# Strength, power and aerobic capacity of transgender athletes: a cross-sectional study

Blair Hamilton [1,2] Andrew Brown [2] Stephanie Montagner-Moraes [2] Cristina Comeras-Chueca [3] Peter G Bush [2] Fergus M Guppy [4] Yannis P Pitsiladis [5,6]

[1]School of Sport and Health Sciences, University of Brighton, Brighton, UK
[2]School of Applied Sciences University, Brighton, UK
[3]Health Sciences Faculty, Universidad San Jorge, Zaragoza, Spain
[4]Heriot-Watt University, Edinburgh, UK
[5]Department of Movement, Human and Health Sciences, University of Rome 'Foro Italico', Rome, Italy
[6]Department of Sport, Physical Education and Health, Hong Kong Baptist University, Hong Kong, Hong Kong SAR

**Correspondence to**
Professor Yannis P Pitsiladis, Department of Sport, Physical Education and Health, Hong Kong Baptist University, Hong Kong, Hong Kong SAR; ypitsiladis@hkbu.edu.hk

Accepted 13 March 2024

## ABSTRACT

**Objective** The primary objective of this cross-sectional study was to compare standard laboratory performance metrics of transgender athletes to cisgender athletes.

**Methods** 19 cisgender men (CM) (mean±SD, age: 37±9 years), 12 transgender men (TM) (age: 34±7 years), 23 transgender women (TW) (age: 34±10 years) and 21 cisgender women (CW) (age: 30±9 years) underwent a series of standard laboratory performance tests, including body composition, lung function, cardiopulmonary exercise testing, strength and lower body power. Haemoglobin concentration in capillary blood and testosterone and oestradiol in serum were also measured.

**Results** In this cohort of athletes, TW had similar testosterone concentration (TW 0.7±0.5 nmol/L, CW 0.9±0.4 nmol/), higher oestrogen (TW 742.4±801.9 pmol/L, CW 336.0±266.3 pmol/L, p=0.045), higher absolute handgrip strength (TW 40.7±6.8 kg, CW 34.2±3.7 kg, p=0.01), lower forced expiratory volume in 1 s:forced vital capacity ratio (TW 0.83±0.07, CW 0.88±0.04, p=0.04), lower relative jump height (TW 0.7±0.2 cm/kg; CW 1.0±0.2 cm/kg, p<0.001) and lower relative $\dot{V}O_2$max (TW 45.1±13.3 mL/kg/min/, CW 54.1±6.0 mL/kg/min, p<0.001) compared with CW athletes. TM had similar testosterone concentration (TM 20.5±5.8 nmol/L, CM 24.8±12.3 nmol/L), lower absolute hand grip strength (TM 38.8±7.5 kg, CM 45.7±6.9 kg, p=0.03) and lower absolute $\dot{V}O_2$max (TM 3635±644 mL/min, CM 4467±641 mL/min p=0.002) than CM.

**Conclusion** While longitudinal transitioning studies of transgender athletes are urgently needed, these results should caution against precautionary bans and sport eligibility exclusions that are not based on sport-specific (or sport-relevant) research.

**WHAT IS ALREADY KNOWN ON THIS TOPIC**

⇒ There is currently a lack of laboratory data on strength, power and $\dot{V}O_2$max from transgender athlete populations.

**WHAT THIS STUDY ADDS**

⇒ This research compares laboratory measures of strength, power and $\dot{V}O_2$max of transgender male and female athletes to their cisgender counterparts.

⇒ Transgender women athletes demonstrated lower performance than cisgender women in the metrics of forced expiratory volume in 1 s:forced vital capacity ratio, jump height and relative $\dot{V}O_2$max.

⇒ Transgender women athletes demonstrated higher absolute handgrip strength than cisgender women, with no difference found relative to fat-free mass or hand size.

**HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY**

⇒ This study provides sport governing bodies with laboratory-based performance-related data from transgender athletes.

⇒ Longitudinal studies are needed to confirm if these results are a direct result of gender affirmation hormone therapy.

⇒ Sports-specific studies are necessary to inform policy-making.

## INTRODUCTION

Transgender athletes can experience conflict between the gender that they were assigned and their experienced gender.[1] The question of integrating transgender athletes into their affirmed gender categories is becoming more prominent, with sports' governing bodies using varied approaches, from bans on transgender women in the female category[2] requiring the reduction of testosterone in the female category for some time[3] to self-identification into the athletes chosen category.[4]

As part of gender affirmation hormone therapy (GAHT), some transgender women undergo testosterone suppression (target ≤1.8 nmol/L[5]) coupled with oestrogen supplementation (target 400–600 pmol/L[5]), while some transgender men undergo testosterone supplementation (National Health Service (NHS, UK) target 15–20 nmol/L,[6] Endocrine Society Target 11–34.7 nmol/L[7]). Testosterone is known to impact sporting performances, with differences in circulating testosterone concentration between cisgender men (CM) and women proposed to explain most of the laboratory-measured differences in sports performance.[8 9] GAHT of transgender men and women alters the body composition of transgender athletes via testosterone-mediated effects on fat-free mass[8] and oestrogens on subcutaneous fat distribution[9] and maintenance of muscle mass.[10] An often-held assumption against transgender women athletes competing in the female category of sport is that transgender women have benefited from a high testosterone concentration from assigned male-at-birth puberty until the administration of GAHT that cannot be mitigated[11] and that cisgender

women competitors are unable to achieve similar benefits naturally.[12] To date, this assumption has yet to be tested and confirmed in transgender athlete cohorts. The low serum testosterone concentrations from an assigned female-at-birth puberty would hypothetically not give transgender men the competitive advantages of higher testosterone concentrations over CM, and this viewpoint is reflected in the current inclusion sports policies for transgender men.[2]

Lab-derived data on a cohort of transgender athletes, as requested in article 6.1b of the International Olympic Committee Framework On Fairness, Inclusion And Non-Discrimination based on Gender Identity and Sex Variations,[4] must be generated to better inform a decision-making process.[13] Therefore, the primary aim of this study was to compare cardiorespiratory fitness, strength and body composition of transgender women and men athletes to that of matched cisgender cohorts.

## METHODS
### Study design
This cross-sectional study involved a single visit to the laboratory at the School of Applied Sciences, University of Brighton, UK. Each participant arrived at ~9:00 hours. after an overnight fast and departed from testing at ~15:00 hours. The complete study design can be found in the study protocol, available as a preprint.[14]

### Recruitment
Following ethical approval (ref: 9496), 75 (19 CM, 12 transgender men, 23 transgender women and 21 cisgender women) participants were recruited through social media advertising on Meta Platforms (Facebook and Instagram, Meta Platforms, California, USA) and X (Twitter, California, USA). Following the initial response, all participants were provided with the participant information sheet by email at least 7 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 at least three times per week. 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 transgender athletes must have completed ≥1 year of GAHT, 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.[14] Two cisgender women and one transgender man could not provide blood samples and were consequently excluded from all analyses as their endocrine profiles could not be verified. Furthermore, two transgender women and one cisgender woman were excluded from all analyses due to testosterone concentrations exceeding recommended female testosterone concentrations (2.7 nmol/L[15]).

### Laboratory assessments
#### Blood sampling and analysis
Prior to venous blood sampling, haemoglobin concentration ((Hb)) was sampled via the third drop of a Unistik 3 Comfort lancet (Owen Mumford, 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 than venous blood.[16] 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°C±5°C) for 1 hour and then stored in a fridge (3°C±2°C) for up to 4 hours before being centrifuged (PK 120 centrifuge, ALC, Winchester, Virginia, USA) using a T515 rotor at 1300G for 10 min at 4°C, before storage at −80°C until analysis. Before analysis, the samples were stored between −25°C and −15°C, thawed at room temp 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 8000 e801, Roche Diagnostics, Burgess Hill, UK).

#### Body composition and bone mass
Participants' body mass was measured (OMRON Healthcare, Kyoto, Japan) while participants were lightly dressed, representing clothed body mass. Body composition and bone mass were measured by DXA (Horizon W, Hologic, Massachusetts, USA). Each participant underwent a whole-body, a proximal-femur and a lumbar spine scan. The participant was asked to lie on the scan bed, and the first author (BH) performed all participant placement and scanning for the three scans. Due to inbuilt assumptions of body fat percentage for the head and scanning bed area imitations, whole-body less head data are reported for the whole-body scan. Body mass index (BMI), Fat Mass Index (FMI) and Fat-Free Mass Index (FFMI) were calculated by taking the appropriate mass value and dividing it by height (m$^2$).

#### Lung function
Lung function was measured using a Vitalograph Alpha spirometer (Vitalograph, Kansas, USA) with an antibacterial filter and a nose clip on the bridge of the participant's nose. Each participant was asked to perform the flow-volume-loop spirometry to test forced vital capacity (FVC), forced expiratory volume in 1 s (FEV$_1$) and peak expiratory flow. The test was repeated until a trend of declining performance occurred. The highest numeric value for each metric obtained during a test with the correct procedure was then recorded. The FEV1:FVC ratio was used to assess the presence of obstructed lung function.

#### Strength
Strength was measured using a handgrip dynamometer (TAKEI 5401, TAKEI Scientific Instruments, Japan). The participants' hand sizes were also measured around the metacarpophalangeal joints of both hands prior to testing. Each hand was tested three times in sequential order of left-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 the countermovement jump on a JUM001 Jump Mat (Probotics, Alabama, USA). During the test, if the participant went beyond 45° of countermovement or the hands came off the hips, the test would be 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 95T 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 (BH) to avoid interinvestigator variability.[17] The ramp protocol of Badawy and Muaidi treadmill $\dot{V}O_2$max testing[18] was used for each $\dot{V}O_2$max test, involving gradual increases in speed every 3 min at a 1% incline. One cisgender man and two cisgender women were excluded from the analysis as they did not meet the required respiratory exchange ratio of ≥1.1 to classify the test as maximal (cisgender men (CM), n=18, transgender men (TM), n=11; cisgender women (CW) n=16; transgender women (TW), n=21).

## Statistical analysis

Data meeting the assumptions of normality and homogeneity of variance were analysed using a one-way analysis of variance along with Bonferroni post hoc corrections for pairwise comparisons. Data not meeting the parametric assumptions were compared using a Kruskal-Wallis ANOVA with Dwass-Steel-Critchlow-Fligner post hoc test for multiple comparisons, with an alpha level of 0.05 for both types of analysis. Statistical analysis and presentation are consistent with the checklist for statistical assessment of medical papers statement[19] found in online supplemental files 1–3 at Hamilton *et al*, The Strength, Power and Aerobic Capacity of Transgender Athletes: A Cross-Sectional Study (Internet). OSF; 2023. Available from: osf.io/a684b.

## Equity, diversity and inclusion statement

The author group consists of early (n=3) and senior researchers (n=3) from different disciplines and universities (n=3). Two authors are members of a marginalised community; the lead early-career author is a transgender woman, and one of the junior authors is a woman from the global south. Our study population included male and female transgender athletes from within the UK participating in competitive sports in comparison with cisgender male and female athletes participating in competitive sports; thus, findings may not be generalisable to global athlete populations.

## RESULTS
### Participant characteristics

Our investigation encompassed a diverse cohort of athletes, with endurance sports representing 36% of the athlete cohort, team sports representing 26% and power sports representing 38%. No cisgender or transgender athletes were competing at the national or international level. No significant differences were found in age ($F_{(3-66)}$=1.9, p=0.14), training intensity score

($\chi^2_{(3)}$=1.2, p=0.76) or length of GAHT between transgender men and transgender women ($F_{(1-32)}$=0.5, p=0.48, table 1).

Significant differences were found in height ($F_{(3-66)}$=21.3, p<0.001), with CM being taller than transgender men ($t_{(66)}$=3.8, p=0.002, table 1). Transgender women were also taller than transgender men ($t_{(66)}$=3.3, p=0.01) and cisgender women ($t_{(66)}$=6.5, p<0.001, table 1).

Significant differences were found in clothed mass ($F_{(3-66)}$=10.6, p<0.001), with transgender women found to be heavier than cisgender women ($t_{(66)}$=5.6, p<0.001, table 1).

BMI was also significantly different between the groups in this Study ($F_{(3-66)}$=3.6, p=0.02). Transgender women athletes demonstrated higher BMI than cisgender women ($t_{(66)}$=2.9, p=0.03, table 1), with no further differences observed.

### Blood measures

There was a significant gender effect on testosterone concentration ($F_{(3-66)}$=80.6, p<0.001). CM (20.5±5.8 nmol/L) exhibited significantly higher total testosterone concentration than transgender women (0.7±0.5 nmol/L, $t_{(66)}$= 11.1, p<0.001, figure 1A). Transgender men (24.8±12.3 nmol/L) had elevated total testosterone concentration compared with transgender women ($t_{(66)}$=11.3) and cisgender women (0.9±0.4 nmol/L, $t_{(66)}$=10.9, both p<0.001, figure 1A). There was also a significant gender effect on oestradiol concentration ($F_{(3-66)}$=7.6, p<0.001), with transgender women (742.4±801.9 pmol/L) showing higher oestradiol concentration than CM (104.3±24.8 pmol/L, $t_{(66)}$=4.4 p<0.001), cisgender women (336.0±266.3 pmol/L, $t_{(66)}$=2.7, p=0.045) and transgender men (150.2±59.4 pmol/L, $t_{(66)}$=3.4, p=0.01, figure 1B).

Transgender women's total testosterone concentration (0.7±0.5 nmol/L) falls within the recommendations for GAHT of ≤1.8 nmol/L,[5] and oestradiol concentrations (742.4±801.9 pmol/L) exceed the target of 400–600 pmol/L[5] for GAHT. Transgender men's testosterone concentration (24.8±12.3 nmol/L) exceeds the NHS target of 15–20 nmol/L[6] for GAHT, although not the Endocrine Society target of 11–34.7 nmol/L.[7]

Differences were reported in (Hb) concentration ($F_{(3-66)}$=3.3, p=0.03), although a post hoc Bonferroni analysis showed no differences between the various groups (CM 142.8±12.5 g/L; transgender men, 143.3±19.5 g/L; transgender women, 131.3±14.2 g/L; cisgender women, 133.3±12.7 g/L; figure 1C).

