Check for updates

Received: 12 March 2022 | Accepted: 5 May 2023

DOI: 10.1111/cpf.12832

Clinical Physiology and Functional Imaging

ORIGINAL ARTICLE

Acute exercise affects dual-energy X-ray absorptiometry body composition estimates but not standardised ultrasound measurements of subcutaneous adipose tissue

Jun N. Ong[1] | Kagan J. Ducker[2] | Bonnie J. Furzer[1] | Michael Dymock[3] | Grant J. Landers[1]

[1]School of Human Sciences (Exercise and Sport Science), The University of Western Australia, Perth, Western Australia, Australia

[2]School of Allied Health, Curtin University, Perth, Western Australia, Australia

[3]Centre for Applied Statistics, The University of Western Australia, Perth, Western Australia, Australia

Correspondence

Jun N. Ong, School of Human Sciences (Exercise and Sport Science), The University of Western Australia, Crawley, Perth, WA 6009 M408, Australia.
Email: julian.ong@uwa.edu.au

Funding information

Australian Commonwealth Government, Grant/Award Number: Research Training Program stipend

Abstract

Ultrasound has been demonstrated to be a highly accurate and reliable tool for measuring subcutaneous adipose tissue thickness and is robust against changes in hydration status or acute food or fluid intake. However, the effect of prior acute exercise is unexamined. This study examined the impact of an acute endurance exercise and resistance exercise session on standardised brightness-mode ultrasound measurements of subcutaneous adipose tissue thickness compared to skinfolds and dual-energy X-ray absorptiometry body composition estimates. In a randomised cross-over design, 30 active adults (24.2 ± 4.9 years) undertook physique assessment via standardised brightness-mode ultrasound, skinfolds and dual-energy X-ray absorptiometry before, immediately and 45 min after an acute endurance or resistance exercise session. The mean sum of eight subcutaneous adipose tissue thickness measured via standardised brightness-mode ultrasound increased (0.6 mm, $p = 0.04$) immediately postendurance exercise but was not meaningful when evaluated against the technical error of measurement of the investigator. A significant ($p = 0.01$) but not meaningful decrease in the sum of eight skinfolds occurred immediately (−1.1 ± 0.4 mm) and 45 min (−1.3 ± 0.4 mm) postresistance exercise. Comparatively, endurance exercise elicited a meaningful decrease of total mass (460 ± 30 g) and trunk lean mass (680 ± 90 g) dual-energy X-ray absorptiometry estimates. Findings from this study indicate standardised client presentation may be unnecessary when employing either standardised brightness-mode ultrasound or skinfolds for body composition assessment unlike dual-energy X-ray absorptiometry.

KEYWORDS

brightness-mode, dual-energy X-ray absorptiometry, skinfold thickness, subcutaneous adipose tissue, ultrasonography

© 2023 Scandinavian Society of Clinical Physiology and Nuclear Medicine.

1 | INTRODUCTION

In 2016, standardised brightness-mode ultrasound (B-mode US) was introduced to measure subcutaneous adipose tissue (SAT) thickness in response to an urgent need for accurate field-based physique assessment methods (Müller et al., 2016). This method has been demonstrated to be highly accurate and reliable for measuring SAT patterning in adults (body of varying mass index [BMI]: 18.6–40.3 $kg \cdot m^{-2}$) (Störchle et al., 2017) and athletes of diverse sports and physiques (Gomes et al., 2020; Müller et al., 2020). For example, standardised B-mode US was found to be capable of monitoring changes of SAT mass in athletes with an accuracy of about 0.2 kg, with median thickness measurement deviations of less than 0.2 mm at the individual eight sites (Müller et al., 2020). In comparison to skinfolds, previous studies have demonstrated that anatomical and individual variation in skin compressibility and thickness (up to 300%) can profoundly influence the accuracy of skinfold measurements (Moore et al., 2003; Müller et al., 2013), therefore compromising the ability to reliably monitor SAT mass changes. It should also be noted that skinfolds measure a compressed double layer of SAT and skin unlike standardised B-mode US (Müller et al., 2013). Additionally, a 1.1% and 1.0% relative measurement deviation of the sum of eight US SAT thickness measurements conducted in lean individuals was achieved in an intraobserver reliability and interobserver reliability analysis, respectively (Störchle et al., 2017). Furthermore, intra-observer reliability analysis revealed an even smaller relative deviation of 0.5% when measuring overweight/obese individuals in the same study (Störchle et al., 2017).

Our group has also previously demonstrated this method to reliably measure SAT thickness across the menstrual cycle in active eumenorrheic females (Ong et al., 2022b), as well as being robust against changes in hydration status or acute food or fluid intake (Ong et al., 2022a). This finding holds significance for standardised B-mode US as a physique assessment method. Potential factors that may redistribute total body water or alter hydration status, including the female menstrual cycle, acute food and fluid intake or prior exercise could have an impact on the accuracy and reliability across common physique assessment methods (Slater et al., 2018). Dual-energy X-ray absorptiometry (DXA) has been widely adopted in assessing the body composition of athletes due to its efficiency and convenience. Nevertheless, general morphological norm assumptions used to develop measurement algorithms in proprietary DXA analysis software may not necessarily hold true for athletic populations, particularly if the athletes are excessively small, large, lean or muscular (Ackland et al., 2012), therefore undermining the accuracy and validity in the utility of DXA in such individuals. For example, resistance-trained athletes have been previously evaluated to possess negative fat on the torso using DXA (Stewart & Hannan, 2000). Additionally, DXA has been systematically demonstrated to produce unreliable results when participants exercised or consumed food or fluid before their assessment (Kerr et al., 2017; Nana et al., 2012, 2013; Ong et al., 2022a; Rodriguez-Sanchez & Galloway, 2015). This necessitates the requirement for pre-assessment preparation such that the participant undertakes their assessment in a standardised presentation (i.e., overnight fasted, euhydrated and abstaining from exercise for the previous 12–24 h) (Ackland et al., 2012; Slater et al., 2018).

