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Title:

Influence of test duration on oxygen uptake attained during treadmill running

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ABSTRACT

Objective: Previous investigations have revealed that in well-trained middle-distance runners the oxygen uptake ($\dot{V}O_2$) does not attain maximal oxygen uptake ($\dot{V}O_{2\max}$) in exhaustive treadmill trials where the $\dot{V}O_2$ demand exceeds $\dot{V}O_{2\max}$. To date, this shortfall in the $\dot{V}O_2$ attained has been demonstrated in trials as short as two minutes in duration. We investigated whether a reduction in exhaustive test duration influences the $\dot{V}O_2$ attained during running on a treadmill.

Design: Six middle-distance runners participated in the study, completing an exhaustive 400-m and 800-m trial. These trials, along with a progressive test to determine $\dot{V}O_{2\max}$, were completed in a counterbalanced order. Oxygen uptake attained during the 400-m and 800-m trials was compared to examine the influence of exhaustive test duration.

Results: A $\dot{V}O_2$ plateau was observed in all participants for the progressive test, demonstrating the attainment of $\dot{V}O_{2\max}$. The speed, duration and resulting distance in the constant speed exhaustive trials were $25.8 \pm 1.2 \text{ km}\cdot\text{h}^{-1}$, $55.8 \pm 2.3 \text{ s}$ and $400.2 \pm 20.2 \text{ m}$ for the 400-m trial and $24.3 \pm 0.8 \text{ km}\cdot\text{h}^{-1}$, $108.4 \pm 21.2 \text{ s}$ and $730.1 \pm 129.1 \text{ m}$ for the 800-m trial respectively. The paired samples t-test revealed a significantly different ($p= 0.018$) % $\dot{V}O_{2\max}$ was attained for the 400-m ($85.7 \pm 3.0\%$) and 800-m ($89.1 \pm 5.0\%$) trials.

Conclusions: $\dot{V}O_2$ does not reach $\dot{V}O_{2\max}$ during the exhaustive constant speed 400-m and 800-m trials, and the test duration does influence the % $\dot{V}O_{2\max}$ achieved. Specifically, $\dot{V}O_2$ attained becomes progressively further below $\dot{V}O_{2\max}$ as trial duration is reduced, such that 89 and 86% $\dot{V}O_{2\max}$ is achieved in

exhaustive 800-m and 400-m constant speed trials respectively.

INTRODUCTION

During the last few years several studies have been performed regarding the oxygen uptake ($\dot{V}O_2$) response to constant load exercise in the severe intensity domain (Burnley *et al*, 2006;Carter *et al*, 2006;Duffield *et al*, 2006;Hill *et al*, 2002;Hill & Stevens, 2005;Hughson *et al*, 2000) which is commonly defined as an exercise intensity which, given a long enough duration, results in the attainment of maximal $\dot{V}O_2$ ($\dot{V}O_{2\max}$) (Gaesser & Poole, 1996). Across all exercise intensity domains, studies have typically examined responses to cycling exercise in subjects who are not well trained (e.g., (Bearden *et al*, 2004;Endo *et al*, 2004;Gerbino *et al*, 1996;Hill *et al*, 2003;Scheuermann & Barstow, 2003;Whipp *et al*, 1982;Wilkerson *et al*, 2004b;Wilkerson *et al*, 2004a)). Few studies have been presented where $\dot{V}O_{2\max}$ of subjects exceeds $60 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ – a common finding in well-trained athletes (Maldonado *et al*, 2002;Svedenhag & Sjodin, 1984;Thomas *et al*, 2005). Relating the findings of some of these studies to models of middle-distance running performance of highly trained athletes could potentially lead to misleading interpretations regarding the energetics of middle-distance running events.