### DXA assessment
#### Fat mass

There was a significant gender effect on percentage fat mass ($F_{(3-66)}$=6.6, p<0.001), with CM having a lower percentage fat

**Table 1** Participant characteristics

| | Cisgender men (n=19) | Transgender men (n=12) | Cisgender women (n=21) | Transgender women (n=23) |
|---|---|---|---|---|
| Age (years) | 37±9 | 34±7 | 30±9 | 34±10 |
| Training intensity | 7 (IQR 2) | 7 (IQR 2) | 7 (IQR 2) | 7 (IQR 2) |
| Length of GAHT (years) | – | 4±5 | – | 6±4 |
| Height (m) | 1.8±0.1* | 1.7±0.1†‡ | 1.6±0.1 | 1.8±0.1* |
| Clothed mass (kg) | 76.4±7.7* | 73.1±12.1 | 60.6±6.6 | 83.9±19.9* |
| BMI (kg/m²) | 23.6±1.8 | 25.7±3.9 | 22.5±1.9 | 26.2±6.0* |

Data represents mean±SD or median (IQR).
*Denotes significantly different from cisgender women.
†Denotes significantly different from cisgender Men.
‡Denotes significantly different from transgender women.
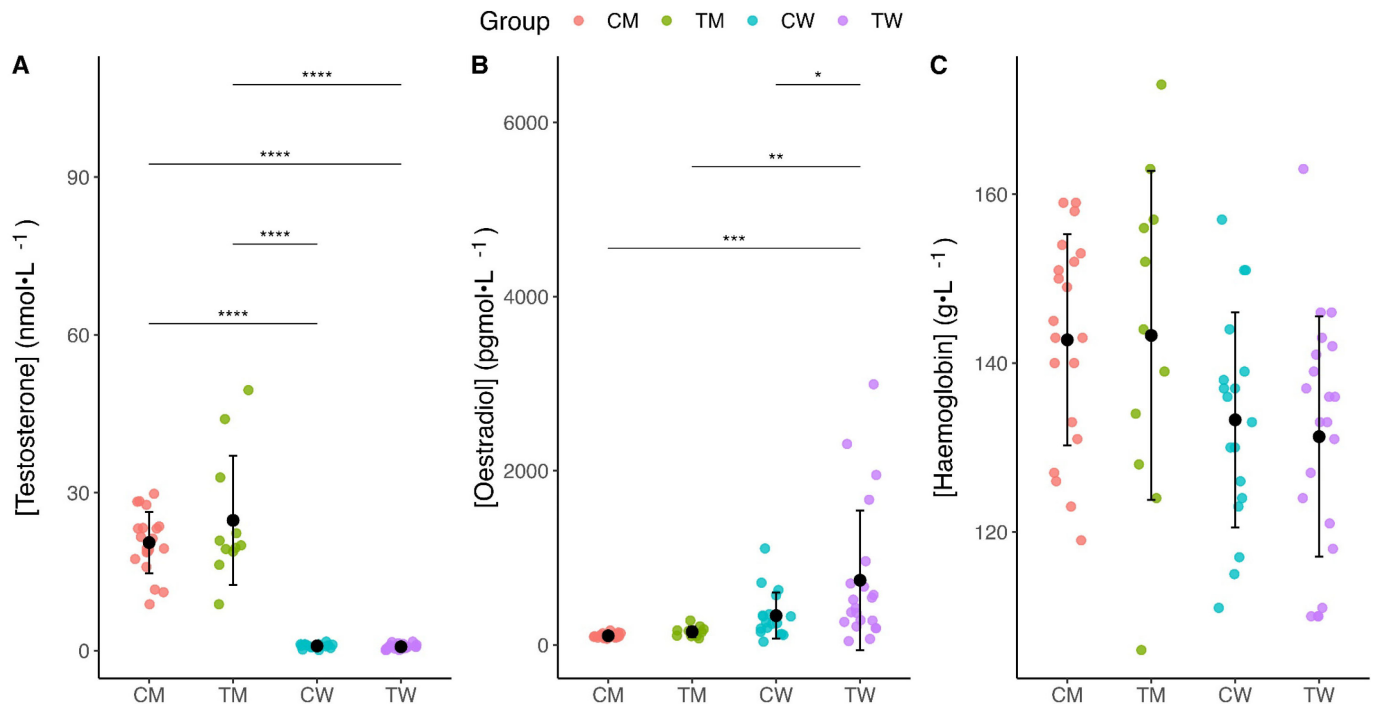BMI, body mass index; GAHT, gender affirmation hormone therapy.

**Figure 1** Blood measures. (A) testosterone; (B) oestradiol; (C) haemoglobin. *p<0.05, **p<0.01, ***p<0.001, ****p<0.0001. CM, cisgender men; CW, cisgender women; TM, transgender men; TW, transgender women.

mass than transgender women ($t_{(66)}=-4.4$, p<0.001, table 2), with no other differences observed. A significant gender effect was also found on absolute fat mass ($F_{(3–66)}=6.6$, p<0.001), with transgender women having more absolute fat mass than CM ($t_{(66)}=3.8$, p=0.002, table 2) and cisgender women ($t_{(66)}=3.9$, p=0.002, table 2). FMI measures revealed a gender effect ($F_{(3–66)}=5.2$, p=0.003), with transgender women found to have a higher FMI than CM ($t_{(66)}=3.7$, p=0.002, table 2) and cisgender women ($t_{(66)}=2.8$, p=0.04, table 2). Android to gynoid ratio analysis ($F_{(3–66)}=10.7$, p<0.001) revealed cisgender women had a lower ratio than transgender men ($t_{(66)}=-2.9$, p=0.03, table 2), and transgender women ($t_{(66)}=-4.0$, p=0.001, table 2).

Fat-free mass
There was a significant gender effect on absolute fat-free mass ($F_{(3–66)}=24.6$, p<0.001), with CM having significantly more absolute fat-free mass than transgender men ($t_{(66)}=3.5$, p=0.01, table 2). Cisgender women had less absolute fat-free mass than transgender men ($t_{(66)}=-3.5$, p=0.01, table 2) and transgender women ($t_{(66)}=-6.6$, p<0.001, table 2). No gender-based effects were found when comparing transgender women athletes to cisgender women athletes, or transgender men athletes to CM athletes in the measures of FFMI ($F_{(3–66)}=3.7$, p=0.02, table 2), percentage of fat-free mass ($F_{(3–66)}=2.4$, p=0.08, table 2) or appendicular FFMI ($F_{(3–66)}=5.1$, p=0.003, table 2).

Bone mineral density
No differences in whole-body bone mineral density (BMD) ($F_{(3–66)}=4.6$, p=0.01), femoral neck BMD ($F_{(3–66)}=1.0$, p=0.39, table 2), total proximal femur BMD ($F_{(3–66)}=1.5$, p=0.22, table 2) or total lumbar spine BMD ($F_{(3–66)}=0.4$, p=0.78, table 2) were found between transgender athletes and cisgender athletes (table 2).

Lung function
Lung function data for all groups can be found in table 2. $FEV_1$ had an effect of gender ($F_{(3–66)}=14.7$, p<0.001), with CM having greater $FEV_1$ than transgender men ($t_{(66)}=4.5$, p<0.001, figure 2A). Transgender women also had greater $FEV_1$ than cisgender women ($t_{(66)}=4.2$, p<0.001, figure 2A) and transgender men ($t_{(66)}=2.9$, p=0.03, figure 2A). There was a similar effect of gender on FVC ($F_{(3–66)}=21.6$, p<0.001, figure 2B), with CM having greater FVC than transgender men ($t_{(66)}=5.2$, p<0.001, figure 2B). Transgender women also had greater FVC than cisgender women ($t_{(66)}=5.6$, p<0.001, figure 2B) and transgender men ($t_{(66)}=4.0$, p=0.001, figure 2B). A significant effect of gender was also seen on the $FEV_1$:FVC ratio ($F_{(3–66)}=3.3$, p=0.03 figure 2C), with transgender women showing a reduced $FEV_1$:FVC ratio compared with cisgender women ($t_{(66)}=-2.8$, p=0.04, figure 2C) with no differences observed in transgender or CM. Peak expiratory flow ($F_{(3–66)}=5.5$, p=0.002) had a minor gender-based effect, with cisgender women having lower peak expiratory flow than transgender women ($t_{(66)}-3.0$, p=0.02, figure 2D).

Handgrip strength
Handgrip strength data can be found in table 2. Absolute right handgrip strength was significantly different between the groups ($F_{(3–66)}=10.5$, p<0.001), with CM having greater absolute right handgrip strength than transgender men ($t_{(66)}=2.9$, p=0.03, figure 3B). Transgender women also had greater absolute right handgrip strength than cisgender women ($t_{(66)}=3.2$, p=0.01, figure 3B). Absolute left handgrip was significantly different between the groups ($F_{(3–66)}=8.6$, p<0.001). However, no differences were found between transgender and cisgender athletes (figure 3A). There was no effect on the right ($F_{(3–66)}=0.8$, p=0.53, figure 3F) or left-hand grip strength ($F_{(3–66)}=1.0$, p=0.39, figure 3E) relative to fat-free mass, nor was there any gender

Hamilton B, *et al*. *Br J Sports Med* 2024;**0**:1–12. doi:10.1136/bjsports-2023-108029

**Table 2** Body composition, BMD data, handgrip strength, lower anaerobic power and cardiopulmonary exercise testing

| | Cisgender men | Transgender men | Cisgender women | Transgender women |
|---|---|---|---|---|
| **Fat mass** | | | | |
| Fat mass (%) | 21.5±5.9 | 27.9±7.4 | 26.6±6.0 | 31.5±9.1* |
| Absolute fat mass (kg) | 15.4±5.5 | 19.3±8.1 | 15.0±4.6 | 25.8±13.2†* |
| Fat Mass Index (kg/m$^2$) | 4.8±1.6 | 6.8±2.8 | 5.5±1.6 | 8.2±4.5†* |
| Android to gynoid ratio | 1.05±0.17 | 0.95±0.14† | 0.78±0.08* | 0.97±0.17† |
| **Fat-free mass** | | | | |
| Fat-free mass (%) | 73±10 | 66±6 | 65±15 | 67±6 |
| Absolute fat-free mass (kg) | 55.2±4.7 | 47.8±5.6* | 40.3±3.8* | 52.4±7.6† |
| Fat-free mass index (kg/m$^2$) | 17.1±2.0 | 16.9±1.9 | 15.0±1.2* | 16.4±2.7 |
| Appendicular fat-free mass index (kg/m$^2$) | 8.6±1.1 | 8.2±1.2 | 7.2±0.6* | 8.0±1.3 |
| **BMD (g/cm$^2$)** | | | | |
| Whole body less head | 1.22±0.10 | 1.15±0.10 | 1.10±0.08* | 1.17±0.13 |
| Femoral neck | 0.95±0.14 | 0.93±0.14 | 0.87±0.11 | 0.92±0.13 |
| Total proximal femur | 1.07±0.11 | 1.05±0.13 | 0.99±0.10 | 1.03±0.14 |
| Total lumbar spine | 1.08±0.12 | 1.11±0.14 | 1.08±0.12 | 1.06±0.14 |
| **Lung function** | | | | |
| FEV$_1$ (L) | 4.5±0.6 | 3.6±0.5‡* | 3.5±0.4‡* | 4.2±0.6 |
| FVC (L) | 5.4±0.7 | 4.1±0.6‡* | 3.9±0.5‡* | 5.1±0.6 |
| FEV$_1$:FVC ratio | 0.84±0.05 | 0.87±0.04 | 0.88±0.04‡ | 0.83±0.07 |
| PEF (L/min$^1$) | 518±92† | 427±98 | 412±79 | 506±113† |
| **Handgrip strength** | | | | |
| Absolute right handgrip (kg) | 45.7±6.9 | 38.8±7.5‡* | 34.3±3.8‡* | 40.7±6.8 |
| Relative right handgrip to hand size (kg/cm) | 0.1±0.0 | 0.1±0.0 | 0.1±0.0 | 0.1±0.0 |
| Relative right handgrip to fat-free mass (kg/kg$^{FFM}$) | 0.8±0.1 | 0.8±0.1 | 0.8±0.2 | 0.9±0.1 |
| **Lower body anaerobic power** | | | | |
| Absolute countermovement jump (cm) | 46.4±6.7 | 43.5±7.9 | 40.7±5.8 | 36.4±7.9* |
| Relative countermovement jump to fat-free mass (cm/kg$^{FFM}$) | 0.8±0.1† | 0.9±0.2‡ | 1.0±0.2‡ | 0.7±0.2 |
| Absolute peak power (W) | 6810±681† | 6560±712† | 5655±588 | 6486±865† |
| Relative peak power to fat-free mass (W/kg$^{FFM}$) | 124±16 | 138±13 | 141±14* | 126±22 |
| Absolute average power (W) | 1078±364† | 1036±397† | 580±311 | 899±460 |
| Relative average power to fat-free mass (W/kg$^{FFM}$) | 20±7 | 21±7 | 14±7 | 17±9 |
| **Cardiopulmonary exercise testing** | | | | |
| Absolute VO$_2$max (mL/min) | 4467±641 | 3635±644* | 3226±450* | 3682±551* |
| Relative VO$_2$max to mass (mL/kg/min) | 59.1±8.4‡ | 50.1±11.5 | 54.1±6.0‡ | 45.1±7.6 |
| Relative VO$_2$max to FFM (mL/kg$^{FFM}$/min) | 81.1±14.4 | 76.2±12.0 | 80.0±8.8 | 71.7±15.2 |
| Anaerobic threshold (%VO$_2$max) | 88.1±8.7 | 85.2±6.1 | 87.3±6.3 | 85.1±6.2 |

Data represent mean±SD.
Data from transgender and cisgender athletes.
*Denotes significantly different from cisgender men.
†Denotes significantly different from cisgender women.
‡Denotes significantly different from transgender women.
BMD, bone mineral density; VO$_2$max, maximal O$_2$ uptake.;

effect on the right ($F_{(3-66)}$=1.6, p=0.20, figure 3D) or left-hand grip-strength ($F_{(3-66)}$=2.1, p=0.11) relative to hand size.