Indeed, road cycling ($n = 14$ males, 27 ± 8 years, 110 ± 42 min) before a DXA assessment demonstrated to increase arm lean mass (LM) and decreased total and trunk LM estimates, while a resistance exercise (RE) session consisting mainly of upper body exercises ($n = 27$ males, 30 ± 6 years) increased arm LM (Nana et al., 2013). Reductions in total LM observed in male cyclists were attributed to dehydration whereas decreases in trunk LM in conjunction with increases in arm LM were due to blood volume being shunted from the trunk to the periphery (Nana et al., 2013). Similarly, total body RE combined with interval running ($n = 21$, seven females, 24 ± 2 years, ~80 min) before a DXA assessment was observed to decrease trunk LM and arm and leg % fat and increased leg LM estimates (Lytle et al., 2020). Additionally, arm LM increased in male participants but decreased in females. Skinfold thickness measurements have also been implicated by prior exercise. For example, six of eight ISAK (International Society for the Advancement of Kinanthropometry) skinfold sites was observed to increase in thickness after a simulated soccer match, attributed to an increased blood flow in the skin (Araújo et al., 2018), whereas Rodriguez-Sanchez and Galloway (2015) ($n = 38$, 15 females, 28 ± 5 years) reported exercise-induced hypohydration decreased the sum of eight skinfolds. In contrast, exercise-induced hypohydration elicited no changes to the sum of seven skinfolds ($n = 8$, four females, 21 ± 2 years) (Norton et al., 1998) or Amplitude modulation (A-mode) US measured sum of eight SAT thickness in participants ($n = 11$, three females, 27 ± 10 years) (Wagner & Cotter 2021). In view of the above observations, it is therefore logical to ascertain whether prior exercise may also affect the reliability of standardised B-mode US measurements of SAT to credibly establish the utility of this method for field depolyment (Müller & Maughan, 2013).

Accordingly, the aim of this study was to examine the impact of endurance exercise (EE) and RE on standardised B-mode US measurements of SAT thickness in active males and females compared to ISAK skinfolds and DXA. It is hypothesised that standardised B-mode US measurements of SAT and ISAK skinfolds are unlikely to be implicated by prior exercise, with no differences between the sexes (Norton et al., 1998; Wagner & Cotter, 2021). However, prior exercise may compromise the precision of DXA body composition estimates with possible disparate outcomes between males and females (Lytle et al., 2020).

2 | METHODS

2.1 | Study participants

Thirty adults (males: $n = 20$, age = 25 ± 5 years, height = 183.2 ± 3.6 cm, body mass (BM) = 81.9 ± 6.5 kg; females: $n = 10$, age = 24 ± 5 years, height = 170.6 ± 6.1 cm, BM = 65.7 ± 10.0 kg) that were recreationally active or trained (McKay et al., 2022), were recruited to participate in the study. Power analyses (G*Power v3.0.10; Heinrich

1475097x, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/cpf.12832 by University Of Western Australia, Wiley Online Library on [10/09/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Heine Universität Düsseldorf; partial $\eta^2 = 0.245$, $\alpha = 0.05$, power = 0.95) from previous research (Lytle et al., 2020) yielded a required sample size of at least nine participants from each sex. Inclusion criteria included: being able to fit within the DXA active scanning bed area (198 × 66 cm), not currently carbohydrate or creatine loading, and exposed to ≤1 mSv of ionising radiation from medical imaging (i.e., >1 spine X-ray or equivalent) in the past 12 months. This study was approved by the Human Research Ethics Committee of the University of Western Australia (2020/ET000207), and informed written consent was obtained from all participants.

2.1.1 | Familiarisation session

Participants attended an initial familiarisation session, followed by two experimental sessions 1 week apart. The experimental sessions consisted of physique assessments using standardised B-mode US, ISAK skinfolds and DXA at baseline followed by either a RE or EE session with re-assessments conducted immediately and at 45 min postexercise. During familiarisation, participants were provided with an information sheet with instructions to record their dietary intake and physical activity, and adhere to standardised participant presentation requirements for 24 h before their first experimental session (Ackland et al., 2012). This was to be replicated on the day before their subsequent session. Participants were also instructed to record their nude body mass (BM) daily for 5 consecutive days upon waking before their first assessment session to determine an average baseline nude BM and maintain their current exercise and dietary routine throughout the study duration.

2.1.2 | Body composition assessments

In the morning of the experimental sessions, participants consumed one sachet (15 g) of Powerade® (Coca-Cola Amatil) made up to 250 mL with water upon waking to standardise fluid intake, and abstained from eating or drinking until session completion. Upon arrival to the laboratory, participants voided their bladder and a mid-stream urine sample was collected for urine specific gravity (USG) analysis with a desktop refractometer (T3-NE, Atago) to verify euhydration status. Participants' nude BM was recorded to the nearest 0.01 kg on digital platform scales (August Sauter GmbH) and height was measured to the nearest 0.1 cm using a wall mounted stadiometer (Novel Products Inc.). Should a USG value of >1.020 be recorded and their laboratory assessed nude BM were <99% of their average baseline nude BM, participants ingested an equivalent mass of water to attain their average baseline nude BM. (Kavouras 2002). Participants were marked up in line with International Association of Sciences in Medicine and Sports (IASMS) (Ackland & Müller, 2018; Müller et al., 2016) and ISAK (Hume et al., 2018) protocols to measure SAT thickness and skinfolds respectively. Ultrasound images were captured in duplicates via B-mode US (Telemed Echo Blaster 128 EXT-1Z REV:C; probe—Telemed Linear Transducer HL9.0/40/128Z-4; software—Telemed Echo Wave II version 3.2.0). Image analysis was conducted with Fat Analysis Tool software (v3.3, Rotosport; rotosport.at) to determine SAT thickness, with a mean sum of eight SAT thicknesses (including embedded structures; S8US) used for data analysis. The interested reader may wish to refer to Müller et al. (2016) for a detailed protocol on the measurement of SAT using standardised B-mode US, including participant positioning and image acquisition and analysis.

Skinfolds were measured in duplicates (triplicate if the difference between the first two measurements was >5%) with callipers (British Indicators) with a mean sum of eight skinfolds (S8SF) used for data analysis. The same ISAK (Level 1 anthropometrist) and IASMS accredited advanced technician took all measurements and analysed the data. Participants undertook whole body DXA scans in standard thickness mode on a narrowed fan-beam DXA machine (Lunar iDXA Advance, GE Healthcare) positioned according to the Nana et al. positioning protocol (Kerr et al., 2016), standardised with Velcro straps and customised radiolucent foam blocks (i.e., a constant distance of 22 cm between the feet and 5 cm between the palms and trunk). Regions of interest in the scans automatically demarcated by the software GE Encore (v16.0, GE Healthcare) were subsequently confirmed by the investigator.

