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Research article

Individual versus Standardized Running Protocols in the Determination of VO_{2max}

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Abstract

The purpose of this study was to determine whether an individually designed incremental exercise protocol results in greater rates of oxygen uptake (VO_{2max}) than standardized testing. Fourteen well-trained, male runners performed five incremental protocols in randomized order to measure their VO_{2max}: i) an incremental test (INC_{S+I}) with pre-defined increases in speed (2 min at 8.64 km·h^{-1}, then a rise of 1.44 km·h^{-1} every 30 s up to 14.4 km·h^{-1}) and thereafter inclination (0.5° every 30 s); ii) an incremental test (INC_I) at constant speed (14.4 km·h^{-1}) and increasing inclination (2° every 2 min from the initial 0°); iii) an incremental test (INC_S) at constant inclination (0°) and increasing speed (0.5 km·h^{-1} every 30 s from the initial 12.0 km·h^{-1}); iv) a graded exercise protocol (GXP) at a 1° incline with increasing speed (initially 8.64 km·h^{-1} + 1.44 km·h^{-1} every 5 min); v) an individual exercise protocol (INDXP) in which the runner chose the inclination and speed. VO_{2max} was lowest (-4.2%) during the GXP ($p = 0.01$; $d = 0.06 - 0.61$) compared to all other tests. The highest rating of perceived exertion, heart rate, ventilation and end-exercise blood lactate concentration were similar between the different protocols ($p < 0.05$). The time to exhaustion ranged from 7 min 18 sec (INC_S) to 25 min 30 sec (GXP) ($p = 0.01$).The VO_{2max} attained by employing an individual treadmill protocol does not differ from the values derived from various standardized incremental protocols.

Key words: Maximum oxygen uptake, aerobic power, treadmill running, ramp test, treadmill protocol.

Introduction

An individual's maximum rate of oxygen uptake (VO_{2max}) has long been considered to be one of the key determinants of endurance performance since the individual's true VO_{2max} sets the "upper limit on an individual's ability to take in and consume O_2" (Bassett, 2002). In recent decades there have been countless attempts to design valid protocols for assessing VO_{2max} in various populations, including athletes and sedentary and/or unhealthy individuals (Jamison et al., 2010; Marinov et al., 2003; Porszasz et al., 2003).

Numerous treadmill protocols have been developed to assess the aerobic power (VO_{2max}) of runners. Many of these protocols differ with respect to speed, level and duration of the steps involved and inclination, leading more or less rapidly to physical exhaustion. This large number of different protocols has stimulated extensive discussion about which procedure is most optimal (Kang et al., 2001; Kuipers et al., 2003; Pollock et al., 1976) and how to calculate and define VO_{2max} (McConnell, 1988; Poole et al., 2008; Roitman and Herridge, 2001).

Recent reports have emphasised that not only aerobic power, but also the central nervous system plays a major role in volitional exercise testing: the athlete's biological condition at the beginning of exercise including the emotional state (e.g. motivational self-belief) and the extent of mental and physical fatigue altogether contribute to the recruitment of an appropriate number of motor units thereby affecting performance (Noakes, 2008; Noakes, 2012). Thus, rather than externally imposed incremental protocols, an individually designed protocol might offer an alternative approach to determine an even higher VO_{2max} value than during standardized test protocols, since an individual protocol allows the athlete to pace himself according to his present biological state. Well-trained runners are experienced in adjusting their speed in response to sensory feedback concerning fuel reserves, thermoregulation and hydration, as well as on the basis of personal characteristics (Noakes, 2008; Ross et al., 2010; Seiler and Sjursen, 2004).

Investigations of a self-paced test (five 2-min stages of cycling at power based on fixed increments by the rating of perceived exertion) by two different groups showed inconsistent results (Chidnok et al., 2013; Mauger and Sculthorpe, 2012). While Mauger and Sculthorpe (2012) observed greater VO_{2max} values for self-paced when compared with standardized incremental tests, Chidnok and colleagues (2013) reported no difference in VO_{2max}.

