Sport Science and Coaching in Paralympic Cycling

Brendan J. Burkett and Rebecca B. Mellifont
Centre for Healthy Activities Sport and Exercise (CHASE), University of the Sunshine Coast, Maroochydore DC, Queensland, 4558, Australia
Email: bburkett@usc.edu.au

ABSTRACT
This research documents the sport science initiatives of the Australian Cycling team in preparation for the 2004 Athens Paralympic Games. The research was driven by the head coach of the cycling program with biomechanical and physiological measures made during competition and/or in a controlled laboratory for six Paralympic cyclists. Half the group modified their setup with seat height decreases within a range of 10-19 mm, the other half with seat height increases within a range of 3-12 mm. All riders required seat fore/aft positioning adjustments of up to 30 mm forward to centre the knee joint over the pedal spindle. The pelvic angle rotation changed by an average of 7 degrees positive tilt (range 5-14 degrees). Relatively simple adjustments to one individual’s setup reduced the cyclist’s frontal-surface height by 0.22 m, with no significant change in power output. The integration of sport science with a high-performance coaching program can enhance the athlete’s performance and safety. The outcomes of this specific research on elite athletes with a disability have guided the future coaching of the national team.

Key words: Cycling, Paralympic, Performance Enhancement

INTRODUCTION
The purpose of this research was to enhance the sporting performance of the Australian Cycling team at the Athens 2004 Paralympic Games. People with a disability often depend on some form of equipment to be able to participate in physical exercise. Past sport science research has identified significant technical developments in wheelchair design and prostheses [1, 2]. In the endeavour to go higher, faster and longer, athletes have found that the standard devices which have been designed for activities of daily living, such as walking, do not match the demands of elite sport and therefore can inhibit their sporting performance [3, 4]. As such, the coach and sport scientist need to be open to new ideas. Radical equipment design such as the J-Leg (for transfemoral throwers), seated throwing chairs (for spinal-cord throwers), and running arms (for arm-amputee runners) have revolutionised the way of thinking in sport science and the options available to coaches and athletes [5, 6]. This demand has also driven the need for sport science to move from within the controlled laboratory and onto the sporting arena [7].

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Holden MacRae (Pepperdine University, USA)
As with other sports, cycling performance is dependent on a number of performance indicators [8]. The bicycle set-up is a complex issue, influenced by the cyclist’s body segments and the bicycle components; namely the bottom bracket, seat height and fore/aft position, and the handlebar height and fore/aft position. The interface or contact points of body with machine are the perineum contact on the seat, the hand-grip point at the handlebars, and shoe/pedal interface via an adjustable cleat or block at the base of the riding shoe. These components all influence the upper- and lower-body reach of the cyclist. Alteration of the rider’s body position can directly affect the aerodynamics and frontal surface-area resistance of the cyclist. Any change in body position comes at the compromise of an altered pelvic position, and therefore the power output generated [9]; whilst changes in knee range-of-motion significantly affect energy demand [10]. A commonly accepted guide to bicycle set-up is the FITKIT® commercial bicycle rider adjustment system [11-14]. This system requires anthropometric measures of foot and in-seam to determine the saddle-to-pedal starting distance, and the torso and arm length to determine the cockpit combination (saddle to handlebar). In this current research, an extension of the FITKIT® system is proposed and the details of the Rider’s Ideal Design Ergonometry (RIDE) are presented within the methods section.

Bicycle set-up for Paralympic cycling opens a whole new paradigm for the sport scientist and coach. The visually impaired athletes ride in tandem, with a sighted rider steering the cycle. The extra length of the tandem frame creates the challenge - what is the appropriate distance between riders and how do you address the flex in the frame? The significant asymmetry between a lower-limb amputee cyclist, or a cyclist with cerebral palsy, again creates a challenge for bicycle set-up. To address these issues, the objectives of this research were:

1. To assess the current bicycle set-up against the predicted Rider’s Ideal Design Ergonometry (RIDE) setup for Paralympic cyclists.
2. To test the individual athlete’s power output as a performance marker under different equipment-design conditions.
3. To explore different bicycle configurations for individual Paralympic cyclists.