2.1.3 | Resistance and endurance exercise

Following completion of the physique assessments, participants were randomly assigned to undertake either a RE or EE session and crossed over to complete the opposite exercise modality at the subsequent session (Figure 1). The EE session was performed on a stationary cycle ergometer (Evolution Performance Cycles), interfaced with an IBM-compatible computer system customised program (Cyclemax, School of Human Sciences—Exercise and Sport Science, The University of Western Australia, Perth, Australia). Participants commenced the endurance session with a 5 min warm-up and cycled at an intensity rating of perceived exertion (RPE) of 7 on the Borg-CR10 scale (Borg 1998) for 40 min. The RE session comprised of: hamstring curl, seated row, bench press, incline leg press, latissimus pull down and military press (warm-up set + 3 working sets × 10 repetitions, 90 s rest intervals). Weights were adjusted after each working set to aim to elicit a RPE of 7 to match the perceived intensities of the RE and EE sessions. Participants were fitted with a heart rate sensor (H7 heart rate sensor, Polar Electro Australia) on both occasions. Following exercise cessation, participants were reweighed, and physique was reassessed via the aforementioned methods immediately and at 45 min postexercise.

2.1.4 | Statistical analysis

To account for the dependence between observations within individuals, linear mixed-effects models were implemented via the *nlme* R package (v 4.05 RStudio Inc.) (R Core Team, 2020) to analyse

1475097x, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/cpf.12832 by University Of Western Australia, Wiley Online Library on [10/09/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

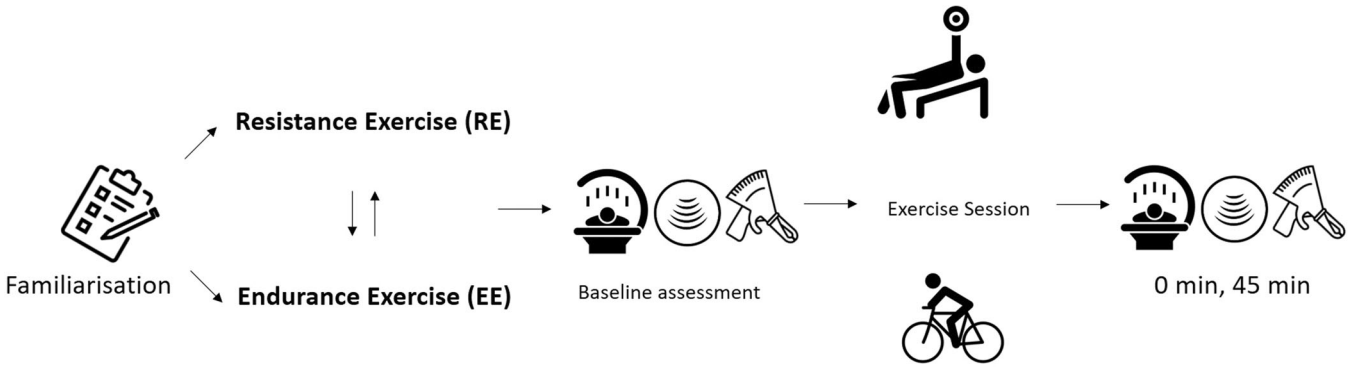

FIGURE 1 Schematic of experimental protocol. Participants were block randomised to undertake either 'Resistance Exercise' or 'Endurance Exercise' in random order and complete the opposite modality in the following week.

the impact of RE and EE on body composition estimates. The fixed effects in the model included participant sex, exercise modality and time. Participants were included as random effects to model the additional within-participant biological variability between sessions. Interaction terms between the fixed effects were evaluated to determine if the effects of exercise modality were dependent on sex and time. 95% confidence intervals (95% CI) of the mean difference between pre- and postexercise were used to interpret statistical significance and clinical meaningfulness of the mean difference. Additionally, the precision error (root-mean-square standard deviation RMS-SD]) and least significant change (LSC 95% CI) were calculated in accordance to Hind et al. (2018). Statistical significance was set at $p < 0.05$.

3 | RESULTS

3.1 | Standardised B-mode US measurements of SAT and skinfolds

The mean heart rate achieved was 136 ± 17 and 98 ± 17 beats per min and session mean RPE was 6.7 ± 0.8 and 6.6 ± 0.8 for EE and RE, respectively. The 95% CI technical error of measurement (TEM-95% CI) of the investigator for S8US and S8SF was ±2.6 ± 4.7 mm, respectively. Accordingly, a nonmeaningful increase in S8US (0.6 mm, $p = 0.04$) was recorded immediately post-EE (Table 1). Decreases to S8SF immediately (−1.1 ± 0.4 mm; $p = 0.01$) and at 45 min (−1.3 ± 0.4 mm; $p = 0.00$) post-RE were also not meaningful (Table 2). The effect of sex on S8US or S8SF was not evident. Individual changes in S8US and S8SF following EE and RE are illustrated in Figure 2.

3.2 | Dual energy X-ray absorptiometry body composition estimates

Total mass, trunk mass and trunk LM DXA estimates decreased ($p = 0.00$) following EE (Table 1) and RE (Table 2). Specifically, total mass (LSC-95% CI = 260 g) was reduced immediately post-EE (460 g) and post-RE (170 g). Trunk mass (RMS-SD = 320 g) and trunk LM (LSC-95% CI = 650 g) also decreased immediately post-EE (680 g, 680 g) and post-RE (340 g, 300 g). Importantly, reductions in total mass and trunk LM following EE were considered meaningful. Immediately post-EE also saw a decrease ($p = 0.00$; 390 g) in total LM (RMS-SD = 220 g).

Increases in limb mass DXA estimates corresponding to exercise modality were also observed. Specifically, leg mass (RMS-SD = 220 g) and leg LM (RMS-SD = 180 g) increased ($p = 0.00$) immediately post-EE (230 g, 290 g), while arm mass (RMS-SD = 270 g) increased ($p = 0.00$) immediately post-RE (180 g). Additionally, there was an effect of sex on arm LM (RMS-SD = 220 g), with males but not females experiencing an increase of 310 g post-RE. While legs (60 g) and arms (70 g) FM decreased ($p = 0.04$) post-RE, these were less than their respective precision error.