## Lower body anaerobic power

Lower body anaerobic power data are shown in table 2. Gender had a significant effect on absolute countermovement jump height ($F_{(3-66)}$=7.2, p<0.001), with CM having greater absolute jump height than transgender women ($t_{(66)}$=4.5, p<0.001, figure 4A). A significant effect of gender was found in countermovement jump height relative to fat-free mass ($F_{(3-66)}$=10.1, p<0.001, figure 4B), with transgender women found to have lower countermovement jump height relative to fat-free mass than both cisgender women ($t_{(66)}$=−5.3, p<0.001) and transgender men ($t_{(66)}$=−3.2, p=0.01, figure 4B).

There was a significant difference in absolute peak power ($F_{(3-66)}$=8.7, p<0.001), with cisgender women having reduced peak power compared with transgender men ($t_{(66)}$=−3.3, p=0.01) and transgender women ($t_{(66)}$=−3.6, p=0.004, figure 4C). Peak power relative to fat-free mass had a more negligible gender effect ($F_{(3-66)}$=4.2, p=0.01), with no difference in peak power relative to fat-free mass found between transgender and cisgender athletes (figure 4D).

There was a significant gender effect of absolute average power ($F_{(3-66)}$=5.9, p=0.001), with cisgender women having reduced absolute average power compared with transgender men ($t_{(66)}$=−3.1, p=0.02, figure 4E). There was no effect of gender on average power relative to fat-free mass ($F_{(3-66)}$=2.6, p=0.06, figure 4F).

## Cardiopulmonary exercise testing

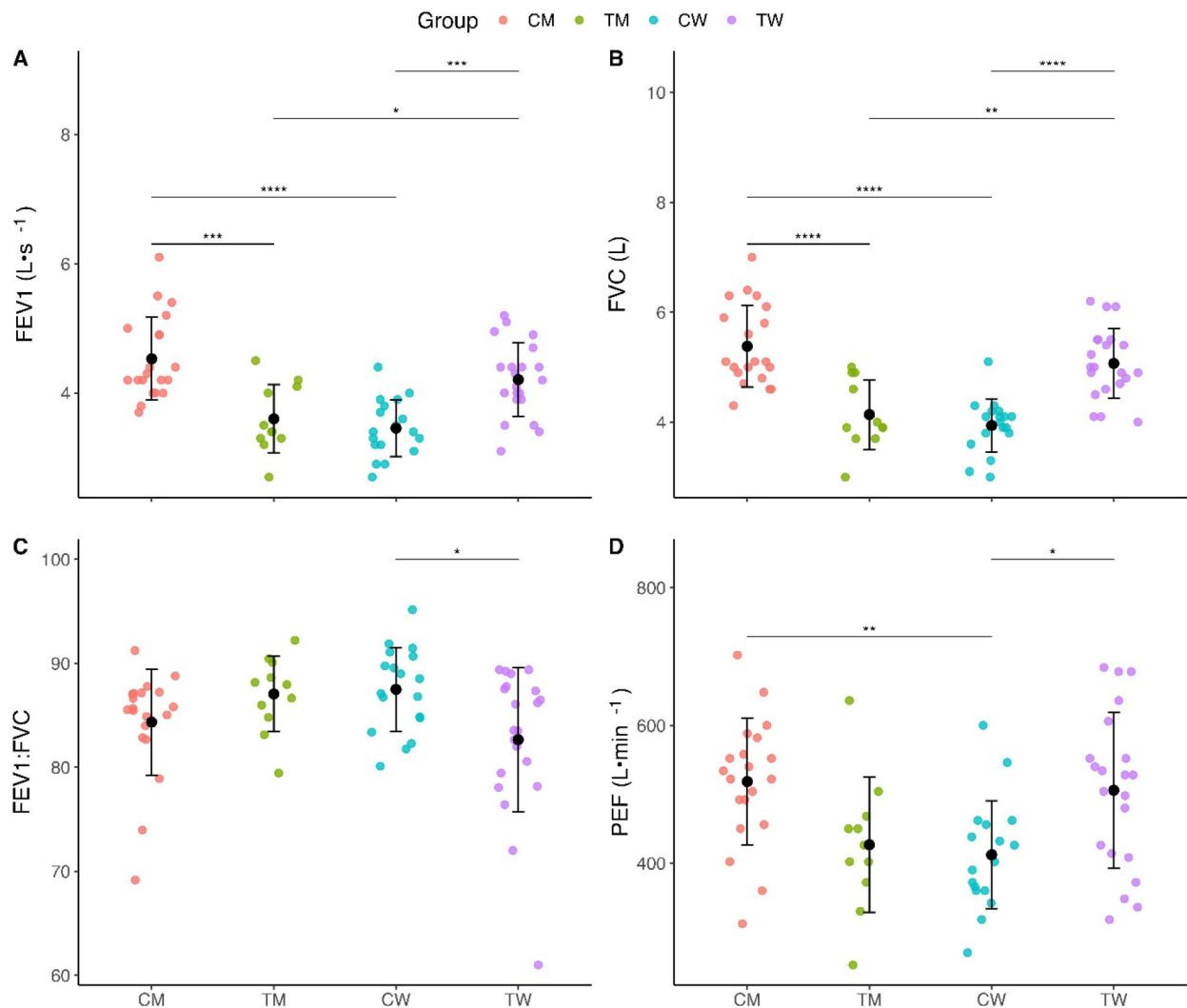Cardiopulmonary exercise testing data are shown in table 2. A significant effect of gender was found on absolute V̇O$_2$max

**Figure 2** Lung function measures. (A) Forced rxpiratory volume in 1 s (FEV$_1$); (B) forced vital capacity (FVC) (C) modified Tiffeneau-Pinelli Index (FEV$_1$:FVC); (D) peak expiratory flow (PEF). *p<0.05, **p<0.01, ***p<0.001, ****p<0.0001. CM, cisgender men; CW, cisgender women; TM, transgender men; TW, transgender women.

($F_{(3-62)}$=14.1, p<0.001) with CM having greater absolute $\dot{V}O_2$max than transgender men ($t_{(66)}$=3.8, p=0.002, figure 5A) and transgender women ($t_{(66)}$=4.3, p<0.001, figure 5A). Relative $\dot{V}O_2$max to body mass also showed a significant gender effect ($F_{(3-62)}$=9.8, p<0.001) with transgender women having lower relative $\dot{V}O_2$max than CM ($t_{(66)}$=−5.3, p<0.001, figure 5B) and cisgender women ($t_{(66)}$=−3.3, p=0.01, figure 5B). No significant gender effect was found on the measure of $\dot{V}O_2$max relative to fat-free mass ($F_{(3-62)}$=2.0, p=0.12).

Gender affected the absolute anaerobic threshold ($F_{(3-62)}$=14.1, p<0.001), with cisgender (3924±628 mL/min) men having a higher absolute anaerobic threshold than transgender men (3089±546 mL/min, $t_{(66)}$=4.2, p<0.001, figure 5C), and transgender women (3122±438 mL/min, $t_{(66)}$=4.8, p<0.001, figure 5C). No significant gender effect was found on the measure of anaerobic threshold as a percentage of $\dot{V}O_2$max ($F_{(3-62)}$=0.8, p=0.51, figure 5D). A gender effect was also seen on the anaerobic threshold relative to body mass ($F_{(3-62)}$=10.7, p<0.001), with transgender women (38.3±6.6 mL/kg/min) showing a lower relative anaerobic threshold than both cisgender women (47.2±6.1 mL/kg/min, $t_{(66)}$=−3.3, p=0.01, figure 5E) and CM (52.2±9.5 mL/kg/min, $t_{(66)}$=−5.4, p<0.001, figure 5E). CM also showed a higher relative anaerobic threshold than transgender

men (42.1±9.9 mL/kg/min, $t_{(66)}$=3.3, p=0.01, figure 5E). Anaerobic threshold relative to fat-free mass also had a small gender effect ($F_{(3-62)}$=3.2, p=0.03), with transgender women (60.8±12.2 mL/kg$^{FFM}$/min) having a lower anaerobic threshold relative to fat-free mass than CM (71.2±13.3 mL/kg$^{FFM}$/min, $t_{(66)}$=−2.8, p=0.045, figure 5F).

## DISCUSSION

The results presented in this study provide valuable insights into laboratory-based performance-related metrics of gender-diverse athletes participating in competitive sports. Given the primary aim of GAHT,[20] it is noteworthy that although this study is cross-sectional in design, transgender women's oestradiol was higher than that of cisgender women (figure 1B). The presence of outliers affecting transgender women's oestrogen concentration (figure 1B) is evident. This underscores that transgender women in this cohort of athletes exhibit a distinct endocrine profile from CM and share a similar endocrine profile with cisgender women, whom many transgender women aim to integrate into a sporting category. One of the most noticeable disparities between gender groups was in height and mass (table 1), with CM and transgender women
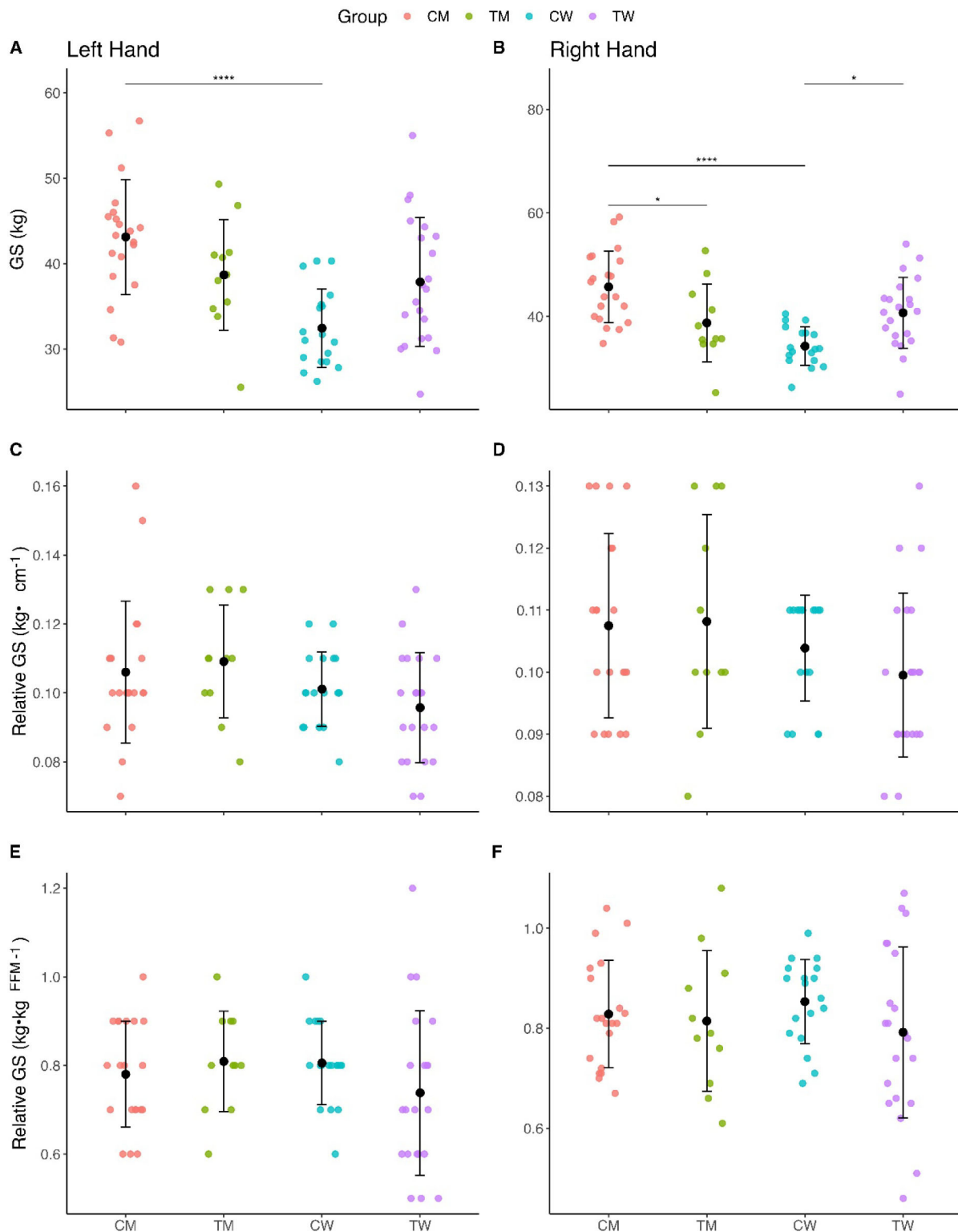
**Figure 3** Absolute and relative handgrip strength (GS) measures. (A) Absolute strength (right hand); B) Absolute strength (left hand) (C) relative strength to hand size (right hand); (D) relative strength to hand size (left hand); (E) relative strength to fat-free mass (FFM) (right hand); (F) relative strength to fat-free mass (left hand). *p<0.05, ***p<0.001, ****p<0.0001. CM, cisgender men; CW, cisgender women; TM, transgender men; TW, transgender women.

being taller and heavier than their cisgender and transgender counterparts (table 1). Body composition measures (fat mass % and fat-free mass %, table 2) between transgender women and cisgender women found no difference. However, transgender women are, on average as a cohort taller and heavier.

