ORIGINAL ARTICLE

Body position affects performance in untrained cyclists

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Objective: To compare cardiovascular and ventilatory variables in upright versus aero cycle ergometry at submaximal and maximal exercise intensities in untrained cyclists.
Method: Ten physically active men (mean (SD) age 19.1 (1.10) years) who were unfamiliar with aerobars underwent maximal exercise testing and steady state cycling at 50, 100, and 150 W.
Results: Participants had significantly greater maxima for oxygen uptake (V_{O_2}), ventilation, heart rate, and workload maximum in the upright position. During steady state cycling at the three workloads, V_{O_2} (ml/kg/min) and gross mechanical efficiency were significantly greater in the upright position.
Conclusions: In untrained subjects performing with maximal effort, the upright position permits greater V_{O_2}, ventilation, heart rate, and workload maxima. Further, in the steady state, exercise cycling may be less costly in the upright position. For this reason, untrained cyclists need to weigh body position effects against the well known aerodynamic advantages of the aero position.

Psychological, physiological, biomechanical, and environmental factors all impact on cycling performance.[1–4] Performance can be improved by refining the human machine—that is, increase judgment, skill, style of training—or by innovations in equipment (aerodynamic helmet, lightweight bicycle, form fitting clothing, aerobars). The aerobar is an extension attached to road bike handlebars that places the cyclist in a lowered position so that the thoracic spine is almost horizontal and the arms are extended forward with elbows tucked in. Aerobars provide an advantage by reducing drag imposed by wind resistance.[5]

Although research has shown that aerobars reduce wind resistance during cycling, there is conflicting evidence as to the physiological response to adopting the aero position. Faria *et al*[6] were among the first to investigate the physiological effects of assuming the near horizontal position during a maximal oxygen uptake (V_{O_2}MAX) test. They found a significant advantage in V_{O_2}MAX, maximum work output, and maximum ventilation in the aero position compared with the upright position. Origenes *et al*[3] hypothesised that cyclists in the aero position should show a higher breathing frequency but smaller tidal volume (as the result of a possible restriction). Some studies[1 3] have suggested that the aero position is like the catch phase of rowing, where restriction is placed on the abdomen and thorax. However, these studies, unlike that of Faria *et al*,[6] failed to show any significant ventilation differences between positions. More recently, Sheel *et al*[7] found that the aero position provided energy savings, whereas Gnehm *et al*[8] concluded that the aero position increased the metabolic costs of cycling, and Grappe *et al*[9] found no difference between positions for some variables.

Most studies on the impact of position on performance have used trained athletes.[1–3 10] Because training creates adaptation to the equipment and the near horizontal position, the physiological response in trained athletes may not generalise to most recreational cyclists. To our knowledge, there are no published studies on the physiological impact of position on untrained participants.

Previous studies of body position and cycling have investigated brief incremental exercise. Berry *et al*[1] suggested that ventilation changes only become apparent after prolonged exhaustive exercise. For example, the restrictive nature of the aero position may impair the ability to sustain the position for long periods. This illustrates the need to investigate the effect of the aero position for various durations and intensities of cycling. Thus, the purpose of this investigation was to measure the cardiorespiratory response of recreationally fit young men, who were unfamiliar with aerobars, in standardised aero and the upright positions. Studies were performed during both maximal testing and submaximal exercise using a test-retest design with the participant acting as their own control.

METHODS

Participants

Twelve healthy, physically active but untrained men were recruited from the University of Adelaide using advertisements on poster boards. The inclusion criteria were non-smokers aged 17–25 years. Recreational or competitive cyclists were excluded from the study as were those with known cardiovascular or respiratory conditions, smokers, and those with aerobar experience. Two participants were excluded because of an inability to complete the exercise protocol.

Each participant was asked to refrain from any stimulants (caffeine, drugs, cigarettes, etc), exercise, or alcohol for 12 hours before the testing. Each had eaten a light breakfast/lunch at least two hours before each experimental protocol. Normal hydration was requested. All testing was completed within a six week period in an air conditioned laboratory with a constant temperature of 21.2°C and 50% humidity. Approval for the experimental protocol was obtained from the human ethics committee of the University of Adelaide. Written informed consent was obtained from the participants.

Experimental design

Each participant completed four tests: V_{O_2}MAX test in the upright and aero positions, in addition to a 45 minute steady state exercise protocol in both aero and upright positions. The tests were performed on four separate days. The 45 minute steady state protocol involved cycling for 15 minutes each at 50, 100, and 150 W. Cadence was maintained at 60 repetitions per minute. Blood samples were taken every 2.5 minutes for lactate analysis. The volume of blood removed by the venous blood sampling was replaced seriatim with an equivalent volume of normal saline to maintain blood volume.