4 | DISCUSSION

Vasodilation and increased blood flow to the skin and working muscles (hyperaemia), along with raised perspiration rates in response to exercise, promotes fluid shifts and redistribution (Saltin, 2007; Senay & Pivarnik 1985). Together with the propensity to reduce glycogen stores (Bone et al., 2017), prior exercise has been demonstrated to introduce biological variability across many common physique assessment methods (Nana et al., 2013; Rodriguez-Sanchez & Galloway, 2015; Slater et al., 2018). Results from this study indicate that the recently standardised B-mode US method of measuring SAT thickness is however not impacted by prior exercise. Neither EE or RE elicited meaningful changes (−0.5 to 0.6 mm) to S8US with the exception of one outlier. This was similar to the findings of Wagner and Cotter (2021), who observed no differences between the pre- and postsum of eight SAT thicknesses using A-mode US in exercise-induced hypohydrated participants (~−2% BM). This lead the authors to conclude that SAT is likely impervious to hydration status since it contains minimal water (Baker, 1969; Thomas, 1962). However, it should be noted that A-mode US used in this study is less accurate

1475097x, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/cpf.12832 by University Of Western Australia, Wiley Online Library on [10/09/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 Standardised brightness-mode ultrasound measurements of sum of eight subcutaneous adipose tissue thickness (S8US), sum of eight skinfold thickness (S8SF) and total and regional dual-energy X-ray absorptiometry (DXA) estimates at pre-, immediately after and 45 min postendurance exercise.

	Sex	Pre- Mean ± SE	0 min Post Mean ± SE	0 min post—Pre ΔMean ± SE (95% confidence interval [CI])	45 min Post Mean ± SE	45 min post—Pre ΔMean ± SE (95% CI)	45 min post—0 min post ΔMean ± SE (95% CI)	RMS SD (LSC 95% CI)
S8US (mm)	-	54.2 ± 5.8	54.7 ± 5.8	0.6 ± 0.3 (0.0, 1.1)*	54.6 ± 5.8	0.4 ± 0.3 (−0.2, 0.9)	−0.2 ± 0.3 (−0.8, 0.4)	
S8SF (mm)	-	70.7 ± 3.7	70.5 ± 3.7	-0.2 ± 0.4 (−1.0, 0.6)	70.2 ± 3.7	−0.6 ± 0.4 (−1.4, 0.2)	-0.4 ± 0.4 (−1.1, 0.4)	
DXA estimates		(kg)	(kg)	(g)	(kg)	(g)	(g)	(g)
Total mass	-	76.46 ± 1.95	76.00 ± 1.95	−460 ± 30 (−510, −400)*	75.98 ± 1.95	−480 ± 30 (−540, −430)*	−20 ± 30 (−80, −30)	90 (260)
Trunk mass	-	34.49 ± 0.87	33.81 ± 0.87	−680 ± 100 (−870, −490)*	34.12 ± 0.87	−370 ± 100 (−560, −180)*	310 ± 100 (120, 500)	320 (880)
Leg mass	-	27.02 ± 0.73	27.24 ± 0.73	230 ± 70 (90, 370)*	27.01 ± 0.73	0 ± 70 (−140, 140)	−230 ± (−370, −90)*	220 (620)
Arm mass	-	9.93 ± 0.36	9.91 ± 0.34	−20 ± 60 (−130, 90)	9.82 ± 0.36	−110 ± 60 (−220, 10)	−90 ± 60 (−200, 30)	270 (750)
Total lean mass	-	58.79 ± 1.95	58.40 ± 1.98	−400 ± 60 (−510, −280)*	58.32 ± 1.95	−480 ± 60 (−590, −360)*	−80 ± 60 (−190, 30)	220 (620)
Trunk lean mass	-	27.47 ± 0.87	26.79 ± 0.87	−680 ± 90 (−850, −500)*	27.02 ± 0.87	−450 ± 90 (−620, −270)*	230 ± 90 (50, 410)*	230 (650)
Leg lean mass	-	20.02 ± 0.71	20.31 ± 0.71	290 ± 60 (170, 410)*	20.07 ± 0.71	50 ± 60 (−70, 170)	-240 ± 60 (−360, −120)*	180 (500)
Arm lean mass[a]	M	9.01 ± 0.21	8.98 ± 0.21	−30 ± 50 (−140, 80)	8.91 ± 0.21	−100 ± 50 (−210, 10)	−70 ± 50 (−180, 40)	220 (600)
	F	5.26 ± 0.29	5.24 ± 0.29	−10 ± 80 (−170, 140)	5.19 ± 0.29	−70 ± 80 (−220, 80)	−60 ± 80 (−210, 100)	220 (620)
Total fat mass	-	14.49 ± 0.76	14.41 ± 0.76	−70 ± 50 (−160, 20)	14.47 ± 0.76	−10 ± 50 (−110, 80)	60 ± 50 (−30, 150)	180 (490)
Trunk fat mass[a]	M	5.76 ± 0.46	5.74 ± 0.46	−20 ± 60 (−130, 100)	5.84 ± 0.46	−90 ± 60 (−30, 200)	100 ± 60 (−10, 220)	210 (570)
	F	6.73 ± 0.66	6.72 ± 0.66	−10 ± 80 (−170, 150)	6.65 ± 0.66	−80 ± 80 (−240, 80)	−70 ± 80 (−230, 90)	180 (510)
Legs fat mass	-	5.78 ± 0.35	5.73 ± 0.35	−60 ± 30 (−120, 0)	5.74 ± 0.35	−50 ± 30 (−110, 20)	10 ± 30 (−50, 70)	80 (220)
Arms fat mass	-	1.71 ± 0.08	1.71 ± 0.08	0 ± 20 (−30, 30)	1.71 ± 0.08	0 ± 20 (−30, 30)	0 ± 20 (−30, 30)	70 (180)
Body mass	-	76.22 ± 1.93	75.78 ± 1.93	−440 ± 30 (−500, −380)*				

Note: ΔMean, change in mean; SE, standard error, reported because results are based on modelling from raw values. M, males, $n = 20$; F, females, $n = 10$; RMS SD, root-mean-square standard deviation (precision error); LSC, least significant change; *$p < 0.05$.