In addition to the self-paced cycling protocol, Faulkner et al. (2014) and Hogg et al. (2014) examined a self-paced running protocol (within a predetermined and fixed range of perceived exertion) on a motorised treadmill. Although a self-paced test on a motorised treadmill is more challenging than completing a predetermined protocol, they found no significant differences in VO_{2max} when compared to a standardized graded exercise test and demonstrated that a self-paced protocol, based on predefined stages of the RPE scale (11, 13, 15, 17, 20), can be an alternative to a predefined incremental test (Faulkner et al., 2014; Hogg et al., 2014).

To date, no study has examined the influence of a

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completely individually chosen protocol, not based on RPE, with freely chosen step duration to elicit exhaustion within a time range of 8-12 min, on a motorized treadmill. Therefore, it is hypothesized that a motorised treadmill protocol based entirely on individual adjustments (speed, inclination, step duration) will result in higher vO_{2max} values than standardized testing procedures. Furthermore, the purpose was to assess the applicability of an individually designed protocol for treadmill experienced runners and the influence of different movement patterns leading to exhaustion (*e.g.* exhaustion by increasing treadmill inclination, speed, or a combination of speed and inclination).

Methods

Subjects

Fourteen healthy, well trained male runners of national level, from local clubs participated (age: 26 ± 4 years, height: 1.84 ± 0.06 m; total body mass 78.5 ± 6.2 kg; total body fat: 11.4 ± 3.4%). All runners were instructed to follow their regular competition preparation strategy (*i.e.* fluid intake, nutrition, timing of going to bed) and to refrain from consuming alcohol or caffeine before each test. Prior to the study, all athletes were informed of the protocol and provided their written, informed consent to participate. All procedures were approved by the ethics committee of the German Sport University Cologne, Germany, and conducted in accordance with the Declaration of Helsinki.

Design

The repeated measures design involved collecting data from five different exercise test protocols on five separate occasions one week apart at the same time of day. As illustrated in Figure 1, all participants first completed a 5 minute warm-up, followed by one of the 5 exercise test protocols (in randomized order), and thereafter 3 min of recovery.

Methodology

Total body weight, lean mass and fat mass were determined using a four-electrode bio-impedance body scale (Tanita BC 418 MA, Tanita Corp., Tokyo, Japan). Thereafter, each participant performed the different exercise protocols to determine their $\dot{V}O_{2max}$: i) an incremental protocol (INC_{S+I}) involving set increases in speed and inclination, 2 min at 8.64 $km \cdot h^{-1}$, thereafter an increase in speed of 1.44 $km \cdot h^{-1}$ every 30 s up to 14.4 $km \cdot h^{-1}$, followed by a rise in the treadmill inclination from the initial 0° by 0.5° every 30 s; ii) incremental test (INC_I) at constant speed (14.4 $km \cdot h^{-1}$) and with increasing inclination (2° every 2 min from the initial 0°); iii) incremental test (INC_S) at a constant inclination of 0° and increasing speed

