Abstract

Purpose: The aim of this study was to investigate the relationship between selected anthropometric, physiological, and upper body strength measures and 15-km handcycling time trial performance.

Methods:
Thirteen, trained H3/H4 male handcyclists performed a 15-km time trial, graded exercise test, 15-s all-out sprint and one repetition maximum assessment of bench press and prone bench pull strength. Relationship between all variables were assessed using a Pearson’s correlation coefficient matrix with mean time trial velocity representing the principal performance outcome.

Results:
Power at a fixed blood lactate concentration of 4 mmol·l⁻¹ (r = .927; p < 0.01) showed an extremely large correlation to TT performance, whilst relative VO₂peak (r = .879; p < 0.01), power-to-mass ratio (r = .879; p < 0.01), peak aerobic power (r = .851; p < 0.01), gross mechanical efficiency (r = 733; p < 0.01), relative prone bench pull strength (r = .770; p = 0.03) relative bench press strength (r = .703, p = 0.11), and maximum anaerobic power (r = .678; p = 0.15) all demonstrated a very large correlation with performance outcomes.

Conclusion: Findings of the present study indicate that power at a fixed blood lactate concentration of 4 mmol·l⁻¹, relative VO₂peak, power-to-mass ratio, peak aerobic power, gross mechanical efficiency, relative upper body strength, and maximum anaerobic power are all significant determinants of 15-km TT performance in H3/H4 handcyclists.

Keywords: Paralympic Sport; Handbiking; Anaerobic Performance; Upper Body Strength; Arm Ergometry
Introduction

Since its formal recognition as a sport by the International Paralympic Committee in 1999, the popularity of handcycling as both a recreational and competitive sport has grown substantially. The sport was first included in the summer 2004 Paralympic Games in Athens and is now also incorporated within the wheelchair classifications of Para-triathlon, a sport that debuted at the summer 2016 Paralympic Games in Rio de Janeiro. Handcyclists are classified into one of five categories (H1 - H5) according to the nature of their physical impairment, with H1 athletes typically having the greatest physical impairment and lowest physical function. Handcycling can be viewed as an endurance sport whereby athletes typically compete in road-races and/or individual time trials (TT) over distances ranging from 37 to 80-km and 10 to 35-km, respectively. Due to varying race formats, terrain, tactics and speeds, handcyclists often use variable pacing strategies, such as frequent short accelerations to push opponents, or drafting behind other riders during road races to reduce overall energy cost. Arguably, a TT represents the most pure challenge to a cyclist as, in this format, athletes ride alone, against the clock. Thus, racing tactics briefly mentioned above become irrelevant and a cyclist’s ability is laid bare.

As with many other Paralympic sports, the performance level of handcycling at the elite level has increased considerably, which underlines the importance of optimising training in order to achieve success. Handcycling performance is ultimately dependent upon the physical capabilities of the individual, the design of the handbike, and the interaction between the rider and their equipment, typically referred to as the handbike-user interface. Whilst the biomechanics, handbike-user interface and physiological characteristics of handcycling performance, namely peak oxygen uptake ($\dot{V}O_{peak}$), peak aerobic power output (PO$_{peak}$) and gross mechanical efficiency (GME) have been extensively investigated, To date, only a handful of studies have examined the relationship between the aforementioned physiological characteristics and handcycling race...
Handcycling Performance

Janssen et al.\textsuperscript{19} investigated how the physical capacity of sixteen male handcyclists with either spinal cord injury, spina bifida or lower limb amputation related to performance during a 10-km handcycling race. Relative $\dot{V}O_{2\text{peak}} (r = .90, p < .01)$, $PO_{\text{peak}} (r = .91, p < .01)$, and power-to-mass ratio ($r = .89, p < .01$) were all demonstrated to be significant predictor of 10-km race performance. Lovell et al.\textsuperscript{21} studied the aerobic performance of ten trained and ten untrained male handcyclists with spinal cord injury. They reported that $PO_{\text{peak}} (r = .87, p < .01)$, $\dot{V}O_{2\text{peak}} (r = .67, p = 0.03)$, and GME ($r = .50, p = 0.04$) were the best predictors of handcycling performance during a laboratory-based, 20-km TT. More recently, Fischer et al.\textsuperscript{13} examined the physiological determinants of handcycling performance of seven, male, H2 handcyclists and found that $\dot{V}O_{2\text{peak}} (r = .89, p < .01)$, $\dot{V}O_{2\text{VT1}} (r = .96, p < .01)$, $\dot{V}O_{2\text{VT2}} (r = .92, p = 0.03)$ and $PO_{\text{peak}} (r = .85, p = 0.02)$ were all significantly correlated with performance during a simulated 22-km TT.