Middle-distance events are commonly considered to embrace the 800- and 1500-m events, and some would consider the 400-m event to be a short middle-distance event rather than a long sprint. Maximal oxygen uptake has been assumed to be of importance in determining the energetics of middle-distance events and, as such, a useful parameter to assess in participants in middle-distance events (Wood DM, 1999). The assumption that during severe intensity running $\dot{V}O_{2\max}$ will

be attained, or at least that the $\dot{V}O_2$ response will tend towards $\dot{V}O_{2\max}$, has received some experimental support (Hill *et al*, 2002; Hill & Ferguson, 1999; Hill & Stevens, 2001). However, the subjects in these studies were of limited aerobic fitness and such a response should not be assumed for well-trained middle-distance athletes. When well-trained subjects have performed running of duration comparable to middle-distance events a different response is evident. Spencer *et al*. (Spencer & Gastin, 1996) investigated the $\dot{V}O_2$ attained during constant speed 800- and 1500-m running using well-trained middle-distance runners, and found that $\dot{V}O_2$ reached a plateau at ~ 90 and $\sim 94\%$ $\dot{V}O_{2\max}$ for the 800- and 1500-m runs, respectively. Spencer and Gastin (Spencer & Gastin, 2001) performed a second similar study in which the $\dot{V}O_2$ attained during running was investigated across a range of simulated middle-distance events in trained middle-distance runners. Consistent with the findings from their first study, $\dot{V}O_2$ was shown to reach only 88 and 94% for the 800- and 1500-m events, respectively. The $\dot{V}O_2$ attained in the 400-m event was also examined, but a different group of athletes with lower aerobic fitness completed the 400-m event, which precluded comparisons across the events. We have previously observed that aerobic fitness is a key determinant of the shortfall in the $\dot{V}O_2$ attained (James *et al*, 2007b). Further methodological aspects of the studies of Spencer and colleagues (Spencer & Gastin, 1996; Spencer & Gastin, 2001) make interpretation difficult. An increasing gradient protocol was used to assess $\dot{V}O_{2\max}$, which may not have been a valid index for the race pace runs that were performed. In comparison with a flat treadmill protocol, a protocol that results in an increased gradient has been shown to result in higher values for $\dot{V}O_{2\max}$ (Draper *et al*, 1998), and such differences

may be attributed to increased muscle activation (Sloniger *et al*, 1997) . Furthermore, Spencer and Gastin (Spencer & Gastin, 2001) allowed the participants to manipulate the treadmill speed according to the race strategies preferred by the athletes; therefore, it is not clear whether the inability to achieve $\dot{V}O_{2\max}$ was due to changing exercise intensity over time. We have, however, observed a similar $\dot{V}O_2$ response even when these methodological concerns have been addressed (Draper *et al*, 2003;Draper & Wood, 2005a;Draper & Wood, 2005b;James *et al*, 2007b;Sandals *et al*, 2006). During genuine square wave transitions at a speed that led to exhaustion in approximately two minutes (the approximate duration of an 800-m run), we have consistently shown $\dot{V}O_2$ to plateau some way below $\dot{V}O_{2\max}$ and the plateau occurs after approximately 60 s of exercise in aerobically fit athletes. Interestingly, recent studies in cycling have also observed a similar shortfall in the $\dot{V}O_2$ attained e.g., (Scheuermann & Barstow, 2003;Wilkerson *et al*, 2004a).

If $\dot{V}O_{2\max}$ is not attained in middle-distance treadmill running at constant pace, this may have important implications for understanding the energetics of these events. Recently, it has been shown that the warm-up strategy, pacing strategy, $\dot{V}O_{2\max}$ and specialist event of the athlete appears to influence the $\dot{V}O_2$ attained during treadmill running (Draper *et al*, 2007;James *et al*, 2007b;James *et al*, 2007a;Sandals *et al*, 2006), although a shortfall in $\dot{V}O_2$ attained still remained. To what extent the $\dot{V}O_2$ attained is a function of event duration remains an interesting question. Although Spencer *et al*. (Spencer & Gastin, 1996) examined the $\dot{V}O_2$ attained in 1500-m and 800-m event durations, they did not examine the $\dot{V}O_2$

attained in the same athletes in the shorter (i.e., 400-m) event, which some consider as a middle-distance event, and others consider as a long sprint event. Therefore, the aim of the present study was to investigate the % $\dot{V}O_{2\max}$ attained during exhaustive 400-m and 800-m running in well-trained middle-distance runners. In doing this, we hoped to establish the influence of exhaustive test duration on the $\dot{V}O_2$ attained.