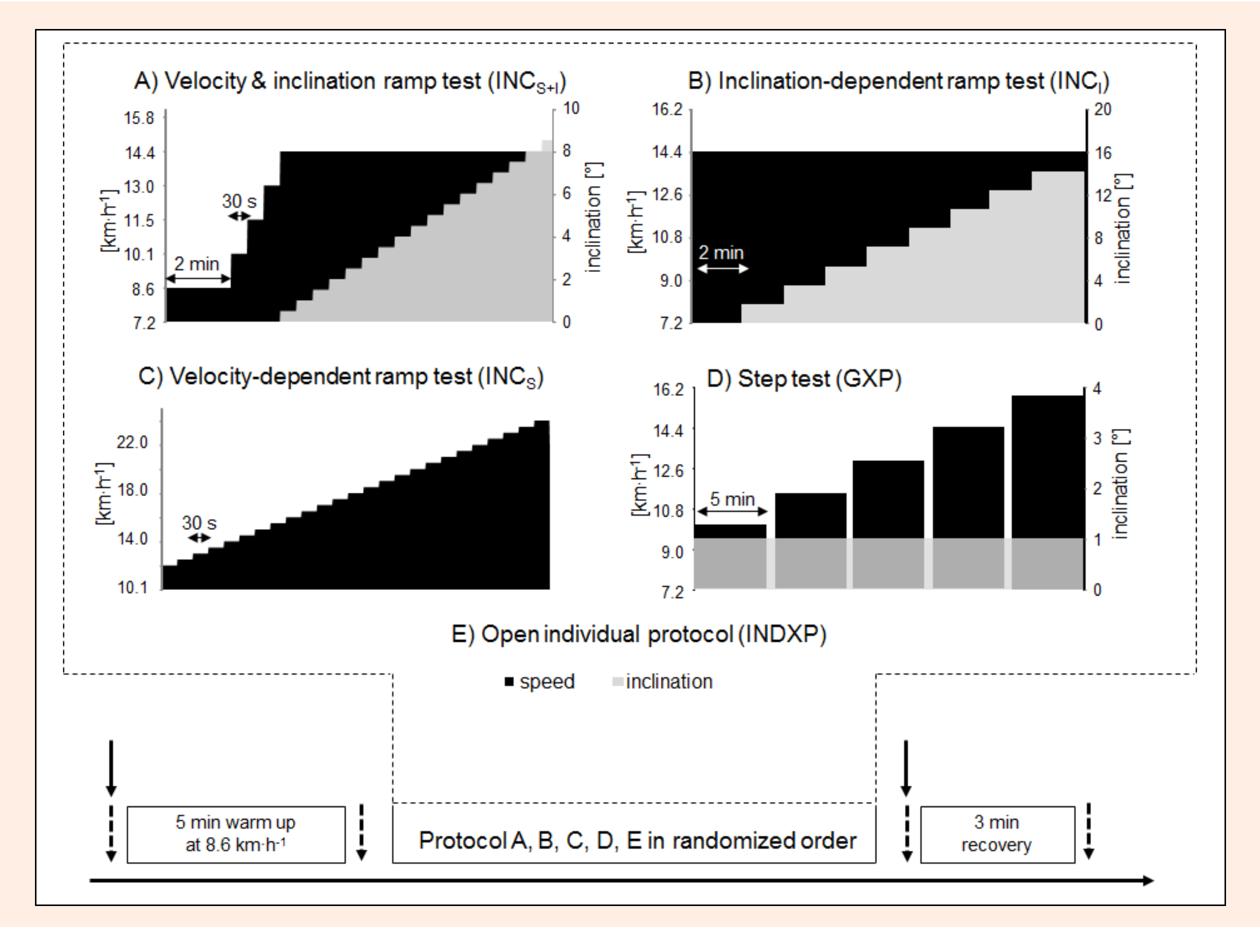

Figure 1. The study design, including warm-up, the various protocols and cool down. The black areas represent changes in speed and the grey areas changes in inclination. The black arrows show the time when blood lactate samples were taken. The dashed arrows show the time when the participants were asked to rate their level of perceived exertion.

Table 1. The mean peak values (±standard deviations) and effect sizes for the various parameters monitored during each test protocol.

Peak values	INC_{S+I}	INC_I	INCs	GXP	INDXP	Cohen's *d* *(Range)*
Oxygen uptake [mL·min^{-1}]	4900 (402)	4930 (356)	4850 (384)	4670 (469) [a]	4830 (426)	.06 - .61
Oxygen uptake [mL·min^{1}·kg^{-1}]	62.2 (5.2)	63.1 (3.3)	61.8 (4.3)	59.5 (4.3) [a]	61.5 (4.5)	.07 - .94
Ventilation [L·min^{-1}]	158 (17)	161 (17)	156 (18)	152 (18)	161 (15)	.00 - .54
Respiratory exchange ratio	1.18 (.06) [b]	1.24 (.10)	1.19 (.06) [b]	1.21 (.07)	1.23 (.08)	.11 - .73
Heart rate [bpm]	189 (11)	189 (9)	190 (9)	190 (10)	189 (10)	.00 - .11
Blood lactate [mmol·L^{1}]	7.67 (2.55)	8.44 (2.26)	7.59 (2.74)	7.17 (2.09)	8.47 (2.65	.01 - .54
Ratings of perceived exertion	18 (1)	19 (1)	18 (1)	18 (1)	19 (1)	.00 - 1.00
Time to exhaustion [min: sec]	10:54 (1:30) [c,d]	7:30 (1:12) [c]	7:18 (1:06) [c]	25:30 (3:00) [c]	9:48 (:54) [c,d]	.09 - 8.05