METHOD

A total of six Paralympic cyclists (Table 1), who were all part of the National team for the 2004 Athens Paralympic Games, were involved in the project. The bicycle measurement conventions are listed in Table 2. These were based on the Australian bicycle industry standards employed by Paralympic Cycling Program team mechanics [15], and were compared to the Australian Institute of Sport Biomechanics bicycle setup methods [16] and national cycling organisations in the USA [17] and the United Kingdom [18].

A Rider’s Ideal Design Ergonometry (RIDE) was derived by the following criteria relating anatomical with the bicycle landmarks, and this was completed for each individual athlete:

1. Seat height = 0.98 x (greater trochanter length + shoe cleat thickness) [16].
2. Upper reach reference: third metacarpal bone of hand at the outer aspect of the deepest point of the handlebars.
4. Knee reference: tibial tuberosity aligned above the pedal spindle with cranks at 90 degrees from top dead centre.
5. Torso position: the angle from horizontal of a line joining greater trochanter of the femur and the acromion process of the scapula.
POWER OUTPUT

A SRM ergometer (Schroberer, Julich, Germany) sampling at 10-second intervals was used to determine power output over a self-paced, 2-minute trial for both the current and the predicted (RIDE) bike setup. This created the reference time point 1. The cyclists compete in two events, the 1 km time trial (completion time of 65-81 seconds, depending on the class of the athlete), and the 3 km pursuit (completion time 3:43 to 4:21 minutes). Based on the average time to complete these two track events, a 2-minute test ride was considered the most representative time frame to assess the cyclist race performance. The cyclists were instructed to cycle at their maximum cycling effort on the cycle ergometer for two minutes. This methodology is common practice for the cyclist as they use the ergometer as part of their warm-up routine as well as for completing specific national-test protocols. The set-up condition was disguised from the rider and staff (by having the bicycle mechanic prepare the bicycle) and to guard against bias, the order of setup was randomised. As in their normal training regimen, heart rate monitoring was included to provide the athletes with feedback on their recovery status, and a heart rate of 65% of MHR was used to indicate that the athlete was in recovery ride. As each cyclist with a disability had a different functional response to exercise and a different MHR, as such their recovery-ride heart rate ranged from 114-134

Table 1. Demographic Summary of Cycling Participants

<table>
<thead>
<tr>
<th>Vision Impaired BI-3</th>
<th>Cerebral Palsy</th>
<th>Locomotor Disability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Female, n=1</strong></td>
<td><strong>Male, n=3</strong></td>
<td><strong>Male, n=1</strong></td>
</tr>
<tr>
<td>Age in years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22.3 (female)</td>
<td>22.1 (male)</td>
<td>22.1 (male)</td>
</tr>
<tr>
<td>22.5 (male)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.73 (female)</td>
<td>1.59 (male)</td>
<td>1.74 (male)</td>
</tr>
<tr>
<td>1.83 (male)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>71.5 (female)</td>
<td>54.9 (male)</td>
<td>67.9 (male)</td>
</tr>
<tr>
<td>82.3 (male)</td>
<td>71.1 (male)</td>
<td>60.1 (male)</td>
</tr>
</tbody>
</table>

Table 2. Bicycle Measurement Convention Definitions (all dimensions in millimetres)

<table>
<thead>
<tr>
<th>Measurement Definition</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saddle Height</td>
<td>Straight edge set at lowest point of saddle, to pedal spindle with cranks set in line with seat tube</td>
</tr>
<tr>
<td>Saddle Setback</td>
<td>Length of vertical line from saddle tip to centre of bottom bracket</td>
</tr>
<tr>
<td>Saddle Tilt</td>
<td>Saddle angle with respect to horizontal</td>
</tr>
<tr>
<td>Handlebar Reach from Saddle</td>
<td>Horizontal line from saddle tip to handlebar attachment at head stem</td>
</tr>
<tr>
<td>Handlebar Drop from Seat</td>
<td>Vertical distance between projection of seat longitudinal axis and top of handlebar attachment at head stem</td>
</tr>
<tr>
<td>Crank Length</td>
<td>Distance from bottom bracket axis to pedal spindle axis</td>
</tr>
<tr>
<td>Saddle Tube Angle</td>
<td>Measured from a horizontal line through the bottom bracket centre to the line of the saddle tube</td>
</tr>
</tbody>
</table>
bpm. Cyclists were given as much recovery time as required, based on the objective MHR measure as well as the cyclist’s subjective feeling of recovery. On average, the recovery time was eleven minutes. Athletes were free to select optimal cadence and were given a rolling start, lead-in time of 60 seconds before starting the test. The entire process (current and predicted) was repeated six weeks later (reference time point 2) at the next national training camp, creating a total of four power output measures.