METHODS

Subjects

Six male runners (age 24.8 ± 3.2 yr; height 1.79 ± 0.1 m; mass 68.3 ± 4.9 kg) with a seasonal best time of 111.8 ± 3.7 s for the 800 m volunteered to participate. All were well habituated with laboratory procedures in general and with motorised treadmill running in particular. Prior to participation, all subjects completed a health screening procedure and were fully informed of the nature of the study. Subjects then provided written consent to participate. The University Research Ethics Committee approved all procedures.

Preliminary tests

On a level motorised treadmill, all subjects completed three familiarization runs; a progressive speed ramped test ($0.16 \text{ km}\cdot\text{h}^{-1}$ per 5 s), and exhaustive constant speed 400-m and 800-m runs. The progressive test allowed an appropriate starting speed to be selected for future progressive tests to ensure that exhaustion would be reached in ~ 10 min (Buchfuhrer *et al*, 1983) for each participant. The $\dot{V}O_2$ at which the gas exchange threshold occurred was determined by means of the v-slope method (Beaver *et al*, 1986) for each subject. The corresponding

speed for this $\dot{V}O_2$ was then determined from each subject's $\dot{V}O_2$ -running speed relationship, and used in the calculation of warm up speed for subsequent tests. The speed for the exhaustive 400-m and 800-m runs was determined from each subject's seasonal best times for the event. Where the distance covered at the point of exhaustion for both the preliminary 400-m and 800-m exhaustive constant speed runs was not exactly 400-m or 800-m respectively, the speed was adjusted depending on the distance error, but this adjustment never exceeded $0.2 \text{ km}\cdot\text{h}^{-1}$.

Procedures

Following the completion of preliminary tests, each subject completed one progressive speed ramped test ($0.16 \text{ km}\cdot\text{h}^{-1}$ per 5 s), and an exhaustive 400-m and 800-m constant speed run. All tests were completed on a level motorised treadmill (Ergo ELG 70, Woodway, Weil and Rhein, Germany) in a counterbalanced design (using a 3x3 Latin square) to control for order and carryover effects. Subjects completed their own sequence of tests at the same time of day. All tests were completed within 14 days, with at least 48 hours between each test. Each of the tests was preceded by a 5 min warm-up at 10% below the speed corresponding to each participant's gas exchange threshold to control for the effects of prior exercise on the $\dot{V}O_2$ response (Gerbino *et al*, 1996).

The speeds for the exhaustive 400-m and 800-m runs were based on the findings from the preliminary tests, where the velocity of each trial was set to result in volitional exhaustion after a distance of ~400-m and ~800-m. Runners were never given feedback during the trials, so they were unaware of the elapsed distance and time during each trial. For each run, the motorised treadmill was set at the

required speed and the experimenter initiated a 10-s countdown when the subject was ready to start the test. The subject stood astride the motorised treadmill belt and at the start of the countdown used the support rails to suspend his body above the belt while he developed cadence in his legs. The test officially started, and the first collection of expirate was initiated, when the subject released the support rails and started running on the treadmill belt. Participants were encouraged to continue running for as long as possible in all tests.

Data Acquisition

Oxygen uptake was determined every ~15 s during the ramp test and throughout the entire duration of the 400-m and 800-m runs using a Douglas bag technique. A whole number of breaths was always collected, and the actual period was never greater than 20 s or less than 10 s. Repeat trials using this technique have shown good reliability (James *et al*, 2007b). Repeat 800-m trials resulted in a bias in the $\dot{V}O_2$ attained of $1.2 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and 95% limits of agreement of $\pm 2.3 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. Procedures for gas exchange determination have been described previously (James *et al*, 2007b).

Data Analysis

A 30-s moving average was used to determine $\dot{V}O_{2\text{max}}$ and the highest $\dot{V}O_2$ attained (i.e., $\dot{V}O_{2\text{peak}}$) during each run. The averaging always started with the final 15-s sampling period and moved back towards the start of the test. All tests were analysed at an alpha level of 0.05 and all data are presented as mean \pm SD unless otherwise stated. The criterion for determination of $\dot{V}O_{2\text{max}}$ was a plateau in $\dot{V}O_2$

with an increase in speed. The $\dot{V}O_{2peak}$ attained during the exhaustive 400-m and 800-m constant speed runs was expressed as a percentage of the reference $\dot{V}O_{2max}$ value determined from the ramp test to give the % $\dot{V}O_{2max}$ attained during the 400-m and 800-m runs, respectively. The paired samples t-test was used to assess if there was a difference in the % $\dot{V}O_{2peak}$ attained between the exhaustive 400-m and 800-m constant speed runs.