S = increase in speed; I = increase in inclination; INC = incremental test; GXP = step test; INDXP = open individual protocol. [a] $p < 0.01$ in comparison to the corresponding values for all of the ramp tests (INC_{s+I}, INC_S, INC_I, INDXP). [b] $p < 0.05$ for INC_s versus INC_I, INC_{S+I} versus INDXP and INC_{S+I} versus INC_I. [c] $p < 0.01$ for the GXP versus all ramp tests, INC_S versus INDXP and INC_{S+I}, and INC_I versus INDXP and INC_{S+I}. [d] $p < 0.05$ for INDXP versus INC_{S+I}. (RER = respiratory exchange ratio, RPE = rating of perceived exertion).

(0.5 km·h^{-1} every 30 s from the initial 12 km·h^{-1}); iv) graded exercise protocol (GXP) at a constant inclination of 1° and increasing speed (1.44 km·h^{-1} every 5 min from the initial 8.64 km·h^{-1}) with 30-seconds of passive rest preceding each increment; and v) individual exercise protocol (INDXP) during which each participant adjusted the treadmill inclination and speed of running at will with the aim of reaching exhaustion within 8-12 min. The participants were asked to independently adjust their running speed and inclination without reducing the speed or inclination. The participants could see their adjusted speed, inclination and elapsed time on the treadmill display (Woodway PPS 55, Lörrach, Germany).

Oxygen uptake was measured with an open-circuit breath-by-breath gas and volume analyser (Cortex Metamax 3B, Leipzig, Germany), which was calibrated prior to each test with gas covering the range of anticipated compositions (15.8% O_2 and 5.0% CO_2 in N_2, Praxair, Düsseldorf, Germany) and a precision 3L syringe (Cortex, Leipzig, Germany). Heart rate was recorded telemetrically (Polar T31, 1Hz, Polar Oy, Kempele, Finland) and was synchronized to the breath-by-breath analyser. The average gas, volume and heart rate values for each 30-s period were used for the statistical analysis, with the highest being defined as the maximum values. This means that the highest $\dot{V}O_2$ in a 30-s period was defined as $\dot{V}O_{2max}$. The presence of a plateau in oxygen uptake can be observed during testing (increase of < 2 mL·kg^{-1}·min^{-1}) despite an increased workload (Åstrand 1960, Nieman 2003).

Blood samples for determination of lactate concentration were collected from the right ear lobe into a capillary tube (Eppendorf AG, Hamburg, Germany) and analysed amperometric-enzymatically using Ebio Plus (Eppendorf AG, Hamburg, Germany). These analyses were performed in duplicate and the averages subjected to statistical analysis.

In connection with the collection of the blood samples, the participants were asked to provide their RPE on the 6 – 20-point Borg scale prior to each warm up and treadmill test as well as immediately and 3 min after each treadmill test (Borg, 1970).

Statistical analyses

All variables were distributed normally, eliminating any need for transformation. All values are presented as means ± standard deviations (SD). The differences between the highest values obtained from each of the five exercise protocols were examined by repeated measures analysis of variance. To test whether these differences were significant Fisher's least significant difference post-hoc test was performed. The effect size, Cohen's *d* [defined as the difference between the means/the standard deviations] (Cohen, 1988) between all protocols was calculated, with small, moderate, and large effects being defined as 0.20, 0.50, and 0.80, respectively (Cohen, 1988). Pearson's product-moment correlation analyses were performed to examine the relation between variables of interest. Bland-Altman analyses were carried out to determine the variability in the absolute differences between the $\dot{V}O_{2max}$ values from all five exercise protocols. An alpha of $p < 0.05$ was considered statistically significant. All data were analysed using the Statistica software package for Windows® (version 7.1, StatSoft Inc., Tulsa, OK, U.S.A).