Whilst extensively examined in able-bodied cycling,\textsuperscript{10,11} few studies have investigated the impact of anaerobic threshold, anaerobic capacity and upper-body strength upon handcycling performance. The attainment of high-power output during an all-out sprint is frequently used as a measure of anaerobic performance in able-bodied cycling\textsuperscript{10,11} and Quittman et al.\textsuperscript{26} recently suggested that an understanding of a handcyclist's physiological profile should be augmented by testing maximal anaerobic power ($PO_{\text{max, AO15}}$). In cycling, anaerobic capacity can be defined as the difference between $PO_{\text{max, AO15}}$ and $PO_{\text{peak}}$ commonly known as the anaerobic power reserve (APR). Several authors have demonstrated that decrements observed in all-out cycling performance seems to conform to a general relationship with a single exponential decay model, which describes a decrement in power versus increasing duration.\textsuperscript{28,35} Therefore, the determination of APR can be viewed as a potentially valid measure of anaerobic capacity in handcyclists. In regard to upper body strength Nevin et al.\textsuperscript{25} demonstrated that 8-weeks of concurrent strength and endurance training enhanced handcycling performance to a
greater degree than endurance training alone, suggesting that enhanced upper body strength may also
be an important determinant of handcycling performance.

Given the current paucity of research relating to the impact of anaerobic threshold, anaerobic capacity
and upper-body strength upon handcycling performance the aim of the present study was to build
upon the existing literature and investigate how relative $\dot{V}O_2$peak, $PO_{peak}$, GME, power at a fixed blood
lactate concentration of 4 mmol·l$^{-1}$ ($PO_4$), $PO_{max, AO15}$, and measures of upper-body strength influence
performance of an ecologically valid (field-based), 15-km TT in a group of trained H3/H4 male
handcyclists. It was hypothesized that relative $\dot{V}O_2$peak, $PO_{peak}$, GME, $PO_4$, $PO_{max, AO15}$, and relative
upper-body strength would all demonstrate a significant correlation with 15-km TT velocity.

Methods

Participants

Thirteen male handcyclists with at least one year’s recreational handcycling experience provided
written informed consent to take part in this study. All participants were classified as either an H3 or
H4 arm-powered handcyclist in accordance with current UCI Paracycling regulations. Six
participants were bi-lateral, above knee amputees (H4); one was a triple amputee (H3); and five were
paraplegic with impairments corresponding to a spinal lesion been levels T1 to T10 (H3). In all
aspects of physiological testing and TT performance, each participant used their own, customised
handbike. Mean ($\pm SD$) participant characteristics were age 37 ± 11 yrs; body mass; 76.6 ±10.1 kg;
and 4-site skinfold summation 50.0 ± 7.2 mm. No medical conditions or upper-body musculoskeletal
injuries were reported prior to the study. Finally, the study was conducted in accordance with the
declaration of Helsinki with approval granted by the Research Ethics Committee of Buckinghamshire
New University, High Wycombe, United Kingdom.
Design

This was a single-cohort, cross-sectional research study to examine the influence of body mass, body composition, relative $\dot{V}O_{peak}$, $PO_{peak}$, $PO_4$, GME, $PO_{max}$, $AO_{15}$, APR and upper-body strength on 15-km TT performance using thirteen experienced H3/H4 male handcyclists. Testing was completed over three consecutive days: 15-km TT (day 1), anthropometric assessment, graded exercise test (GTX), and 15-s all-out sprint test (day 2); and 1 repetition maximum (1RM) strength testing (day 3). A period of 24 hours separated testing sessions in order to limit the impact of fatigue. Before testing, participants were asked to abstain from strenuous exercise and refrain from consuming alcohol for at least 48 hours. Outdoor TT testing was conducted in dry and stable meteorological conditions (19 ± 2° C, <10 km·h⁻¹ wind speed) whilst, laboratory testing was performed indoors, under controlled environmental conditions (18° C, 50 – 60% relative humidity).