Abbreviations: V_{O_2}MAX, maximal oxygen uptake; V_E, minute volume; GME, gross mechanical efficiency

Table 1 Results of maximal performance testing in the upright and the positions

Measurement	Upright	Aero	p Value
Vo_2MAX (ml/kg/min)	52.85 (5.11)	50.25 (4.23)	0.038*
HRMAX (beats/min)	195.18 (4.53)	190.92 (3.64)	0.015*
VEMAX (1itres/min)	130.12 (14.45)	116.65 (13.14)	0.0008*
Workload max (W)	285.0 (21.08)	272.5 (24.86)	0.035*

Values are mean (SD).
*Difference significant.
HR, Heart rate; VE, minute ventilation.

Aero and upright position
Participants were randomised into two groups (n = 5). Group 1 exercised first in the upright position, then in the aero position, on different days. Group 2 exercised in the aero position first, then in the upright position, again on different days. In the upright position participants sat with their trunk perpendicular to the ground. They maintained an anterior pelvic tilt and kept their trunk in the upright cycling position. In the aero position the participants assumed a crouched position, with their trunk held parallel to the ground. They were asked to maintain a posterior pelvic tilt and to allow their thoracic spine to "drop" towards their thighs. Wrists and hands rested on the aerobars. All participants were monitored and given verbal feedback to maintain the positions.

Maximal oxygen uptake
Two Vo_2MAX tests were completed on each participant (aero and upright). Vo_2 was measured with an online, indirect calorimetry system. Participants exercised on a Monark stationary bicycle. The standard Monark handlebars were modified with clip on aerobars (Bioarm, Italy) with forearm pads for the aero position. Seat height was set for each participant with 25–30° flexion in the extended leg. Seat height for each participant remained constant for the four protocols. Leg length was measured from the anterior superior iliac spine to the distal portion of the lateral malleolus.

Each participant was fitted with a nose clip and mouthpiece attached to a Hans Rudolph two way R2700 valve. This was passed through a metre of large bore tubing to a 2.6 1itre mixing chamber from which dried gas was sampled continuously. A Labview On-line computer system was used to perform the calculation of Vco_2, Vo_2, minute ventilation (VE), tidal volume, and respiratory exchange ratio every 30 seconds. Heart rate was recorded continuously using a Polar Electro PE3000 Sportstester heart rate monitor (information recorded every 15 seconds).

The protocol for both maximum tests started with a five minute warm up followed by a five minute rest. The participant then began cycling at 50 W increasing to 100 W after one minute. The workload was then increased by 25 W every minute until volitional exhaustion or he reached a plateau in heart rate and/or Vo_2 response. The max tests were performed on two different days at approximately the same time, one to two weeks apart.

Steady state sessions
After the participant had assumed the experimental position (aero or upright), exercise started at 50 W and continued for 45 minutes at the three absolute workloads previously outlined. Blood samples were taken every 2.5 minutes as previously described.

Blood collection
Venous catheters were inserted into the antecubital vein. An initial 2 ml of the catheter system contents (blood saline mixture) was discarded before withdrawal of the main 3 ml sample. Between samples, the catheter system was flushed with 12 ml heparinised saline to prevent clotting. From each main sample, 1 ml was immediately deproteinised in 2 ml ice cold 8% perchloric acid. The samples were vortex mixed and centrifuged, and the supernatant was frozen at −20°C for later enzymatic analysis of lactate.

Gross mechanical efficiency
The percentage gross mechanical efficiency (%GME) was calculated from the following equation at the final minute of each workload (steady state):

$$\%GME = \text{work output}/\text{energy expended}$$

Statistical analysis
Individual mean maximal exercise data were analysed with a paired *t* test. The steady state exercise data were analysed using the last five minutes of each of the three levels of intensity (50, 100, 150 W). Submaximal exercise data were analysed using paired *t* tests and repeated measures analysis of variance. Data are reported as mean (SD).

RESULTS
The participants had a mean age of 19.1 (1.10) years, height of 181.95 (4.27) cm, mass of 70.98 (3.12) kg, and body mass index of 21.46 (1.21).

Maximal exercise
Table 1 summarises maximal values for participants in both aero and upright positions during one minute of incremental exercise testing. Participants had a significantly higher Vo_2MAX (ml/kg/min), heart rate maximum, and VEMAX, and achieved a greater workload in the upright position. There was no significant difference between positions for Vo_2MAX measured in litres/min.