[a]Significant effect of sex.

14750976, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/cpf.12832 by University Of Western Australia, Wiley Online Library on [10/09/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 2 Standardised brightness-mode ultrasound measurements of sum of eight subcutaneous adipose tissue thickness (S8US), sum of eight skinfold thickness (S8SF) and total and regional dual-energy X-ray absorptiometry (DXA) estimates at pre-, immediately after and 45 min postresistance exercise.

	Sex	Pre- Mean ± SE	0 min Post Mean ± SE	0 min post—Pre ΔMean ± (95% confidence interval [CI])	45 min Post Mean ± SE	45 min post—Pre ΔMean ± SE (95% CI)	45 min post—0 min post ΔMean ± SE (95% CI)	RMS SD (LSC 95% CI)
S8US (mm)	-	54.8 ± 5.9	54.5 ± 5.9	−0.3 ± 0.3 (−0.9, 0.2)	54.3 ± 5.9	−0.5 ± 0.3 (−1.0, 0.1)	−0.2 ± 0.3 (−0.7, 0.4)	
S8SF (mm)	-	70.5 ± 3.8	69.5 ± 3.8	−1.1 ± 0.4 (−1.9, −0.3)*	69.3 ± 3.8	−1.3 ± 0.4 (−2.1, −0.5)*	−0.2 ± 0.4 (−1.0, 0.6)	
DXA estimates		(kg)	(g)	(kg)	(g)	(g)	(g)	(g)
Total mass	-	76.37 ± 1.91	76.19 ± 1.91	−170 ± 30 (−230, −120)*	76.19 ± 1.91	−170 ± 30 (−230, −120)*	0 ± 30 (−50, 50)	90 (260)
Trunk mass	-	33.95 ± 0.84	33.95 ± 0.84	−340 ± 100 (-530, -150)*	34.24 ± 0.84	−40 ± 100 (−230, 150)	290 ± 100 (100, 480)*	320 (880)
Leg mass	-	27.07 ± 0.72	27.09 ± 0.72	10 ± 70 (-130, 150)	27.02 ± 0.72	−50 ± 70 (−190, 90)	−60 ±± 70 (−200, 80)	220 (620)
Arm mass	-	9.95 ± 0.36	10.13 ± 0.36	180 ± 60 (70, 290)*	9.89 ± 0.36	−70 ± 60 (−180, 40)	−260 ± 60 (−370, −140)*	270 (750)
Total lean mass	-	58.65 ± 1.90	58.58 ± 1.90	−70 ± 60 (−190, 40)	58.56 ± 1.90	−90 ± 60 (−210, 20)	−20 ± 60 (−130, 100)	220 (620)
Trunk lean mass	-	27.27 ± 0.83	26.97 ± 0.83	−300 ± 90 (−480, −120)*	27.21 ± 0.83	−60 ± 90 (−240, 110)	230 ± 90 (60, 410)*	230 (650)
Leg lean mass	-	20.08 ± 0.70	20.10 ± 0.70	30 ± 60 (−90, 150)	20.05 ± 0.70	−30 ± 60 (−150, 90)	−60 ± 60 (−180, 70)	180 (500)
Arm lean mass[a]	M	8.95 ± 0.20	9.26 ± 0.20	310 ± 50 (210, 420)*	9.00 ± 0.20	50 ± 50 (-60, 150)	−270 ± 50 (−380, −160)*	220 (600)
	F	5.35 ± 0.29	5.35 ± 0.29	0 ± 80 (−150, 150)	5.23 ± 0.29	−120 ± 80 (−270, 30)	−120 ± 80 (−270, 150)	220 (620)
Total fat mass	-	14.51 ± 0.76	14.43 ± 0.76	80 ± 50 (−170, 10)	14.44 ± 0.76	−70 ± 50 (−160, 20)	10 ± 50 (−80, 100)	180 (490)
Trunk fat mass[a]	M	5.83 ± 0.47	5.75 ± 0.47	−80 ± 60 (−190, 40)	5.87 ± 0.47	40 ± 60 (−70, 160)	120 ± 60 (10, 240)*	210 (570)
	F	6.56 ± 0.66	6.62 ± 0.66	70 ± 80 (−100, 20)	6.54 ± 0.66	−20 ± 82 (−180, 140)	−80 ± 80 (−250, 80)	180 (510)
Legs fat mass	-	5.83 ± 0.35	5.77 ± 0.35	−60 ± 30 (−120, 0)	5.76 ± 0.35	−60 ± 30 (−120, 0)*	0 ± 30 (−60, 60)	80 (220)
Arms fat mass	-	1.73 ± 0.08	1.71 ± 0.08	−20 ± 20 (−50, 10)	1.67 ± 0.08	−70 ± 20 (−100, −40)*	−40 ± 20 (−70, −10)*	70 (180)
Body mass	-	76.09 ± 1.89	75.92 ± 1.89	−170 ± 30 (−230, −110)*				

Note: ΔMean, change in mean; SE, standard error, reported because results are based on modelling from raw values. M, males, $n = 20$; F, females, $n = 10$; RMS SD, root-mean-square standard deviation (precision error); LSC, least significant change; *$p < 0.05$.

[a]Significant effect of sex.

1475097x, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/cpf.12832 by University Of Western Australia, Wiley Online Library on [10/09/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

