Research Article

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A unique pseudo-eligibility analysis of longitudinal laboratory performance data from a transgender female competitive cyclist

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Abstract

Background and Aims: The Union Cycliste Internationale has deemed transgender female athlete's ineligible for the female category due to concerns about performance advantages. We conducted a follow-up analysis on laboratory-based performance indicators of sports performance using data from a longitudinally assessed transgender woman athlete undergoing gender-affirming hormone therapy (GAHT).

Methods: We evaluated laboratory performance indicators in transgender and cisgender women athletes using dual-energy X-ray absorptiometry scanning, handgrip strength measurement, jump testing, and cardiopulmonary exercise. Additionally, we assessed a transgender sub-elite cyclist before and after undergoing GAHT.

Results: After one year of GAHT, the transgender athlete showed declines in handgrip strength (7–13 %), countermovement jump (23–29 %), and $\dot{V}O_2max$ (15–30 %). After 3 months, several performance indicators (absolute handgrip, peak power, relative peak power, average power, relative average power, $\dot{V}O_2max$ and relative $\dot{V}O_2max$) were above the mean of cisgender female athletes, while others (Relative handgrip, countermovement jump and relative countermovement jump) were below. Similar trends were observed at 6 months and 1 year.

Summary: This hypothetical analysis, although with limited evidence, suggests the transgender athlete could compete equitably in elite cycling events within the female category after one year of GAHT. Adjustments based on competition data would ensure fairness. Further analysis after an additional 12 months is recommended to assess the impact of 2 years of GAHT. An outright ineligibility for the female category for transgender women athletes would hinder a true assessment of performance fairness.

Keywords: transgender; athlete; cycling; gender-affirming hormone therapy; performance

Introduction

Today's transgender population is ~3 % of the world's population [n=~241,359,343 [1]] and the prevalence of elite athletes in the general population is estimated to be ~0.0003 % [2]], therefore, there is potential for ~72,408 transgender athletes globally. The question of how and where to integrate transgender athletes into every level of competitive sport is being debated rigorously [3–11], and the International Olympic Committee's Framework, although criticised [4, 12], states that any eligibility decision should be "*largely based on data collected from a demographic group that is consistent in gender and athletic engagement with the group that the eligibility criteria aim to regulate* [13]". The regulations set by the Union Cycliste Internationale (UCI) [14], which is the world governing body for cycling sports, stipulates a specific ineligibility for transgender women athletes in the female category. The UCI cites concerns about potential unfair performance advantages despite the lack of supporting athlete data despite using cisgender performance differences as a proxy for transgender performance [6, 7]. We investigated the likely effects on laboratory-based performance indicators in response to these policy changes cross-sectionally [15], but the design of this study does not show the effect of gender-affirming hormone treatment (GAHT) over time. Our research group also pioneered a

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decision-making framework for transgender athletes' eligibility in 2021 [5]; however, the framework was demonstrated by employing cisgender archery and shooting performance as a proxy for transgender performance in those sports [6, 7]. To address the shortcomings of the cross-sectional analysis and the decision-making framework, and that it is vital to understand the level of performance transgender athletes possess relative to their cisgender counterparts [7]; the primary aim of this manuscript is to perform a pseudo-eligibility analysis of a longitudinally assessed transgender athlete using laboratory measures of athletic performance under the same conditions, compared with cross-sectionally assessed cisgender and transgender athletes [15]. The primary objective is to present a case study of data from a transgender female athlete over one year of GAHT; the secondary objective is to analyse where this athlete sits within a group of cross-sectionally assessed transgender and cisgender women athletes. The final objective is to use our laboratory's decision-making framework [5] to perform a pseudo-eligibility analysis for the sport of cycling, demonstrating the efficacy of the process. Any recommendations should be treated cautiously as sport's governing bodies are best placed to determine their priorities and eligibility policies, and the data fuelling it is limited [15]. The summary of this article is presented in Figure 1.

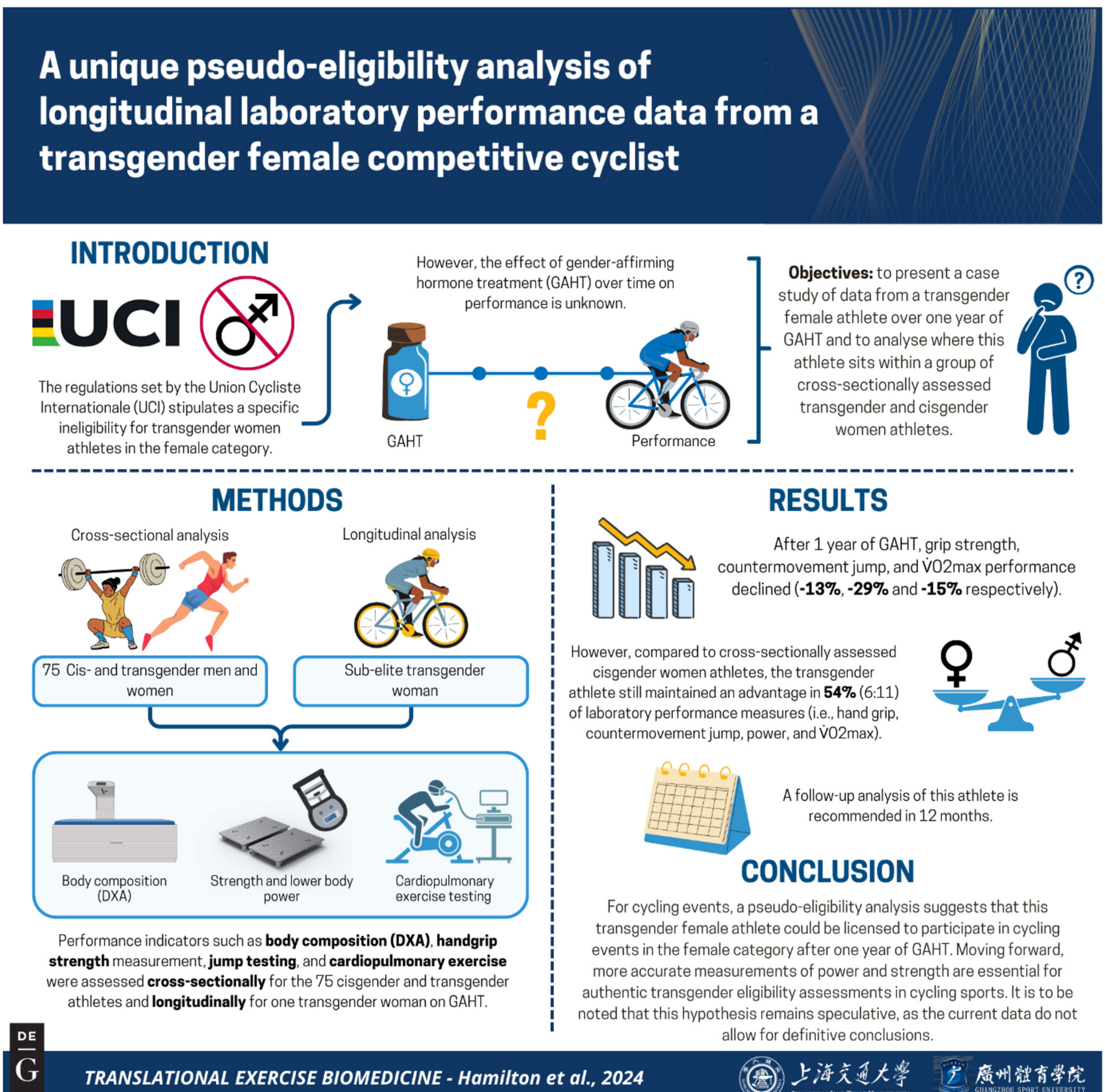

Figure 1: Graphical representation of this article. Figure created with BioRender.

