Changes in dual energy X-ray absorptiometry body composition scores in females following exercise-induced body fluid redistribution

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ABSTRACT

Objectives: The aim of the study was to determine changes in dual energy X-ray absorptiometry (DXA) body composition scores in females following exercise-induced body fluid redistribution.

Methods: Thirty females completed sessions of upper-body exercise (UBE), lower-body exercise (LBE), and a seated control (NEC), and body composition was assessed before and after sessions. ANOVA computed interactions between experimental conditions and body composition measurements.

Results: For the arms region, fat tissue showed mean differences for NEC ($M = 0.56 \pm 0.20\%$; $p = 0.009$) and UBE ($M = 0.68 \pm 0.18\%$; $p = 0.001$). The fat region showed mean differences for NEC ($M = 0.54 \pm 0.19\%$; $p = 0.007$) and UBE ($M = 0.59 \pm 0.17\%$; $p = 0.002$). The UBE showed mean differences for tissue ($M = 0.24 \pm 0.03$ kg; $p \leq 0.0001$), lean mass ($M = 0.19 \pm 0.02$ kg; $p \leq 0.0001$), and total mass ($M = 0.24 \pm 0.03$ kg; $p \leq 0.0001$). The legs region showed for UBE a mean difference for fat tissue ($M = 0.32 \pm 0.14\%$; $p = 0.025$), fat region ($M = 0.31 \pm 0.13\%$; $p = 0.026$), and lean mass ($M = 0.17 \pm 0.07$ kg; $p = 0.021$). For the total body region, significant mean differences were found for UBE ($M = 0.11 \pm 0.02$ kg; $p \leq 0.0001$) and LBE ($M = 0.20 \pm 0.03$ kg; $p \leq 0.0001$). Total mass for UBE ($M = 0.14 \pm 0.03$ kg; $p \leq 0.0001$) and LBE ($M = 0.21 \pm 0.03$kg; $p \leq 0.0001$) showed significant mean differences. Reliability scores were high within experimental conditions (CV = 0.17% to 3.76%).

Conclusion: Exercise-induced body fluid redistribution in females elicited small and reliable changes in body composition scores.

KEYWORDS

reliability; body mass; measurement; evaluation; DXA

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INTRODUCTION

The dual-energy X-ray absorptiometry (DXA) technology is available for body composition monitoring in clinical and non-clinical populations. Bone mineral content, lean mass for the entire body, and particular anatomical locations are some of the variables frequently examined at a minimal radiation dose and scanning time (Messina et al., 2015; Nana et al., 2015). DXA is considered a gold standard for bone mineral density and is commonly used for body composition assessment, yet biological and technical errors affect the validity and reliability of the scores (Messina et al., 2020). Among the biological variables that might impact body composition scores assessed by DXA are food and drink consumption before a scanning, unsuitable resting, and hydration (Nana et al., 2015). Current evidence (Chacón-Araya et al., 2024; Karahan et al., 2016; McNamara et al., 2015; Messina et al., 2020; Messina et al., 2015) suggests that technical errors can occur due to inaccurate equipment calibration, unreliable technician performance, patient positioning, image data analysis, artifacts such as coins, keys, or jewelry, clothing's fabrics, and the DXA's equipment scanning mode. Since no specific standard DXA scanning protocol exists, good practices have been recommended (Hume et al., 2018). Under these suggestions, individuals undergoing scanning should arrive at a testing site fasted and at rest since prior meals and physical activity increase errors in DXA measurements (Messina et al., 2020; Nana et al., 2015).

The evidence on the potential noise of food and drink consumption before DXA scans are controversial; it is necessary to conduct a meta-analysis to determine the magnitude if any, of the effect of food intake hours or minutes before a body composition assessment using DXA (Kerr et al., 2017; Nana et al., 2015). Physiologically, lean tissue in the human body contains around 73% water (Pietrobelli et al., 1998); thus, blood flow redistribution caused by food intake digestion and physical activity may change X-ray attenuation and, as a result, the reported body composition values might be biased (Toomey et al., 2017). Previous evidence indicates that variations in the hydration status of lean tissue affect DXA results (Fosbøl & Zerahn, 2015); for instance, hydration status had a 1% impact on the accuracy of fat content measurement (Pietrobelli et al., 1998). In clinical patients (Formica et al., 1993; LaForgia et al., 2009), variations in body fluids had no impact on the values of fat mass assessed by DXA. Lean mass responsible for muscular contraction has more water, and fluid shifts before DXA measurements might cause noise and reduce validity; therefore, there must be thoroughly evaluated in controlled studies (Nana et al., 2013).