Individual 15-km Time Trial

In order to assess real world, ecologically valid handcycling performance, a 15-km individual TT was completed at a closed, cycling racing circuit (Odd Down, Bath, England). This location provided an undulating 1.5-km, smooth tarmac circuit with a total elevation loss and gain of 9 m per lap. Following two familiarisation laps, each participant was required to complete ten laps of the 1.5-km circuit as quickly as possible. Participants were monitored by means of a GPS receiver (Garmin Edge 1000, Garmin Ltd, USA), and data were used to establish TT performance in the form of mean velocity (km·h⁻¹).

Anthropometry

Body mass was measured to the nearest 0.1 kg using a calibrated scale (Seca 714, Hamburg, Germany); whilst skinfold thicknesses were measured to the nearest mm using a pair of skinfold
callipers (accurate to 0.2 mm) from the Harpenden range of anthropometric instruments (Holtain, Ltd, UK). All anthropometric measurements including body mass and four-site skinfold thickness summation (chest, triceps, subscapular, and iliac crest), were performed in accordance with International Society for the Advancement of Kinanthropometry guidelines.\textsuperscript{17} Percentage body fat was not calculated as no validated four-site skinfold predication equations currently exists in the literature for disabled population groups with substantial body asymmetry as a result of amputation or lower body muscular atrophy due to spinal cord injury.\textsuperscript{15}

**Graded Exercise Test**

For both the GTX and 15-s all-out sprint tests, each participant’s bike was fitted to a standard, indoor cycling turbo trainer (Fluid 2, CycleOps, USA). Mechanical power output was measured using an instrumented front wheel hub (Powertap, G3, CycleOps. USA, 1.5% accuracy between 0 and 1999 W, sample frequency 0.2 Hz). The Powertap has been shown to be a reliable instrument (CV 0.9 – 2.9%) for the measurement of power whilst cycling\textsuperscript{7} and was calibrated prior to testing, in accordance with the manufacturer’s instructions. Oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation (VE), and respiratory exchange ratio (RER) were continuously monitored using a calibrated, online gas analysis system (Oxycon Pro, Jeager, Warwick, Warwickshire, UK) whilst heart rate (HR) was logged using a commercially available receiver (Garmin Edge 1000, Garmin Ltd, USA).

Following a 10-min warm-up at a self-selected mechanical power output, participants were requested to start the test protocol at a work rate of 40 W with subsequent 20 W increments every 5-mins until the required mechanical power output could no longer be maintained, or until participants reached volitional exhaustion.\textsuperscript{2,27,31} $\dot{V}O_{2\text{peak}}$ and $PO_{\text{peak}}$ were identified as the respective mechanical power output and peak oxygen consumption achieved during the last fully completed 30-s.
test, participants were free to adjust their gear ratio and/or crank rate as needed in order to maintain the required mechanical power output. Every 5-mins and upon immediate completion of the test, participants were asked to indicate their global rating of perceived exertion (RPE) using a 6 to 20 Borg scale. All respiratory parameters were calculated for each breath and averaged at 1-min intervals at rest and every 30-s during each exercise stage.

At the end of each stage and at the point of volitional exhaustion, a small sample of capillary blood was collected from an earlobe to measure blood lactate concentration. These data were used to identify fixed blood lactate concentrations of 2 and 4 mmol·l⁻¹. Once collected, capillary blood samples were treated, analysed and disposed of immediately using a fully automated analyser (Biosen C-line, EKF Diagnostics, Barleban, Germany). GME was calculated as the ratio of external work produced to the amount of energy expended when a fixed blood lactate concentration of 2 mmol·l⁻¹ was reached. This metabolic parameter was selected as it represents a consistent, submaximal exercise intensity during which energy production is predominantly achieved via aerobic metabolic pathways. Metabolic energy expenditure was calculated from associated \( \dot{VO}_2 \) and RER data according to Garby and Astrup \(^4\) and expressed as a percentage value:

Equation 1: \( \text{GME} = \frac{\text{external work done}}{\text{energy expenditure}} \times 100 \) (%).