Methods

Study design

The cross-sectional study involved a single visit to the laboratory at the School of Applied Sciences, University of Brighton, UK. Each participant arrived at ~9 a.m. after an overnight fast and departed from testing at ~3 p.m. The complete study design can be found in the study protocol, available as a preprint [16]. The longitudinal study involved four visits to the laboratory at the School of Applied Sciences, University of Brighton, UK, over one year: at baseline (before administration of GAHT), three months, six months, and 12 months post-GAHT administration.

Recruitment

Following Ethical Approval (Ref: 9,496) for both the cross-sectional and longitudinal analysis, seventy-five (19 cisgender men, 12 transgender men, 23 transgender women, and 21 cisgender women) cross-sectional participants and one sub-elite transgender woman cyclist for longitudinal analysis were recruited through social media advertising on Meta Platforms (Facebook and Instagram, Meta Platforms, Inc., California, USA) and X (Twitter, Inc., California, USA). Following the initial response, all participants were provided with the participant information sheet by email at least seven days before being invited to travel to the laboratory, with further oral information about the study procedures and written informed consent provided on their visit to the laboratory.

Participants and eligibility criteria

Participants were required to participate in competitive sports or undergo physical training a minimum of thrice weekly. Following written consent, participants were asked to record their last four training sessions and self-rate their training intensity for each session on a scale of 1–10 (10=Maximum Intensity). The mean of the four sessions was recorded to represent the athletes' training intensity. The cross-sectional transgender athletes must have completed ≥1 year of GAHT, and the longitudinal transgender athlete must not have started GAHT. Both instances were voluntarily disclosed during consent and verified during blood test analysis. The full inclusion/exclusion criteria can be found in the study protocol, available as a preprint [16]. Two cisgender women and one transgender man could not provide blood samples and were consequently excluded from the cross-sectional analyses as their endocrine profiles could not be verified. Furthermore, two transgender women and one cisgender woman were excluded from the cross-sectional analyses due to testosterone concentrations exceeding recommended female testosterone concentrations (2.7 nmol.L^{-1} [17]).

Laboratory assessments

Blood sampling and analysis

Before venous blood sampling, haemoglobin concentration ([Hb]) was sampled via the third drop of a Unistik® 3 Comfort lancet (Owen Mumford Ltd, Woodstock, UK) finger prick capillary blood sample analysed immediately using a HemoCue® 201+ (HemoCue AB, Ängelholm, Sweden). Capillary blood was used for [Hb] analysis for practical reasons such as ease of use. It is important to note that the HemoCue® 201+ used in the present study is expected to yield higher [Hb] values in arterial blood than venous blood [18]. After capillary sampling, one 10 mL whole venous blood sample was collected from an antecubital vein into a BD® serum tube (Becton, Dickinson, and Company, Wokingham, Berkshire, UK) for serum extraction. Once collected, the tubes were left at room temperature (18 ± 5 °C) for 1 h and then stored in a fridge (3 ± 2 °C) for up to 4 h before being centrifuged (PK 120 centrifuge, ALC, Winchester, VA, USA) using a T515 rotor at 1300G for 10 minutes at 4 °C, before storage at −80 °C until analysis. Before analysis, the samples were stored between −25 and −15°C, thawed at room temperature until liquid, vortexing to remix samples, centrifuged at 2876G for 8 min to remove any precipitant and then analysed for participant's testosterone and oestradiol concentrations on an immunoassay analyser (Roche Cobas 8,000 e801, Roche Diagnostics Limited, Burgess Hill, UK).

Body composition

Body composition was measured by DXA (Horizon W, Hologic Inc., Massachusetts, USA). Each cross-sectional participant underwent a whole-body scan. The longitudinal athlete underwent a whole-body scan on each visit. The participant was asked to lie on the scan bed, and the first author (BRH) performed all participant placement and scanning. Due to inbuilt assumptions of body fat percentage for the head and scanning bed area limitations, whole-body less head data is reported for the whole-body scan.

Strength

Strength was measured using a handgrip dynamometer (TAKEI 5401, TAKEI Scientific Instruments Co., Ltd, Japan) with participants seated, elbow flexed to right angles (90°), and a neutral wrist position. Each hand was evaluated three times in sequential order, left and then right, to allow each hand to rest; the mean scores were taken from the three attempts for each hand.

Lower body power

Lower body power was measured with a countermovement jump on a JUM001 Jump Mat (Probotics Inc, Alabama, USA). During the test, if the participant went beyond 45° of countermovement or the hands came off the hips, the test was declared void for that attempt. After recording three legitimate attempts, the mean scores were recorded.

Cardiopulmonary Exercise Testing

Cardiopulmonary Exercise Testing was performed using a 95 T Engage Treadmill ergometer (Life Fitness, Illinois, USA) and a COSMED QUARK™ (COSMED, Rome, Italy). All $\dot{V}O_2$max tests were conducted and analysed by the first author (BRH) to avoid inter-investigator variability [19]. A ramp protocol of treadmill $\dot{V}O_2$max testing was used for each $\dot{V}O_2$max test [20], involving gradual increases in speed every 3 min at a 1 % incline. One cisgender man and two cisgender women were excluded from the cross-sectional analysis as they did not meet the required criteria to classify the test as maximal [16] (cisgender men, n=18, transgender men, n=11; transgender women, n=21; cisgender women n=16).

Statistical analysis

For cross-sectional analysis [15], data meeting the assumptions of normality and homogeneity of variance were analysed using a one-way ANOVA and Bonferroni post-hoc corrections for pairwise comparisons. An alpha level of 0.05 was set for the analysis. Data was analysed and illustrated using Jamovi [21]. The percentage differences between cross-sectional and longitudinal were calculated using the following equation:

$$\frac{|V1 - V2|}{\left[\frac{V1+V2}{2}\right]} \times 100 = ?\%$$

Framework

The decision-making frameworks sliding scale and declared weightings models are described in Hamilton et al. [5]. The sliding scale model adjusts the eligibility criteria based on the degree of contact with the opponents and the degree of power strength and speed advantages or disadvantages held, while the declared weightings model assigns specific importance to fairness, safety, or inclusion to determine overall eligibility.

Results

Participant characteristics

The longitudinal athlete, a 27-year-old sub-elite cyclist riding in UCI Road events under their national governing body licence, presented for testing at baseline in early March 2023. Table 1 shows the athlete's intensity and weekly training minutes during the four visits from March 2023 until March 2024 compared with the cross-sectional transgender women and cisgender women groups [15]. It should be noted that the national governing body of cycling for this athlete declared transgender women ineligible from the female category in May 2023 [22], which coincided with the 3-month visit (Table 1).

Table 1: Training time, intensity, anthropometry, and blood measures during one year of GAHT were compared to cross-sectional assessments of transgender and cisgender women Athletes.