Results

The maximum rate of oxygen uptake, ventilation, respiratory exchange ratio, heart rate, end-exercise blood lactate concentration, end-exercise ratings of perceived exertion and time to exhaustion of the five different test protocols are shown in Table 1.

The maximum oxygen uptake was significantly lower (approximately -4.2%) with the GXP compared to all other exercise protocols (p = 0.01; effect sizes = 0.06 - 0.61). The highest values for ventilation, heart rate, end-exercise blood level of lactate and RER did not differ between the protocols ($p > 0.05$). The exceptions were significant differences between the RER values for INC_S versus INC_I, INC_{S+I} versus INDXP, and INC_{S+I} versus INC_I. The time to exhaustion ranged from 7 min 18 sec (INC_S) to 25 min 30 sec (GXP) (p = 0.01).

The Bland-Altman plots for mean differences (including 95% limits of agreement) in maximum oxygen uptake between the test protocols are depicted in Figure 2. The differences between the INDXP and INC_{S+I}, INC_I, INC_S, and GXP were -77 ± 270, -101 ± 225, -24 ± 251 and 153 ± 268 mL·min^{-1}, respectively, i.e., the inter-individual variance was considerable.

Each participant reached a levelling off in VO_2 in association with the INC_I protocol, while 71% fulfilled