Steady state exercise
During submaximal work at three absolute work outputs (50, 100, 150 W), variables increased in a stepwise fashion as intensity of exercise increased (table 2). A significant difference was found between positions for Vo_2 using a repeated measures analysis of variance. Other variables did not differ between groups (figs 1 and 2).

Table 2 Cardiorespiratory variables measured during steady state exercise in the upright and aero positions

Measurement	50U	50A	100U	100A	150U	150A	p Value
Tidal volume (litres)	1.04 (0.27)	1.05 (0.17)	1.43 (0.24)	1.37 (0.26)	1.79 (0.21)	1.68 (0.26)	0.21
Breathing frequency (breaths/min)	24 (6)	25 (3)	27 (6)	29 (7)	32 (7)	35 (9)	0.07
Respiratory exchange ratio	0.94 (0.04)	0.94 (0.05)	0.96 (0.03)	0.97 (0.04)	0.98 (0.02)	0.99 (0.04)	0.58
Minute ventilation (litres/min)	24.79 (1.57)	26.12 (2.25)	37.39 (3.04)	39.51 (2.39)	56.16 (7.58)	56.49 (8.36)	0.13
Heart rate (beats/min)	111 (13)	113 (7)	140 (13)	141 (7)	168 (12)	167 (11)	0.87
Vo_2 (ml/kg/min)	16.06 (1.15)	17.34 (0.91)	24.04 (1.08)	25.80 (1.45)	33.62 (2.30)	34.46 (2.50)	0.00*

Values are mean (SD).
U, Upright; A, aero; 50U means exercise at 50 W in upright position, etc.
*Differences significant.

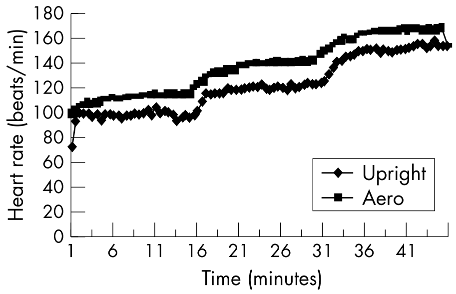

Figure 1 Heart rate response to three levels of exercise intensity in the steady state investigation. Exercise progressed in a stepwise fashion.

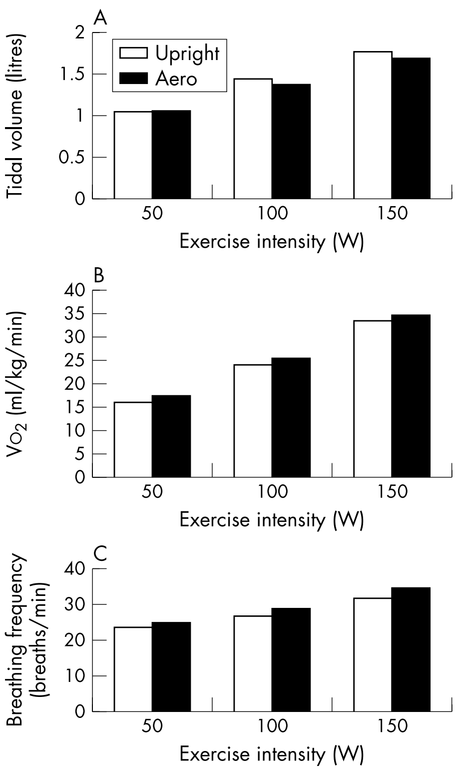

Figure 2 (A) Steady state tidal volume response, (B) V_{O_2} response, and (C) breathing response.

Gross mechanical efficiency

The %GME increased as exercise progressed in both positions. There was a significantly higher value obtained for the upright position at 50 and 100 W, which was not significant at 150 W.

DISCUSSION

Physiological response to the aero position is not well understood, and previous results using "trained" participants are inconsistent. The conflict of previous results may be due to different experimental controls, experience of the cyclists, or the adaptation of training. To our knowledge, no studies have investigated the response of untrained cyclists to the variation of positions. For this reason, this study is unique in that: participants were unfamiliar with aerobars and the crouched position; results were obtained using standardised positions and several different exercise intensities and durations were tested.

In the maximal exercise testing, significant differences were found in V_{O_2}MAX, VE, heart rate maximum, and maximal workload. The crouched aero position was associated with smaller increases in tidal volume compared with the upright position. Subsequent reliance on increased breathing frequency was associated with earlier termination of exercise. Origenes *et al*[3] believed that cyclists in the aero position should show a higher breathing frequency but smaller tidal volume and therefore higher inspiratory flows caused by a possible restriction imposed by the position.