	Cross-sectional [15]		Longitudinal transgender woman athlete			
	CW	TW	Baseline	3 Months	6 Months	12 Months
Age (yrs.)	30 ± 9	34 ± 10	27	27	27	28
Training time, mins per wk.	–	–	320	200	310	360
Length of GAHT (yrs.)	–	6 ± 4	0	0.3	0.5	1
Average training intensity, RPE	7 [2]	7 [2]	7	7	7	7
Height, m	1.6 ± 0.1	1.8 ± 0.1	1.7	1.7	1.7	1.7
Body Mass, kg	60.6 ± 6.6	83.9 ± 19.9	86.0	79.7	83.0	89.4
Fat Mass, kg	15.0 ± 4.6	25.8 ± 13.2	20.6	21.4	23.8	27.6
Fat-free Mass, kg	40.3 ± 3.8	52.4 ± 7.7	51.6	52.3	52.6	54.5
Testosterone, $nmol \cdot L^{-1}$	0.9 ± 0.4	0.7 ± 0.5	25.2	5.1	2.8	2.1
Oestradiol, $pmol \cdot L^{-1}$	336 ± 266	742 ± 802	132	171	166	861
Hb, $g \cdot L^{-1}$	133 ± 13	131 ± 14	140	145	138	127

Cross-sectional data is presented as means ± SD, or median [IQR], Mins, minutes; wk., week; RPE, ratings of perceived exertion; m, metres; kg, kilogram; $nmol \cdot L^{-1}$, nanomoles per litre; $pmol \cdot L^{-1}$, picomoles per litre.

Cross-sectionally, no significant differences were found in age training intensity score between cisgender and transgender women, The longitudinal transgender athlete is younger than both groups and had a similar training intensity. Cross-sectionally assessed Transgender women were also taller than cisgender women ($t_{(66)}$=6.5, p<0.001, Table 1). The longitudinal athlete was an intermediate height compared to the two cross-sectional cohorts (Table 1). Cross-sectionally assessed Transgender women were found to be heavier than cisgender women ($t_{(66)}$=5.6, p<0.001), the longitudinal athlete presented heavier than the cross-sectional transgender women at baseline and gained body mass by the one-year measure (Table 1). Transgender women had more fat mass than cisgender women cross-sectionally ($t_{(66)}$=3.9, p<0.01, Table 1). The longitudinal transgender athlete had an intermediate fat mass compared to cross-sectionally assessed athletes (Table 1) at baseline but then progressed to have greater fat mass after 1 year. Cisgender women had less fat-free mass than transgender women ($t_{(66)}$=−6.6, p<0.001, Table 1). The longitudinal athlete presented a similar fat-free mass profile compared to cross-sectional transgender women athletes at baseline and after one year of GAHT.

Blood measures

No difference in testosterone or [Hb] concentrations was found between cross-sectional transgender and cisgender women athletes (Table 1). In comparison, the longitudinal athlete presented with a two-fold greater testosterone concentration after one year compared to the transgender women in the cross-sectional study, with higher [Hb] at baseline progressing to lower [Hb] after one year. Transgender women show higher oestradiol concentrations than cisgender women ($t_{(66)}$=2.7, p<0.05) cross-sectionally, After 1 year, the longitudinal athlete presented with similar elevated oestradiol concentrations as reported in the transgender women of the cross-sectional study (Table 1).

Handgrip

Cross-sectional Transgender women also had greater absolute right handgrip strength than cisgender women ($t_{(66)}$=3.2, p<0.05, Figure 2a) The transgender athlete exhibited a reduction in absolute (7 %, Figure 2a) over one year to exhibit a

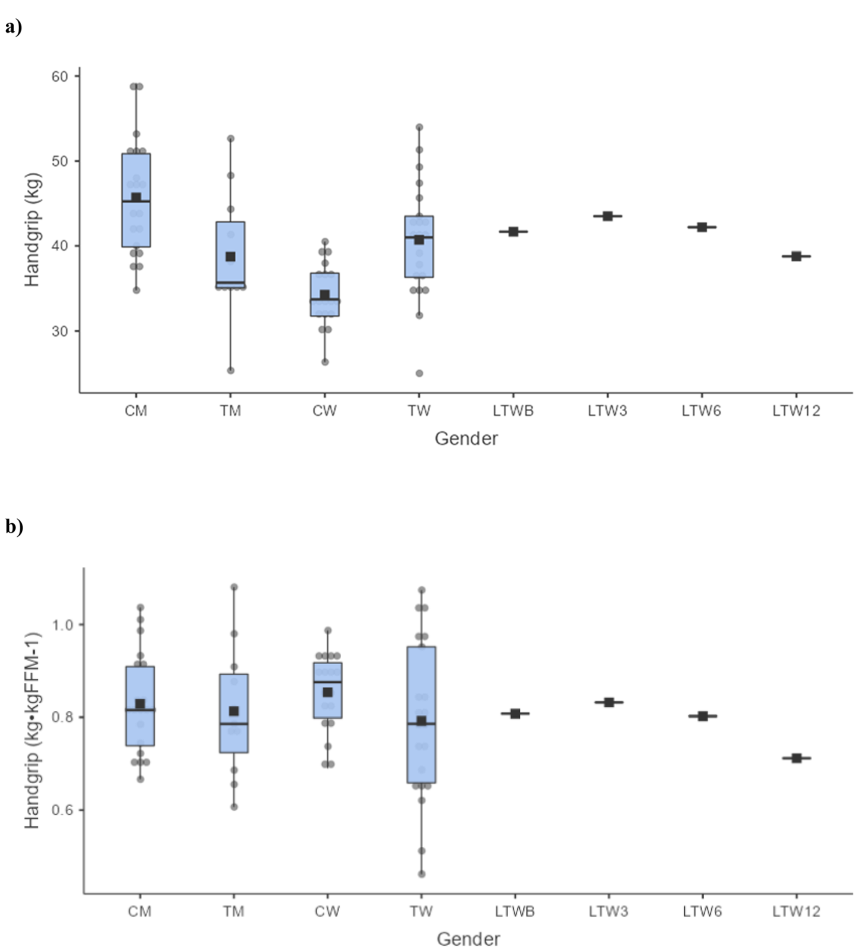

Figure 2: Comparisons of absolute (a) and relative (b) handgrip performance measures in cross-sectional athletes and during one year of GAHT in a transgender woman athlete. Notes: kg, kilogram; FFM, fat-free mass; CM, cisgender men; TM, transgender men; CW, cisgender women; TW, transgender women; LTWB, longitudinal transgender women baseline; LTW3, longitudinal transgender women 3 months; LTW6, longitudinal transgender women 6 months; LTW12, longitudinal transgender women 12 months. The grey dots represent individual data points. The grey lines indicate the range. The top and bottom of the blue box indicate the upper and lower quartile values and the bold black dash indicates the median value. The black box indicates the mean value.

similar handgrip profile to cross-sectional transgender women. No differences were found cross-sectionally in the relative handgrip to fat-free mass transgender and cisgender women and the longitudinal athlete showed a reduction of 13 % after one year (Figure 2b). After 3 months, the absolute handgrip remained 24 % above the mean of cisgender women (Figure 2a) and relative handgrip was 2 % below cisgender women (Figure 2b). After 6 months, the absolute handgrip remained 21 % above the mean of cisgender women (Figure 2a) and relative handgrip was 6 % below cisgender women (Figure 2b). After 12 months, the absolute handgrip remained 12 % above the mean of cisgender women (Figure 2a) and relative handgrip was 17 % below cisgender women (Figure 2b).

Countermovement jump

No differences were found between cross-sectionally assessed transgender and cisgender women in absolute countermovement jump performance (Figure 3a) The longitudinal transgender athlete exhibited a reduction in absolute (23 %, Figure 3a) after one year. Cross-sectional transgender women were found to have lower countermovement jump height relative to fat-free mass than cisgender women ($t_{(66)}$=–5.3, p<0.001) and the longitudinal athlete exhibited a 29 % reduction after one year (Figure 3b). After 3 months, the absolute countermovement jump was 5 % below the mean of cisgender women (Figure 3a) and the relative countermovement jump was 32 % below cisgender women (Figure 3b). After 6 months, the absolute countermovement jump was 8 % below the mean of cisgender women (Figure 3a) and the relative countermovement jump was 36 % below cisgender women (Figure 3b). After 12 months, the absolute countermovement jump was 19 % below the mean of cisgender women (Figure 3a) and the relative countermovement jump was 48 % below cisgender women (Figure 3b).