Centre of flexion/extension (sagittal plane) for hip, knee and ankle joints were located by the methods described by Gore [19]. Subjects were instructed to wear garments that allowed exposure of bony landmarks at joint centres of rotation. The greater trochanter was located in standing position and a highly visible adhesive pad (ECG conductive pads) attached directly to the skin. A stud on each pad designed to attach to ECG leads was centred over the cross for the bony landmark. All test rounds were filmed using three CCD digital video cameras (Sony TRV 950, shutter 1/125) connected via a firewire to a laptop. Joint angles were measured post test using DartTrainer® Professional Suite (version 2.5.3).

The output data were statistically tested using paired t-tests (2-tailed). Repeated measures of power output were compared between a rider’s existing bicycle configuration, and the RIDE position.

RESULTS

The results of the change in bicycle set-up and associated power output are listed in Table 3. As seen in this table, half the group achieved a RIDE setup with seat height decreases within a range of 10-19 mm, the other half with a seat height increases within a range of 3-12 mm. All riders required seat fore/aft positioning adjustments of up to 30 mm forward to centre the knee joint over pedal spindle. The pelvic angle rotation changed an average of 7 degrees positive tilt (range 5-14 degrees).

Table 3. Power Output and Bicycle Set-up for Each Paralympic Cyclist

<table>
<thead>
<tr>
<th>Subject</th>
<th>Class</th>
<th>Current Setup</th>
<th>Predicted Setup</th>
<th>Current Power (W) @ time point 1</th>
<th>Predicted Power (W) @ time point 2</th>
<th>Bike setup changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CP4</td>
<td>225.7</td>
<td>226.0</td>
<td>224.9</td>
<td>230.6</td>
<td>8 mm increase, 11 mm fore, 10° positive</td>
</tr>
<tr>
<td>2</td>
<td>CP3</td>
<td>225.7</td>
<td>228.8</td>
<td>225.2</td>
<td>226.1</td>
<td>16 mm decrease, 18 mm fore, 12° positive</td>
</tr>
<tr>
<td>3</td>
<td>LC4</td>
<td>180.4</td>
<td>180.5</td>
<td>201.4</td>
<td>206.9</td>
<td>19 mm decrease, 18 mm fore, 5° positive</td>
</tr>
<tr>
<td>4</td>
<td>CP4</td>
<td>239.6</td>
<td>240.5</td>
<td>239.5</td>
<td>240.3</td>
<td>12 mm increase, 20 mm fore, 7° positive</td>
</tr>
<tr>
<td>5</td>
<td>VB2</td>
<td>342.3</td>
<td>344.0</td>
<td>343.7</td>
<td>335.4</td>
<td>3 mm increase, 30 mm fore, 14° positive</td>
</tr>
<tr>
<td>6</td>
<td>VB3</td>
<td>437.2</td>
<td>440.9</td>
<td>443.3</td>
<td>443.5</td>
<td>10 mm decrease, 5 mm fore, 5° positive</td>
</tr>
</tbody>
</table>

Note: No significant difference was observed between the average power outputs.