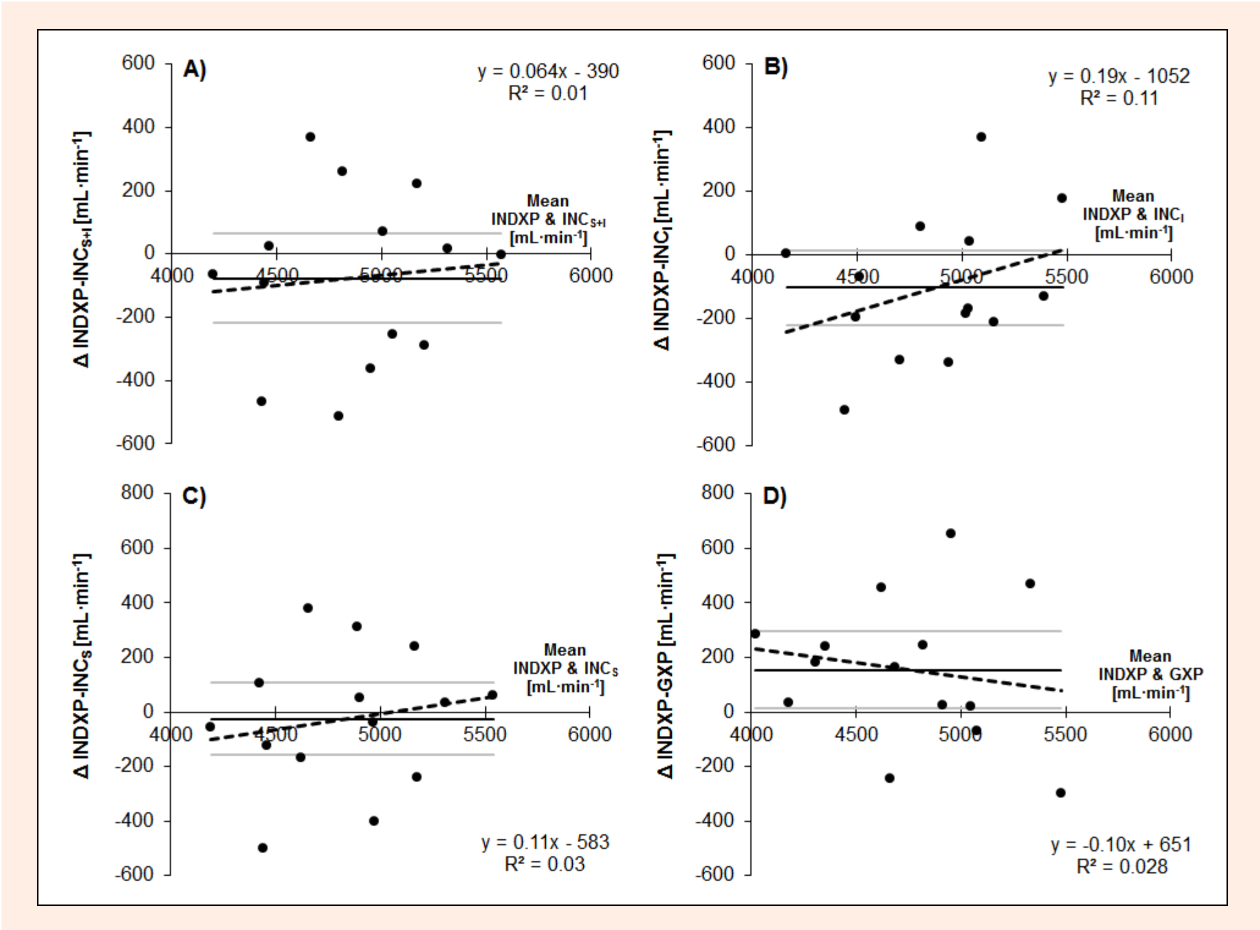

Figure 2. **Bland-Altman plots with mean bias (solid black lines) and 95% limits of agreement (grey lines) for the differences in peak oxygen uptake between INDXP, INC_{S+I}, INC_I, INC_S and GXP.**

this criterion during the INDXP and GXP tests and 64% in the case of the INC_{S+I} and INC_S. Altogether, a plateau in VO_2 was achieved in 51 of the 70 tests.

The individual speed and inclination profiles for each participant during the individual protocol (n = 14) are illustrated in Figure 3. Ten participants altered their speed and inclination, three increased only their speed, and one increased only the inclination of the treadmill.

Discussion

The current study was designed to determine whether an individually designed protocol would elicit higher values of oxygen uptake than standardized testing of well-trained runners. The results indicate that: i) the INDXP did not result in greater rates of oxygen uptake than standardized incremental tests; ii) the mean maximum oxygen uptake during the GXP was lower than during the other tests; and, iii) the differences in the maximum rate of oxygen uptake between the different tests exhibited considerable inter-individual variance.

From the current findings, it can be concluded that well-trained athletes are able to perform an individually designed running protocol. Based on our findings an individually designed protocol elicits similar values for maximum oxygen uptake when compared to the pre-set protocols. These findings are similar to studies which examined different self-paced protocols (Faulkner et al., 2014; Hogg et al., 2014). However, these earlier protocols differ with respect to the step duration (freely selectable vs. fixed 2 min steps), the possibility to reduce speed and/or inclination and the selectable movement patterns (speed and inclination vs. just speed) and therefore are not comparable (Faulkner et al., 2014; Hogg et al., 2014). Furthermore, the current study compared different ways of eliciting exhaustion (inclination, speed, inclination and speed and GXP) to measure VO_{2max}.

A steady increase in load during an incremental test (every 30 - 60 s) allows the cardiopulmonary system to respond gradually (Fleg et al., 2000). In this context, the ideal duration of a test for determination of peak oxygen uptake has been reported to be 8-12 min (Buchfuhrer et al., 1983; Myers et al., 1991; Yoon et al., 2007). Continuous incremental tests of shorter duration might involve a non-linear association between VO_2 and work load (Fleg et al., 2000), whereas tests longer than 12 min may lead to limitations due to thermal changes and muscle fatigue (González-Alonso and Calbet, 2003). The lower values for VO_{2max} in the present study, recorded during the GXP, support these earlier findings.

The time to exhaustion in our INDXP, INC_{S+I}, INC_I and INC_S tests ranged from 7-11 min, whereas the GXP lasted significantly longer (25:30 min ± 3:00 min). Thus, these results confirm the findings of Astorino et al.