In this cohort, the average difference in haemoglobin (Hb) between cisgender women and CM athletes was 7% (figure 1C), lower than previously described (12%[8]). Notably, the (Hb) profiles of all the athlete groups were not significantly different, concurring with earlier research[21] and contradicting research in
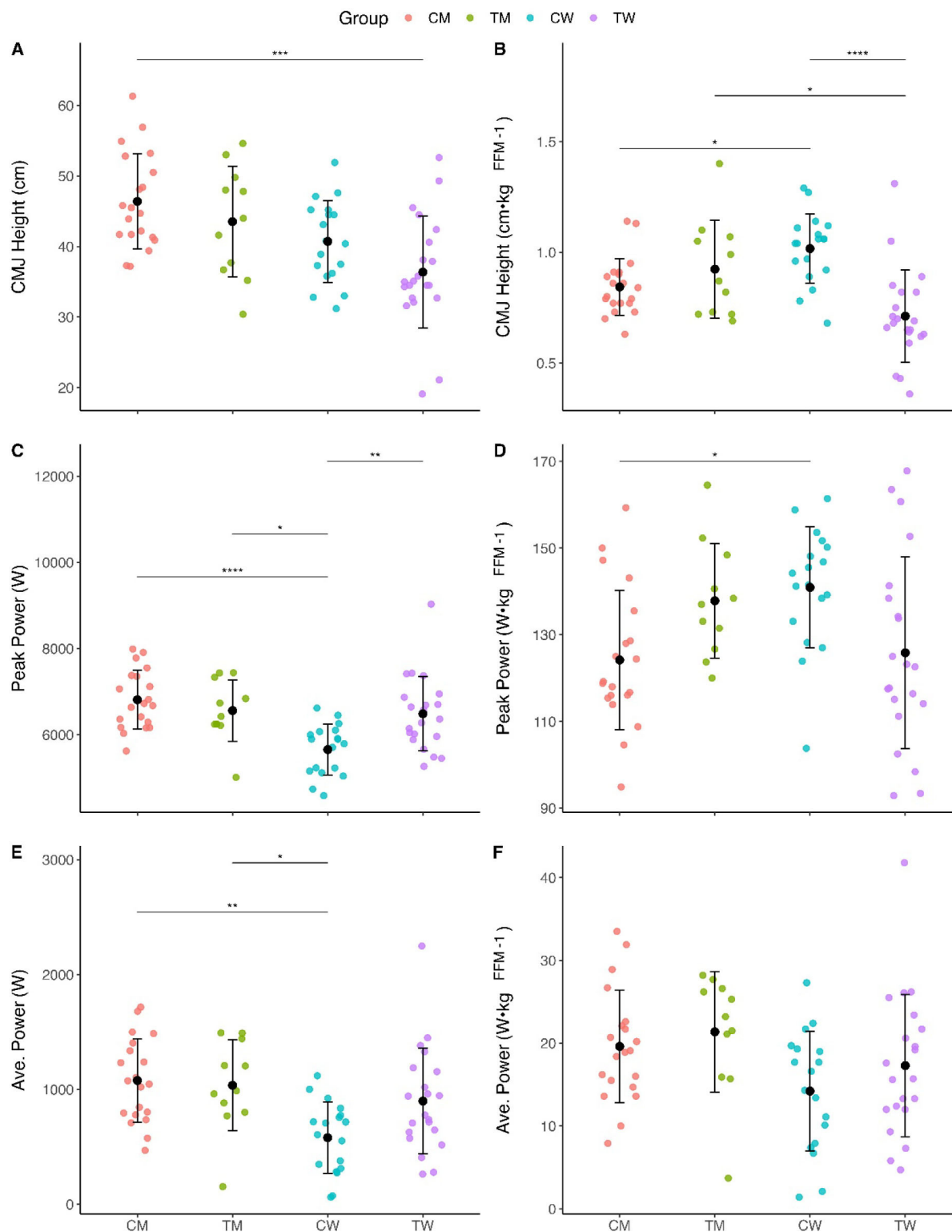
**Figure 4** Absolute and relative anaerobic power measures. (A) Absolute CMJ height; B) Relative CMJ height to fat-free mass (FFM); (C) absolute peak power; (D) relative peak power to FFM; (E) absolute average power; (F) relative average power to FFM. *p<0.05, **p<0.01, ***p<0.001, ****p<0.0001. CM, cisgender men; CMJ, Counter Movement Jump; CW, cisgender women; TM, transgender men; TW, transgender women.

sedentary populations.[22] (Hb) is crucial in $O_2$ transport[23] and vital for endurance sports performance,[24] with $O_2$ delivery to the tissues a limiting factor in $\dot{V}O_2$max attainment.[25] The lack of differences in (Hb) is consistent with the lack of observed difference in absolute $\dot{V}O_2$max between transgender women, transgender men and cisgender women in this cohort. However, as

cardiac output, the most crucial variable influencing $\dot{V}O_2$max[25] was not assessed in the present study, a more comprehensive mechanistic explanation for the similar maximal aerobic capacity between groups cannot be provided.

No differences in BMD were observed between transgender and cisgender women athletes in this study (table 2), despite
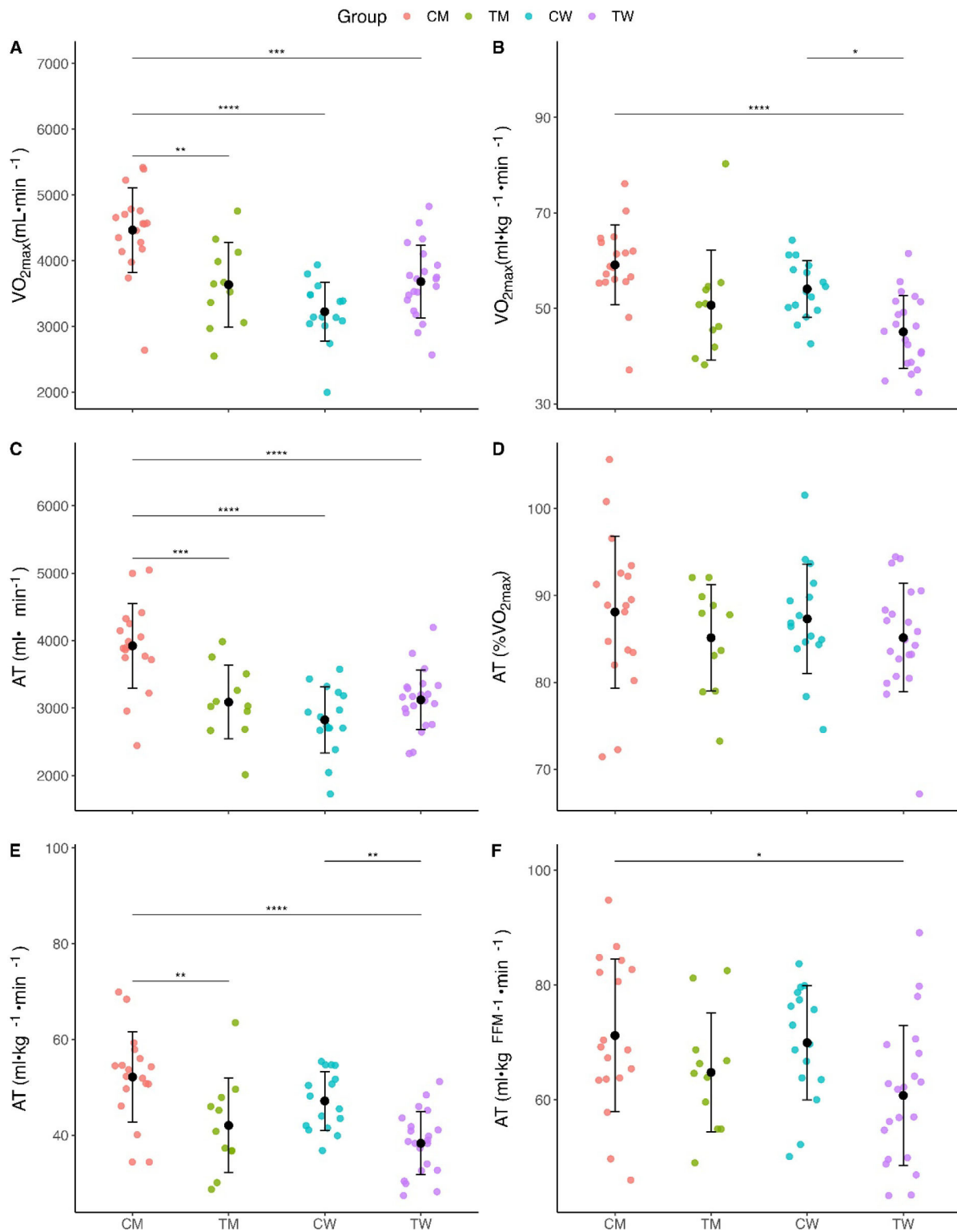
**Figure 5** Absolute and relative cardiopulmonary exercise testing measures. (A) Absolute $VO_{2max}$; (B) relative $VO_{2max}$ to body weight; (C) absolute anaerobic threshold (AT); (D) anaerobic threshold (%$VO_{2max}$); (E) relative anaerobic threshold relative to body mass; (F) AT relative to at-free mass (FFM). *$p<0.05$, **$p<0.01$, ***$p<0.001$, ****$p<0.0001$. CM, cisgender men; CW, cisgender women; TM, transgender men; TW, transgender women.

prior research hypothesising that transgender women athletes have a significant BMD advantage over cisgender women.[11] The sample size for each gender was n<30 participants and may be insufficient to characterise BMD differences reliably. Exercise has been shown to have a protective effect on BMD in CM[26] and CW,[27] and our results suggest a protective effect of exercise in transgender women, given that there is evidence of low BMD in transgender women with low weekly sports activity.[28] Nevertheless, the results suggest the complexity of bone health in athlete populations and the need for a more comprehensive assessment to understand the long-term impact of GAHT on transgender athletes' BMD.

The differences observed in body composition in this population (table 2) indirectly show the potential role of androgens in body composition, owing to the role of oestradiol in fat accumulation[29] and transgender women's oestradiol concentrations (figure 1B) and fat mass (table 2) being greater than all other groups. Body composition differences may have implications for sports that prioritise exercise economy,[30] defined as the average $\dot{V}O_2$ relative to body mass between submaximal intensities,[31] as athletes with a higher fat mass percentage will present with a lower exercise economy owing to the increased $O_2$ cost of exercise.[32] The android-to-gynoid ratio analysis (table 2) suggests that hormone therapy (figure 1A,B) influences differences in fat distribution patterns. However, fat distribution patterns of the present transgender female athlete cohort (table 2) do not reach ratios previously reported in cisgender female populations (0.8).[33] Understanding these variations is essential for evaluating performance in sports where body composition is a determining factor, for example, weightlifting or boxing.

Cisgender women had lower absolute fat-free mass than transgender men and transgender women (table 2). When analysing absolute fat and fat-free mass data (table 2), these results can be affected by sample size and/or athlete diversity limitations. A purposefully designed future study with height-matched and sport-matched cisgender and transgender female athletes is crucial to understanding differences in these parameters, as they are influenced by height disparities (table 1) and variations in sampled sports.

FVC, $FEV_1$ and $FEV_1$:FVC ratio are higher in athletes than in the normal sedentary control individuals,[34] and there is no difference in all three metrics between aerobic athletes and anaerobic athletes.[35] Therefore, the lung function differences observed in figure 2A,B may be attributed to factors such as skeletal size benefiting lung capacity and function,[36] with transgender women's FVC results (figure 2B) suggesting gender-affirming hormone care did not impact changing lung volumes owing to the GAHTs lack of effect on skeletal stature.[11] Transgender women showed a significantly reduced $FEV_1$:FVC ratio compared with cisgender women (figure 2C). The $FEV_1$:FVC ratio has been used as a screening index for identifying obstructive lung conditions globally,[37] as a lower $FEV_1$ owing to obstruction of air escaping from the lungs will reduce the $FEV_1$:FVC ratio. Transgender women's results (figure 2C) suggest obstructed airflow in the lungs[38] when compared with cisgender women. However, this observation of transgender women is unlikely to be pathological (<0.70),[39] as seen in chronic obstructive pulmonary disease.

Nevertheless, this reduced airflow could potentially lead to exercise-induced dyspnoea, resulting in performance limitations[40] in comparison to cisgender women. When comparing both the CM and transgender women athletes' groups with identical heights (1.8 m, table 1), while both groups exhibit similar FVC, transgender women demonstrate a lower $FEV_1$, leading to a reduced $FEV_1$:FVC ratio compared with CM, although not significant. If there were a significant difference between CM and transgender women, our preliminary hypothesis would have attributed this divergence to testosterone suppression in transgender women. However, comparing transgender women to cisgender women who do not share similar height and or exhibit a comparable FVC, the observed differences become more complex to interpret. The possibility arises that factors beyond hormonal influences, such as varying levels of aerobic training, may contribute to the significant difference found in the $FEV_1$:FVC ratio between transgender women and cisgender women. Further longitudinal investigation is required to elucidate if the causation underlying these pulmonary function disparities is indeed testosterone suppression.

Strength results in figure 3 disagree with previous literature in a non-athlete transgender cohort using the same methodology that showed transgender women and CM had significantly different absolute and relative hand grip strength.[41] Our results showed no differences in absolute strength between transgender women and CM and no difference in relative handgrip between any of the groups in this study (figure 3). These results highlight the differences between athlete and sedentary populations. However, the results relative to hand size also concur with the notion that greater handgrip strength is caused by greater hand size,[42] as there were no differences in results between the four groups when normalised for hand size (figure 3C,D). Therefore, investigations with more accurate measures of strength are warranted in transgender athletes.

Transgender women presented lower absolute jump height than CM and lower relative jump height, normalised for fat-free mass, than transgender men and cisgender women (figure 4). These results in this study cohort suggest that transgender women lack lower body anaerobic power compared with the other groups. Transgender women's higher absolute peak power than cisgender women (figure 4C), coupled with higher fat mass potentially driven by higher oestradiol concentrations (figure 1B), suggest that transgender women had more inertia to overcome during the explosive phase of the countermovement jump, which may lead to decreased performance. However, when normalised for fat-free mass (figure 4D), transgender women's peak power was lower than that of cisgender women, showing that this cohort also lacks peak power relatively, indicating that the higher fat mass may not be the primary contributing factor. Further investigations are warranted to find the causation of this poor lower anaerobic power performance in transgender women.