As an approximation of anaerobic threshold, power output corresponding to the onset of blood lactate accumulation (OBLA) at a fixed blood lactate concentration 4 mmol·l⁻¹ was also identified.

15-s All-Out Sprint Test

Following the GTX, participants were given a one-hour recovery period prior to completing a 15-s all-out sprint protocol to assess anaerobic performance. Participants were asked to complete a 10-
Handcycling Performance

min warm up at a self-selected mechanical power output. Prior to commencement of the test protocol participants were requested to adopt their highest gear ratio (50/11). Once the participant acknowledged that they were ready, the test was initiated. Throughout the test protocol participants were verbally encouraged to exert maximum, physical effort with the greatest mechanical power output subsequently recorded. APR was established using the following formula:\(^{35}\)

\[
\text{Equation 2: APR} = \text{PO}_{\text{max,AO15}} - \text{PO}_{\text{peak}}.
\]

Upper-Body Strength Testing

In order to evaluate upper body strength, maximal and relative values of bench press and prone bench pull 1RM were determined. Strength testing was conducted on a specifically designed, IPC Para-powerlifting bench (Eleiko, Sweden) and a prone-pull bench (Pullum Sports, England) using a 20 kg Olympic barbell, 450 mm diameter barbell plates (25, 20, 15 and 10 kg), 200 mm diameter barbell plates (5, 2.5, 2.0, 1.5, 1.0 and 0.5 kg), two safety locks and two Velcro securing straps (Eleiko, Sweden).

Both bench press and prone bench pull 1RM testing was conducted in line with the protocols proposed by Haff and Triplett.\(^{16}\) Participants were instructed to perform a light warm-up with the bar only, performing 5 – 10 repetitions. Following a 1-min recovery period, a second set of 3 – 5 repetitions was performed with an estimated 60% 1RM load. After a 3-min recovery period another set of 2 – 3 repetitions, was performed with an estimated 80% 1RM load. Thereafter, an estimated 1RM load was selected and the participant asked to perform a single repetition. If successful, the participant was given a 3-min recovery period prior to performing a further 1RM attempt with an increased load.
Participants were allowed, to perform 3 – 5 more 1RM attempts with 3-min recovery between sets until their 1RM had been established within a precision of 1.0 kg.

Statistical Analyses

All data are reported as mean (± SD) with a level of significance for all statistical analyses set at $p < 0.05$. Statistical analyses were performed using SPSS Version 25.0 (SPSS Inc, Chicago, USA). Parameters were checked for normal distribution using the Shapiro-Wilk test with the Spearman’s coefficient used in cases of violation. Pearson’s product-moment correlation coefficients ($r$) were calculated to establish the relationships between 15-km TT velocity (dependent variable), body mass, 4-site skinfold summation, relative VO$_{2\text{peak}}$, PO$_{\text{peak}}$, power-to-mass ratio (W·kg$^{-1}$), PO$_4$, GME, PO$_{\text{max, AO15}}$, APR, and maximal (kg) and relative (kg·kg$^{-1}$ body mass) bench press and prone bench pull 1 RM (independent variables). Correlation coefficients were evaluated as follows $>0.1$ small, $>0.3$ moderate, $>0.5$ large, $>0.7$ very large, and $>0.9$ extremely large.$^{17}$