Franke *et al*[2] found that the aero position gave higher stroke volume at rest resulting from an increased pre-load. They did not find this phenomenon during exercise. If the assumption that the aero position provides a greater stroke volume is true, but heart rate remains the same in both positions, one would expect to see some advantages resulting from greater cardiac output. However, this may be difficult to measure non-invasively. The crouched aerobar position may impair the ability to increase tidal volume, and subsequent increased breathing frequency may lead to earlier termination of exercise compared with the upright position. It may be that the combination of limitations imposed by restricted ventilation, increased energy cost, and the subsequent resultant fatigue outweigh any cardiovascular advantages that may be present in the aero position.

In the steady state exercise, physiological responses parallelled those seen in the maximal exercise tests. Overall, there was a trend towards better respiratory response in the upright position as reflected by a larger tidal volume and lower breathing frequency. Although not statistically significant, a trend was observed in the respiratory exchange ratio, which was higher in the aero than the upright position for the same absolute workload. This indicates that the participants worked harder in the aero position and is supported by the significantly greater %GME observed in the upright position at 50 and 100 W. The only significant differences found between positions were for V_{O_2} and GME, with the upright cyclists having greater V_{O_2} and %GME.

This study is novel in that all participants were unfamiliar with cycling and therefore with the use of aerobars. Training may develop adaptations to the near horizontal position. In previous studies of trained cyclists,[1–3 7–9 11] time to fatigue was found to be shorter in riders in the aero position. Berry *et al*[1] recommended that cyclists who raced with aerobars should also train with aerobars. Also, Gnehm *et al*[8] observed that elite cyclists suffered a disadvantage in the aero position.

On the other hand, Sheel *et al*[7] observed an advantage for cyclists in the aero position compared with the upright position during a submaximal exercise protocol. The differences between studies may result from the fact that the participants in the study of Sheel *et al* were trained athletes experienced in using aerobars for at least one year. Furthermore, the cyclists in that study did not use their own bicycle, and wind velocity was not measured. Wind velocity is an important variable, as the aero position reduces the wind resistance.[5] Our study investigated the physiological response while controlling for environmental factors.

Unlike most other studies, the present research examined performance in both the maximal and a longer steady state exercise setting. Except for Berry *et al*[1] and Gnehm *et al*,[8] who measured response to position in trained subjects at high prolonged intensities, previous research compared the response between positions during brief incremental exercise protocols. Ventilation changes may only become apparent after prolonged exhaustive exercise.[1] Body position may therefore only influence physiological variables after a longer period of cycling. Although Berry *et al*[1] found no significant differences between positions during longer duration exercise, Gnehm *et al*[8] observed a significant disadvantage to the aero position during prolonged exercise.

Studies of body position in cycling must attend closely to the experimental position adopted by the participants. Biomechanical efficiency is important when cycling, and a strength of this study is the standardised position assumed by the participants. Too[4] suggests that, during cycle ergometry,

Take home message

Under standardised conditions, untrained participants who assume the aero position while cycling gain no physiological advantage.

changing to the aero position can affect the "joint angles, muscle lengths, the muscle arm lengths thus affecting the tension-length, force velocity-power relationship . . . and (therefore) the effectiveness of force production" (p 286). Both Too[4] and Heil *et al*[11] argued that in previous studies, hip angle, a difficult measurement, was not adequately controlled for and therefore not a "true aero position". In a full forward aero position, where the trunk is parallel to the thighs, the quadriceps may be placed at a disadvantage because of excessive shortening. In the length/tension relation the force obtained may decline at extreme ranges of the muscle. The mechanical advantage/disadvantage is related to how far forward the cyclist is. Jeukendrup and Martin[12] state that the aero position may improve aerodynamic drag, but consideration must be given to the impact on joint angle and muscular output. In reality, during competition, most cyclists do not "freeze" in a single position. Rather, the cyclist adjusts to find the most comfortable and/or efficient position ("preferred" versus "optimal" positioning during cycling).[11]

This study provides insight into an untrained physiological response to a standardised aerobar position in the laboratory setting where environmental conditions were closely controlled. It suggests that untrained cyclists cannot assume that their cardiorespiratory function will improve on adopting the aero position. It may be that a period of training and adaptation is necessary to optimise performance using aerobars, although this study was not designed to examine this. The results of this study may be useful in exercise prescription in untrained subjects to assist the best individual performance at an energy efficient cost.

In conclusion, we found evidence of limitation in ventilation in young men cycling in the unfamiliar aerobar position. Inexperience and cycling position is offered to account for the differences observed. Future studies investigating the changes that occur with adaptation and training aerobars would provide valuable information.

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