AIM

With no previous evidence on the effects of acute body fluid redistribution on DXA scores, examining technical mistakes and their magnitude on DXA readings requires more investigation (Nana et al., 2015). Therefore, in a sample of young Hispanic females, this study aimed to evaluate the impact of acute exercise-induced body fluid redistribution on DXA body composition scores. We hypothesized that acute exercise would change body composition scores.

METHODS

Study design

Using a repeated-measures experimental design, body composition as determined by DXA was investigated before (pre) and after (post) each of the three experimental conditions: a) upper-body exercise (UBE), b) lower-body exercise (LBE), and c) non-exercise control (NEC).

Participants

For the study, thirty apparently healthy male college students were recruited. Participants were required to be between 18 and 40 yr. and fit into the densitometer measuring region. The trial was not open to volunteers having a history of metabolic, skeletal muscle-related, or other health problems (Calbet et al., 2001). The research did not include volunteers who were presently smokers, above 272 kg or had recently received radioactive contrast agents (International Society for Clinical Densitometry, 2019; Lewiecki et al., 2016).

Measurement instruments

Body weight (kg) and height (cm) were measured using a Seca ultrasound measuring station, model 256 dp (Chino, CA). Body weight and height measures were accurate within 50 g and 1 mm, respectively. Body mass index (BMI in kg m^{-2}) was then obtained as body weight (kg)/body height (m^2). Body composition was assessed using a DXA machine, General Electric, model Lunar Prodigy Advance (GE Medical Systems Lunar, Madison, WI), and enCORE 2011 software, version 13.60.033. We performed a daily apparatus calibration according to the manufacturer's guidelines as part of the DXA quality control process (Thurlow et al., 2018).

We collected a urine sample and recorded the urine specific gravity (USG) to assess the participant's baseline level of hydration using an Atago (Japan) refractometer, model URC/N, with a graduation range from 1.000–1.050 units. In addition, total body water (TBW) was calculated using a Seca bioelectrical impedance analysis (BIA) equipment, model mBCA 514 (Chino, CA). The BIA analysis was gathered from the hands and feet using a multi-frequency mode.

A Wakeman fitness pedal exerciser, model 80-5113 (Trademark Global, LLC, China), was used for the upper-body exercise experimental condition. On a Cybex recumbent bicycle, model 770R (Cybex International, Inc., Medway, MA), the lower-body exercise experimental condition was conducted. A Polar Electro (Oy, Kempele, Finland) telemetric heart rate (HR) monitor, model FT7, was used to control exercise intensity.

Procedures

Potential volunteers were recruited from all-college requirement physical activity courses. The evaluations were completed at the Body Composition Laboratory at the University of Costa Rica, under stable 22°C and 80% relative humidity conditions. Each participant received a personal appointment and was told to arrive at 7:00 am after a 10-h fast. Participants read and signed an informed consent form already authorized by the University of Costa Rica's Scientific Ethics Committee. Participants next collected a urine sample for refractometer examination. Those whose USG levels

were ≥ 1.020 (Armstrong, 2007; Oppliger et al., 2005), were considered dehydrated and rescheduled for body composition measurements.

In order to evaluate the precision of the measurements that the researchers collected, a precision study was carried out (International Society for Clinical Densitometry, 2019). International standards mandate that a technician conduct an *in vivo* precision study with the target population for all relevant body composition variables. Additionally, to attain statistical power, the International Society for Clinical Densitometry (2019) advises that each technician assess 30 participants twice with repositioning. In order to calculate the precision error, two researchers (EC-R and YC-A) recruited 30 individuals unrelated to the study, scanned them using repositioning, and put the recorded results into the ISCD online calculator. Based on the coefficient of variation for the researchers EC-R (0.4%) and YC-A (< 0.2%), the precision error was judged acceptable.

After taking a deep breath, participants were directed to proceed onto the body height scale while facing the stadiometer with their feet at a 60°, barefoot, upright, and with no shoes. Height and weight were then recorded. Participants were then instructed to get off the scale and position themselves on the BIA apparatus, placing their feet on the platform's electrodes while holding onto the grips next to the electrodes. The operator then began calculating the amount of total body water.