Separate to the RIDE reconfiguration, additional modifications were made to the bicycle and rider configuration, and these were done on a case-by-case basis depending on the unique disability of the Paralympic cyclist. An example of the changes in bicycle setup is shown in Figure 1. The image on the left indicates a modified frontal height resistance of 1.26 m, measured from the axle of the crank to the highest body landmark, compared to the image on the right which shows the original frontal height resistance of 1.48 m. Despite changing the riding position to only one attached leg, there was no discernable difference in the power output, 277.2 +/-0.6 watts, compared to 278.3 +/-0.9 watts.
DISCUSSION
The first objective of this research was to assess the current bicycle set-up against the predicted RIDE setup for Paralympic cyclists. All of the riders in this study required a modification of their bicycle setup of up to 19 mm decrease in seat height, and 30 mm forward shift of the seat. The change in seat height is not uncommon for cyclists with past research finding 25 to 50 mm variations [20, 21]. One of the issues in modifying the bicycle set-up, which is a similar challenge in any intervention, is that the elite athlete is well trained and accustomed to their current configuration and there could be resistance from the athlete to any changes that are different from the norm. Other intervention studies that modified the bicycle set-up from current to preferred found subjects optimised their energy cost at cycle geometries that were similar to their preferred (or current) lower-limb configuration [22]. Within the current study, both coach and athlete were receptive to interventions, which is an important component required for a successful performance enhancement. It is believed this acceptance by the athlete and coach was based on the positive experience they received via slow-motion video playback live at the track. The slow motion (1/25 second) and frame-by-frame analysis while on the track was the most common request from the coach and athlete.

Union Cycliste Internationale (UCI) regulations have outlawed various aerodynamically designed frames allowing only a standard diamond shaped frame. This has simplified frame selection criteria. There are several guidelines for coaches on the bicycle set-up, and the Level 2 Cycling Coaching Manual [16] recommends measuring leg length via the inseam as the anthropometric key to selecting a road or track frame. The frame seat tube should be 65% of leg length using the centre of its junction with the top tube [16]. This guideline is similar to other references such as Giant®, which recommend the seat tube length up to an intersection point with the virtual horizontal top tube should match 65% of leg length [23]. This current research found similar results of optimal set-up at 65% of leg length.

The second objective was to test the individual athlete’s power output as a performance marker under different equipment-design conditions. As the athlete’s power characteristics can fluctuate within the training season, the riders current bicycle set-up was measured at both time points to allow a reference for the modified set-up. As seen in Table 3, there was
no significant difference in the power output of the cyclists in the two set-ups. This finding of no significant change in power output is similar to other studies [20], where the change in seat tube angle from 72° to 82° did not significantly affect power production, but there was a significant decrease in the muscular activation of the biceps femoris muscle, and ultimately reduced energy expenditure. Electromyography was not recorded within this present study, but could be included in future research to record muscle activity.

The third objective of the research was to explore the different bicycle configurations for individual Paralympic cyclists. Due to the unique disabilities of the cyclists, each was treated on a case-by-case basis. The example in Figure 1 shows the unique modification for an athlete, who had a fused left hip, and in his current set-up would cycle with both feet attached to the cleats. The modified set-up removed the cyclist’s left foot from the cleat, thus reducing the frontal height resistance by 20 cm. Although the athlete cycled with only one leg, the same power output was maintained. This improved aerodynamic and ergonomic profile resulted in a faster and/or more efficient performance. There was no specific rule applied to this process other than using generic biomechanical principles of assessing the current ergonomic status and making modifications to the set-up that improve the ergonomic profile relative to that sport. The subjects within this study did produce personal best performances and win Paralympic medals, but the authors wish to make it clear that the performance enhancement can be due to a number of factors (e.g., race tactics, power outputs, fitness, recovery status, state of mind, and the athlete’s integration with the bicycle set-up).

Other research has observed that cyclists become less effective during the recovery phase, which increased the demand for forces during the propulsive phase [24]. Training of the pattern of force application is required to improve effectiveness for endurance riding, and the current research suggests that subtle changes in riding technique with only a 0.4 to 2.1 percent (or 3 mm to 19 mm) change in seat height required to achieve optimal bicycle set-up. From past training camps and data collection such as lactate profiles, this combination of a recovery ride (at 65% of MHR) in combination with the subjective ‘feel’ from the cyclist has been found to be suitable for determining recovery status. The average recovery time of 11 minutes is similar to other studies which found muscle blood flow returns to resting levels within approximately 10 minutes of ceasing exercise [25]. The amount of recovery time has varied in other studies, for example Korff et al. [26], utilised a six minute passive recovery following a six-minute cycle; whilst Burnley et al. [27] investigated varying recovery times from 10 to 60 minutes following a six minute cycle, finding elevated lactate levels 20-60 minutes following the six-minute bout. The recovery parameters for the two-minute cycle within the current study were monitored and found to be similar to some previous studies, but as there is variability in the findings from other research this could be an interesting topic for future research.