Results

Mean (± SD) data are summarised in Table 1. Pearson product-moment correlation coefficients were calculated between 15-km TT velocity and all other anthropometric, GTX, 15-s all-out sprint and strength testing variables (Table 2). PO$_4$ ($r = .927; p < 0.01$) showed an extremely large correlation whilst relative VO$_{2\text{peak}}$ ($r = .879; p < 0.01$), power-to-mass ratio ($r = .879; p < 0.01$), PO$_{\text{peak}}$ ($r = .851; p < 0.01$), body mass ($r = -.783; p < 0.01$), GME ($r = .733; p < 0.01$), relative prone bench pull strength ($r = .770; p = 0.03$) relative bench press strength ($r = .703, p = 0.11$) and PO$_{\text{max, AO15}}$ ($r = .678; p = 0.15$) all demonstrated very large correlation with 15-km TT velocity. APR demonstrated a large correlation ($r = .548; p = 0.65$) whilst, body composition ($r = -.448; p = 0.14$), bench press 1RM ($r = -.423; p = 0.17$) and prone bench pull 1RM ($r = .447; p = 0.14$) revealed only a moderate correlation with performance outcomes.
Handcycling Performance

##Insert Table 1 Here##

##Insert Table 2 Here##

##Insert Figure 1 Here##
Discussion

The aim of this study was to investigate the relationship between selected anthropometric, physiological, and upper body strength measures and 15-km handcycling time trial performance. The main findings based upon the data collected were that PO₄, relative VO₂peak, power-to-mass ratio, POpeak, GME, relative upper body strength and PO_max,AO15 all demonstrated a significant correlation with handcycling performance (Figure 1).

Anthropometrics

In agreement with the findings of De Groot et al, the present study demonstrated that body mass displayed a considerable, negative association with 15-km TT velocity. When relative POpeak was examined, another large and meaningful relationship was observed. These finding concur with those of Janssen et al, who demonstrated that power-to-mass ratio was a significant predictor of 10-km handcycling race performance. De Groot et al, reported that a lower waist circumference was a good predictor of handcycling performance, therefore, it can be inferred that a lower fat mass would result in improved 15-km TT performance. However, findings of the current study revealed that body composition, as assessed via 4-site skinfold summation exhibited only a moderate, negative relationship with performance. These findings were somewhat surprising as greater skinfold summation (e.g., higher fat mass) would have been expected to have a larger negative impact upon 15-km TT velocity. Goosey-Tolfrey et al, suggested that skinfold estimations may not be a valid assessment tool of body composition in disabled population groups and the findings of the present study support this position. Another point to note is that the combined rider-bike mass is also likely to be important and negatively linked to TT velocity. Thus, where feasible, it is recommended that the combined mass of a handcyclist and their bike be minimised in an attempt to optimise TT performance.
Aerobic Performance

Relative \( \dot{V}O_2 \text{peak} \) and, to a slightly lesser extent \( PO_{\text{peak}} \) and GME demonstrated a very large correlation with 15-km TT performance. These finding are in agreement with previous studies that have shown relative \( \dot{V}O_2 \text{peak} \), and \( PO_{\text{peak}} \) to be significant determinants of handcycling performance during TT, \(^{13,18,19}\) ultra-endurance, \(^{1,2}\) and mountain climbing, \(^{9}\) events. GME has also been demonstrated to be a significant determinant of handcycling performance. \(^{19}\) Participants in the present study achieved a mean GME value of 13.4 ± 2.7% which is similar to a previous reports of 11.5 ± 0.8%, \(^{19}\) 14.1 ± 2.0%, \(^{21}\) and 13.5 ± 1.4% \(^{25}\) for trained handcyclists. GME is of particular importance to handcyclists as improvements in efficiency will likely translate to a reduction in relative workload at a given mechanical power output. Theoretically, this should enable a rider to produce a higher mechanical power output for an equivalent amount of energy expended (e.g., improved performance) or alternatively result in a longer time to exhaustion at a given rate of work (e.g., improved endurance capacity), with both scenarios holding the potential to enhance an athlete’s performance.