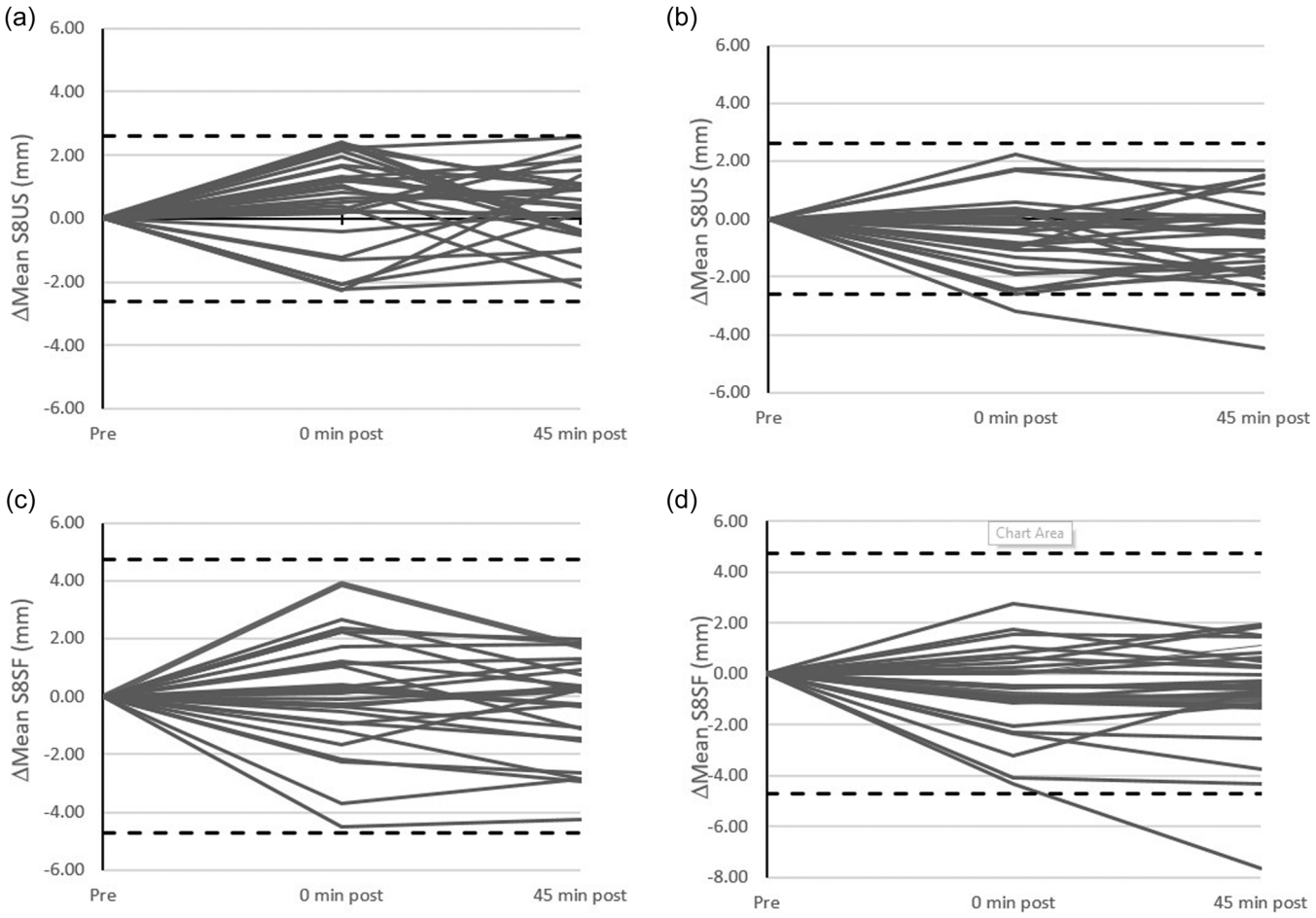

FIGURE 2 Individual changes in mean ultrasound measurements of sum of eight subcutaneous adipose tissue thickness (S8US) at pre-, immediately and 45 min post (a) endurance and (b) resistance exercise. Bold dash lines (- - -) indicate 95% confidence interval of technical error of measurement of technician = 2.6 mm. Individual changes in mean sum of eight skinfold thickness as (S8SF) at pre-, immediately and 45 min post (c) endurance and (d) resistance exercise. Bold dash lines indicate 95% confidence interval of technical error of measurement of technician = 4.7 mm. ΔMean = change in mean.

and reliable compared to standardised B-mode US. A-mode US systems typically use only 2.5 MHz probes for image acquisition compared to B-mode US systems that employ 12–18 MHz (Wagner et al., 2018), which translates to an accuracy magnitude of 5–10 times lower than that of B-mode US systems. Additionally, there is increased susceptibility of SAT compressions through uncontrolled pressure variation on the skin when moving the transducer to acquire measurements with A-mode US (Wagner, 2013).

Although heat dissipation through redistribution of blood flow to the skin surface in response to exercise is purported to induce hyperaemia (Araújo et al., 2018; Norton et al., 1998), this has been demonstrated to not affect skinfold values (Norton et al., 1998). Indeed, changes to S8SF in our study ranged from −1.3 to −0.6 mm immediately and at 45 min post-EE or -RE and were not considered meaningful, except for one outlier. Correspondingly, there were no changes to the sum of seven skinfolds (−4.1 ± 8.2 mm, $p = 0.15$) in recreationally active individuals ($n = 8$; age = 21 ± 3 years) following exercise-induced hypohydration (−2% to −2.5% BM) (Norton et al., 1998). Like B-mode US, skinfolds sample the SAT, albeit measured together with skin in a compressed state, which is mostly anhydrous and thus resistant to fluid shifts.

Our study identified both acute EE and RE to decrease total mass, trunk mass and trunk LM DXA estimates. Although not suggestive of exercise-induced hypohydration (i.e., ≥2% BM) (Maughan & Shirreffs, 2008), this decrease exceeded their respective precision errors. Total and trunk mass, total and trunk LM also decreased to a greater extent immediately post-EE than RE, likely due to greater losses in muscle glycogen and fluid via perspiration with EE (Bone et al., 2017). This was similarly observed in males that completed 110 ± 42 min of road cycling compared to 62 ± 10 min of RE (Nana et al., 2013). Importantly, our study found decreases in total mass and trunk LM post-EE amounted to meaningful changes when assessed against respective LSC-95% CIs.

Reductions in DXA total mass, trunk mass and trunk LM estimates were also observed in strength-trained individuals following a strength and conditioning session (Lytle et al., 2020). Additionally, the authors observed increased leg mass (200 g) and leg LM (300 g) in all participants but only males increased arm mass (320 g)

1475097x, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/cpf.12832 by University Of Western Australia, Wiley Online Library on [10/09/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

and arm LM (350 g). This finding was similar to Nana et al. (2013) where leg mass and leg LM of males increased following road cycling and arm mass (220 g) and arm LM (240 g) increased following RE. Although not qualified to be meaningful, our study also observed transient increases in leg mass (230 g) and leg LM (290) and arm mass (180 g) and arm LM (310 g, in males only) following EE (Table 1) and RE (Table 2), respectively. Collectively, these observations suggest that the modality of acute exercise has a direct impact on the DXA estimates of the working muscle group.

