THE OPTIMIZATION OF TRUNK POSITION FOR THE 2016 RIO PARALYMPIC WHEELCHAIR RACING FINALS

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This research investigated the relationship between athlete aerodynamics (based on peak frontal area during recovery phase) and finishing position for athletes in the 100m-5000m wheelchair Athletics events. A retrospective analysis was performed on T54 classified male and female finalists (n=86) at the 2016 Rio Paralympic Games. Medalling female athletes more consistently favoured an aerodynamic position than was observed for males, who may be more inclined to overcome additional resistive forces through powerful techniques due to enhanced strength capacities. Whilst aerodynamics does not appear the sole performance requirement for male athletes, time savings of up to 116s over a 5000m race can be obtained, if athletes improve their aerodynamics, without compromising force generating capacity, demonstrating its importance to athletes.

KEY WORDS: wheelchair racing, aerodynamics, physical strength.

INTRODUCTION: Performance in wheelchair racing is speed dependent (Fuss & Subic, 2013), with winning velocities obtained through maximising physical capabilities, whilst reducing resistive forces (rolling friction (Fr) and aerodynamic drag (Fd) (Forte, Barbosa, & Marinho, 2015)). Highly trained athletes have limited potential for further physical gains, particularly those with physical impairments, making aerodynamic improvements more readily available, with Fd representing 90% of the total resistive force at speeds exceeding 5m/s (LaMere & Labanowich, 1984). Based on the well-established Fd relationship (Forte et al., 2015), to reduce aerodynamic resistance, athletes must minimise their frontal area.
Aerodynamically optimised wheelchairs reduce frontal area by almost half (0.37m^2 in upright positions in conventional chairs (Hoffman, Millet, Hoch, & Candau, 2003) as compared to 0.17m^2 for the same position in a racing wheelchair (Barbosa, Forte, Estrela, & Coelho, 2016)), with further reductions obtained through body positioning. Cycling research has demonstrated that a flexed upper trunk position reduces frontal area by 20–29% (Burke, 1986), however the same position has only a 3-4% improvement in wheelchair racing (Hedrick, Wang, Moeinzadeh, & Adrian, 1990). This difference may be the consequence of wheelchair athletes using arms for propulsion, compromising athlete aerodynamics with each stroke.
Two distinct wheelchair propulsion strategies exist: high stroke count (frequency) or high power. A frequency strategy is more aerodynamic, but may have limited contact range, and thus lower momentum generated. A power strategy however increases frontal area (during recovery), as athletes increase vertical trunk motion in order to contact the pushrim as close to the top as possible, and maximise input torque (Costa, Rubio, Belloch, & Soriano, 2009). Athletes will typically adopt a technique thought to best suit their specific physical capabilities. As the recovery phase can range between 49.6% and 78.4% of stroke time throughout a 100m race (Chow & Chae, 2007), poor aerodynamic technique is costly. This study examined the propulsion methods used by wheelchair racing finalists in the 100m–5000m Track events at the 2016 Rio Paralympic Games, and determine whether any relationships exist between athlete placings, and technique, specifically concerning trunk position.

METHODS: Male and female athletes with a T54 classification; those with paraplegia, having normal hand and arm function, normal or limited trunk function, and no leg function

(Tweedy & Bourke, 2009) formed the population sample. Athlete performance, over each distance final (100m, 200m, 400m, 1500m, and 5000m) was analysed independently (n=86; males = 43, females = 43). Race times were obtained from the official website of the Paralympic Movement (http://www.paralympic.org/), with video data obtained from the public domain (https://www.youtube.com/). Ethical approval was obtained from the University of Adelaide Human Research Ethics Committee.

Peak vertical range of trunk motion (during recovery) and stroke count over the final 100m of racing was calculated for all athletes. Athletes were manually classified into one of three groups (Figure 1) based on visual inspection: Low-Trunk remains parallel to track surface; Moderate-Thoracic region elevates from lower extremity, head remains in tucked position; High–Trunk opens fully, head un-tucked). Intra-rater reliability measures were performed to ensure consistency of classification and stroke count.

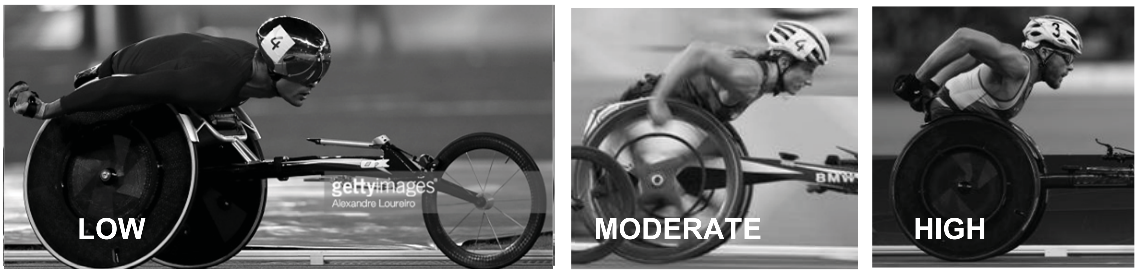

Figure 1: Groupings of athlete vertical trunk range (Images sourced from: http://www.gettyimages.fr, http://www.dailymail.co.uk, and http://www.theherald.com.au)