To optimise maximum muscle power output, past studies have found that a change in one parameter can alter other parameters [28-30]. In particular, a change in bicycle set-up influences the power generated at the hip. It has also been found that the maximum power output is influenced by crank length, and this crank length is determined by leg length [31]. This iterative process of adjustment, analysis and feedback was found to be critical in the current study and highlights the relationship required between coach, athlete and sport scientist. A change in bicycle set-up directly influences trunk angle, which then influences muscle recruitment and (inter)muscular dynamics in the entire limb [21]. This current research also found modifications in the seat height to have the greatest influence on trunk angle. As seen in Figure 1, the lowering of torso angle resulted in an improved aerodynamic streamlining, with no adverse effect on power output. This finding was consistent with other
studies which tested the effect of the forward hip position characteristic of aerodynamic bicycle set-up (mean angle of the pelvis, knee, or ankle) and found no significant differences in these variables [32]. There was no significant difference in the kinematic profile for the hip, knee and ankle for the lower-limb affected Paralympic cyclists; i.e., the leg amputee or cerebral palsy cyclist. This relation was also found in other studies [33], which compared the lower-extremity kinematic profile of 10 hemiplegic patients to 10 non-hemiplegic subjects. The only significant kinematic variables observed were the control of ankle displacement and velocity of the lower extremity during pedalling.

PARALYMPIC CYCLING CHALLENGES

There are several challenges for tandem, visually impaired cycling; in particular, the communication between the visually impaired rider and the pilot rider. The pilot is responsible for steering, gear changing (road cycling only) and tactics; while the visually impaired cyclist must respond instantly to cadence increases, change from seated to standing cycling posture on verbal cue, remain calm and balanced when sprint match races require sudden movements up and down steep track banks and generally be alert and instantly responsive to changes in race conditions. The mechanical design of the tandem bicycle requires the riders to be as close as possible to improve their aerodynamics, which also improves energy transfer along the chain, and the shorter frame will have less flex when the two riders increase load on the bicycle. The human requirement is that both riders can comfortably fit on the bicycle and still produce pedal power. Early research has found the more upright the rider, the more power the cyclist can develop; but this upright body position does increase the aerodynamic drag. Within the current research, the set-up was determined for the individual cyclist first, and then fore/aft adjustments were made as they sat on the tandem cycle, with particular emphasis on minimising frame length. Cyclists with lower-limb disabilities, such as cerebral palsy or leg amputation, also call for unique cycle set-up. The most effective mechanism was to initially match the set-up to the strongest anatomical leg and to keep the pelvis level. In the case of leg amputation, the UCI rules allow the cyclist to wear a prosthesis during performance. The use of a specific cycling prosthesis will depend on the individual’s stump length and remaining musculature as well their sensitivity to “prosthetic rubbing” associated with cycling.

There are several documented factors that influence cycling [17, 23, 28, 35] and until the current research was conducted there was no system documented on the appropriate bicycle set-up for the Paralympic cyclist. The Australian national team now utilises this procedure. A key feature of the RIDE configuration was a lowering of the torso position to improve aerodynamic streamlining. All riders adopted the new bicycle set-up with no adverse effect on power output. Due to the large range of unique disabilities, each set-up was specific for the individual cyclist. This database will continue to expand over the next few years and it is envisaged that by the 2008 Beijing Paralympics some guidelines for the different disability classifications will be possible.

CONCLUSION

The athlete’s performance and safety can be improved by simple, but effective, modifications to their technique and equipment design. The outcomes of the current research on elite athletes with a disability in cycling have been embraced by international coaches and athletes. Further work is required in sport science to satisfy the demands of the high-performance coach and athlete.
ACKNOWLEDGEMENTS

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REFERENCES