RESULTS

During the progressive test, a $\dot{V}O_2$ -plateau was evident in all participants. The mean value for $\dot{V}O_{2max}$, derived from the 30-s moving average approach, was $69.3 \pm 4.5 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. The peak speed attained on the ramp test was $22.3 \pm 0.8 \text{ km}\cdot\text{h}^{-1}$. This compared to speeds of $25.8 \pm 1.2 \text{ km}\cdot\text{h}^{-1}$ and $24.3 \pm 0.8 \text{ km}\cdot\text{h}^{-1}$ for the exhaustive 400-m and 800-m runs, respectively.

The test duration was $55.8 \pm 2.3 \text{ s}$ and $108.4 \pm 21.2 \text{ s}$, resulting in distances of $400.2 \pm 20.2 \text{ m}$ and $730.1 \pm 129.1 \text{ m}$ for the exhaustive 400-m and 800-m runs, respectively. The mean $\dot{V}O_{2peak}$ during the exhaustive 400-m and 800-m constant speed runs was $59.4 \pm 4.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ and $61.7 \pm 5.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, respectively. The mean % $\dot{V}O_{2max}$ attained was $85.7 \pm 3.0\%$ and $89.1 \pm 5.0\%$ for the 400-m and 800-m runs, respectively. In figure 1, these group data for the % $\dot{V}O_{2max}$ attained are given for both the 400-m and 800-m exhaustive runs. The paired t-test returned a significant difference ($p = 0.018$) in the % $\dot{V}O_{2max}$ attained between the exhaustive 400-m and 800-m runs.

DISCUSSION

We investigated the influence of exhaustive test duration on the $\dot{V}O_2$ attained during treadmill middle-distance running, having previously noted that in the longer middle-distance events (i.e., 800- and 1500-m) the highest $\dot{V}O_2$ attained falls short of $\dot{V}O_{2max}$. We set treadmill speed, based on seasonal best performance times of subjects, to result in exhaustion at ~400-m and ~800-m. For the group as a whole, the 400-m test was conducted at a speed of 25.8 km·h⁻¹ (7.17 m·s⁻¹) and completed in 55.8 s, giving a test distance of 400.2 m. The 800-m test was conducted at an average speed of 24.3 km·h⁻¹ (6.75 m·s⁻¹) and completed in 108.4 s, giving a test distance of 730.1 m. These results suggest that we were reasonably successful in determining the appropriate speed for treadmill running performance of 400-m and 800-m. The respective speeds for the 400-m and 800-m trials equate to 116% and 109% of the final speed attained in the progressive test. Therefore, the exhaustive trials clearly had a $\dot{V}O_2$ demand well in excess of $\dot{V}O_{2max}$. In this regard, and coupled with the sustained durations, there is little doubt that participants ran to complete exhaustion. The attained $\dot{V}O_2$ differed between 800-m and 400-m running, where relative to $\dot{V}O_{2max}$ ($\dot{V}O_{2max}$ of 69.3 ± 4.5 ml·kg⁻¹·min⁻¹) the highest $\dot{V}O_2$ achieved was lower as the exhaustive test duration was reduced from 108.4 s (89% $\dot{V}O_{2max}$) to 55.8 s (86% $\dot{V}O_{2max}$).