Theoretical race times were calculated for Moderate and High classified athletes, using an Fd measure calculated from the frontal area of Low athletes. Effective frontal area of the athletes was estimated using still images (5000m and Marathon races) in the frontal plane; to prevent parallax and perspective errors. Background pixels of each image were removed using custom code developed in MATLAB (Student Version 2015a). Image calibration assumed athletes utilised a standard 22” front wheel, enabling a measure of pixels per square metre, and thus an estimate of athlete frontal area. Percentage difference to the mean measure of frontal area from the Low classified group was obtained, and used as a scaling factor for the measure of frontal area presented in the research by Barbosa et al. (2016). Fd was calculated using average velocity over the duration of the race (as final 100m split times were not available, and assuming air density to be 1.2041kg/m^3 (Barbosa et al., 2016). It was assumed reductions in Fd did not impact other stroke characteristics when estimating theoretical race time.

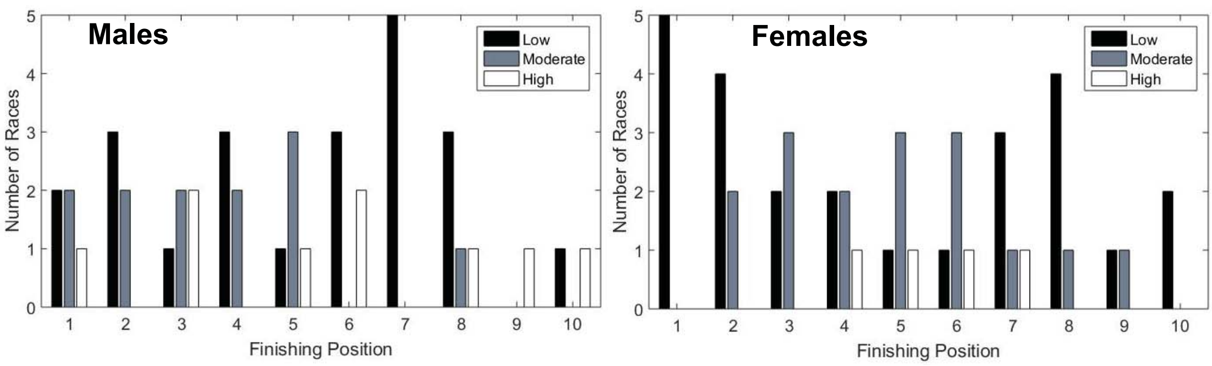

Figure 2: Influence of vertical position on athlete finishing place.

RESULTS: Excellent intra-rater reliability was observed for the manual digitisation of classification (ICC>0.89) and stroke count (ICC>0.99). Female athletes demonstrated a strong trend of High vertical range of motion not medalling, with medallists more frequently assuming a Low or Moderate Position (Figure 1). The same trend was not observed for male athletes, with no preference observed in sprint or endurance events. Weak negative correlations were observed between vertical range of trunk motion and stroke count (Figure 3) for both males (R^2 = 0.30) and females (R^2 = 0.17). Weak correlations were also observed between stroke count and finishing position, which was positive for males (R^2 = 0.11) and negative for females (R^2 = 0.17). The weakness of the correlations suggests that variation exists between athletes, which can be expected due to the different physical functionalities within this population. Females assuming a Low vertical trunk motion have a higher stroke count over the final 100m assessed. However, males are less consistent, with some athletes having a low position, as well as a low stroke count, potentially suggesting an optimised kinematic technique.

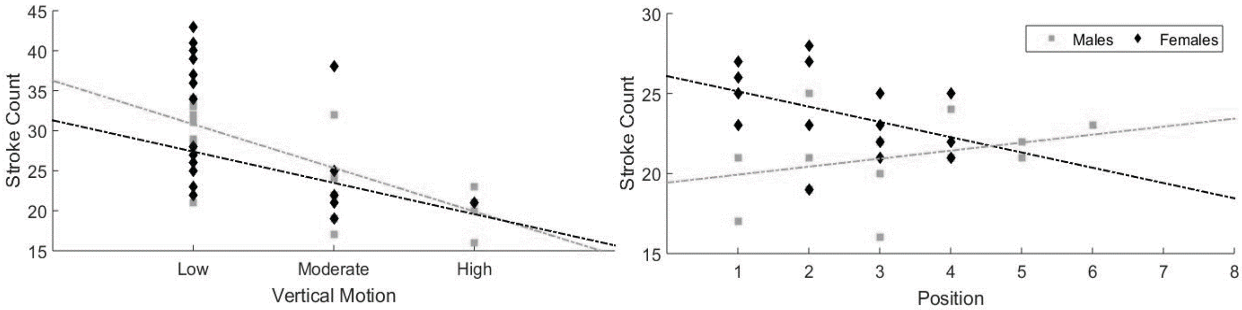

Figure 3: Influence of Vertical Motion (Left) and Finishing Position on stroke count.