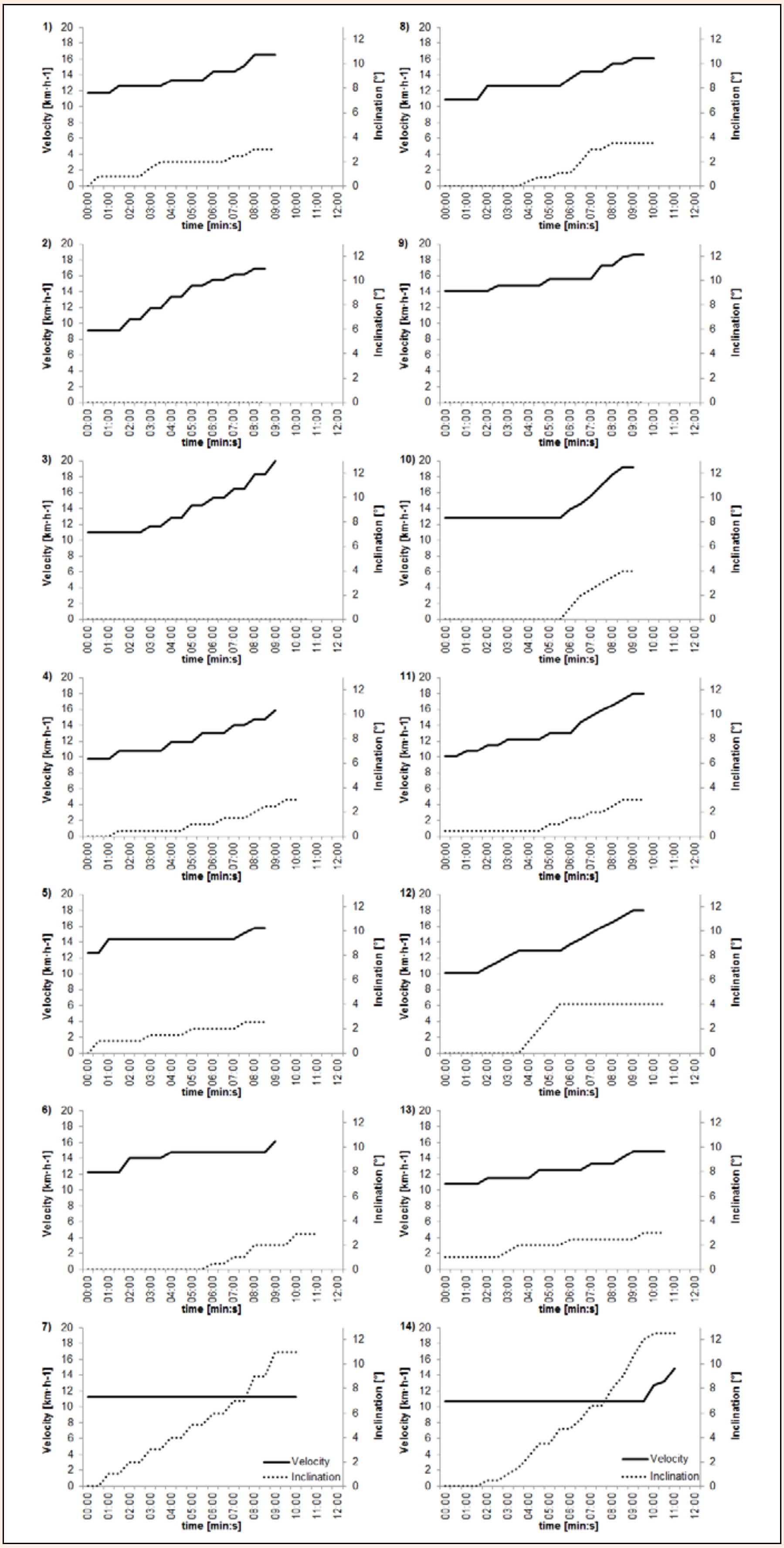

Figure 3. The time-course of individually regulated changes in speed and inclination for the 14 athletes during the individually designed protocol.

