON BETWEEN THE CARDIORESPIRATORY RESPONSES OF MOTORIZED AND NON-MOTORIZED TREADMILL PROTOCOLS

REFERENCE NUMBERS: (NWU- 00201-01-15-A1)

PRINCIPAL INVESTIGATOR:

MRS JANA STORM

ADDRESS:

NORTH-WEST UNIVERSITY

FACULTY OF HEALTH SCIENCES

PRIVATE BAG X6001

POTCHESFSTROOM

2522

CONTACT NUMBER:

018 299 4441

You are being invited to take part in a research project that forms part of my Masters Study. Please take some time to read the information presented here, which will explain the details of this project. Please ask the researcher any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the Health Research Ethics Committee of the Faculty of Health Sciences of the North-West University (NWU- 00201-01-15-A1) and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki and the ethical guidelines of the National Health Research Ethics Council. It might be necessary for the research ethics committee members or relevant authorities to inspect the research records.

What is this research study all about?

- *This study will be conducted in the lab of the Institute for Sport Science and Development at the High Performance Institute of the North West University, Potchefstroom Campus.*

- *This will involve a Sport Scientist measuring your maximal aerobic capacity ($\dot{V}O_{2max}$) by using three different treadmill protocols. The size of this group will be between at least 20 participants.*
- *The objectives of this research are to:*
- *Compare the cardiorespiratory responses (RER, VT, RCP, VE, $\dot{V}O_{2max}$, time to exhaustion) of distance runners when performing two different incremental MT protocols (incremental speed and combined incremental speed and incline protocol).*
- *Compare the cardiorespiratory responses (RER, VT, RCP, VE, $\dot{V}O_{2max}$, time to exhaustion) of distance runners when performing an incremental MT and NMT protocol.*

Why have you been invited to participate?

- *You have been invited to participate in this study because you are an elite male university-level distance runner at senior level from the North-West University, Potchefstroom Campus.*
- *You have also complied with the following inclusion criteria:*
 - *You are between 18 and 25 years old;*
 - *You participate in university student track and cross-country competition during the 2015 season;*
 - *You are free of injuries at the time of the study;*
 - *You are willing to complete the proposed familiarization sessions;*
 - *You are willing to provide voluntary consent to participate in this study;*
 - *You are willing to complete the hydration status recovery questionnaire (Appendix E) as well as the Physical Activity Readiness Questionnaire PAR-Q (Appendix D) on all occasions;*
 - *You are willing to indicate your level of perceived exertion by indicating the appropriate Borg Scale level during execution of the treadmill tests as well as answer all questions after execution of each treadmill protocol, and*
 - *You adhere to the following guidelines:*
 - *Do not eat two hours prior the tests;*
 - *Do not drink alcohol or coffee 12 hours prior the tests;*
 - *Maintain the same diet during the week of the tests;*
 - *Arrive hydrated and fully rested;*
 - *Do not train hard 48 hours prior the tests (the coach will be asked to provide information regarding the last 48 hours' training sessions); and*
- *You will be excluded if:*
 - *You do not adhere to the above mentioned criteria;*

- You become injured or fall ill any time during the study, and
- You voluntarily withdraw from the study.

What will your responsibilities be?

➤ You will be expected to:

- Follow the above mentioned guidelines;
- Complete an Informed Consent Form after being informed of the purpose as well as a detailed explanation of the study design. Complete all familiarization sessions:
- Each familiarization session starts off with a warm-up for 5 minutes at 10 km/h on the specified MT and NMT (Incremental Speed and Incline Protocol (ISIP) and Adapted Incremental Speed Protocol (AISP) on the motorized Woodway treadmill; Adapted Non-Motorized Incremental Protocol (ANMIP) on the non-motorized Curve treadmill). After completing the warm-up continue with the prescribed stretching program. Only part of the protocol will be completed during the familiarization sessions because of the physical strain of each of the protocols. The familiarization session demand nothing more than a comfortable running pace as participants do in regular training. This pace can differ from one participant to the next. Followed by the suited treadmill protocol:
 - ISIP simulation- - the starting speed will be set at 10 km/h after which a speed increase of 1 km/h every minute for 3 minutes will be set. For each minute after the 3 minute duration the incline will be increased by 1 degree until a comfortable pace is reached. The athlete will then be required to maintain this running speed for 10 minutes.
 - AISP simulation - the starting speed will be set at 10 km/h after which a speed increase of 1 km/h every minute will be set until a comfortable pace is reached. The athlete will then be required to maintain this running speed for 10 minutes.
 - ANMIP simulation - the starting speed will be set at 10 km/h after which a speed increase of 2 km/h every 2 minutes will be set until a comfortable pace is reached. The athlete will then be required to maintain this running speed for 10 minutes.
- Learn how to stop the test voluntarily on the MT and how to decelerate the NMT to a stop.
- Complete a hydration status and recovery questionnaire (Appendix E) as well as the activity questionnaire PAR-Q (Appendix D) after each testing day.