No relationship was present in stroke count for athletes in respective postural classifications. Athletes classified as Moderate and High Vertical Trunk range of motion displayed respective frontal area 113.2% and 147.0% greater than that of a Low athlete. Estimated race times of Moderate and High athletes modelled using a Low Fd are presented in Table 1. Reductions in race times were meaningful, with all athletes improving their performance outcome, under the assumption that force generating capacity was not compromised.

Table 1
Possible male time reductions if athletes maintained a Low trunk position.

Height	100m (n = 16)	400m (n = 16)	800m (n = 16)	1500m (n = 19)	5000m (n = 19)
Moderate	0.86*	2.83±0.66	5.70±0.01	10.89±0.03	39.80±0.03
High	NA	8.26±0.07	16.68*	31.85±0.04	116.17±0.10

*** Denotes single athlete with specific position during event.**

DISCUSSION: A retrospective analysis of the influence of vertical trunk motion on finals placing of T54 athletes at the 2016 Rio Paralympics was performed. Females tended to show a greater reliance on aerodynamic positioning than males. A positive relationship between stroke count and finishing positon was observed for male athletes only, highlighting the balance between aerodynamics and physical capabilities, as low stroke counts can be considered as being associated with a more powerful technique.

Whilst females were more likely to win with improved aerodynamic positions, it appears males can better overcome the additional resistive forces of poor aerodynamic positioning due to their enhanced strength capabilities. For males, this aerodynamic position does not appear the decisive factor for winning a race; however, this research clearly demonstrates that if already powerful athletes can adopt Low positions, without compromising their power generating capabilities, they will increase their potential for winning. However, in achieving this optimised position, peak force generating capacity may be impaired, as athletes are likely to have a reduced push length on the wheel and hence aerodynamics must not be optimised in isolation. Over-correction of aerodynamic positioning may ultimately adapt technique towards that of a T53 athlete, who has no trunk function and hence is forced to adopt a Low position, however all have slower finishing times. Thus, further kinematic exploration into upper extremity joint kinematics, applied kinetics and contact parameters (contact and release angles) should be examined across athletes demonstrating Low vertical trunk motion to ascertain relationships with athlete speed, to optimise athlete technique. Such assessments were limited in this research as no high speed footage was available.

These same limitations prevented the quantification of frontal area of all athletes, which would have assisted in providing a more reliable athlete classification methodology.
Low positions were more frequent in the 100m race, likely due to the negligible steering requirements (manoeuvring the bend, and avoiding other athletes). However, some athletes still presented moderate frontal areas, which may be due to the presence of leg mass, which increased trunk inclination and frontal area, preventing athletes obtaining optimal positions. Wheelchair racing chairs are yet to have the capacity for changing seating inclination, despite being within sport guidelines; however, is under investigation in other wheelchair sports (Vanlandewijck, Verellen, & Tweedy, 2011). Forward-inclined seats may counteract this presence of leg mass, whilst also placing athletes in a more powerful propulsion.
Tabulated reductions in time overestimate actual benefits, as they assume athletes maintain a Low position throughout the duration of the race, with no reduction in power generation, which is implausible due to aforementioned steering requirements. Additionally, peak vertical trunk motion varies considerably throughout a race, particularly when drafting, whereby athletes assume lower positioning, suggesting the limitation of assessing only the final 100m sprint, where athletes may adapt their technique. This limitation arose from the limited footage available. Classification of trunk height, and calculation of frontal area may have been impacted by human error, however, intra-rater reliability measures were obtained to ensure these effects were minimal. Further research could optimise the individual power and aerodynamic balance, taking into consideration unique strength, physiology and physical capabilities. Additionally, with more footage, the presented trends could be investigated over the duration of a race for a wider range of athletes, particularly comparing those who do and do not make finals, and competitions where head winds were considered influential.

CONCLUSION: This study assessed the vertical trunk motion of male and female T54 classified wheelchair racing finalists at the 2016 Rio Paralympics. Winning female athletes were identified as using more aerodynamic positions, whilst more variation in aerodynamic, and non-aerodynamic postures were identified in the male athletes. This difference in aerodynamic prioritisation is due to their increased ability for force production, and hence optimal position for each athlete may differ and hence requires further kinematic exploration.

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