Power

Cross-sectional cisgender women were found to have reduced peak power compared with transgender women ($t_{(66)}$=–3.6, p<0.01, Figure 4a) with the longitudinal transgender athlete exhibiting a reduction of 3 % peak power over one year (Figure 4a). Cross-sectional transgender women were found to have no difference in peak power relative to

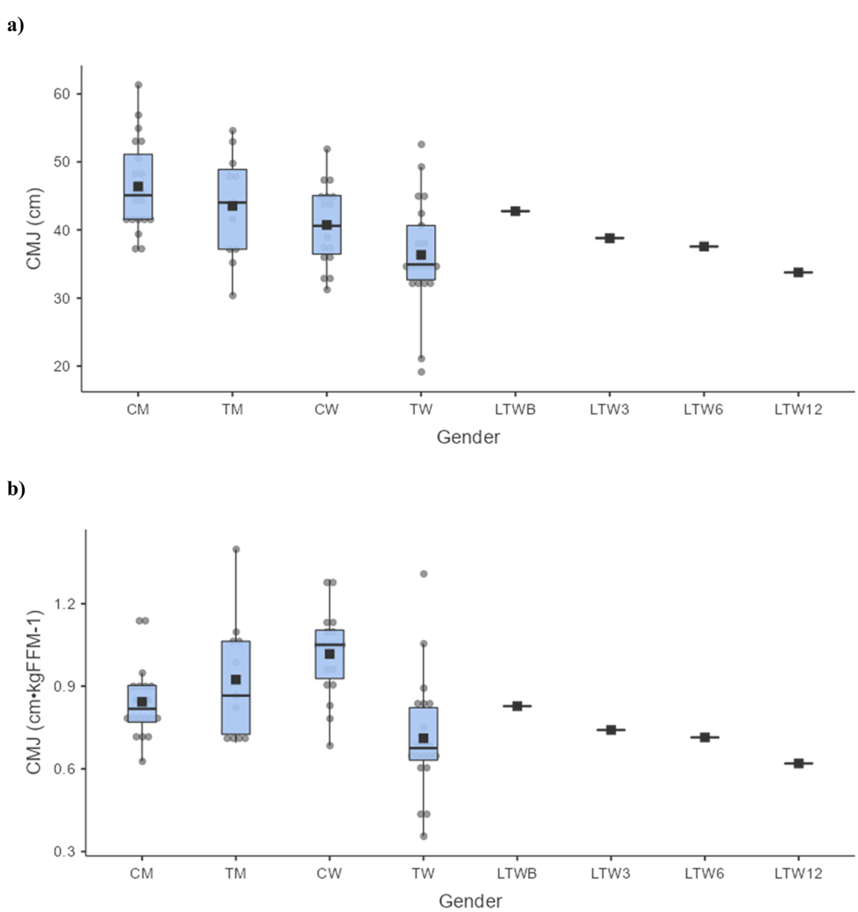

Figure 3: Comparisons of absolute (a) and relative (b) counter movement jump performance measures in cross-sectional athletes and during one year of gaht in a transgender woman athlete. Notes: cm, centimetre; FFM, fat-free mass; CM, cisgender men; TM, transgender men; CW, cisgender women; TW, transgender women; LTWB, longitudinal transgender women baseline; LTW3, longitudinal transgender women 3 months; LTW6, longitudinal transgender women 6 months; LTW12, longitudinal transgender women 12 months. The grey dots represent individual data points. The grey lines indicate the range. The top and bottom of the blue box indicate the upper and lower quartile values and the bold black dash indicates the median value. The black box indicates the mean value.

fat-free mass than cisgender women with the longitudinal transgender athlete exhibiting a reduction of 8 % peak power relative to fat-free mass over one year (Figure 4b). Cross-sectional cisgender women were found to have reduced average power compared with transgender women ($t_{(66)}$=−3.0, p<0.01, Figure 4c) with the longitudinal transgender athlete exhibiting a reduction of 3 % average power over one year (Figure 4c). Cross-sectional transgender