(2015) that the shorter incremental tests resulted in higher VO_{2max} values than longer ones. However, the GXP offers certain advantages, such as the possibility of measuring blood lactate between steps, as well as obtaining submaximal values for, e.g., oxygen uptake. Nevertheless, the values of VO_{2max} measured at the end of the GXP should not necessarily be interpreted as the individual's "true" maximum oxygen uptake.

One classical criterion for attainment of maximum oxygen uptake is the occurrence of a plateau in VO_2 even though the work rate is further increased (Åstrand, 1960). However, it has been shown that such a plateau does not necessarily occur when exhaustion is near (Day et al., 2003; Poole et al., 2008; Rossiter et al., 2006). The use of secondary criteria reflecting physical exertion including peak values for heart rate, the end-exercise respiratory exchange ratio and blood concentration of lactate should be considered with caution (Poole et al., 2008). However, the use of such criteria during incremental testing might lead to an underestimation of maximum oxygen values (Poole et al., 2008). In fact, all of our subjects demonstrated a plateau in oxygen uptake during the INC_I, but not the other tests. On the basis of the current observations, it is suggested that if a plateau is the primary criterion employed for maximum oxygen uptake in well-trained runners an INC_I-like protocol should be used.

Investigations have shown that different VO_{2max} values can be achieved in connection with incremental testing of different designs (Pokan et al., 1995) or by allowing the subjects to self-pace their own rate of work while cycling (Mauger and Sculthorpe, 2012). With regards to the controversy (Beltrami et al., 2012; Brink-Elfegoun et al., 2007) concerning whether "a true VO_{2max}" should be based on the "levelling-off phenomenon", the results cannot confirm that certain runners achieved a higher $\dot{V}O_{2max}$ in connection with the INDXP than the more standardized ramp and incremental tests. Although the runners were instructed to run until exhaustion, which requires a high motivational state, we cannot be certain that the runners exploited their full potential to take up oxygen.

The main limitation of the current study was that the participants were not allowed to reduce their speed and inclination within their individually designed protocol. On the one hand this made it more similar to commonly used incremental and ramp protocols, on the other hand it is not a self-paced protocol where the decrease of speed and inclination is a key element. However, some of the runners might have over-paced during INDXP and since they were not allowed to reduce speed or inclination we cannot exclude the possibility that some of the runners prematurely experienced fatigue and therefore did not achieve their individual VO_{2max}. Further investigations may focus on an examination of complete self-paced protocols.

Finally, it is important to note that the INDXP was performed only once, therefore its reliability was not assessed. It is possible that runners performing the INDXP protocol would choose variable profiles (*i.e.* speed, inclination) on subsequent attempts depending on their level of motivation or fatigue, but the chosen profile should not lead to greater than normal variability in VO_{2max} values.

Conclusion

The main findings of the current study, which was designed to investigate whether an individually designed protocol would result in higher values of maximum oxygen uptake than standardized testing of well-trained runners, were that the INDXP maximum oxygen uptake did not differ from that during standardized incremental protocols. On the basis of the current findings, it is concluded that an INDXP may allow determination of maximum oxygen uptake similar to set protocols, in well-trained runners, thereby eliminating the need to decide on an appropriate initial speed, incremental changes and the test duration. Certain practical considerations speak in favour of using individually designed protocols as suggested elsewhere (Lander et al., 2009): i) such protocols appear to be less challenging physiologically, lowering perception of dyspnoea, muscle ache and discomfort and thereby promoting greater physical exertion; ii) with an individually designed approach the researcher does not need to decide about the appropriate initial speed, incremental changes and duration of the test. The disadvantages associated with an INDXP, as with other incremental tests include the difficulty of determining submaximal values and the limited applicability since the participant must be accustomed to treadmill running.

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Key points

- The mean maximum oxygen uptake during the GXP was lower than for all other tests.
- Differences in the maximum rate of oxygen uptake between the various protocols exhibited considerable inter-individual variation.
- From the current findings, it can be concluded that well trained athletes are able to perform an individually designed treadmill running protocol.

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