Spencer and Gastin (Spencer & Gastin, 1996) showed that the % $\dot{V}O_{2max}$ attained by 800/1500-m event specialists during both 1500-m and 800-m running decreased from ~ 94 to ~ 90% $\dot{V}O_{2max}$ as test duration decreased. Similarly, Spencer and Gastin (Spencer & Gastin, 2001) showed that % $\dot{V}O_{2max}$ attained by

1500- and 800-m event specialists in their specialist events decreased from ~ 94 to ~ 88% $\dot{V}O_{2\max}$. There is close agreement between our 800-m test findings and those of Spencer and colleagues, which is not surprising given the similar type of subjects recruited. In addition to all subjects being competitive middle-distance runners, physiologically they were very similar. The subjects in the Spencer studies (Spencer & Gastin, 1996; Spencer & Gastin, 2001) had a $\dot{V}O_{2\max}$ of 65 and 67 ml·kg⁻¹·min⁻¹, respectively, compared with 69 ml·kg⁻¹·min⁻¹ in the present study. The confirmation of the findings of Spencer and colleagues was possible even though we addressed some key methodological aspects of these studies. Specifically, we used a flat treadmill for the progressive ramp test to determine $\dot{V}O_{2\max}$, whereas Spencer and colleagues used a gradient. A treadmill gradient has been shown to increase the $\dot{V}O_{2\max}$ determined during a progressive test (Draper *et al*, 1998). It has been demonstrated that muscle activation is increased in the key locomotor's muscles (Sloniger *et al*, 1997). Although unlikely in the trained athletes in the present study, leg speed has also been suggested as a factor that might limit the $\dot{V}O_2$ attained during progressive exercise involving an increase in speed on a level treadmill.

A more recent study has found that aerobically fit ($\dot{V}O_{2\max}$ of 58 ml·kg⁻¹·min⁻¹) subjects (but not trained middle-distance runners) who attain $\dot{V}O_{2\max}$ in exhaustive square wave runs lasting 480 or 300 s, also fail to attain $\dot{V}O_{2\max}$ (92% $\dot{V}O_{2\max}$) when the duration is reduced to ~ 120 s (Draper *et al*, 2003). Findings from the present study extend these observations to show an even greater deficit in the attainment of $\dot{V}O_{2\max}$ during exhaustive exercise when the duration is reduced

further to ~55 s. In middle-distance events, the event duration appears to be an important determinant of whether $\dot{V}O_{2\max}$ is attained in exhaustive trials.

It is an interesting question whether, during the exhaustive 400-m trial, the primary $\dot{V}O_2$ response is complete. Draper and Wood (Draper & Wood, 2005b) reported that in aerobically trained runners (mean $\dot{V}O_{2\max}$ of 69 ml·kg⁻¹·min⁻¹) the $\dot{V}O_2$ response may be considerably quicker than that which has been reported in previous studies of treadmill running (Carter *et al*, 2000; Carter *et al*, 2002; Hill *et al*, 2003). For the mono-exponential response described, the time constant averaged 10.7 s, emerging after an average delay of 11.2 s, suggesting a complete response in ~54 s (i.e., delay + [4 x time constant]). More recently, Carter *et al*. (Carter *et al*, 2006) have also found that in reasonably aerobically fit subjects (mean $\dot{V}O_{2\max}$ of 59 ml·kg⁻¹·min⁻¹) exercising at 120% $\dot{V}O_{2\max}$, the time constant averaged 12.5 s, emerging after a 15 s delay, suggesting a complete response in ~65 s. These findings are consistent with the early observation by Hagberg *et al*. (Hagberg *et al*, 1980) and more recent observations during severe intensity exercise that the time constant for the primary component of the $\dot{V}O_2$ response is negatively correlated with $\dot{V}O_{2\max}$ (Scheuermann & Barstow, 2003) and explains why the $\dot{V}O_2$ response of the 800-m specialists in the present study appeared to level off over the final seconds of the 400-m run (fig. 1). We can therefore be satisfied that the primary $\dot{V}O_2$ response is nearing completion in the exhaustive 400-m trial in our aerobically fit subjects. However, a potential limitation of the present study is that the Douglas bag technique, although based on short (~15 s) collections, would perhaps lead to an underestimation of the $\dot{V}O_2$ attained during

the final seconds of the 400 m trial. The Douglas bag technique effectively 'averages' over a number of breaths, and clearly the final few breaths might have demonstrated a higher $\dot{V}O_2$. Therefore, it should not be discounted that, in the shorter 400 m trial, our finding is partly related to the gas exchange determination technique.