The lack of differences in anaerobic threshold (%$\dot{V}O_2$max, figure 5D) suggests that the athletes in this study had a similar fitness status, which is an essential underlying finding given that CM showed greater absolute $\dot{V}O_2$max than all groups (figure 5A), with no differences between transgender women and cisgender women found, and transgender women exhibited lower relative $\dot{V}O_2$max compared with both CM and women (figure 5B). In this cohort, the finding of no statistical difference in absolute $\dot{V}O_2$max between transgender women and cisgender women contrasts the idea that transgender women's bigger lung size (table 2) is an inherent respiratory function advantage over cisgender women.[11] Both the absolute and relative $\dot{V}O_2$max differences between groups contradict one previous study in non-athlete transgender populations that found transgender women had higher absolute $\dot{V}O_2$peak and no difference in relative $\dot{V}O_2$peak compared with cisgender women.[41] This contradictory finding further highlights population differences between non-athlete and athlete cohorts while also contradicting literature hypothesising that there would be a baseline gap in aerobic capacity between transgender women and cisgender women.[11] The results in this athlete cohort warrant further research to elucidate the mechanisms behind this deviation, as they may be metabolic, as transgender women also exhibited a lower relative anaerobic threshold (figure 5E). The findings in table 2 reveal notable disparities in fat mass, fat-free mass, laboratory sports performance measures and hand-grip strength measures between cisgender male and transgender female athletes. These differences underscore the inadequacy of using cisgender male athletes as proxies for transgender women athletes. Therefore, based on these limited findings, we recommend that transgender

women athletes be evaluated as their own demographic group, in accordance with the principles outlined in Article 6.1b of the International Olympic Committee Framework on Fairness, Inclusion and Non-Discrimination based on Gender Identity and Sex Variations.[4]

## Study limitations

The limitations of this study primarily relate to its cross-sectional design, making it challenging to establish causation or examine if the performance of athletes changes as a result of undergoing GAHT. Longitudinal studies are needed to examine how GAHT, and other factors impact athletes' physiology and performance over time. Additionally, the composition of the study cohort may not fully represent the diversity of athletes in elite sports from worldwide populations. Athletes from various sporting disciplines and performance levels were included, and the athlete training intensity was self-reported. Therefore, the results may suffer from selection and recall bias.[43] The results may not apply to all levels or ages of athletes, specifically as this research did not include any adolescent athletes competing at the national or international level. The athletes participating in the present study represented a variety of different sports, and this would have undoubtedly impacted the results of the study as different sports stress different training and sports modalities. Exercise type, intensity and duration all have an impact on physiological responses and overall laboratory performance metrics.[44] The subgroups of sports that emerged were also too dissimilar to allow meaningful subgroup analysis. The complexity and difficulty of this area of activity means that while this study provides a starting point for understanding the complex physiology in GAHT and athletic performance, this study does not provide evidence that is sufficient to influence policy for either inclusion or exclusion. However, this is the first study to assess laboratory-based measures of performance in transgender athletes, and this opens up interesting avenues for replication and extension into the longitudinal effects of GAHT on athletic performance.

Future research should include more extensive and diverse samples to enhance the generalisability of findings or smaller, more specific cohorts to hone in on a particular sports discipline. However, such studies may be complex due to the low numbers of transgender athletes. The recruitment method of this study also provided a limitation as social media advertising was used rather than recruitment from a clinical provider. Social media recruitment leaves this study open to sample bias as social media advertising, although great for recruiting hard-to-reach participants for observational studies,[44 45] does not represent a clinical population in 86% of comparisons.[44] As the participants were not recruited from a clinic, this also means that the gender-affirming treatment of the transgender athletes was not controlled. For example, different testosterone suppression methods have different efficacies,[46] and future studies should consider differences in the prescribed GAHT to participants. Lastly, the participants were not screened by a clinician before participation, and any medical conditions were self-reported in the physical activity readiness questionnaire (PAR-Q). This method of medical reporting leaves the data open to self-reporting bias, which can mislead descriptive statistics and causal inferences[47] as participants' cognitive processes, such as social desirability, can alter participants' responses.[48] Therefore, it is recommended to use a clinic to screen and recruit participants to avoid such bias in a longitudinal study of transgender athlete sports performance.

## CONCLUSIONS

This research compares transgender male and transgender female athletes to their cisgender counterparts. Compared with cisgender women, transgender women have decreased lung function, increasing their work in breathing. Regardless of fat-free mass distribution, transgender women performed worse on the countermovement jump than cisgender women and CM. Although transgender women have comparable absolute $\dot{V}O_2max$ values to cisgender women, when normalised for body weight, transgender women's cardiovascular fitness is lower than CM and women. Therefore, this research shows the potential complexity of transgender athlete physiology and its effects on the laboratory measures of physical performance. A long-term longitudinal study is needed to confirm whether these findings are directly related to gender-affirming hormone therapy owing to the study's shortcomings, particularly its cross-sectional design and limited sample size, which make confirming the causal effect of gender-affirmative care on sports performance problematic.

**X** Blair Hamilton @BlairH_PhD

**ORCID iDs**
Blair Hamilton http://orcid.org/0000-0001-7412-1188
Andrew Brown http://orcid.org/0009-0005-9553-3081
Stephanie Montagner-Moraes http://orcid.org/0009-0007-0957-5002
Cristina Comeras-Chueca http://orcid.org/0000-0001-9483-3262
Peter G Bush http://orcid.org/0000-0001-8609-2812
Fergus M Guppy http://orcid.org/0000-0002-8526-9169
Yannis P Pitsiladis http://orcid.org/0000-0001-6210-2449

## REFERENCES

1 Jones BA, Arcelus J, Bouman WP, *et al*. Sport and Transgender people: a systematic review of the literature relating to sport participation and competitive sport policies. *Sports Med* 2017;47:701–16.

2 World Aquatics. Policy on eligibility for the men's and women's competition categories. F 3 and 4, 2022. Available: https://resources.fina.org/fina/document/2022/06/19/525de003-51f4-47d3-8d5a-716dac5f77c7/FINA-INCLUSION-POLICY-AND-APPENDICES-FINAL-.pdf

3 USA Gymnastics. USA gymnastic policy for transgender inclusion, 2020. Available: https://usagym.org/PDFs/About%20USA%20Gymnastics/transgender_policy.pdf

4 International Olympic Committee. Framework on fairness, inclusion and non-discrimination on the basis of gender identity and sex variations, 2021. Available: https://stillmed.olympics.com/media/Documents/News/2021/11/IOC-Framework-Fairness-Inclusion-Non-discrimination-2021.pdf

5 National Health Service. Shared Care Prescribing Guidance For Treatment of Gender Dysphoria in People Assigned Male at Birth Transitioning to a Feminine Gender Identity, 2022. Available: https://gic.nhs.uk/wp-content/uploads/2022/12/Shared-Care-Protocol-Trans-Feminine-v10.3_approved-22.12.2022.pdf

6 National Health Service. Shared Care Prescribing Guidance For Treatment of Gender Dysphoria in People Assigned Female at Birth Transitioning to a Masculine Gender Identity, 2022. Available: https://gic.nhs.uk/wp-content/uploads/2022/12/Shared-Care-Protocol-Trans-Masculine-v12.3_approved-22.12.2022.pdf

7 Hembree WC, Cohen-Kettenis PT, Gooren L, *et al*. Endocrine treatment of gender-Dysphoric/gender-Incongruent persons: an endocrine society clinical practice guideline. *J Clin Endocrinol Metab* 2017;102:3869–903.

8 Handelsman DJ, Hirschberg AL, Bermon S. Circulating testosterone as the hormonal basis of sex differences in athletic performance. *Endocr Rev* 2018;39:803–29.

9 Alvero-Cruz JR, Brikis M, Chilibeck P, *et al*. Age-related decline in vertical jumping performance in masters track and field athletes: concomitant influence of body composition. *Front Physiol* 2021;12:643649.

10 Gharahdaghi N, Phillips BE, Szewczyk NJ, *et al*. Links between testosterone, oestrogen, and the growth hormone/insulin-like growth factor axis and resistance exercise muscle adaptations. *Front Physiol* 2020;11:621226.

11 Hilton EN, Lundberg TR. Transgender women in the female category of sport: perspectives on testosterone suppression and performance advantage. *Sports Med* 2021;51:199–214.

12 Bianchi A. Transgender women in sport. *J Philosophy Sport* 2017;44:229–42.

13 Hamilton BR, Guppy FM, Barrett J, *et al*. Integrating Transwomen athletes into elite competition: the case of elite archery and shooting. *Eur J Sport Sci* 2021;21:1500–9.

14 Hamilton B, Comeras-Chueca C, Bush P, *et al*. Sporting performance of athletes of the gender spectrum: A cross-sectional comparison study protocol. *SportRxiv* 2022;1.

15 National Health Service. Testosterone. 2022. Available: https://www.nbt.nhs.uk/severn-pathology/requesting/test-information/testosterone

16 Patel AJ, Wesley R, Leitman SF, *et al*. Capillary versus venous Haemoglobin determination in the assessment of healthy blood donors. *Vox Sang* 2013;104:317–23.

17 Popović ZB, Thomas JD. Assessing observer variability: a user's guide. *Cardiovasc Diagn Ther* 2017;7:317–24.

18 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.

19 Mansournia MA, Collins GS, Nielsen RO, *et al*. A checklist for statistical assessment of medical papers (the CHAMP statement): explanation and elaboration. *Br J Sports Med* 2021;55:1009–17.

20 National Health Service. Gender dysphoria, 2020. Available: https://www.nhs.uk/conditions/gender-dysphoria/

21 Malczewska-Lenczowska J, Sitkowski D, Orysiak J, *et al*. Total Haemoglobin mass, blood volume and morphological indices among athletes from different sport disciplines. *Arch Med Sci* 2013;9:780–7.

22 Roberts TK, Kraft CS, French D, *et al*. Interpreting laboratory results in Transgender patients on hormone therapy. *Am J Med* 2014;127:159–62.

23 Pittman RN. Oxygen transport in the Microcirculation and its regulation. *Microcirculation* 2013;20:117–37.

24 Schmidt W, Prommer N. Impact of alterations in total hemoglobin mass on Vo2Max. *Exerc Sport Sci Rev* 2010;38:68–75.

25 Bassett DR, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Med Sci Sports Exerc* 2000;32:70–84.

26 Hamilton BR, Staines KA, Kelley GA, *et al*. The effects of exercise on bone mineral density in men: a systematic review and meta-analysis of randomised controlled trials. *Calcif Tissue Int* 2022;110:41–56.

27 Hejazi K, Askari R, Hofmeister M. Effects of physical exercise on bone mineral density in older postmenopausal women: A systematic review and meta-analysis of randomized controlled trials. *Arch Osteoporos* 2022;17:102.

28 Rothman MS, Iwamoto SJ. Bone health in the Transgender population. *Clin Rev Bone Miner Metab* 2019;17:77–85.

29 Wesp LM, Deutsch MB. Hormonal and surgical treatment options for Transgender women and Transfeminine spectrum persons. *Psychiatr Clin North Am* 2017;40:99–111.

30 Genton L, Mareschal J, Karsegard VL, *et al*. An increase in fat mass index predicts a deterioration of running speed. *Nutrients* 2019;11:701.

31 Losnegard T, Schäfer D, Hallén J. Exercise economy in skiing and running. *Front Physiol* 2014;5:5.

32 V Mendonca G, Matos P, Correia JM. Running economy in recreational male and female runners with similar levels of cardiovascular fitness. *J Appl Physiol (1985)* 2020;129:508–15.

33 Imboden MT, Welch WA, Swartz AM, *et al*. Reference standards for body fat measures using GE dual energy X-ray Absorptiometry in Caucasian adults. *PLoS One* 2017;12:e0175110.

34 Vedala S, Paul N, Mane AB. Differences in pulmonary function test among the athletic and sedentary population. *Natl J Physiol Pharm Pharmacol* 2013;3:118.

35 Rajaure YS, Thapa B, Budhathoki L, *et al*. Comparison of Spirometric parameters in athletes engaged in aerobic and anaerobic sports: a cross-sectional study. *Ann Med Surg (Lond)* 2023;85:2502–5.

36 van der Plaat D, Lenoir A, Dharmage S, *et al*. T2 Effect of testosterone and sex hormone-binding globulin on lung function: a mendelian randomisation study. British Thoracic Society Winter Meeting, Wednesday 17 to Friday 19 February 2021, Programme and Abstracts; February 2021

37 Kim SH, Kim HS, Min HK, *et al*. Obstructive Spirometry pattern and the risk of chronic kidney disease: analysis from the community-based prospective Ansan-Ansung cohort in Korea. *BMJ Open* 2021;11:e043432.

38 Torén K, Schiöler L, Lindberg A, *et al*. The ratio Fev1/FVC and its Association to respiratory symptoms—A Swedish general population study. *Clin Physiol Funct Imaging* 2021;41:181–91.

39 Singh D, Agusti A, Anzueto A, *et al*. Global strategy for the diagnosis, management, and prevention of chronic obstructive lung disease: the GOLD science Committee report 2019. *Eur Respir J* 2019;53:1900164.

40 Cooper CB. Airflow obstruction and exercise. *Respir Med* 2009;103:325–34.

41 Alvares LAM, Santos MR, Souza FR, *et al*. Correction: cardiopulmonary capacity and muscle strength in Transgender women on long-term gender-affirming hormone therapy: a cross-sectional study. *Br J Sports Med* 2022;56:1292–8.

42 Alahmari KA, Kakaraparthi VN, Reddy RS, *et al*. Percentage difference of hand dimensions and their correlation with hand grip and pinch strength among schoolchildren in Saudi Arabia. *Niger J Clin Pract* 2019;22:1356–64.

43 Tripepi G, Jager KJ, Dekker FW, *et al*. Selection bias and information bias in clinical research. *Nephron Clin Pract* 2010;115:c94–9.

44 Topolovec-Vranic J, Natarajan K. The use of social media in recruitment for medical research studies: a Scoping review. *J Med Internet Res* 2016;18:e286e286.

45 Whitaker C, Stevelink S, Fear N. The use of Facebook in recruiting participants for health research purposes: a systematic review. *J Med Internet Res* 2017;19:e290.

46 Angus L, Leemaqz S, Ooi O, *et al*. Cyproterone acetate or spironolactone in lowering testosterone concentrations for Transgender individuals receiving Oestradiol therapy. *Endocr Connect* 2019;8:935–40.

47 Bauhoff S. Self-report bias in estimating cross-sectional and treatment effects. *Encyclopedia of Quality of Life and Well-Being Research* 2014;5798–800.