Indeed, we captured temporal physiological changes associated with exercise hyperaemia (Saltin, 2007; Sjogaard & Saltin, 1982) (i.e., fasted participants experiencing vasodilation with increased blood flow and fluid re-compartmentalisation towards working muscle group). Specifically, EE increased leg mass and leg LM estimates, while RE increased arm mass and arm LM immediately postexercise, both of which subsided at 45 min post-EE and RE, respectively. Noteworthy is that decreases in trunk LM approximated the sum of decreases in total LM and increases in leg or arm LM (e.g., decrease in trunk LM [680 g] ≈ decrease in total LM [400 g] post-EE + increase in leg LM [290 g]), indicating the shunting of blood volume from the trunk to the periphery.

4.1 | Limitations

One of the main limitations of our study was that we could not comprehensively match the intensities of the EE and RE sessions as suggested by the disparate average heart rates achieved. This could have possibly provided a more meaningful comparison on the impact of different acute exercise modalities on the reliability of physique assessments. However, it would be impractical to achieve consistency across all participants and exercise modalities, since each individual would have disparate training histories and thus different levels of fitness or training adaptations, in addition to the different energetics between the exercise modalities (aerobic vs. anaerobic).

5 | PRACTICAL APPLICATIONS AND CONCLUSIONS

In conclusion, our findings confirm that standardised client presentation may be unnecessary when employing either standardised B-mode US and ISAK skinfolds for physique assessment but verifies that the measurement precision of total and trunk mass as well as lean components of DXA body composition estimates can be implicated by prior exercise. Additionally, estimates of the exercising body region (e.g., leg mass and leg LM with cycling) can be directly impacted by the modality of the exercise likely associated with exercise hyperaemia. Despite our findings, exercise in the 12 h before any body composition assessment is still cautioned against, since certain types of exercises and sporting activities (e.g., water-based) and those of higher intensity and duration (e.g., ultra-endurance events) not examined in this study, as well as exercising in unaccustomed environmental conditions may compromise measurement technique (e.g. via higher retention of skin surface moisture) and thus introduce technical variability.

AUTHOR CONTRIBUTIONS

Jun N. Ong had a role in all aspects of the study (inception and design, subject recruitment, data collection, data analysis and interpretation, manuscript preparation and final approval). Kagan J. Ducker was involved in study design/approval, data interpretation, manuscript preparation and final approval. Bonnie J. Furze was involved in study design/approval, manuscript preparation and final approval. Grant J. Landers was involved in study design/approval, data interpretation, manuscript preparation and final approval. Michael Dymock was involved in data analysis and interpretation, manuscript preparation and final approval.

ACKNOWLEDGEMENTS

The authors would like to thank all the participants in dedicating their valuable time to be part of the study. Jun N. Ong was in receipt of an Australian Government Research Training Program Scholarship at The University of Western Australia that made funding for this investigation possible.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study may be accessed via https://doi.org/10.26182/rzaq-6675

ORCID

Jun N. Ong http://orcid.org/0000-0003-3941-9784

REFERENCES

Ackland, T.R., Lohman, T.G., Sundgot-Borgen, J., Maughan, R.J., Meyer, N.L., Stewart, A.D. et al. (2012) Current status of body composition assessment in sport: review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical Commission. *Sports Medicine*, 42, 227–249.

Ackland, T.R. & Müller, W. (2018) Imaging method: Ultrasound. In: Hume, P.A., Kerr, D.A. & Ackland, T.R. (Eds.) *Best practice protocols for physique assessment in sport*. Springer Singapore, pp. 131–141.

Araújo, D., Teixeira, V.H., Carvalho, P. & Amaral, T.F. (2018) Exercise induced dehydration status and skinfold compressibility in athletes: an intervention study. *Asia Pacific Journal of Clinical Nutrition*, 27, 189–194.

Baker, G.L. (1969) Human adipose tissue composition and age. *The American Journal of Clinical Nutrition*, 22, 829–835.

Bone, J.L., Ross, M.L., Tomcik, K.A., Jeacocke, N.A., Hopkins, W.G. & Burke, L.M. (2017) Manipulation of muscle creatine and glycogen changes DXA estimates of body composition. *Medicine and Science in Sports and Exercise*, 49, 1029–1035.

Borg, G. (1998) *Borg's perceived exertion and pain scales*. Human Kinetics, Champaign.

Gomes, A.C., Landers, G.J., Binnie, M.J., Goods, P.S.R., Fulton, S.K. & Ackland, T.R. (2020) Body composition assessment in athletes: Comparison of a novel ultrasound technique to traditional skinfold

1475097x, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/cpf.12832 by University Of Western Australia, Wiley Online Library on [10/09/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