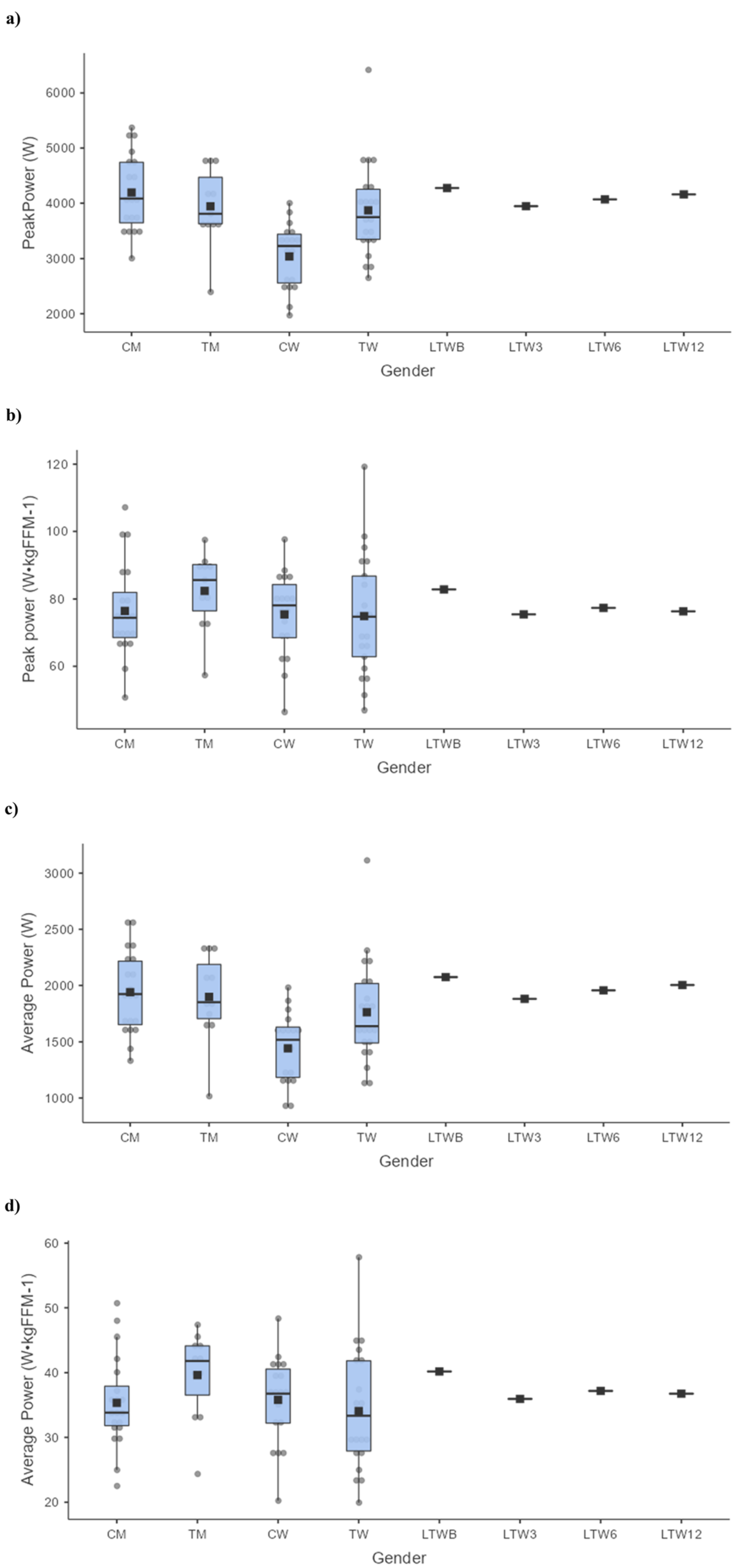

Figure 4: Comparisons of peak power (a) peak power relative to fat-free mass (b) average power (c) and average power relative to fat-free mass (d) in cross-sectional athletes and during one year of GAHT in a transgender woman athlete. Notes: W, watts; FFM, fat-free mass; CM, cisgender men; TM, transgender men; CW, cisgender women; TW, transgender women; LTWB, longitudinal transgender women baseline; LTW3, longitudinal transgender women 3 months; LTW6, longitudinal transgender women 6 months; LTW12, longitudinal transgender women 12 months. The grey dots represent individual data points. The grey lines indicate the range. The top and bottom of the blue box indicate the upper and lower quartile values and the bold black dash indicates the median value. The black box indicates the mean value.

women were found to have no difference in average relative to fat-free mass than cisgender women with the longitudinal transgender athlete exhibiting a reduction of 9 % peak power relative to fat-free mass over one year (Figure 4d). After 3 months, peak power was 26 % above the mean of cisgender women (Figure 4a) and relative peak power 1 % above (Figure 4b). The average power was 26 % above cisgender women (Figure 4c) and relative average power 3 % above (Figure 4d). After 6 months, peak power was 29 % above the mean of cisgender women (Figure 4a) and relative peak power was matched (Figure 4b). The average power was 30 % above cisgender women (Figure 4c) and relative average power was matched (Figure 4d). After 12 months, peak power was 31 % above the mean of cisgender women (Figure 4a) and relative peak power 1 % above (Figure 4b). The average power was 32 % above cisgender women (Figure 4c) and relative average power 3 % above (Figure 4d).

Maximal oxygen uptake ($\dot{V}O_2max$)

No differences were found cross-sectionally in absolute $\dot{V}O_2max$ between cisgender and transgender women (Figure 5a) and the longitudinal transgender athlete exhibited a reduction of 15 % in $\dot{V}O_2max$ over 1 year (Figure 5a). Cross-sectionally, transgender women had lower relative $\dot{V}O_2max$ than cisgender women ($t_{(66)}$=–3.3, p=0.01, Figure 5b) and after one year of GAHT, the longitudinal athlete presented with a 30 % loss in relative $\dot{V}O_2max$ to body mass (Figure 5b). After 3 months, $\dot{V}O_2max$ was 30 % above the mean of cisgender women (Figure 5a) and relative $\dot{V}O_2max$ was 2 % above cisgender women (Figure 5b). After 6 months, $\dot{V}O_2max$ was 13 % above the mean of cisgender women (Figure 5a) and relative $\dot{V}O_2max$ was 19 % below cisgender women (Figure 5b). After 12 months, $\dot{V}O_2max$ was 15 % above the mean of cisgender women (Figure 5a) and relative $\dot{V}O_2max$ was 25 % below cisgender women (Figure 5b).

Discussion

The findings of this pilot longitudinal study provide insights into changes in laboratory-based performance measurements of a transgender athlete undergoing 1-year GAHT. Given the purpose of GAHT [23] and that this study addressed the cross-sectional limitations of Hamilton [15]; this pilot investigation corroborated that transgender women's

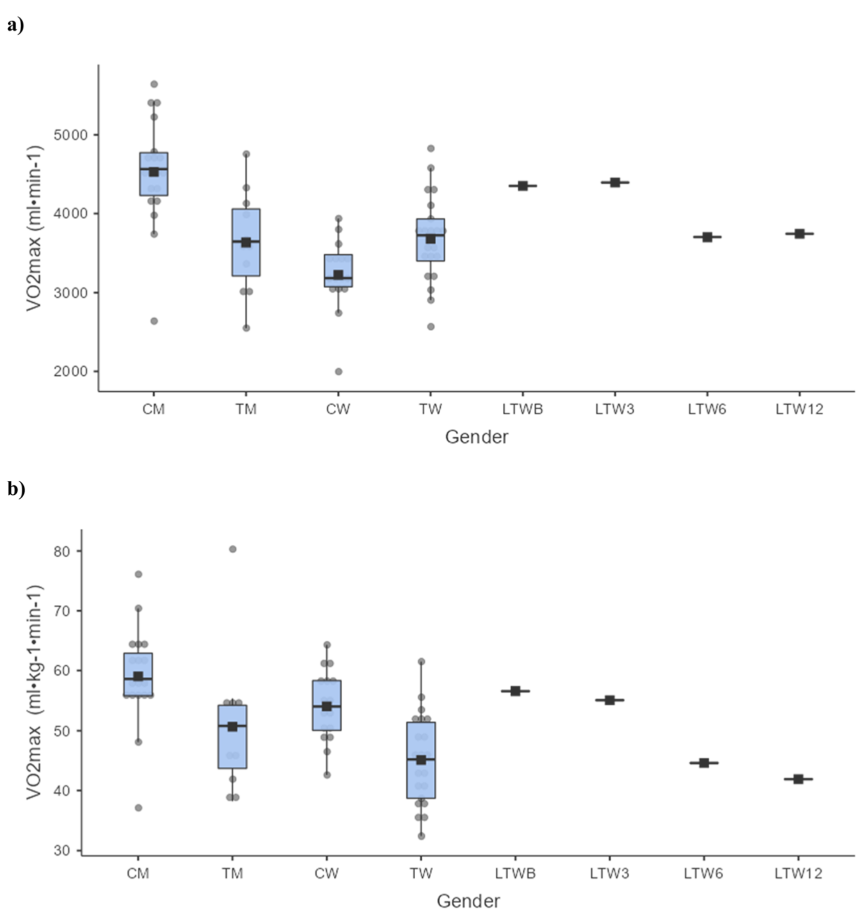

Figure 5: Comparisons of absolute (a) and relative (b) $\dot{V}O_2max$ in cross-sectional athletes and during one year of GAHT in a transgender woman athlete. Notes: ml·min^{-1}, millilitres per min; ml·kg^{-1}·min^{-1}, millilitres per kilogram of body mass per minute; CM, cisgender men; TM, transgender men; CW, cisgender women; TW, transgender women; LTWB, longitudinal transgender women baseline; LTW3, longitudinal transgender women 3 months; LTW6, longitudinal transgender women 6 months; LTW12, longitudinal transgender women 12 months. The grey dots represent individual data points. The grey lines indicate the range. The top and bottom of the blue box indicate the upper and lower quartile values and the bold black dash indicates the median value. The black box indicates the mean value.

oestradiol was higher than that of cisgender women after one year of GAHT (Table 1). Demonstrating longitudinally that this transgender women athlete shares a similar endocrine profile with cisgender women and that these high oestradiol concentrations could be consistent with GAHT in transgender women athletes. Notably, the [Hb] profiles of the transgender women athlete were lower than those of the cisgender female athlete references (Table 1); However, a 7 % decline in transgender women athletes' [Hb] after one year of GAHT is consistent with the work of Wiik [24] and Olson-Kennedy [25] in sedentary transgender women.