Tests:

- *On arrival body composition measurements will be taken namely stature and body weight. These measurements will be taken in a private and designated area. You will be requested to wear minimal clothing as is comfortable to you.*
- *Three maximal aerobic tests will be conducted two days apart. Each test will be explained on the designated days of testing. Tests will be conducted in the following order – 1. ISIP; 2. AISP and 3. NMIP. Each test will be conducted at the same time of day.*
- *The protocol being tested on the day will be explained in depth (ISIP, AISP, or ANMIP)*
- *You will complete a 5-min warm-up at a speed of 10 km/h on the specific treadmill on which the test will be conducted for that day (Davies et al., 1984:75). One set of dynamic stretches of 10 repetitions will be performed for the upper and lower body with the focus placed on muscles that are primarily involved during running: hip, knee and ankle flexors and extensors as well as shoulder extensors and flexors. Protocol A and B's warm-up will be done on the motorized Woodway treadmill and protocol C's warm-up will be done on the non-motorized Curve treadmill.*
- *Before the test can start you will be fitted with a breathing mask, Polar S3 stride sensor and Polar heart rate monitor followed by a spirometry test which is part of the calibration.*
- *The following three protocols will be conducted on designated days:*
 - **A Incremental Speed and Incline Protocol (ISIP)** – *The test will start at a starting speed of 10 km/h with increases of 1 km/h each minute until a speed of 15 km/h is reached. Thereafter the incline will be increased each minute by 1 degree until voluntary exhaustion (Hamlin et al., 2012:99);*
 - **B Adapted Incremental Speed Protocol (AISP)** – *The test will start at a starting speed of 10 km/h with increases of 1 km/h each minute until voluntary exhaustion; and*
 - **C Adapted Non-motorized Incremental Speed Protocol (ANMIP)** - *The test will start at a starting speed 10 km/h with a 2 km/h increase every 2 min until voluntary exhaustion.*
 - *You will be asked to rate the perceived exertion on a Borg scale from one to ten of each completed level as the test is conducted (0 - feeling nothing at all, to 10 - very very hard).*
 - *After each protocol a series of questions will be posed that must be answered truthfully:*
 - *What caused you to stop the test?*
 - *Are you cardiovascularly exhausted or is your body tired?*
 - *At what level did you start to experience difficulty in executing the test?*
 - *Are you completely exhausted or would you be able to go further?*
 - *After completing all three test protocols, you will then be asked to name the most exhausting test, and*
 - *To place them in order from easy to hard.*

Will you benefit from taking part in this research?

-
- The direct benefits for you as a participant will be that you will have access to your results by means of a personal report which they will receive two weeks after all tests have been conducted.
 - . The data gathered could enable you as middle and long distance runner, as well as your coach, to individualize and specify your training program accordingly, and help you to improve your performance.
 - Your coach will also receive a complete report of all participants' data.
 - The indirect benefit will be broadening sport science knowledge with regard to middle and long distance runner's aerobic ability. This includes the effect different protocols have on cardiorespiratory parameters as well as the effect different testing apparatus will have on these parameters. This knowledge could be used in other testing facilities to achieve optimal values from distance runners.

Are there risks involved in your taking part in this research?

- The risks in this study are:
- Physical discomfort: No more physical discomfort will be encountered than discomfort normally felt by participating in middle and long distance running. Our team of researchers and assisting sport scientists will take responsibility for the warm-up. An accredited level 2 first aid consultant will be present throughout the duration of the study with a medical practitioner on standby at all times (a phone call away: Dr. Koba van der Walt);
- Physical exhaustion: The maximal aerobic capacity test is a maximal performance test and needs to be done till complete exhaustion. You are free to stop the test at any time in case of nausea, fatigue, exhaustion, light headedness, shortness of breath or at the presence of a headache. An Automated External Defibrillator (AED) will also be available in case of an emergency;
- Social stress: No negative influence due to the presence of other participant's are anticipated. Each participant will be tested separately and will be motivated to achieve the highest level;
- Injury during the experimental period: The participants will not be exposed to additional risk due to the research being conducted, in addition to that related to participating in middle and long distance runners. An accredited level 2 first aid consultant will be present throughout the duration of the study with a medical practitioner on standby at all times; and
- Anonymity: Anonymity will be partial to protect the participants as individuals. Confidentiality will be ensured by assigning a code to each participant only known by the researchers. In the final dataset it will not be possible to identify participants. Reporting of findings will be anonymous by not using any individual identifiers in any publications resulting from this study. Only researchers involved in this study will have access to the

data. All data will be locked up in cupboard in the researcher's office. All electronic data will be erased from all computers and a single copy will be password protected and kept with the hard copies of data in the locked cupboard for 7 years.