Experimental conditions

The participants completed the three experimental conditions in a random order. For the UBE condition, the participants performed 30-min aerobic exercise on a pedal exerciser apparatus at an intensity of 70% of the reserve HR obtained by the formula: HRR = [(HRmax – RHR) × % intensity] + RHR (American College of Sports Medicine, 2021), where HRR = HR reserve, RHR = resting HR (measured after 10 min rest) and HRmax = maximum HR (208 – 0.7 × age in yr.) (Tanaka et al., 2001). The LBE program included exercising for 30-min on a recumbent bike while maintaining a heart rate of 70%. In the NEC condition, the individual sat still for 30-min without engaging in any physical activity. Participants were not allowed to consume food or beverages while undergoing any of the regimens, and a telemetric HR monitor enabled regulating the exercise intensity.

Body composition assessment

The following seven variables were used to estimate body composition variables in three regions (arms, legs, and total body): fat mass (%), region fat (%), fat mass (kg), fat mass (kg), lean mass (kg), bone mineral content (kg), and total mass (kg). The participant arrived at the assessment site fasted, hydrated, and without exercising the day before to comply with best practices for body composition assessment (Hume et al., 2018). The participant was instructed to be well hydrated (i.e., drink lots of water and eat typical foods) and to refrain from exercising the day before the test to reduce the risk of dehydration and inadequate rehydration to ensure that they met these requirements. Each participant was required to remove any metal jewelry from their person and to dress in athletic attire once the study staff verified these requirements. Afterward, participants were positioned dorsally on the DXA bed and told to keep quiet during the scan. After the initial DXA scan, participants were invited to wear their training clothes. They were then requested to wipe perspiration off their bodies

with towels after the activity before having another DXA scan. As a result, the procedure was carried out twice during the same session – once before the experimental condition (Pre) and once after it (Post). Also, the fluid loss due to dehydration was assessed with the body mass information before and after exercise or non-exercise control condition using the equation: (Final weight in kg – Initial weight in kg). After finishing the second DXA scan, participants were given a standardized breakfast with an energy content of 1570.1 kJ.

Statistical analysis

The IBM-SPSS Statistics program, version 26 (Armonk, NY), was used to calculate the statistical analyses. The mean and standard deviation (M ± SD) described the dependent variables. A 3 × 2 repeated measures ANOVA (3 experimental conditions × 2 measurements) determined significant interactions between experimental conditions and measurements. Fisher's Least Significant Difference (LSD) *post hoc* test followed-up significant interactions, and the 95% confidence interval ($CI95\%_{diff}$) for the mean differences were also reported.

The magnitude of the observed effects was calculated as partial eta-squares (η_p^2) and were interpreted as small (0.01), medium (0.06), and large (0.14) (Cohen, 1988). For all inferential analysis, the statistical significance was set *a priori* at $p < 0.05$. The absolute reliability in body composition scores was studied by the typical error of the measurement (TEM) and the coefficient of variability (CV[%]) (Currell & Jeukendrup, 2008). The smallest worthwhile change (SWC) in body composition scores was computed as $SWC = TEM \times \sqrt{2} \times 0.2$ (Hopkins, 2000).

RESULTS

Participants

Volunteers were 30 female college students (age = 19.78 ± 1.74 yr., weight = 57.0 ± 9.4 kg, height = 159.2 ± 6.4 cm, BMI = 22.4 ± 3.3 kg m^{-2}. The BIA-derived TBW for the NEC (29.1 ± 3.58 L), UBE (29.1 ± 3.44 L), and LBE (29.2 ± 3.61 L) were insignificant ($p = 0.748$). Descriptive and inferential statistics for arm and leg segments and total body before and after the experimental conditions are presented in table 1.

Body fluid changes

The body fluid loss as determined by the difference from pre to post were significant for total mass for NEC (0.05 ± 0.18 kg), UBE (0.14 ± 0.17 kg), and LBE (0.21 ± 0.19 kg) ($p = 0.004$; $\eta_p^2 = 0.17$). Post-hoc analyses showed significant mean differences between NEC and UBE ($CI95\%_{diff}$ = –0.19 to –0.01 kg), and NEC and LBE ($CI95\%_{diff}$ = –0.26 to –0.06 kg). Insignificant mean differences were observed between UBE and LBE ($CI95\%_{diff}$ = –0.16 to 0.03 kg).

Body composition changes

Statistically significant interactions were found in the arms and legs regions in five out of seven body composition scores following the experimental conditions. For the total body, significant interactions were found in two out of seven body composition scores following experimental conditions (Table 2).

Table 1 Descriptive and inferential statistics of body composition variables by anatomical region in individuals undergoing three experimental sessions (n = 30). The statistical significance ($p \leq$) is shown between pre- and post-test of each experimental condition.