It was hypothesised in the cross-sectional analysis that the differences observed in body composition in the cross-sectional sample indirectly showed the potential role of androgens in body composition [15]. Specifically, oestradiol's role in fat accumulation [26] as the transgender women's oestradiol concentrations and fat mass were greater than those of cisgender women. Although this pilot longitudinal study has no statistical power, a strong correlation (r=0.91) between oestradiol and fat mass accumulation was found over one year of GAHT. With testosterone reductions not resulting in declines in fat-free mass after one year in this transgender woman athlete (Table 1) and the athlete training intensity was consistent (Table 1), the hypothesis that oestradiol is the primary androgen in altering body composition in transgender women is strengthened, though not confirmed, as research with greater statistical power is required to confirm this hypothesis.

Investigations using more precise strength assessments are necessary for transgender athletes [22] as increased hand size predicts handgrip strength [15]. However, this pilot's longitudinal nature allows the assessment of GAHT's effects on handgrip strength over one year. The loss of absolute (Figure 2) handgrip strength without negative changes in exercise intensity and exercise time (Table 1), the 4.5 to 7.1 % reductions in handgrip strength seen in sedentary transgender women [8, 27, 28] and relative handgrip loss exceeds 7.1 % (Figure 2). These results conflict with the maintenance of strength reported by Wiik [24], although Wiik [24] measured strength with the more accurate isokinetic knee dynamometer.

According to the cross-sectional analysis, transgender women have less lower-body anaerobic power than cisgender women [15]. After one year of GAHT, the transgender female sub-elite athlete was found to have 17 % less countermovement jump height than cisgender women (Figure 3), a 1.5-fold greater rate of decrease than what was found cross-sectionally [15], and the transgender athlete's countermovement jump height had decreased by 19 % from baseline (Figure 3). This longitudinal data suggests that the changes in absolute and relative countermovement jump performance are brought on by increased fat mass owing to the increased oestrogen brought on by GAHT (Table 1). This hypothesis is strengthened by the moderate reductions in peak and average power (Figure 4). This leads to the notion that the increasing inertia caused by the increase in non-contractile fat mass is the primary limiting factor in this transgender woman's poor countermovement jump performance. High oestrogen levels have been found to decrease power and performance in cisgender women [29], and more work is needed to confirm or refute this hypothesis in transgender women athletes.

In the cross-sectional analysis [15], no differences were found between transgender women athletes and cisgender women athletes in absolute $\dot{V}O_2$max. Transgender women exhibited lower relative $\dot{V}O_2$max compared to cisgender women (Figure 5). This sub-elite transgender women cyclist exhibited a higher absolute $\dot{V}O_2$max than reference cisgender women after one year of GAHT, with a 14 % reduction from baseline (Figure 5). Relative to body mass, this transgender women athlete showed a 26 % decline in relative $\dot{V}O_2$max from baseline that was notably lower than the reference cisgender women (Figure 5). O_2 delivery to tissues is a limiting factor in $\dot{V}O_{2max}$ proficiency, as [Hb] plays a significant role in O_2 transport [30] and endurance sports like cycling [31]. Table 1 shows a decrease in [Hb], which correlates (r=0.74) with a reduction of $\dot{V}O_{2max}$ after one year of GAHT. This suggests that loss of [Hb] during GAHT is crucial in reducing $\dot{V}O_{2max}$ performance. The association between these variables, along with lung function measurements [15], should be investigated with greater statistical power to determine which is more damaging to performance in transgender female athletes transitioning with GAHT.

To fulfil the third objective of this study, a pseudo-decision-making process for this athlete's eligibility for the sport of cycling will be made using the decision-making tools set out in Hamilton [5]. Deciding on this athlete's eligibility in cycling requires understanding the sport's indices. Power output [32–36], $\dot{V}O_2$max [37–43] and, to a lesser extent, strength [44–46] are crucial to the sport of cycling. Isometric strength doesn't predict cyclist performance, whereas higher maximal $\dot{V}O_2$max and peak power do [47]. The power test this athlete undertook (Countermovement Jump) is a reliable measure of power [48], however, a measure of direct power via cycle ergometer would have been better in judging this case [49]. The athlete only undertook handgrip strength and, again, a better measurement of strength, such as a leg press [48], would have been preferable. However, grip strength seems to be a temporary factor in cycling performance when riding for extended periods [50]. Nevertheless, GAHT had a significant effect on this athlete's laboratory performance after one year of GAHT, as their grip strength (Figure 2), countermovement jump (Figure 3), and $\dot{V}O_2$max (Figure 5) declined.

The question at hand is whether one year of GAHT is enough to negate any advantages of a high testosterone puberty [51] in this athlete to participate in the sport of cycling in the female category. To answer this and fulfil the request of the International Olympic Committee Framework [13], we must compare data generated from the transgender athlete with cisgender women athletes tested under the same conditions and measures of elite cisgender cyclist cohorts in the literature. Compared to the cisgender women of Hamilton [15], this transgender woman athlete maintained an advantage in 54 % (6:11) of laboratory performance measures (measured from hand grip, countermovement jump, and $\dot{V}O_2$max). First, the transgender athlete has greater absolute and relative grip strength (Figure 2). Therefore, a grip strength advantage is apparent after one year of GAHT. Countermovement jump performance was absolutely and relatively less than cisgender women (Figure 3). Therefore, a jump performance disadvantage exists after one year. Peak power was above that of cisgender women (Figure 4a). Therefore, a peak power advantage exists after one year. The average power was higher than that of cisgender women (Figure 4b). Therefore, an average power advantage exists after one year. $\dot{V}O_2$max performance was absolutely above cisgender women (Figure 5a), although relatively (Figure 5b) below cisgender women. Therefore, a $\dot{V}O_2$max performance advantage is likely not to be present. Compared to cisgender women cyclists in the literature, this transgender athlete has a 14 % disadvantage (48.9 mL·kg^{-1}·min^{-1} [52] vs. 41.9 mL·kg^{-1}·min^{-1} [LTW12 Figure 5]) in $\dot{V}O_2$max, likely confirming the lack of $\dot{V}O_2$max performance advantage in this athlete. Comparing countermovement jump performance with a cohort of eight elite sprint track cyclists (Male=4, Female=4), the transgender women athletes' average power was similar to elite sprint (2039 [53] vs. 2003 [LTW12 Figure 4c) but above elite endurance (1,668 [53]vs. 2003 [LTW12 Figure 4c] W) performance. Therefore, a disadvantage or advantage in average power for this transgender female athlete in the elite category of women's cycling is unlikely to exist. However, the transgender women athletes' peak power did match those of sprint cyclists (4,110 [53] vs. 4,160 [LTW12 Figure 4a] W) and was above endurance cyclists (3,184 [53] vs. 4,160 [LTW12 Figure 4a] W). Therefore, a disadvantage or advantage peak average power for this transgender female athlete in the elite category of women's cycling is unlikely to exist.