Anaerobic Threshold

As an approximation of anaerobic threshold, mechanical power output corresponding to OBLA at a fixed blood lactate concentration of 4 mmol·l\(^{-1}\) \((PO_4)\) was utilised. Power at this threshold demonstrated an extremely large relationship with 15-km TT velocity. These finding are in agreement with findings of several other studies, demonstrating a strong relationship between \( PO_4 \) and performance in both handcyclists \(^{2,23}\) and able-bodied road cyclists. \(^{10,11}\) OBLA can be defined as the point at which blood lactate concentration increases exponentially, with the rate of production outstripping removal and leading to acute metabolic acidosis. The validity of using OBLA at a fixed blood lactate concentration of 4 mmol·l\(^{-1}\) to identify the shift from predominantly aerobic energy turnover to anaerobic energy production has been questioned previously. \(^{10,11,30}\) Indeed, the threshold at which anaerobic metabolism starts to predominate is strongly influenced by individual lactate...
Handcycling Performance

kinetics, which varies depending upon the activity and volume of skeletal muscle mass.\(^\text{26}\) Therefore, OBLA at a fixed blood lactate concentration of 4 mmol·l\(^{-1}\) may either over- or underestimate anaerobic threshold depending upon the individual athlete, exercise modality and intensity. Nevertheless, findings of the present study demonstrated that anaerobic threshold, as estimated by PO\(_4\) to be a very strong indicator of 15-km handcycling TT performance.

**Anaerobic Performance**

Anaerobic performance assessed by the maximum power output generated during a 15-s all-out sprint test produced a large correlation with 15-km TT performance. In order to assess anaerobic capacity, the difference between PO\(_{\text{max, AO15}}\) and PO\(_{\text{peak}}\) commonly known as APR was also investigated. The concept of APR has been suggested to be a valid measure of anaerobic capacity in able-bodied road cyclists\(^{28,35}\) and findings of the current study showed large correlation between handcycling APR and 15-km TT velocity. Given the nature of an individual TT, it can be reasoned that riders in the present study maintained a velocity at, or just below their anaerobic threshold and were unlikely to have utilised their APR to a great extent. Despite this, it can be strongly argued that in the context of a road race competitive handcyclists require a high APR to repeatedly generate and recover from the production of high power outputs over short periods of time. This will allow a rider to either close a gap on an opponent, break away from other riders, or win in a sprint finish.

**Maximal and Relative Upper Body Strength**

Maximal and relative upper body strength in the present study was determined by assessing bench press and prone bench pull 1RM. These exercises were chosen as they closely mimic the synchronistic, horizontal push/pull force production movement pattern observed during handcycling.\(^{25}\) Bench press and prone bench pull 1RM demonstrated only a moderate relationship with 15-km TT velocity. However, when relative upper body strength was examined, both bench
press and prone bench pull displayed a significant influence upon 15-km TT velocity, further confirming the relative importance of body mass to handcycling performance.

Relative strength is the product of one’s ability to generate considerable maximal forces relative to one’s body mass. Therefore, it can be inferred that greater maximal upper body strength, at a given body mass or in combination with a reduction in non-functional body mass (e.g., adipose tissue) may result in an improvement in an individual’s handcycling performance capabilities. Interestingly, relative upper body pulling strength demonstrated a larger correlation with 15-km TT velocity than relative pushing strength. This is in agreement with previously published studies which have demonstrated that a greater proportion of the work generated during the propulsion cycle of handcycling occurs during the pull phase with an increase in pulling torque and concomitant decrease in pushing torque observed at progressively higher power outputs.\textsuperscript{5,27,34} Therefore, based upon these observations it can be inferred that greater relative upper body pulling strength may enhance handcycling performance. Strength training should, therefore, form a central component of any successful handcyclists training programme.

Limitations
While these findings provide a novel insight into the determinants of TT performance in trained H3/H4 handcyclists, it must be noted that there are several limitations associated with the study and its design. Firstly, as is usually the case in this area of research, sample size was small and the participant group relatively heterogeneous in terms of age, performance level, and disability which resulted in considerable variance within the group. The small sample size also meant that it was not possible to conduct a multiple regression analysis in order to develop a accurate handcycling performance model. A further limitation was that the 15-km TT was a self-paced time trial, which was conducted in variable climactic conditions. Such an approach represents a less controlled
environment compared to sterile laboratory conditions; however, this approach does add a degree of ecological validity as it more closely resembles real-world handcycling race conditions. Additionally, whilst the Powertap power measuring device has been shown to be a reliable instrument for the measurement of mechanical power output whilst cycling, its sampling frequency (0.2 Hz) is relatively low for the purpose of measuring $PO_{max,AO15}$. Thus, it is recommended that future studies use a more sensitive instrument for the measurement of mechanical power output such as the Cyclus 2 ergometer (8 Hz, RBM Electronic automation GmbH, Leipzig, Germany). However, it could also be argued that, from a consistency of power measurement perspective and to facilitate meaningful comparison, the same measuring device should be used in a laboratory and field-based environment if possible. Finally, as with all criterion validity studies exploring links between independent variables and, in this case, a (dependent) performance outcome measure, correlational analyses do not necessarily confirm causation, thus additional studies should be conducted to provide further, confirmatory evidence.

