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The effect of pitched and vertical ladder ergometer climbing on cardiorespiratory and psychophysical variables

P.J. Barron*, K. Burgess, K. Cooper, A.D. Stewart

School of Health Sciences, Robert Gordon University, Aberdeen, United Kingdom

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ABSTRACT

This study aimed to assess whether modifying the pitch of a 75° ladder ergometer to vertical had a cardiorespiratory or psychophysical effect on climbing. Nine male participants climbed a ladder ergometer at 75° and subsequently at 90°, adjusted for an equivalent vertical climb rate, completing three climbing bouts at different vertical speeds. One participant dropped out being unable to complete the climb under the 90° condition. Each was monitored for heart rate (HR), $\dot{V}O_2$ and rating of perceived exertion (RPE). Results showed vertical climbing induced higher $\dot{V}O_2$ (mean increase 17.3%), higher HR (mean increase 15.8%), and higher RPE at all speeds and that moving from 75°to vertical exacerbates the effect of speed on the cardiorespiratory response to climbing. This may be explained by increased force production required to maintain balance in a vertical climbing position when the body's centre of mass is not above the feet.

1. Introduction

Many occupational roles require employees to climb long vertical ladders for an extended period of time including crane drivers, mast engineers or wind turbine technicians. Research related to energy demands and physiological requirements of professionals in such fields is scarce due to the practical limitations of investigating vertical ladder climbing. These limitations may include: sourcing a suitable venue with the appropriate ladder pitch and length, the cost of shutting active industrial sites down for research purposes, as well as the need to ensure all participants comply with the necessary regulations for working at height. All of these factors impact on the ability of researchers to generate reliable data on the physiology of vertical ladder climbing. An alternative solution is to conduct research on a ladder ergometer, which acts as an endless pitched ladder operating in a manner similar to a treadmill. Ladder ergometers have previously been used in research due to their ability to deliver a constant work requirement, thus enabling steady state oxygen consumption to be achieved at fixed speeds avoiding the challenges and regulations involved when climbing at height.

Ladder ergometers were used in research completed by Kamon (1970), Kamon and Pandolf (1972) and Kamon et al. (1973) when investigating ladder climbing with reported ergometer pitches between 60° and 80°. To date no reported research has been conducted on a vertical ladder ergometer (90° pitch). Currently available ladder ergometers, such as the H/P Cosmos discovery (Nubdorf, Germany) are pitched and unless they are modified, cannot be used to conduct vertical ladder climbing research. As a result, most ladder climbing research has been completed either on short fixed vertical ladders (Milligan, 2013; Vi, 2008) or on pitched ladder ergometers (Kamon, 1970; Kamon and Pandolf, 1972; Kamon et al., 1973).

Vi (2008) conducted a study investigating the difference in energy expenditure and heart rate (HR) when repeatedly ascending and descending a 6.1 m height on both a vertical ladder and a ladder pitched at 75°. Participants were required to climb for at least 5 min at a rate which elicited a HR response of either greater than 90 beats per minute or 60% of age-predicted HR max, whichever was lower. Climb rate, recovery interval, total climbing time and test order were not reported, but there was a significant difference between both energy expenditure (11.4 kcal/min v. 13.1 kcal/min) and mean HR (142 bpm v. 155 bpm) when climbing at 75° and 90° respectively. Although the study by Vi (2008) highlighted that climbing at 90° has a larger energetic demand compared to that at 75°, it is unclear as to whether the climbing speed was consistent throughout and how the data were analysed. The use of short ladders with alternating climbing and descent involves a variable energy demand in contrast to prolonged ascending on longer ladders, potentially limiting the generalisability of the study.

* Corresponding author. Sir Ian Wood Building, Robert Gordon University, Garthdee Road, Aberdeen, City of Aberdeen, AB10 7GJ, United Kingdom.
E-mail address: p.barron@rgu.ac.uk (P.J. Barron).

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This issue was alluded to by Milligan (2013) who suggested the use of short ladders for physiological testing of ladder climbing will fail to show the true demands due to combined ascending and descending the ladder rather than solely ascending. This is most likely due to the partial recovery participants can expect during descending which has a lower physiological demand. Whilst Kamon (1970) found a 26% decrease in oxygen consumption when descending a ladder ergometer compared to ascending, the recent work of Barron et al. (2016) observed a much greater decrease of 48% in oxygen consumption when comparing when climbing a 30 m vertical ladder.

In summary, data yielded from the extant literature cannot be generalised to long ladders typically used in wind and offshore energy applications, either because the research involved short ladder length mandating alternating ascent and descent cycles, or because of the non-vertical pitch, which potentially lowers the energy cost (Vi, 2008). These shortcomings mean such studies are of limited applicability of to a range of professional groups for whom reliable data on energy cost are currently unavailable.