The observed performance metrics of the athlete, particularly the increased peak power compared to cisgender women, may be attributed to their specialisation as a sprint cyclist. However, it is essential to note that this hypothesis remains speculative, as the current data do not allow for definitive conclusions. Notably, the athlete's overall performance trajectory indicates a downward trend. Further, longitudinal studies are necessary to ascertain the specific factors contributing to these performance changes and to determine the extent to which they may be influenced by the athlete's training regimen, physiological adaptations, or other external variables. Given the data analyses and using the tools of Hamilton et al. [5] it can clearly be defined as a fairness analysis (Figure 6a) as there is no contact with the opponent in cycling to provide an athlete-to-athlete contact safety concern, and there are some metrics that advantages are still held after one year of GAHT, which highlights fairness as the motivating factor (Figure 6b) behind the eligibility decision. Given that the transgender women cyclist in this analysis holds an advantage in 33 % (5:15) measures analysed, it could be warranted that this transgender cyclist be allowed to compete in the female

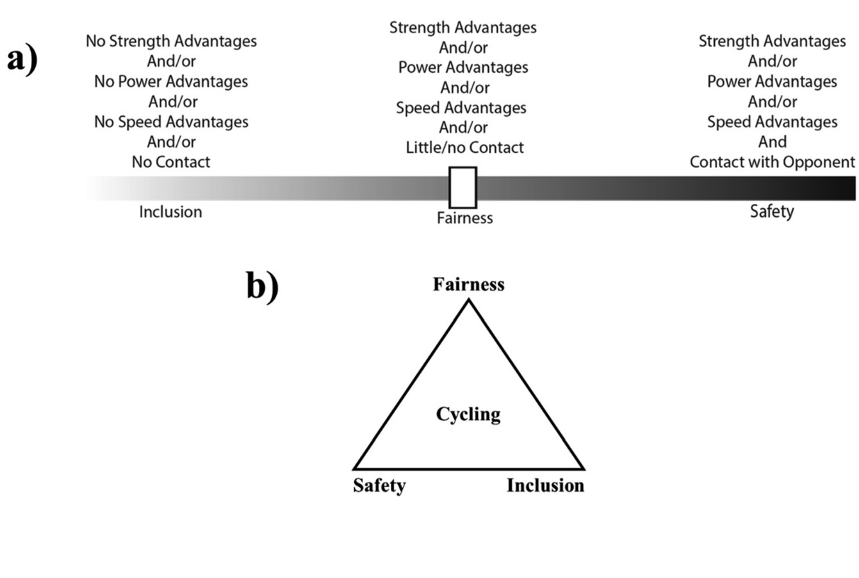

Figure 6: The sliding scale (a) and declared weightings model of fairness (b) adapted from Hamilton [5].

category after one year of GAHT. A follow-up analysis should be performed in 12 months to see if 2 years of GAHT has a more significant effect, and the athlete's eligibility should be re-evaluated. As this transgender cyclist matches sprint cyclists from the literature [53] appropriate future testing measures could be the Wingate anaerobic test or a six-second 'all-out' test as a more valid measures of peak power in cycling [54]. Nevertheless, the current data suggest that, even after one year of GAHT, some transgender female athletes may be fairly integrated into the female category on a provisional basis. Should subsequent competition data indicate unfair performance advantages, this decision could be reversed, or the GAHT requirement could be extended to two years or more. Conversely, an outright ineligibility for the female category on transgender women athletes in a specific sport precludes the opportunity to ascertain the true impact of GAHT on performance fairness, leaving the issue subject to speculation.

Summary

In summary, this study aimed to assess the impact of one year of GAHT on a longitudinally examined transgender athlete's laboratory performance. The findings revealed that GAHT declined grip strength, countermovement jump, and $\dot{V}O_2max$ performance. However, compared to cross-sectionally assessed cisgender women athletes, the transgender athlete still maintained an advantage in 54 % (6:11) of laboratory performance measures (measured from hand grip, countermovement jump, power, and $\dot{V}O_2max$). For cycling events, a pseudo-eligibility analysis suggests that this transgender female athlete could be licensed to participate in cycling events in the female category after one year of GAHT. Moving forward, more accurate measurements of power and strength are essential for authentic transgender eligibility assessments in cycling sports. A follow-up analysis of this athlete is recommended in 12 months.

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Data availability: The anonymised data supporting the findings of this study are openly accessible under the terms of the Creative Commons Attribution 4.0 International License (CC-BY 4.0). The dataset and supplementary materials can be accessed at the following location: Hamilton BR, et al. The Strength, Power, and Aerobic Capacity of Transgender Athletes: A Cross-Sectional Study: 2022. DOI: osf.io/a684b.

References

1. Statista. Share of people identifying as transgender, gender fluid, non-binary, or other ways worldwide as of 2023, by country; 2023. https://www.statista.com/statistics/1269778/gender-identity-worldwide-country/.
2. The Dutch Olympic Committee*Dutch Sports Federation. Facts and figures; 2023. [cited 2023 December 7th]; Available from https://nocnsf.nl/en/about-nocnsf/facts-and-figures.
3. Hilton EN, Lundberg TR. Transgender women in the female category of sport: perspectives on testosterone suppression and performance advantage. Sports Med 2020;51:199–214.
4. Lundberg TR, Tucker R, McGawley K, Williams AG, Millet GP, Sandbakk Ø, et al. The International Olympic Committee framework on fairness, inclusion and nondiscrimination on the basis of gender identity and sex variations does not protect fairness for female athletes. Scand J Med Sci Sports 2024;34:e14581.
5. Hamilton BR, Guppy FM, Barrett J, Seal L, Pitsiladis Y. Integrating transwomen athletes into elite competition: the case of elite archery and shooting. Eur J Sport Sci 2021;21:1500–9.
6. Hamilton B, Guppy F, Pitsiladis Y. Comment on:"Transgender women in the female category of sport: perspectives on testosterone suppression and performance advantage". Sports Med 2024;54:237–42.
7. Oberlin D. Sex differences and athletic performance. Where do trans individuals fit into sports and athletics based on current research? Frontiers in Sports and Active Living 2023;5. https://doi.org/10.3389/fspor.2023.1224476.
8. Harper J, O'Donnell E, Khorashad BS, McDermott H, Witcomb GL. How does hormone transition in transgender women change body composition, muscle strength and haemoglobin? Systematic review with a focus on the implications for sport participation. Br J Sports Med 2021. https://doi.org/10.1136/bjsports-2020-103106.
9. Senefeld JW, Hunter SK, Coleman D, Joyner MJ. Case studies in physiology: male to female transgender swimmer in college athletics. J Appl Physiol 2023;134:1032–7.
10. Cheung AS, Zwickl S, Miller K, Nolan BJ, Wong AFQ, Jones P, et al. The impact of gender-affirming hormone therapy on physical performance. J Clin Endocrinol Metabol 2024;109:e455–65.
11. Pike J. Why 'Meaningful Competition'is not fair competition. J Philos Sport 2023;50:1–17.