48 Bound J, Brown C, Mathiowetz N. Measurement Error in Survey Data. Handbook of Econometrics: Elsevier, 2001:3705–843.

### Appendix. CHAMP: CHecklist for statistical Assessment of Medical Papers

***Design and conduct***

| | | | | |
|---|---|---|---|---|
| 1. | Clear description of the goal of research, study objective(s), study design, and study population | Yes | Unclear | No |
| 2. | Clear description of outcomes, exposures/treatments and covariates, and their measurement methods | Yes | Unclear | No |
| 3. | Validity of study design | Yes | Unclear | No |
| 4. | Clear statement and justification of sample size | Yes | Unclear | No |
| 5. | Clear declaration of design violations and acceptability of the design violations | Yes | Unclear | No |
| 6. | Consistency between the paper and its previously published protocol | Yes | Unclear | No |

***Data analysis***

| | | | | |
|---|---|---|---|---|
| 7. | Correct and complete description of statistical methods | Yes | Unclear | No |
| 8. | Valid statistical methods used and assumptions outlined | Yes | Unclear | No |
| 9. | Appropriate assessment of treatment effect or interaction between treatment and another covariate | Yes | Unclear | No |
| 10. | Correct use of correlation and associational statistical testing | Yes | Unclear | No |
| 11. | Appropriate handling of continuous predictors | Yes | Unclear | No |
| 12. | Confidence intervals do not include impossible values | Yes | Unclear | No |
| 13. | Appropriate comparison of baseline characteristics between the study arms in randomized trials | Yes | Unclear | No |
| 14. | Correct assessment and adjustment of confounding | Yes | Unclear | No |
| 15. | Avoiding model extrapolation not supported by data | Yes | Unclear | No |
| 16. | Adequate handling of missing data | Yes | Unclear | No |

***Reporting and presentation***

| | | | | |
|---|---|---|---|---|
| 17. | Adequate and correct description of the data | Yes | Unclear | No |
| 18. | Descriptive results provided as occurrence measures with confidence intervals, and analytic results provided as association measures and confidence intervals along with P-values | Yes | Unclear | No |
| 19. | Confidence intervals provided for the contrast between groups rather than for each group | Yes | Unclear | No |
| 20. | Avoiding selective reporting of analyses and P-hacking | Yes | Unclear | No |
| 21. | Appropriate and consistent numerical precisions for effect sizes, test statistics, and P-values, and reporting the P-values rather their range | Yes | Unclear | No |
| 22. | Providing sufficient numerical results that could be included in a subsequent meta-analysis | Yes | Unclear | No |
| 23. | Acceptable presentation of the figures and tables | Yes | Unclear | No |

***Interpretation***

| | | | | |
|---|---|---|---|---|
| 24. | Interpreting the results based on association measures and 95% confidence intervals along with P-values, and correctly interpreting large P-values as indecisive results, not evidence of absence of an effect | Yes | Unclear | No |
| 25. | Using confidence intervals rather than post-hoc power analysis for interpreting the results of studies | Yes | Unclear | No |
| 26. | Correctly interpreting occurrence or association measures | Yes | Unclear | No |
| 27. | Distinguishing causation from association and correlation | Yes | Unclear | No |
| 28. | Results of pre-specified analyses are distinguished from the results of exploratory analyses in the interpretation | Yes | Unclear | No |
| 29. | Appropriate discussion of the study methodological limitations | Yes | Unclear | No |
| 30. | Drawing only conclusions supported by the statistical analysis and no generalization of the results to subjects outside the target population | Yes | Unclear | No |

**Supplementary Table 1**  Participant Characteristics

| | Cisgender Men (*n* = 19) | Transgender Men (*n* = 12) | Cisgender Women (*n* = 21) | Transgender Women (*n* = 23) |
|---|---|---|---|---|
| Age (yrs.) | 37 ± 9 | 34 ± 7 | 30 ± 9 | 34 ± 10 |
| Training Intensity | 7 [IQR 2] | 7 [IQR 2] | 7 [IQR 2] | 7 [IQR 2] |
| Length of GAHT (yrs.) | - | 4 ± 5 | - | 6 ± 4 |
| Height (m) | 1.8 ± 0.1$^\$$ | 1.7 ± 0.1$^{*\#}$ | 1.6 ± 0.1 | 1.8 ± 0.1$^\$$ |
| Clothed mass (kg) | 76.4 ± 7.7$^\$$ | 73.1 ± 12.1 | 60.6 ± 6.6 | 83.9 ± 19.9$^\$$ |
| BMI (kg•m$^{-2}$) | 23.6 ± 1.8 | 25.7 ± 3.9 | 22.5 ± 1.9 | 26.2 ± 6.0$^\$$ |

Data represents Mean ± Standard Deviation, or Median [Inter Quartile Range]. *denotes significantly different from Cisgender Men; $^\$$ denotes significantly different from Cisgender Women. # denotes significantly different from Transgender Women; *yrs., years; m, metres; kg, kilogram; kg•m$^{-2}$, kilograms per metre squared.*

1     Sporting Performance of Athletes of the Gender Spectrum: A Cross-sectional

2     Comparison Study Protocol.

3

4     Blair R. Hamilton[1-3], Cristina Comeras-Chueca[5-7], Peter Bush[1,4], Fergus M. Guppy[8], Yannis

5     Pitsiladis[1,3,9-12]

6

7     [1] Centre for Stress and Age-related Disease, University of Brighton, Brighton, UK

8     [2] The Gender Identity Clinic Tavistock and Portman NHS Foundation Trust, London, UK

9     [3] School of Sport and Health Sciences, University of Brighton, Brighton, UK

10     [4] School of Applied Sciences, University of Brighton, Brighton, UK

11     [5] Faculty of Health and Sport Science (FCSD), Department of Physiatry and Nursing,
12     Universidad de Zaragoza, 50009 Zaragoza, Spain.

13     [6] Growth, Exercise, Nutrition and Development Research Group, Department of Physiatry
14     and Nursing, Universidad de Zaragoza, 50009 Zaragoza, Spain.

15     [7] EXERNET Red de Investigación en Ejercicio Físico y Salud, 50009 Zaragoza, Spain.

16     [8] Institute of Life and Earth Sciences, Heriot-Watt University, Edinburgh, UK.

17     [9] University of Rome "Foro Italico," Rome, Italy

18     [10] Centre for Exercise Sciences and Sports Medicine, FIMS Collaborating Centre of Sports
19     Medicine, Rome, Italy

20     [11] European Federation of Sports Medicine Associations (EFSMA), Lausanne, Switzerland

21     [12] International Federation of Sports Medicine (FIMS), Lausanne, Switzerland

22

32

33

1  Abstract

2  The question of integrating transgender athletes into their affirmed gender categories is becoming

3  more prominent with sport's governing bodies portraying mixed messaging when it comes to

4  answering this question. Testosterone is beneficial to baseline sports performance, and it has been

5  suggested that the differences in circulating testosterone concentrations between cisgender men and

6  cisgender women explain most of the baseline differences in sports performance between the two

7  groups. However, a secondary factor relative to sports performance is the physiological re-distribution

8  of fat mass driven by gender-affirming hormone treatment (GAHT) and the loss of/gain of muscle

9  mass with GAHT in both trans women and trans men and their effects on transgender sporting

10  performance. Previous studies lack data on sports performance measures outside muscular strength

11  and performance measures such as aerobic capacity, power and strength should be studied in tandem

12  within an athletic cohort of trans women and trans men and compared with cisgender women and

13  cisgender male athletes to ascertain whether any lasting advantages are present. New sports

14  performance data on transgender athletes must be generated to inform a decision-making process to

15  inform if the current policies in place are accurate or inexact to maintain fairness and the integrity of

16  sport. Accordingly, this manuscript aims to further provide sports performance and anthropometrical

17  data from a cross-sectional analysis of athletes from 4 groups, trans men (n = ≥6 ) and trans women (n

18  = ≥6) who have undergone ≥ 1 year of GAHT, cis men (n = ≥6) and cis women (n = ≥6)  to provide

19  further evidence and consequently, guidance to sport's governing bodies for the eligibility of

20  transgender athletes

1  ## 1. Background

2  Transgender athletes experience conflict between the gender that they were assigned at birth and their

3  experienced gender[1-3]. Some [3-5] but not all [2, 3, 6] will choose to undergo gender-affirming

4  hormone therapy (GAHT) and patients accessing transgender health services have increased

5  considerably in recent years in many European countries [7-9]. The question of integrating

6  transgender athletes into their affirmed gender categories is becoming more prominent with sport's

7  governing bodies portraying mixed messaging when it comes to answering this question, with some

8  opting for blanket bans on trans women in the female category [10, 11], some opting to ask for the

9  reduction of testosterone in the female category for a period of time [12, 13] and the IOC opting for

10 the premise of self-identification into the athletes chosen category [14].

11 Testosterone is beneficial to baseline sports performance, and it has been suggested that the

12 differences in circulating testosterone concentrations between cisgender men and cisgender women

13 explain most of the baseline differences in sports performance between the two groups [15] before an

14 athletes skill or opportunities in the sport are considered. Circulating testosterone is greatly correlated

15 with fat free mass ($R = 0.73$, $p < 0.0001$), ), thigh ($R = 0.66$, $p < 0.0001$) and quadricep ($R = 0.73$, $p <$

16 $0.0001$) muscle volume, while being moderately correlated with leg strength ($R = 0.48$, $p < 0.0005$)

17 [15]. The argument against trans women competing in the female category of sport assumes that trans

18 women have benefitted from high testosterone concentrations from the onset of puberty until the

19 administration of GAHT, that this assumed benefit cannot be mitigated [16], and those cisgender

20 female competitors cannot naturally possess this benefit of high testosterone concentrations [17]. This

21 argument is not present in trans men, as serum testosterone concentrations are recommended to be

22 maintained in the mid-normal range for healthy young men from the onset of GAHT [18],

23 hypothetically not giving trans men the competitive advantages of exogenous testosterone

24 concentrations over cisgender men and this viewpoint is reflected in the current inclusion sports

25 policies for trans men [10-12], although this hypothesis is as yet unconfirmed. It should also be noted,

26 the presence of high circulating testosterone concentrations does not guarantee increased

27 performance, but the way an individual's body physiologically responds to testosterone does [15].

28 Loss of muscle mass has been reported in trans women following GAHT [19-24] and gains in muscle

29 mass have been shown in trans men [20, 22-24]. Studies have shown that testosterone suppression in

30 cisgender men resulted in decreased muscular strength [25, 26] although this result has been disputed

31 in trans women, with some studies showing increases of 0.5-2% in muscle strength [22, 27, 28] and

32 others showing decreases between 4.3-25% [29-31]. Trans men's muscular strength has been shown

33 to improve by 12-26% during GAHT [22, 31]. However, a secondary factor relative to sports

34 performance is the physiological distribution of fat mass driven by GAHT in both trans women and

35 trans men. As a result of testosterone suppression and oestradiol (E2) supplementation, total body fat

36 has been shown to consistently increase in trans women by 20 - 30% [23, 24, 32, 33] and testosterone

1     administration decreases body fat in trans men by 11 - 20% [23, 24, 32, 33]. The data above shows

2     trans women reducing their percentage of fat-free mass and trans men increasing their percentage of

3     fat-free mass. This data is intriguing as the differences in percentages of fat-free mass are suggested as

4     the cause of the difference in sports performance between cisgender males, and cisgender females [34,

5     35]. Cisgender men and women have been shown to have similar relative muscular strength and trans

6     women have also been shown to have 33.8 % weaker relative muscular strength than cisgender men

7     and women while showing a similar absolute strength to cisgender women (31.9 kg ± 2.4 vs. 29.2 kg

8     ± 4.4, [35]).

9     Previous studies lack data on sports performance measures outside muscular strength. Performance

10    measures such as aerobic capacity, power and strength should be studied in tandem within a cohort of

11    trans women and trans men and compared with cisgender women and cisgender male athletes to

12    ascertain whether any lasting advantages are present. To the author's knowledge, only one study

13    assessed $\dot{V}O_{2max}$ in trans women ($n = 8$) after GAHT (~15 years), discovering that trans women's

14    absolute $\dot{V}O_{2max}$ sat between cisgender men and cisgender women's $\dot{V}O_{2max}$ [36]. Like muscular

15    strength discussed above [35], dividing absolute $\dot{V}O_{2max}$ by their fat-free mass, trans women again

16    came out below both cisgender men and women, showing relatively, trans women's maximum $O_2$

17    uptake is inferior to cisgender men and women. No $\dot{V}O_{2max}$ data has been gained from athletic trans

18    men. It is a well-accepted concept that Hb and Hct concentrations of trans women drop to cisgender

19    female levels after 3-6 months [16, 37, 38] and that trans men's Hb and Hct rise to cisgender male

20    concentrations [38]. It is also well-accepted that reductions in Hb are generally associated with a

21    reduced aerobic capacity [16, 39, 40]. Therefore, lung function should be measured independently and

22    in conjunction with Hb concentrations to understand if any changes in Hb concentrations cause any

23    effect on the $VO_{2max}$ of transgender athletes independent or dependent of lung size.

24    In contrast to the growing amounts of data highlighting the effects of GAHT in non-athletic

25    transgender populations, sports performance data on transgender athletes is scarce. Roberts *et al* [41],

26    retrospectively found in an athletically trained transgender population that was compared against am

27    athletically trained cisgender population, the upper body strength (37.09%) and core strength

28    (15.94%) baseline advantages of trans women over cisgender women had been reduced (upper body

29    6.26%, core -1.99%) after 2 years of GAHT while running performance over 1.5-miles remained 12%

30    (baseline 18.81%) faster after 2 years of GAHT [41]. Trans men's upper body strength (-35.42%) and

31    core strength disadvantages (-3.89%) over cisgender men had been overturned into an advantage

32    (upper body 8.55%, core 10.66%) after 2 years of GAHT while trans men's running performance over

33    1.5-miles was 1.26% (baseline -16.70%) faster than cisgender men after 2 years of GAHT [41]. These

34    findings would suggest a different t rate and extent of mitigation of any potential sporting performance

35    advantage conferred by pubertal high testosterone concentrations of trans women given that strength

36    advantages, but not cardiovascular advantages of trans women were mitigated after 2 years of GAHT.