Therefore the aim of this study was to ascertain the effect of altering a ladder ergometer from a pitch of 75° to vertical at three different speeds on $\dot{V}O_2$ consumption, HR, and the rate of perceived exertion (RPE) during ladder climbing. This is important because it could indicate the appropriateness of using existing research on pitched ladders to infer demands of vertical ladder climbing. In addition this study will also assess the demands of steady state vertical ladder climbing at different speeds without the confounding variable of ascending and descending. It was hypothesised that modifying the ladder ergometer to vertical would lead to an increase in $\dot{V}O_2$ consumption, HR and RPE at all speeds.

2. Methods and materials

2.1. Study design and justification

The study was a crossover design with the order of the speeds randomised within each ladder ergometer pitch (Randomizer.org 2015). All participants completed both ladder pitches with the testing at 75° first and the vertical condition second. However, this was unavoidable due to the modification required to make the commercially available pitched ladder ergometer vertical being irreversible. As a result of this modification process, the minimum time between testing sessions was approximately 21 days. The modification involved stabilisation and re-calibration of the ladder ergometer in a vertical orientation, achieved by placing a wedge underneath its base, and new anchors to the floor, walls and roof. All testing took place at the Robert Gordon University, Aberdeen. The School of Health Sciences ethics review panel at Robert Gordon University, Aberdeen approved the study.

2.2. Participants

Nine healthy male participants with no previous ladder climbing experience were recruited from a student population via emails, posters and word of mouth. Eight participants completed the study and their mean demographics are summarised in Table 1. Due to the inability to control for menstrual cycle and the unknown nature of the differences between the testing days for pitched and vertical climbing trials, only males were recruited. Although it has generally been seen not to affect aerobic performance (Constantini et al., 2005) the effect is individualised and by only recruiting male participants it removed gender and menstrual cycle as potential confounding factors. All participants completed a pre activity readiness questionnaire (PARQ) and provided informed consent.

Table 1
Physical and demographic data of participants (n = 8).

Age (years)	Stature (cm)	Mass (kg)	Body Mass Index ($kg.m^{-2}$)
19.8 (±1.7)	178.9 (±6.6)	70.8 (±4.6)	22.1 (±1.4)

Values are mean and SD.

2.3. Experimental protocol

All participants were given a minimum of one familiarisation session on the ladder ergometer (H/P Cosmos discovery, Nubdorf, Germany) which had rung spacing of 24.4 cm and width of 49.5 cm. This session involved 3 × 5 min bouts of climbing at the test speeds with the ergometer being accelerated up to test speed during the first 30 s of the 5 min exercise bout. The order of the speeds was slowest to fastest for familiarisation. These three speeds for the 75° pitch were slow (9.8 m per minute), medium (12.8 m per minute) and fast (15.4 m per minute). These speeds corresponded to the previous work of Kamon (1970). Participants were deemed to be competent after completing this successfully.

On the first day of testing participants had their stature and mass measured and recorded in accordance with a standard protocol (Stewart et al., 2011). Each Participant was then fitted with a heart rate monitor strap (Polar FI, Kempele, Finland) that was worn for the duration of the testing session. Participants were familiarised with the Borg (1982) 10 point rating of perceived exertion (RPE) scale before completing a 5 min warm up at a self-selected climbing rate no greater than 7.5 m per minute. The Borg CR-10 scale was used for its ease of use with fewer points than the 6–20 scale and increased number of anchoring terms. This allowed participants to glance at the scale to obtain a value and maintain concentration when climbing. They then rested for 5 min whilst a Cosmed K4 B2 (Cosmed, Rome, Italy) gas analysis system was fitted to them. At this point the participants were informed of the test order of the speeds they would be climbing at. Participants then completed the three 5 min climbing bouts with 5 min' recovery between each. 5 min exercise bouts were used as at moderate intensity steady state oxygen consumption should be achieved in 3 min (Burnley and Jones, 2007). Whilst similar studies have used 3 and 5 min respectively to achieve steady state oxygen consumption (Bilzon et al., 2001; Milligan, 2013). During the last 30s of each bout of climbing participants were asked for their RPE. $\dot{V}O_2$ and HR were averaged over the last minute of each stage.

Between the first and second testing sessions the ladder ergometer was modified altering the pitch from 75° to 90° (see Fig. 1). The speeds climbed were altered to match the vertical height gained when the ladder was pitched, as shown by equation (1). The corresponding speeds for slow, medium and fast speeds were 9.5, 12.4 and 14.9 m per minute.

Participants were familiarised at these speeds following the same process as per the initial familiarisation at 75°.

$$\text{Vertical speed} = (75^\circ \text{ climb speed}) * (\sin 75) \quad (1)$$

The testing procedure previously outlined for 75° was replicated with the ladder ergometer at 90°. Participants had their stature and mass measured and recorded prior to testing in order to assess for any change in either since the first testing date. The 5 min self-selected warm up was altered to account for the change in ladder pitch with participants warming up at a rate less than 7.3 m per minute rather than 7.5 m per minute at 75°. No other alterations were made to the testing protocol.