12. Pigozzi F, Bigard X, Steinacker J, Wolfarth B, Badtieva V, Schneider C, et al. Joint position statement of the International Federation of Sports Medicine (FIMS) and European Federation of Sports Medicine Associations (EFSMA) on the IOC framework on fairness, inclusion and non-discrimination based on gender identity and sex variations. BMJ Open Sport & Exercise Med 2022;8:e001273.
13. Martowicz M, Budgett R, Pape M, Mascagni K, Engebretsen L, Dienstbach-Wech L, et al. Position statement: IOC framework on fairness, inclusion and non-discrimination on the basis of gender identity and sex variations. Br J Sports Med 2023;57:26–32.
14. Union Cycliste Internationale. The UCI adapts its rules on the participation of transgender athletes in international competitions. Online; 2023.
15. Hamilton B, Brown A, Montagner-Moraes S, Comeras-Chueca C, Bush PG, Guppy FM, et al. Strength, power and aerobic capacity of transgender athletes: a cross-sectional study. Br J Sports Med 2024;58: 586–97.
16. Hamilton B, Comeras-Chueca C, Bush P, Seal L, Guppy F, Pitsiladis Y. Sporting performance of athletes of the gender spectrum: a cross-sectional comparison study protocol. SportRxiv 2022;1.
17. National Health Service. Testosterone; 2022. [cited 2023 September, 25th]; Available from: https://www.nbt.nhs.uk/severn-pathology/requesting/test-information/testosterone.
18. Patel AJ, Wesley R, Leitman SF, Bryant BJ. Capillary versus venous haemoglobin determination in the assessment of healthy blood donors. Vox Sang 2013;104:317–23.
19. Popović ZB, Thomas JD. Assessing observer variability: a user's guide. Cardiovasc Diagn Ther 2017;7:317.
20. Badawy MM, Muaidi QI. Cardio respiratory response: validation of new modifications of Bruce protocol for exercise testing and training in elite Saudi triathlon and soccer players. Saudi J Biol Sci 2019;26:105–11.
21. Jamovi. The Jamovi project. 2021 [cited 2022 May 9th]; Version 1.6; [Available from: https://www.jamovi.org.
22. British Cycling. Update: transgender and non-binary participation policies; 2023. 26th May 2023 [cited 2024 15th June]; Available from: https://www.britishcycling.org.uk/about/article/20230526-about-bc-static-Update–Transgender-and-Non-Binary-Participation-policies-0.
23. National Health Service. Gender dysphoria; 2020. [cited 2020 29th July]; Available from: https://www.nhs.uk/conditions/gender-dysphoria/.
24. Wiik A, Lundberg T, Rullman E, Andersson D, Holmberg M, Mandić M, et al. Muscle strength, size, and composition following 12 months of gender-affirming treatment in transgender individuals. J Clin Endocrinol Metabol 2020;105. https://doi.org/10.1210/clinem/dgz247.
25. Olson-Kennedy J, Okonta V, Clark LF, Belzer M. Physiologic response to gender-affirming hormones among transgender youth. J Adolesc Health 2018;62:397–401.
26. Wesp LM, Deutsch MB. Hormonal and surgical treatment options for transgender women and transfeminine spectrum persons. Psychiatr Clin 2017;40:99–111.
27. Van Caenegem E, Wierckx K, Taes Y, Schreiner T, Vandewalle S, Toye K, et al. Preservation of volumetric bone density and geometry in trans women during cross-sex hormonal therapy: a prospective observational study. Osteoporosis Int 2015;26:35–47.
28. Scharff M, Wiepjes CM, Klaver M, Schreiner T, T'Sjoen G, den HM. Change in grip strength in trans people and its association with lean body mass and bone density. Endocrine Connections 2019;8: 1020–8.
29. Chidi-Ogbolu N, Baar K. Effect of estrogen on musculoskeletal performance and injury risk. Front Physiol 2019;9:421933.
30. Pittman RN. Oxygen transport in the microcirculation and its regulation. Microcirculation 2013;20:117–37.
31. Schmidt W, Prommer N. Impact of alterations in total hemoglobin mass on VO2max. Exercise and sport sciences reviews. 2010;38:68-75.
32. Gardner SA, Martin TD, Barras M, Jenkins GD, Hahn GA. Power output demands of elite track sprint cycling. Int J Perform Anal Sport 2005;5: 149–54.
33. Atkinson G, Peacock O, St Clair Gibson A, Tucker R. Distribution of power output during cycling: impact and mechanisms. Sports Med 2007;37:647–67.
34. Granier C, Abbiss CR, Aubry A, Vauchez Y, Dorel S, Hausswirth C, et al. Power output and pacing during international cross-country mountain bike cycling. Int J Sports Physiol Perform 2018;13:1243–9.
35. Kordi M, Folland J, Goodall S, Haralabidis N, Maden-Wilkinson T, Sarika PT, et al. Mechanical and morphological determinants of peak power output in elite cyclists. Scand J Med Sci Sports 2020;30:227–37.
36. Kordi M, Folland JP, Goodall S, Menzies C, Patel TS, Evans M, et al. Cycling-specific isometric resistance training improves peak power output in elite sprint cyclists. Scand J Med Sci Sports 2020;30:1594–604.
37. Boussana A, Hue O, Matecki S, Galy O, Ramonatxo M, Varray A, et al. The effect of cycling followed by running on respiratory muscle performance in elite and competition triathletes. Eur J Appl Physiol 2002;87:441–7.
38. Coyle EF, Feltner ME, Kautz SA, Hamilton MT, Montain SJ, Baylor AM, et al. Physiological and biomechanical factors associated with elite endurance cycling performance. Med Sci Sports Exerc 1991;23:93–107.
39. Lamberts RP. Predicting cycling performance in trained to elite male and female cyclists. Int J Sports Physiol Perform 2014;9:610–4.
40. Lounana J, Campion F, Noakes TD, Medelli J. Relationship between % HRmax, %HR reserve, %VO2max, and %VO2 reserve in elite cyclists. Med Sci Sports Exerc 2007;39:350–7.
41. Schneider DA, Lacroix KA, Atkinson GR, Troped PJ, Pollack J. Ventilatory threshold and maximal oxygen uptake during cycling and running in triathletes. Med Sci Sports Exerc 1990;22:257–64.
42. Støren Ø, Bratland-Sanda S, Haave M, Helgerud J. Improved VO2max and time trial performance with more high aerobic intensity interval training and reduced training volume: a case study on an elite national cyclist. J Strength Cond Res 2012;26:2705–11.
43. Warburton DE, Gledhill N, Jamnik VK, Krip B, Card N. Induced hypervolemia, cardiac function, VO2max, and performance of elite cyclists. Med Sci Sports Exerc 1999;31:800–8.
44. Rønnestad BR, Hansen J, Hollan I, Ellefsen S. Strength training improves performance and pedaling characteristics in elite cyclists. Scand J Med Sci Sports 2015;25:e89–8.
45. Sunde A, Støren Ø, Bjerkaas M, Larsen MH, Hoff J, Helgerud J. Maximal strength training improves cycling economy in competitive cyclists. J Strength Condit Res 2010;24:2157–65.
46. Rønnestad BR, Hansen J, Nygaard H. 10 weeks of heavy strength training improves performance-related measurements in elite cyclists. J Sports Sci 2017;35:1435–41.
47. Cesanelli L, Ylaite B, Ja FL, Volungevičius G, Lagoute T, Venckunas T. Cycling through the ranks: a cross-sectional analysis of endurance, strength and body composition indicators in junior, elite, and amateur competitive road cyclists. J Sports Med Phys Fit 2023;64:371–82.
48. Lindberg K, Solberg P, Bjørnsen T, Helland C, Rønnestad B, Frank MT, et al. Strength and power testing of athletes: a

multicenter study of test–retest reliability. Int J Sports Physiol Perform 2022;17:1103–10.
49. Paton CD, Hopkins WG. Tests of cycling performance. Sports Med 2001; 31:489–96.
50. Canivel R, Wyatt FB, Prajapati K, Almeida N, Patel S, Patel D, et al. The influence of handgrip and pedal cadence during sustained cycling power outputs. Int J Exercise Sci: Conf Proc 2010;2010:35.
51. Handelsman DJ, Hirschberg AL, Bermon S. Circulating testosterone as the hormonal basis of sex differences in athletic performance. Endocr Rev 2018;39:803–29.
52. Hopker J, Jobson S, Carter H, Passfield L. Cycling efficiency in trained male and female competitive cyclists. J Sports Sci Med 2010;9:332.
53. Lewis MD, Young WB, Knapstein L, Lavender A, Talpey SW. Countermovement jump variables not tensiomyography can distinguish between sprint and endurance focused track cyclists. Biol Sport 2022;39:67–72.
54. Herbert P, Sculthorpe N, Baker JS, Grace FM. Validation of a six second cycle test for the determination of peak power output. Res Sports Med 2015;23:115–25.