**Practical Applications**

In order to better optimise handcycling performance capability, it is recommended that an emphasis be placed upon the development and frequent monitoring of the following parameters: $PO_{4}$, relative $\dot{VO}_{2peak}$, power-to-mass ratio, $PO_{peak}$, GME, relative upper body strength and $PO_{max,AO15}$. Particular attention should be placed upon the development of upper body pulling strength in order to enhance the force production during the pulling phase of the handcycling propulsion cycle. Finally, whilst not confirmed by the findings of this study, riders should aim to reduce their overall body fat summation in order to further improve handcycling performance capabilities. Linked to this point, it follows that it would also be prudent for a competitive handcycle to be as lightweight as possible.
Conclusion

In conclusion, the findings of the present study indicate that PO₄, relative VO₂peak, power-to-mass ratio, PO_peak, GME, relative upper body strength, PO_max,AO₁₅ and APR all have significant impact upon 15-km TT velocity in H3/H4 handcyclists. To the best of the authors’ knowledge, this is the first study to investigate the combined impact of anaerobic threshold, anaerobic capacity and upper-body strength upon real-world handcycling TT performance. Based upon our findings it is recommended that future research associated with establishing determinants of handcycling performance use a larger, more homogenous, group of competitive, preferably elite handcyclists. If sufficient data could be collected it would be possible to construct an accurate performance model using multiple regression analysis.

Declaration of Interest

There is no conflict of interest to declare for the present article.

References

Handcycling Performance


Handcycling Performance


34. Vegter RJK, Mason, BS, Sporrel B, Stone B, Van Der Woude, LHV & Goosey-Tolfrey VL. Crank fore-aft position alters the distribution of work over the push and pull phase during...

Table 1. Mean (+ SD) values of participant testing data

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 km Time Trial Velocity (km·h⁻¹)</td>
<td>28.6 ± 6.3</td>
</tr>
<tr>
<td>Peak Heart Rate (bpm)</td>
<td>174 ±12</td>
</tr>
<tr>
<td>Peak Blood Lactate (mmol·l⁻¹)</td>
<td>11.9 ± 1.8</td>
</tr>
<tr>
<td>(\dot{V}O_2)peak (l·min⁻¹)</td>
<td>2.8 ± 0.5</td>
</tr>
<tr>
<td>Relative (\dot{V}O_2)peak (ml·kg⁻¹·min⁻¹)</td>
<td>36.8 ± 10</td>
</tr>
<tr>
<td>PO\textsubscript{peak} (W)</td>
<td>160 ± 26.7</td>
</tr>
<tr>
<td>Relative PO\textsubscript{peak} (W·kg⁻¹)</td>
<td>2.2 ± 0.7</td>
</tr>
<tr>
<td>GME (%)</td>
<td>13.4 ± 2.7</td>
</tr>
<tr>
<td>PO\textsubscript{4} (W)</td>
<td>119 ± 26</td>
</tr>
<tr>
<td>PO\textsubscript{max,AO15} (W)</td>
<td>547 ± 120</td>
</tr>
<tr>
<td>APR (W)</td>
<td>387 ± 107</td>
</tr>
<tr>
<td>Bench Press 1RM (kg)</td>
<td>90.2 ± 16.7</td>
</tr>
<tr>
<td>Relative Bench Press Strength (kg·kg⁻¹ body mass)</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td>Prone Bench Pull 1RM (kg)</td>
<td>77.8 ± 13.2</td>
</tr>
<tr>
<td>Relative Prone Bench Pull Strength (kg·kg⁻¹ body mass)</td>
<td>1.0 ± 0.3</td>
</tr>
</tbody>
</table>
Table 2. Correlations among parameters of 15-km TT performance