- These risks are seen as minimal risks,
- The benefits outweigh the risk.

What will happen in the unlikely event of some form of discomfort occurring as a direct result of your taking part in this research study?

- ***Should you have the need for further discussion after the physical or social discomfort which might be experienced after the testing procedure, an opportunity will be arranged for you to consult with the research team.***

Who will have access to the data?

- *Anonymity will be partial to protect you as an individual. Confidentiality will be ensured by assigning a code to you only known by the researcher. It will not be possible to identify you in the final data set. Reporting of findings will be anonymous by not using any individual identifiers in any publications resulting from this study. Only researchers involved in this study will have access to the data. All data will be locked up in cupboard in the researcher's office. All electronic data will be erased from all computers and a single copy will be password protected and kept with the hard copies of data in the locked cupboard for 7 years whereafter it will be destroyed.*

What will happen with the data/samples?

- *This is a once off collection that will take place in the 2015/2016 middle and long distance season, data will be analyzed here in South Africa.*

Will you be paid to take part in this study and are there any costs involved?

No, you will not be paid to take part in the study but water and Energade will be provided during and after the testing. You will receive a report of your testing results and will receive a voucher for a maximal aerobic test valid for the following 6 months to if you complete all aspects of the study project. There will be no costs involved for you as participant if you do take part. You are a NWU students and the ISSD is situated at your training grounds. You will have no additional travel expenses during the testing period, as the test will be the only activity you will have to perform that day.

Is there anything else that you should know or do?

- You can contact Mrs Jana Storm at 018 299 441 if you have any further queries or encounter any problems.
- You can contact the Health Research Ethics Committee via Mrs Carolien van Zyl at 018 299 2089; carolien.vanzyl@nwu.ac.za if you have any concerns or complaints that have not been adequately addressed by the researcher.
- You will receive a copy of this information and consent form for your own records.

How will you know about the findings?

- *The findings of the research will be shared with you if you are interested. You are welcome to contact us regarding the findings of the research. We will be sharing the findings with you as soon as it is available by providing you with a personal report of each of the tests conducted by e-mail. You will receive a report of your results by means of a personal report which you will receive two weeks after all tests have been conducted*

Declaration by participant

By signing below, I agree to take part in a research study titled: Maximal oxygen consumption during an incremental aerobic test: A comparative study between motorized and non-motorized treadmill protocols

I declare that:

- I have read this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions to both the person obtaining consent, as well as the researcher and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurized to take part.
- I may choose to leave the study at any time and will not be penalized or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) on (*date*) 20....

.....

Signature of participant

.....

Signature of witness

Declaration by person obtaining consent

I (*name*) declare that:

- I explained the information in this document to
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter.

Signed at (*place*) on (*date*) 20....

.....
Signature of person obtaining consent

.....
Signature of witness

Declaration by researcher

I (*name*) declare that:

- I explained the information in this document to
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter.

Signed at (*place*) on (*date*) 20....

.....
Signature of researcher

.....
Signature of witness

APPENDIX D: PHYSICAL ACTIVITY AND READINESS QUESTIONNAIRE

Physical Activity Readiness Questionnaire (PAR-Q) and You

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly:

YES	NO		
<input type="checkbox"/>	<input type="checkbox"/>	1.	Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2.	Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3.	In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4.	Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5.	Do you have a bone or joint problem that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7.	Do you know of <u>any other reason</u> why you should not do physical activity?

If you answered:	YES to one or more questions
	<p>Talk to your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.</p> <ul style="list-style-type: none"> You may be able to do any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.

NO to all questions	<p>Delay becoming much more active:</p> <ul style="list-style-type: none"> If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or If you are or may be pregnant – talk to your doctor before you start becoming more active.
<p>If you answered NO honestly to <u>all</u> PAR-Q questions, you can be reasonably sure that you can:</p> <ul style="list-style-type: none"> Start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go. Take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. 	<p>Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.</p>

Informed use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Name _____

Signature _____

Signature of Parent _____

or Guardian (for participants under the age of majority)

Date _____

Witness _____

APPENDIX E: HYDRATION STATUS AND RECOVERY QUESTIONNAIRE


Hydration status and recovery questionnaire:
Study Project Title: A comparison between the cardiorespiratory responses of motorized and non-motorized treadmill protocols
Name and Surname: _____

Date: _____

Please complete the following questions that are related to your participation in this study project:

1. Which protocol will you be participating in today?

Mark correct block

ISIP	
AISP	
ANMIP	

2. How many hours did you sleep during the previous night?

2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	8 hours	9 hours	10 hours
---------	---------	---------	---------	---------	---------	---------	---------	----------

3. Rate the quality of sleep of the previous night:

Very Poor	Poor	Average	Good	Very Good
-----------	------	---------	------	-----------

4. Are you currently experiencing any muscle soreness?

None	Some	A lot
------	------	-------

5. How much fluid have you consumed in the last 24hrs:

500ml	1l	1.5l	2l	3l	3.5l	4l
-------	----	------	----	----	------	----

APPENDIX F: EXAMPLE OF DATA SHEET

ISIP DATA SHEET

Date of test: _____

Protocol 1**ISIP**

Name and Surname: _____

Birth date: _____

Height: _____

Weight: _____

ISIP				
Time	Interval	Speed	Heart rate	RPE
01:00	1	10		
02:00	2	11		
03:00	3	12		
04:00	4	13		
05:00	5	14		
06:00	6	15		
07:00	7	15+1		
08:00	8	15+2		
09:00	9	15+3		
10:00	10	15+4		
11:00	11	15+5		
12:00	12	15+6		
13:00	13	15+7		
14:00	14	15+8		
15:00	15	15+9		
16:00	16	15+10		
17:00	17	15+11		
18:00	18	15+12		
19:00	19	15+13		
20:00	20	15+14		
RECOVERY				
1 min				
3 min				
5 min				

AISP DATA SHEET

Date of test: _____

Protocol 2**AISP**

Name and Surname: _____

Birth date: _____

Height: _____

Weight: _____

AISP				
Time	Interval	Speed	Heart rate	RPE
01:00	1	10		
02:00	2	11		
03:00	3	12		
04:00	4	13		
05:00	5	14		
06:00	6	15		
07:00	7	16		
08:00	8	17		
09:00	9	18		
10:00	10	19		
11:00	11	20		
12:00	12	21		
13:00	13	22		
14:00	14	23		
15:00	15	24		
16:00	16	25		
17:00	17			
18:00	18			
19:00	19			
20:00	20			
RECOVERY				
1 min				
3 min				
5 min				

ANMIP DATA SHEET

Date of test: _____

Protocol 3**ANMIP**

Name and Surname: _____

Birth date: _____

Height: _____

Weight: _____

ANMIP				
Time	Interval	Speed	Heart rate	RPE
01:00				
02:00	1	10		
03:00				
04:00	2	12		
05:00				
06:00	3	14		
07:00				
08:00	4	16		
09:00				
10:00	5	18		
11:00				
12:00	6	20		
13:00				
14:00	7	22		
15:00				
16:00	8	24		
17:00				
18:00	9	26		
19:00				
20:00	10	28		
RECOVERY				
1 min				
3 min				
5 min				

APPENDIX G: INSTRUCTIONS FOR AUTHORS
FROM THE *JOURNAL OF SCIENCE AND*
MEDICINE IN SPORT

JOURNAL OF SCIENCE AND MEDICINE IN SPORT

INTRODUCTION

The Journal of Science and Medicine in Sport considers for publication manuscripts in the categories of:

- Original Research
- Review Article

The manuscripts must be in one of the following sub-disciplines relating generally to the broad sports medicine and sports science fields: sports medicine, sports injury (including injury epidemiology and injury prevention), physiotherapy, podiatry, physical activity and health, sports science, biomechanics, exercise physiology, motor control and learning, sport and exercise psychology, sports nutrition, public health (as relevant to sport and exercise), and rehabilitation and injury management. Manuscripts with an interdisciplinary perspective with specific applications to sport and exercise and its interaction with health will also be considered.

Only studies involving human subjects will be considered. Authors must declare that manuscripts submitted to the Journal have not been published elsewhere or are not being considered for publication elsewhere and that the research reported will not be submitted for publication elsewhere until a final decision has been made as to its acceptability by the Journal.

PLEASE NOTE: papers which do not meet the criteria below will be rejected immediately:

- Ensure that English is of good standard
- Ensure Ethics Committee details are as complete as possible
- Ensure all headings and subheadings conform to the Guide for Authors
- References, both in-text and reference list, must be formatted according to the Guide for Authors
- Provide the Figure Legends as part of the text file, at the end of the manuscript
- Include Acknowledgements (this is mandatory)

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APPENDIX H: PROOF OF LANGUAGE EDITING

M.B. BRADLEY

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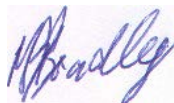
Date

2017/02/03

Document submitted for editing

**A comparison between the cardiorespiratory responses of motorized
and non-motorized treadmill protocols**

- The above dissertation was submitted to me for language editing, which was completed on 7 February 2017.



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