Supplemental material

BMJ Publishing Group Limited (BMJ) disclaims all liability and responsibility arising from any reliance placed on this supplemental material which has been supplied by the author(s)

*Br J Sports Med*

1    The data above also highlights the performance-enhancing effect of trans men's exogenous

2    testosterone administration and highlights the need to investigate the effects of GAHT on their

3    sporting performance. Particularly, as all 3 metrics had baseline disadvantages under cisgender men

4    ranging from -3.89% to -35.42%, overturned into advantages over cisgender men ranging from 1.66%

5    to 10.66% after 2 years of GAHT. Due to the retrospective and uncontrolled nature of this research,

6    this data requires replication in trained trans women and trans men athletes before any firm

7    conclusions can be drawn.

8    As a consequence of the little performance data for sport's governing bodies to centre their decisions

9    on, new sports performance data on transgender athletes must be generated to inform a decision-

10   making process, as previously illustrated [42], to inform if the current policies in place are accurate or

11   inexact to maintain fairness and the integrity of sport. Accordingly, this manuscript aims to further

12   provide sports performance and anthropometrical data from a cross-sectional analysis of athletes from

13   4 groups of the gender spectrum to provide further evidence and consequently, recommendations to

14   sports governing bodies for the eligibility of transgender athletes.

15   **2. Methods**

16   2.1. Study design

17   This cross-sectional study involves one visit to the laboratory at the School of Applied Sciences,

18   University of Brighton, UK. Each participant will arrive at ~9 am after an overnight fast and depart

19   from testing at ~3 pm. The full study design and the order of tests that will be undertaken by the

20   participants can be found in Figure 1.

21
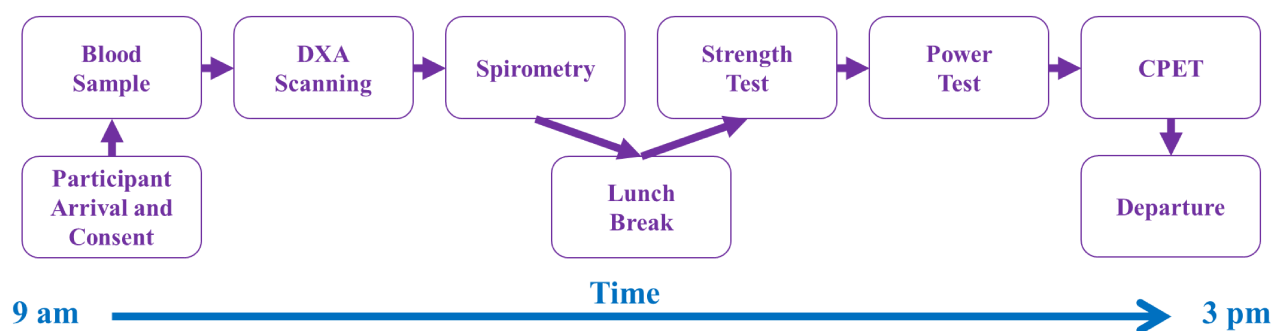


22

23   Figure 1. Schedule of activities during participant testing in the laboratory. *DXA, Dual-energy X-ray*

24   *Absorptiometry; CPET, Cardiopulmonary Exercise Testing.*

Supplemental material

BMJ Publishing Group Limited (BMJ) disclaims all liability and responsibility arising from any reliance placed on this supplemental material which has been supplied by the author(s)

*Br J Sports Med*

1   2.2. Recruitment

2   Participants will be recruited through social media advertising on Facebook (Meta Platforms, Inc,

3   California, USA), Instagram (Meta Platforms, Inc, California, USA), and Twitter (Twitter, Inc,

4   California, USA) with the recruitment poster that is supplied in the supplementary materials. All

5   participants will contact the first author (BH) through the email provided in the advert. After the

6   participant responds to the advert, the first author (BH) will email the participant information sheet in

7   return, on the reception of the participant information sheet the participant will have a minimum of 1

8   week to consider their participation before being invited to travel to the laboratory in Brighton.

9   Before participation, all participants will be orally informed of the study procedures and their written

10  informed consent will be obtained.

11  2.3. Participants and eligibility criteria

12  24 participants (6 trans men, 6 trans women, 6 cisgender men, and 6 cisgender women) will be

13  sought that participate in a sport at a competitive level or undergo physical training three times per

14  week. Trans men and trans women athletes must have completed $\geq 1$ year of GAHT, which will be

15  voluntarily disclosed during consent and verified during blood test analysis. The full

16  inclusion/exclusion criteria can be found in Table 1.

17  Table 1: Inclusion/exclusion criteria for a study participants

**Primary Inclusion Criteria**

| Trans Men and Trans Women | Cisgender Men and Cisgender Women |
| --- | --- |
| GAHT for +1 year. | - |
| Play a Competitive Sport | Play a Competitive Sport |
| or | or |
| Physically train 3x per week | Physically train 3x per week |

**Secondary Exclusion Criteria**

The Physical Activity Readiness Questionnaire highlights health/fitness concerns

Exclude from DXA scanning only if the participant is:

1. pregnant
2. has a total annual radiation dose above 1mSV

*Notes: GAHT, Gender-Affirming Hormone Therapy; DXA, Dual-energy X-ray absorptiometry; mSV, millisievert.*

18

19

Supplemental material

BMJ Publishing Group Limited (BMJ) disclaims all liability and responsibility arising from any reliance placed on this supplemental material which has been supplied by the author(s)

*Br J Sports Med*

1    ## 2.4. Laboratory assessments

2    ### 2.4.1.Blood sampling

3    Capillary blood samples will be collected from the ring finger of the non-dominant hand via a

4    Unistik® 3 Comfort lancet (Owen Mumford Ltd, Woodstock, UK) due to capillary samples yielding a

5    higher Hb value than venous samples [43]. Venous blood samples will be collected by the first author

6    (BH) or the third author (FG) from an antecubital vein utilizing a closed vacuette system. Two 10 mL

7    whole blood samples will be collected into a BD® serum tube (Becton, Dickinson, and Company,

8    Wokingham, Berkshire, UK) for serum extraction. Once collected the tubes will be left at room

9    temperature ($18 \pm 5°C$) for 1 hour and then stored in a fridge ($3 \pm 2°C$) for up to 4 hours maximum

10    before being centrifuged by the first (BH) or second (CC) author at 1300G for 10 min at 4°C.

11    ### 2.4.2.  Body composition and Bone Mass

12    The participants will undertake a pre-DXA health questionnaire to screen for previous radiation

13    exposure and a Physical Activity Readiness Questionnaire for Everyone to screen the participant's

14    ability to undertake exercise. Body composition and Bone Mass will then be measured by DXA

15    (Horizon W, Hologic Inc., Massachusetts, USA). Each participant will undergo a whole-body scan, a

16    femoral neck scan and a lumbar spine scan in succession. The participant will be asked to lie on the

17    scan bed and all participant placement for the three scans will be done by the first author (BH).

18    ### 2.4.3.  Lung Function

19    Lung function will be measured using a Vitalograph Alpha spirometer (Vitalograph Inc, Kansas,

20    USA) with an antibacterial filter placed on the spirometer and a nose clip placed on the bridge of the

21    participant's nose. Each participant will be asked to perform 2 tests, the Vital Capacity (VC), and the

22    Forced Vital Capacity (FVC) test. The participant will be seated in a slightly reclined chair so as not

23    to close the lungs.  For the VC test, the participant will be asked to breathe maximally and then exhale

24    into the spirometer as forcefully and as long as possible. For the FVC test, the participant will perform

25    a flow-volume loop manoeuvre with the nose clip on by inhaling as deeply as possible with their lips

26    tightly over the tube followed by exhaling as forcefully as the participant can, repeating this

27    manoeuvre twice. The two tests will be repeated until a trend of declining performance occurs for

28    each test. The best result for each test will then be recorded.

29    ### 2.4.4.  Strength

30    Testing of strength will be measured with a handgrip dynamometer (TAKEI 5401, TAKEI Scientific

31    Instruments Co., Ltd, Japan). The participant's hand size will be measured around the

32    metacarpophalangeal joints of both hands before the testing begins, afterwards, the participants will

33    be seated in a chair with their ankles placed against the legs of the chair and their backs against to

34    back of the chair. The participants will then place their non-testing hand on their closest thigh, while

Supplemental material

BMJ Publishing Group Limited (BMJ) disclaims all liability and responsibility arising from any reliance placed on this supplemental material which has been supplied by the author(s)

*Br J Sports Med*

1  their testing arm is flexed to a 90° angle, with the palm facing medially. If the participants feet or
2  hands move from the protocol during their attempt this will render that attempt void and this data will
3  be excluded. The dynamometer will then be placed in their hand by the first (BH) or second author
4  (CC) and the participant will be asked to squeeze for 10 seconds. Each hand will be tested 3 times in
5  sequential order of left-right to allow each hand to rest, for a total of 6 repetitions and the mean scores
6  will be taken for each hand.

7  ### 2.4.5.  Lower Body Power

8  Lower body power will be measured with the counter-movement jump (CMJ) manoeuvre on a
9  JUM001 Jump Mat (Probotics Inc, Alabama, USA). Before testing, the participants will be asked to
10  cycle on a cycle ergometer (Monark Exercise AB, Vansbro, Sweden) for 20 minutes at 60 revolutions
11  per minute to warm up the muscle groups of the legs. During this cycle, the participants will be shown
12  the technique of the CMJ procedure by the first (BH) or second author (CC). The test will be
13  controlled to ~45° of counter-movement and hands must be placed on hips to prevent arm swing. The
14  participant will then be allowed a period of sub-maximal familiarization and coaching by the first
15  (BH) or second author (CC). During the test, if the participant went beyond 45° of counter-movement,
16  or the hands came off the hips the test would be declared void for that attempt. After the recording of
17  3 legal maximal attempts, the mean scores will be recorded.

18  ### 2.4.6.  Cardiopulmonary Exercise Testing (CPET)

19  CPET will be performed using a 95T Engage Treadmill ergometer (Life Fitness, Illinois, USA). A
20  landing crash mat was placed behind the treadmill for participant safety in case of falls. To ensure test
21  accuracy, the metabolic gas will be calibrated before each test with COSMED™ certified reference
22  gas of 16% $O_2$ and 5% $CO_2$ and the turbine flowmeter will be calibrated before each test using a
23  certified 3L calibration syringe (Hans Rudolph, Kansas, USA) according to manufacturer instructions.
24  The participants will wear a mask (Hans Rudolph, Kansas, USA) that will be strapped to the
25  participant's head via Velcro™ straps and the participants' inspiration and expiration will be measured
26  by $O_2$ and $CO_2$ analysers in the flowmeter sample line via breath-by-breath analysis (Omnia, Quark
27  CPET, COSMED™ Srl, Rome, Italy). Heart Rate (HR and $HR_{Max}$ will be recorded using Huawei
28  Watch GT smartwatch HR technology (Huawei Technologies Co., Ltd, Shenzhen, China) secured to
29  the participant's right wrist. The participants will be monitored under relaxed conditions for ~5
30  minutes to make sure that their resting Respiratory Quotient (RQ) will be ~0.80 and the participant's
31  resting $\dot{V}O_2$ is ~ 500ml/min to prevent a false positive test.  During the test, the participant's HR was
32  monitored every minute and recorded after 2 minutes of each elevation of workload and the
33  participant was then also asked to point to or signal a Rating of Perceived Exertion (RPE) scale
34  (revised Borg 10-grade scale), allowing for compensation of each workload to occur. The participant
35  will be considered to have reached their $\dot{V}O_{2max}$ if three out of four of the following occurred: a
36  plateau or 'peaking over' in oxygen uptake, an RQ of ≥1.1, maximal HR is reached, and/or volitional

Supplemental material

BMJ Publishing Group Limited (BMJ) disclaims all liability and responsibility arising from any reliance placed on this supplemental material which has been supplied by the author(s)

*Br J Sports Med*

1   exhaustion. If three out of the four do not occur, then the test will not be considered for analysis. All

2   $\dot{V}O_{2max}$ tests will be conducted and analysed by the first author (BH) to avoid any inter-investigator

3   variability. The ramp protocol of Badawy and Muaidi [44] treadmill $\dot{V}O2max$ testing will be used for

4   each $\dot{V}O_{2max}$ test.

## 2.5. Outcome measures

### 2.5.1. Blood measurements

7   Capillary Hb will be analysed by a HemoCue® 201+ (HemoCue AB, Ängelholm, Sweden) reported

8   in grams per litre (g/l), Oestradiol (E2) concentrations in serum will be measured using tandem mass

9   spectrometry (Model to be confirmed) and will be reported in picograms per millilitre (pg/mL), and

10   testosterone in serum concentrations will also be measured using tandem mass spectrometry and will

11   be reported in nanomoles per litre (nmol/L).

### 2.5.2. Body composition and Bone Mass

13   All analysis will be completed immediately after the 3 scans using Apex v5.6.0.5 software (Hologic,

14   Connecticut, USA) by the first author (BH). Due to the in-built analysis assumptions regarding the

15   measurement of head fat mass and percentage fat of 17%, subtotal data (whole-body less head) data

16   will be used to report anthropometric data, which will also be reported regionally. Anthropometric

17   data will be reported as fat mass (Kg), lean mass (Kg), and Fat-free mass (Kg). Bone measures will be

18   reported as bone area (cm$^{-3}$), bone mineral content (BMC, g) and bone mineral density (BMD,

19   g·cm$^3$). A report of the DXA analysis will be given to each participant.

### 2.5.3. Lung function

21   All lung function tests will be analysed by the inbuilt analysis hardware of the Vitalograph Alpha

22   spirometer. Lung function data will be presented as vital capacity (VC) in litres (L), to determine the

23   maximum amount of air exhaled in a relaxed state; forced vital capacity (FVC) in L to determine the

24   maximum volume of air exhaled forcefully; forced expiratory volume in 1 second (FEV$^1$) in L to

25   determine the volume of air that the participant can forcibly expire in the first 1 second; FEV$^{1\%}$ as a

26   percentage (%), to determine the proportion of the participants VC that they can expire in the FEV$^1$ to

27   the full, FVC; peak expiratory flow (PEF) in L per minute (L/min), to determine the maximum speed

28   of maximally forced expiration initiated at full inspiration. Lastly, forced expiratory flow (FEF$^{25-75}$) in

29   L to determine the mean flow of expired air between 25-75% of FVC. A report of the lung function

30   analysis will be given to each participant.