Although we did not set out to examine the nature of the $\dot{V}O_2$ response, it is evident from figure 1 that the speed of the response might be quite different across the two trials. For example, after ~45 s of exercise, a difference of ~10% is evident in the $\dot{V}O_2$ attained across the two trials. One interpretation of this finding is that in manipulating the exhaustive duration of the exercise, we have clearly manipulated the intensity (speed) of the exercise, and therefore we have not strictly only examined the influence of exercise duration. We were keen to ensure that we compared two 'exhaustive' trials of different duration, rather than fix the intensity (speed). It should, therefore, be acknowledged that exercise duration was not the only manipulated independent variable in the present study.

Potential explanations for the lower % $\dot{V}O_{2max}$ attained in the shorter 400-m event might be a lack of time to redistribute blood flow to areas of demand, or recruitment of a greater proportion of type II fibres. A lower gain of the primary component of $\dot{V}O_2$ kinetics has been associated with larger proportions of type II fibres in the working muscles (Pringle *et al*, 2003). In this regard it is interesting to note that the speed in the shorter 400-m event was higher, and therefore altered

fibre recruitment in the working musculature remains a possible mechanism for our findings.

In conclusion, during exhaustive treadmill running at constant pace the lack of attainment of $\dot{V}O_{2\max}$ in well-trained aerobically fit middle-distance runners is influenced by event duration. The greater shortfall in attained $\dot{V}O_2$ in the shorter middle distance events has implications for the energetics of middle-distance running. In particular, the contribution of aerobic metabolism to energy provision is likely to be less than traditionally assumed. Research exploring training and preparation strategies for middle-distance athletes might usefully consider whether the attained $\dot{V}O_2$ is trainable or acutely modifiable.

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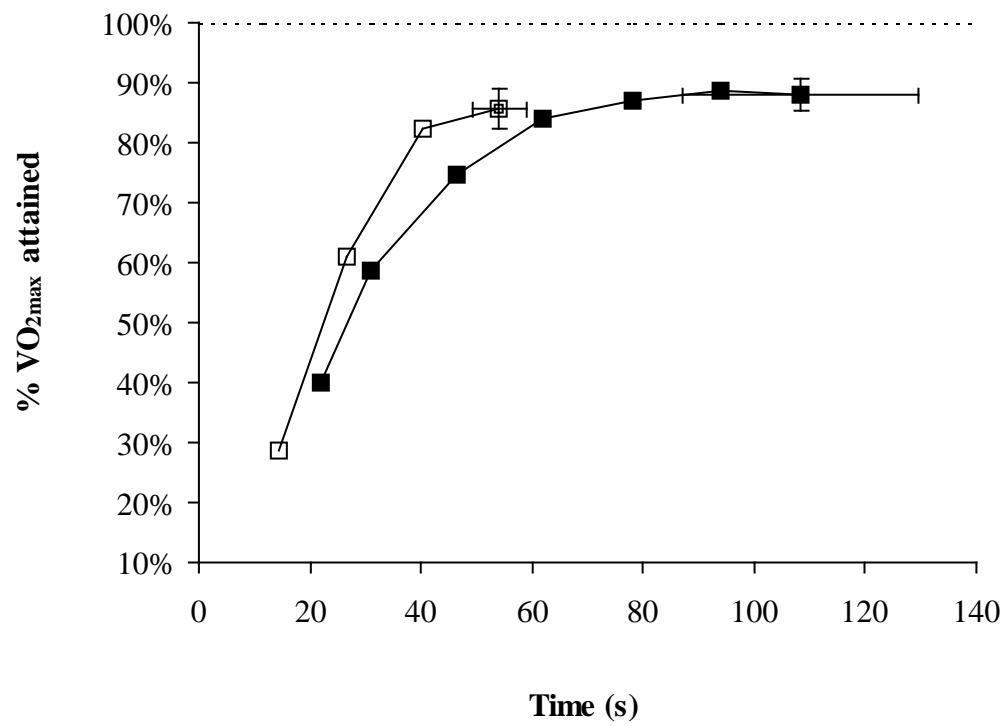


Figure 1. % $\dot{V}O_{2max}$ attained during the constant speed 400 m (\square) and 800 m (\blacksquare) runs