measures and criterion DXA measure. *Journal of Science and Medicine in Sport*, 23, 1006–1010.
Hind, K., Slater, G., Oldroyd, B., Lees, M., Thurlow, S., Barlow, M. et al. (2018) Interpretation of dual-energy X-ray absorptiometry-derived body composition change in athletes: a review and recommendations for best practice. *Journal of Clinical Densitometry*, 21, 429–443.
Hume, P.A., Sheerin, K.R. & de Ridder, J.H. (2018) Non-imaging method: Surface anthropometry. In: Hume, P.A., Kerr, D.A. & Ackland, T.R. (Eds.) *Best practice protocols for physique assessment in sport*. Springer Singapore, pp. 61–70.
Kavouras, S.A. (2002) Assessing hydration status. *Current Opinion in Clinical Nutrition and Metabolic Care*, 5, 519–524.
Kerr, A., Slater, G.J. & Byrne, N. (2017) Impact of food and fluid intake on technical and biological measurement error in body composition assessment methods in athletes. *British Journal of Nutrition*, 117, 591–601.
Kerr, A., Slater, G.J., Byrne, N. & Nana, A. (2016) Reliability of 2 different positioning protocols for dual-energy X-ray absorptiometry measurement of body composition in healthy adults. *Journal of Clinical Densitometry*, 19, 282–289.
Lytle, J.R., Stanelle, S.T., Kravits, D.M., Ellsworth, R.L., Martin, S.E., Green, J.S. et al. (2020) Effects of an acute strength and conditioning training session on dual-energy X-ray absorptiometry results. *Journal of Strength and Conditioning Research*, 34, 901–904.
Maughan, R.J. & Shirreffs, S.M. (2008) Development of individual hydration strategies for athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, 18, 457–472.
McKay, A.K.A., Stellingwerff, T., Smith, E.S., Martin, D.T., Mujika, I., Goosey-Tolfrey, V.L. et al. (2022) Defining training and performance caliber: a participant classification framework. *International Journal of Sports Physiology and Performance*, 17, 317–331.
Moore, T.L. (2003) Seventeen-point dermal ultrasound scoring system—a reliable measure of skin thickness in patients with systemic sclerosis. *Rheumatology*, 42, 1559–1563.
Müller, W., Fürhapter-Rieger, A., Ahammer, H., Lohman, T.G., Meyer, N.L., Sardinha, L.B. et al. (2020) Relative body weight and standardised brightness-mode ultrasound measurement of subcutaneous fat in athletes: an international multicentre reliability study, under the auspices of the IOC medical commission. *Sports Medicine*, 50, 597–614.
Müller, W., Horn, M., Fürhapter-Rieger, A., Kainz, P., Kröpfl, J.M., Maughan, R.J. et al. (2013) Body composition in sport: a comparison of a novel ultrasound imaging technique to measure subcutaneous fat tissue compared with skinfold measurement. *British Journal of Sports Medicine*, 47, 1028–1035.
Müller, W., Lohman, T.G., Stewart, A.D., Maughan, R.J., Meyer, N.L., Sardinha, L.B. et al. (2016) Subcutaneous fat patterning in athletes: selection of appropriate sites and standardisation of a novel ultrasound measurement technique: ad hoc working group on body composition, health and performance, under the auspices of the IOC Medical Commission. *British Journal of Sports Medicine*, 50, 45–54.
Müller, W. & Maughan, R.J. (2013) The need for a novel approach to measure body composition: is ultrasound an answer? *British Journal of Sports Medicine*, 47, 1001–1002.
Nana, A., Slater, G.J., Hopkins, W.G. & Burke, L.M. (2012) Effects of daily activities on dual-energy X-ray absorptiometry measurements of body composition in active people. *Medicine & Science in Sports & Exercise*, 44, 180–189.
Nana, A., Slater, G.J., Hopkins, W.G. & Burke, L.M. (2013) Effects of exercise sessions on DXA measurements of body composition in active people. *Medicine & Science in Sports & Exercise*, 45, 178–185.
Norton, K., Hayward, S., Charles, S. & Rees, M. (1998) The effects of hypohydration and hyperhydration on skinfold measurements. In: Norton, K., Olds, T. & Dollman, J. (Eds.) *Kinanthropometry VI: proceedings of the sixth scientific conference of the international society for the advancement of kinanthropometry*. International Society for the Advancement of Kinanthropometry, pp. 253–266.
Ong, J.N., Ducker, K.J., Furzer, B.J., Dymock, M. & Landers, G.J. (2022a) Food and fluid intake and hydration status does not affect ultrasound measurements of subcutaneous adipose tissue in active adults. *Journal of Science and Medicine in Sport*, 25, 548–552.
Ong, J.N., Ducker, K.J., Furzer, B.J., Dymock, M. & Landers, G.J. (2022b) Measures of body composition via dual-energy X-ray absorptiometry, ultrasound and skinfolds are not impacted by the menstrual cycle in active eumenorrheic females. *Journal of Science and Medicine in Sport*, 25, 115–121.
R Core Team. (2020) *R: A language and environment for statistical computing R Foundation for Statistical Computing*. R Core Team.
Rodriguez-Sanchez, N. & Galloway, S.D.R. (2015) Errors in dual-energy X-ray absorptiometry estimation of body composition induced by hypohydration. *International Journal of Sport Nutrition and Exercise Metabolism*, 25, 60–68.
Saltin, B. (2007) Exercise hyperaemia: Magnitude and aspects on regulation in humans. *The Journal of Physiology*, 583, 819–823.
Senay, Jr. L.C. & Pivarnik, J.M. (1985) Fluid shifts during exercise. *Exercise and Sport Sciences Reviews*, 13, 335–388.
Sjogaard, G. & Saltin, B. (1982) Extra- and intracellular water spaces in muscles of man at rest and with dynamic exercise. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, 243, R271–R280.
Slater, G.J., Shaw, G. & Kerr, A. (2018) Athlete considerations for physique measurement. In: Hume, P.A., Kerr, D.A. & Ackland, T.R. (Eds.) *Best Practice Protocols for Physique Assessment in Sport*. Springer Singapore, pp. 47–60.
Stewart, A.D. & Hannan, W.J. (2000) Prediction of fat and fat-free mass in male athletes using dual X-ray absorptiometry as the reference method. *Journal of Sports Sciences*, 18, 263–274.
Störchle, P., Müller, W., Sengeis, M., Ahammer, H., Fürhapter-Rieger, A., Bachl, N. et al. (2017) Standardized ultrasound measurement of subcutaneous fat patterning: high reliability and accuracy in groups ranging from lean to obese. *Ultrasound in Medicine & Biology*, 43, 427–438.
Thomas, L.W. (1962) The chemical composition of adipose tissue of man and mice. *Quarterly Journal of Experimental Physiology and Cognate Medical Sciences*, 47, 179–188.
Wagner, D.R. (2013) Ultrasound as a tool to assess body fat. *Journal of Obesity*, 2013, 1–9.
Wagner, D.R. & Cotter, J.D. (2021) Ultrasound measurements of subcutaneous fat thickness are robust against hydration changes. *International Journal of Sports Nutrition and Exercise Metabolism*, 31, 244–249.
Wagner, D.R., Thompson, B.J., Anderson, D.A. & Schwartz, S (2019) A-mode and B-mode ultrasound measurement of fat thickness: a cadaver validation study. *European Journal of Clinical Nutrition*, 73, 518–523.

How to cite this article: Ong, J.N., Ducker, K.J., Furzer, B.J., Dymock, M. & Landers, G.J. (2023) Acute exercise affects dual-energy X-ray absorptiometry body composition estimates but not standardised ultrasound measurements of subcutaneous adipose tissue. *Clinical Physiology and Functional Imaging*, 43, 345–353. https://doi.org/10.1111/cpf.12832

1475097x, 2023, 5, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/cpf.12832 by University Of Western Australia, Wiley Online Library on [10/09/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License