### 2.5.4. Muscular Strength

32   Hand size for both the participant's right hand and the left hand will be presented in centimetres (cm).

33   Absolute handgrip scores will be presented in Kg, relative handgrip scores will be presented as the

1  absolute handgrip score divided by hand size (kg/cm) and the absolute hand grip score divided by

2  FFM reported by DXA (kg/kg).

3  ### 2.5.5. Lower Body Power

4  Counter movement jump height in inches (in) and airtime will be reported in seconds (s) and analysed

5  by the inbuilt hardware of the JUM001 Jump Mat. Jump height will be converted to cm by

6  multiplying the result in inches by 2.54. Peak power in watts (W) and Average power in W will be

7  determined by the equations developed by Johnson and Bahamonde [45] shown below:

8  $Peak\ power\ (W)$

9  $$= \left( (78.6 \times Jump\ Height[cm]) + (60.3 \times mass[kg]) \right)$$

10 $$- \left( (15.3 \times height\ [cm]) - 1308 \right)$$

11 $Average\ Power\ (W)$

12 $$= \left( (43.8 \times Jump\ Height[cm]) + (32.7 \times mass[kg]) \right)$$

13 $$- \left( (16.8 \times height\ [cm]) + 431 \right)$$

14 ### 2.5.6. Maximal Oxygen Uptake ($\dot{V}O_{2max}$)

15 Each $\dot{V}O_{2max}$ test will be analysed immediately using COSMED Omnia software (COSMED Srl,

16 Rome, Italy) while the participant is in a cool-down period and the results will be immediately

17 emailed to the participant. Absolute $\dot{V}O_{2max}$ and absolute anaerobic threshold (AT) will be reported in

18 millilitres per min (ml/min). Relative $\dot{V}O_{2max}$ and AT will be presented by dividing ml/min by body

19 mass (ml/min/kg) and FFM reported by DXA (ml/min/kg). The respiratory quotient (RQ) at $\dot{V}O_{2max}$,

20 defined as the volume of carbon dioxide released over the volume of oxygen absorbed during

21 respiration, will be reported alongside the $HR_{max}$ recorded at the participant's $\dot{V}O_{2max}$.

22 ## 2.6. Statistical analyses

23 Statistical analysis was performed using Jamovi [46]. The mean and standard deviations (SD) will be

24 presented to compare the differences between the means. The mean scores for the measures of,

25 testosterone, E2, and Hb will be compared using a two-way ANOVA with the two factors of gender

26 and length of GAHT. The measures of body composition and bone mass will be compared with a

27 three-way ANOVA with three factors being gender, testosterone and E2. Lung function, muscular

28 strength, lower body power and maximal oxygen uptake will be compared with a four-way ANOVA

29 with the four factors being gender, testosterone, E2 and FFM. All ANOVAs will be combined with a

30 Turkey post-hoc correction. Pearson's correlation coefficient will be used to assess the relationship

31 between the blood measures of testosterone, E2 and Hb, in addition to the DXA measure of FFM,

32 with the measures of muscular strength, lower body power, and maximal oxygen uptake. Due to the

33 large number of comparisons expected, a Bonferroni correction will be applied for the correlation

1    analysis which will be determined by $\alpha = \frac{\alpha}{m}$ where α is the desired alpha level of 0.05 and $m$ is the

2    number of hypotheses tested. This will be calculated manually.

### 2.7. Ethical Approval and Funding

### Acknowledgements

### Competing interests

All authors declare no competing interests in this research.

### Author Contributions

Conceptualization, BH and FG; Methodology, BH; Data Collection: BH and CC; writing–original draft preparation: BH, CC and FG Writing–review and editing: ALL.

### Data Availability

An Open Science Framework project titled Sporting Performance of Athletes of the Gender Spectrum: A Cross-sectional Comparison Study with all materials can be found here: (insert link)

# References

1. Jones BA, Arcelus J, Bouman WP, Haycraft E. Sport and transgender people: a systematic review of the literature relating to sport participation and competitive sport policies. Sports Medicine. 2017;47(4):701-16.

2. Kuyper L, Wijsen C. Gender identities and gender dysphoria in the Netherlands. Archives of sexual behavior. 2014;43(2):377-85.

3. NHS. Gender dysphoria. 2020 28th May 2020 [cited 2020 29th July ]; Available from: https://www.nhs.uk/conditions/gender-dysphoria/

4. Coleman E, Bockting W, Botzer M, Cohen-Kettenis P, DeCuypere G, Feldman J, et al. Standards of care for the health of transsexual, transgender, and gender-nonconforming people, version 7. International journal of transgenderism. 2012;13(4):165-232.

5. Wylie K, Barrett J, Besser M, Bouman WP, Bridgman M, Clayton A, et al. Good practice guidelines for the assessment and treatment of adults with gender dysphoria. Sexual and Relationship Therapy. 2014;29(2):154-214.

6. Hargie OD, Mitchell DH, Somerville IJ. 'People have a knack of making you feel excluded if they catch on to your difference': Transgender experiences of exclusion in sport. International Review for the Sociology of Sport. 2017;52(2):223-39.

7. Arcelus J, Bouman WP, Van Den Noortgate W, Claes L, Witcomb G, Fernandez-Aranda F. Systematic review and meta-analysis of prevalence studies in transsexualism. European Psychiatry. 2015;30(6):807-15.

8. Aitken M, Steensma TD, Blanchard R, VanderLaan DP, Wood H, Fuentes A, et al. Evidence for an altered sex ratio in clinic-referred adolescents with gender dysphoria. The Journal of Sexual Medicine. 2015;12(3):756-63.

9. De Vries A, Kreukels B, T'sjoen G, Ålgars M, Mattila A. Increase of referrals to gender identity clinics: a European trend. Transgender healthcare in Europe Book of abstracts. 2015:10.

10. World Rugby. World Rugby Transgender Guideline. 2020 October 9th 2020 [cited 2021 November, 29th]; Available from: https://playerwelfare.worldrugby.org/?documentid=231

11. FINA. Policy on eligibility for the men's and women's competition categories. In: FINA, editor. Online; 2022.

12. Union Cycliste Internationale. Chapter V Eligibilty Regulations for Transgender Athletes. In: Union Cycliste Internationale, editor. Part 13 Medical Rules. Online; 2022.

13. USA Gymnastics. USA gymnastic policy for transgender inclusion. 2020 [cited 2021 November, 29th]; Available from: https://usagym.org/PDFs/About%20USA%20Gymnastics/transgender_policy.pdf

14. International Olympic Committee. Framework on fairness, inclusion and non-discrimination on the basis of gender identity and sex variations. 2021 [cited 2021 November, 29th]; Available from: https://stillmed.olympics.com/media/Documents/News/2021/11/IOC-Framework-Fairness-Inclusion-Non-discrimination-2021.pdf

15. Handelsman DJ, Hirschberg AL, Bermon S. Circulating testosterone as the hormonal basis of sex differences in athletic performance. Endocrine reviews. 2018;39(5):803-29.

16. Hilton EN, Lundberg TR. Transgender women in the female category of sport: perspectives on testosterone suppression and performance advantage. Sports Med. 2020 2020/12/08.

17. Bianchi A. Transgender women in sport. Journal of the Philosophy of Sport. 2017;44(2):229-42.

18. Bhasin S, Brito JP, Cunningham GR, Hayes FJ, Hodis HN, Matsumoto AM, et al. Testosterone therapy in men with hypogonadism: an Endocrine Society clinical practice guideline. The Journal of Clinical Endocrinology & Metabolism. 2018;103(5):1715-44.

19. Elbers J, Asscheman H, Seidell J, Gooren LJ. Effects of sex steroid hormones on regional fat depots as assessed by magnetic resonance imaging in transsexuals. American Journal of Physiology-Endocrinology and Metabolism. 1999;276(2):E317-E25.

20. Gooren LJ, Bunck MC. Transsexuals and competitive sports. European Journal of Endocrinology. 2004;151(4):425-30.

Supplemental material

BMJ Publishing Group Limited (BMJ) disclaims all liability and responsibility arising from any reliance placed on this supplemental material which has been supplied by the author(s)

*Br J Sports Med*

21.  T'Sjoen G, Weyers S, Taes Y, Lapauw B, Toye K, Goemaere S, et al. Prevalence of low bone mass in relation to estrogen treatment and body composition in male-to-female transsexual persons. Journal of Clinical Densitometry. 2009;12(3):306-13.

22.  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. The Journal of clinical endocrinology and metabolism. 2020;105(3).

23.  Klaver M, van Velzen D, de Blok C, Nota N, Wiepjes C, Defreyne J, et al. Change in visceral fat and total body fat and the effect on cardiometabolic risk factors during transgender hormone therapy. The Journal of Clinical Endocrinology & Metabolism. 2022;107(1):e153-e64.

24.  Klaver M, De Blok C, Wiepjes C, Nota NM, Dekker MJ, de Mutsert R, et al. Changes in regional body fat, lean body mass and body shape in trans persons using cross-sex hormonal therapy: results from a multicenter prospective study. European Journal of Endocrinology. 2018;178(2):163-71.

25.  Mauras N, Hayes V, Welch S, Rini A, Helgeson K, Dokler M, et al. Testosterone deficiency in young men: marked alterations in whole body protein kinetics, strength, and adiposity. The Journal of Clinical Endocrinology & Metabolism. 1998;83(6):1886-92.

26.  Kvorning T, Andersen M, Brixen K, Madsen K. Suppression of endogenous testosterone production attenuates the response to strength training: a randomized, placebo-controlled, and blinded intervention study. Am J Physiol Endocrinol Metab. 2006;291(6):E1325-E32.

27.  Tack LJ, Heyse R, Craen M, Dhondt K, Bossche HV, Laridaen J, et al. Consecutive cyproterone acetate and estradiol treatment in late-pubertal transgender female adolescents. The journal of sexual medicine. 2017;14(5):747-57.

28.  Auer MK, Cecil A, Roepke Y, Bultynck C, Pas C, Fuss J, et al. 12-months metabolic changes among gender dysphoric individuals under cross-sex hormone treatment: a targeted metabolomics study. Scientific reports. 2016;6(1):1-10.

29.  Lapauw B, Taes Y, Simoens S, Van Caenegem E, Weyers S, Goemaere S, et al. Body composition, volumetric and areal bone parameters in male-to-female transsexual persons. Bone. 2008;43(6):1016-21.

30.  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 International. 2015;26(1):35-47.

31.  Scharff M, Wiepjes CM, Klaver M, Schreiner T, t'Sjoen G, Den Heijer M. Change in grip strength in trans people and its association with lean body mass and bone density. Endocrine connections. 2019;8(7):1020-8.

32.  Klaver M, Dekker M, de Mutsert R, Twisk J, den Heijer M. Cross-sex hormone therapy in transgender persons affects total body weight, body fat and lean body mass: a meta-analysis. Andrologia. 2017;49(5):e12660.

33.  Spanos C, Bretherton I, Zajac JD, Cheung AS. Effects of gender-affirming hormone therapy on insulin resistance and body composition in transgender individuals: a systematic review. World journal of diabetes. 2020;11(3):66.

34.  Nickerson BS, McLester CN, McLester JR, Kliszczewicz BM. Relative accuracy of anthropometric-based body fat equations in males and females with varying BMI classifications. Clinical nutrition ESPEN. 2020;35:136-40.

35.  Alvares LA, Santos MR, Souza FR, Santos LM, Ramos HA, Mendonca BB, et al. Muscle Strength in Transgender Women After Long-Term Hormone Therapy: A Cross-Sectional Study. Journal of the Endocrine Society. 2021;5(Suppl 1):A792.

36.  Alvares LA, Santos MR, Souza FR, Santos LM, Mendonca BB, Alves M-JNN, et al. First Evidence of Cardiopulmonary Adaptation to Physical Effort in Transgender Women After Long-Term Hormone Therapy: A Cross-Sectional Study. Journal of the Endocrine Society. 2021;5(Supplement_1):A790-A1.

37.  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. British Journal of Sports Medicine. 2021.

Supplemental material

BMJ Publishing Group Limited (BMJ) disclaims all liability and responsibility arising from any reliance placed on this supplemental material which has been supplied by the author(s)

*Br J Sports Med*

38.     Antun A, Zhang Q, Bhasin S, Bradlyn A, Flanders WD, Getahun D, et al. Longitudinal changes in hematologic parameters among transgender people receiving hormone therapy. Journal of the Endocrine Society. 2020;4(11):bvaa119.

39.     Kanstrup I-L, Ekblom B. Blood volume and hemoglobin concentration as determinants of maximal aerobic power. Medicine and science in sports and exercise. 1984;16(3):256-62.

40.     Otto JM, Montgomery HE, Richards T. Haemoglobin concentration and mass as determinants of exercise performance and of surgical outcome. Extreme physiology & medicine. 2013;2(1):1-8.

41.     Roberts TA, Smalley J, Ahrendt D. Effect of gender affirming hormones on athletic performance in transwomen and transmen: implications for sporting organisations and legislators. British Journal of Sports Medicine. 2020:bjsports-2020-102329.

42.     Hamilton BR, Guppy FM, Barrett J, Seal L, Pitsiladis Y. Integrating transwomen athletes into elite competition: the case of elite archery and shooting. European Journal of Sport Science. 2021:1-22.

43.     Patel AJ, Wesley R, Leitman SF, Bryant BJ. Capillary versus venous haemoglobin determination in the assessment of healthy blood donors. Vox sanguinis. 2013;104(4):317-23.

44.     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 journal of biological sciences. 2019;26(1):105-11.

45.     Johnson DL, Bahamonde R. Power output estimate in university athletes. Journal of strength and Conditioning Research. 1996;10:161-6.

46.     Jamovi. The Jamovi Project.  2021  [cited 2022 May 9th]; Version 1.6:[Available from: https://www.jamovi.org