<table>
<thead>
<tr>
<th></th>
<th>Velocity (km·h⁻¹)</th>
<th>Body Mass (kg)</th>
<th>4-Site Skin Fold Summation (mm)</th>
<th>Relative VO₂peak (ml·kg⁻¹·min⁻¹)</th>
<th>POₚₑᵃᵏ (W)</th>
<th>Power-to-Mass Ratio (W·kg⁻¹)</th>
<th>GME (%)</th>
<th>POₐ (W)</th>
<th>POₚₐₘₐₓ,AO¹⁵ (W)</th>
<th>APR (W)</th>
<th>Bench Press 1RM (kg)</th>
<th>Relative Bench Press Strength (kg·kg⁻¹ body mass)</th>
<th>Prone Bench Pull 1RM (kg)</th>
<th>Relative Prone Bench Pull Strength (kg·kg⁻¹ body mass)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity (km·h⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body Mass (kg)</td>
<td>-.783*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-Site Skin Fold Summation (mm)</td>
<td>-.448</td>
<td>.151</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative VO₂peak (ml·kg⁻¹·min⁻¹)</td>
<td>.879**</td>
<td>-.835*</td>
<td>-.510*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POₚₑᵃᵏ (W)</td>
<td>.851**</td>
<td>-.825**</td>
<td>-.494</td>
<td>.774**</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power-to-Mass Ratio (W·kg⁻¹)</td>
<td>.879**</td>
<td>-.921**</td>
<td>-.391</td>
<td>.831**</td>
<td>.964**</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GME (%)</td>
<td>.733**</td>
<td>-.821**</td>
<td>-.528</td>
<td>.853**</td>
<td>.717**</td>
<td>.798**</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POₐ (W)</td>
<td>.927**</td>
<td>-.668*</td>
<td>-.637</td>
<td>.861**</td>
<td>.842**</td>
<td>.827**</td>
<td>.700**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>POₚₐₘₐₓ,AO¹⁵ (W)</td>
<td>.678</td>
<td>-.571</td>
<td>-.383</td>
<td>.775**</td>
<td>.572</td>
<td>.563</td>
<td>.641*</td>
<td>.595*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APR (W)</td>
<td>.548</td>
<td>-.435</td>
<td>-.306</td>
<td>.676*</td>
<td>.392</td>
<td>.302</td>
<td>.540</td>
<td>.457</td>
<td>.979**</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bench Press 1RM (kg)</td>
<td>.423</td>
<td>-.505</td>
<td>-.271</td>
<td>.603*</td>
<td>.310</td>
<td>.379</td>
<td>.686*</td>
<td>.346</td>
<td>.684*</td>
<td>.690*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Bench Press Strength (kg·kg⁻¹ body mass)</td>
<td>.703*</td>
<td>-.814**</td>
<td>-.313</td>
<td>.822**</td>
<td>.647*</td>
<td>.735**</td>
<td>.871**</td>
<td>.615*</td>
<td>.734**</td>
<td>.662*</td>
<td>.899**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prone Bench Pull 1RM (kg)</td>
<td>.447</td>
<td>-.363</td>
<td>-.331</td>
<td>.506</td>
<td>.275</td>
<td>.285</td>
<td>.498</td>
<td>.358</td>
<td>.566</td>
<td>.657</td>
<td>.865**</td>
<td>.728**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Prone Bench Pull Strength (kg·kg⁻¹ body mass)</td>
<td>.770**</td>
<td>-.793**</td>
<td>-.356</td>
<td>.819**</td>
<td>.621**</td>
<td>.734**</td>
<td>.811**</td>
<td>.661*</td>
<td>.701*</td>
<td>.619*</td>
<td>.852**</td>
<td>.949**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Correlation is significant at the <0.01 level (2-tailed)
* Correlation is significant at the < 0.05 level (2-tailed)
**Figure 1.** Correlation plots between 15-km TT velocity and parameters of exercise testing.