Region	Non-Exercise Control			Upper-Body Exercise			Lower-Body Exercise		
	Pre	Post	$p \leq$	Pre	Post	$p \leq$	Pre	Post	$p \leq$
Arms									
Tissue fat (%)	31.46 ± 7.47	32.02 ± 7.42	0.009	31.51 ± 7.00	30.84 ± 7.21	0.001	31.57 ± 7.28	31.57 ± 7.38	1.000
Region fat (%)	30.02 ± 7.25	30.56 ± 7.24	0.007	30.06 ± 6.83	29.48 ± 7.01	0.002	30.15 ± 7.09	30.14 ± 7.19	0.986
Tissue (kg)	5.11 ± 1.08	5.11 ± 1.06	0.991	5.11 ± 1.08	5.34 ± 1.12	0.0001	5.16 ± 1.04	5.18 ± 1.13	0.445
Fat mass (kg)	1.65 ± 0.64	1.67 ± 0.64	0.076	1.64 ± 0.63	1.69 ± 0.66	0.013	1.66 ± 0.64	1.67 ± 0.68	0.505
Lean mass (kg)	3.47 ± 0.65	3.44 ± 0.64	0.174	3.46 ± 0.65	3.66 ± 0.67	0.0001	3.49 ± 0.63	3.50 ± 0.67	0.558
BMC (kg)	0.25 ± 0.05	0.25 ± 0.05	0.266	0.25 ± 0.05	0.25 ± 0.05	0.033	0.25 ± 0.05	0.25 ± 0.05	0.305
Total mass (kg)	5.36 ± 1.11	5.36 ± 1.09	0.902	5.35 ± 1.12	5.59 ± 1.17	0.0001	5.40 ± 1.08	5.43 ± 1.17	0.280
Legs									
Tissue fat (%)	39.75 ± 7.19	39.86 ± 7.05	0.407	39.55 ± 7.21	39.87 ± 7.26	0.025	39.66 ± 7.15	39.52 ± 7.30	0.269
Region fat (%)	38.25 ± 7.01	38.38 ± 6.88	0.258	38.06 ± 7.03	38.37 ± 7.07	0.026	38.16 ± 7.00	38.04 ± 7.14	0.289
Tissue (kg)	1.88 ± 3.55	1.90 ± 3.65	0.060	1.91 ± 3.64	1.89 ± 3.63	0.093	1.91 ± 3.55	1.90 ± 3.55	0.430
Fat mass (kg)	7.62 ± 2.54	7.71 ± 2.59	0.087	7.69 ± 2.63	7.69 ± 2.63	0.935	7.72 ± 2.58	7.40 ± 2.88	0.242
Lean mass (kg)	11.70 ± 1.66	11.24 ± 1.72	0.121	11.36 ± 1.69	11.19 ± 1.69	0.021	11.34 ± 1.65	11.32 ± 1.67	0.769
BMC (kg)	0.74 ± 0.14	0.74 ± 0.14	0.177	0.74 ± 0.14	0.74 ± 0.14	0.331	0.74 ± 0.14	0.74 ± 0.14	0.691
Total mass (kg)	19.54 ± 3.66	19.69 ± 3.77	0.077	19.80 ± 3.75	19.62 ± 3.74	0.081	19.81 ± 3.66	19.73 ± 3.66	0.467
Total body									
Tissue fat (%)	35.77 ± 6.91	35.88 ± 6.77	0.428	35.59 ± 6.73	35.67 ± 6.62	0.523	35.66 ± 6.93	35.75 ± 6.97	0.563
Region fat (%)	34.40 ± 6.69	34.49 ± 6.56	0.440	34.23 ± 6.54	34.33 ± 6.44	0.424	34.30 ± 6.71	34.38 ± 6.76	0.581

Region	Non-Exercise Control			Upper-Body Exercise			Lower-Body Exercise		
	Pre	Post	p ≤	Pre	Post	p ≤	Pre	Post	p ≤
Tissue (kg)	5.37 ± 8.85	5.36 ± 8.85	0.179	5.39 ± 8.92	5.38 ± 8.92	0.0001	5.39 ± 8.80	5.37 ± 8.81	0.0001
Fat mass (kg)	19.55 ± 6.31	19.57 ± 6.18	0.759	18.74 ± 6.88	19.54 ± 6.23	0.319	19.59 ± 6.41	19.57 ± 6.50	0.870
Lean mass (kg)	34.11 ± 4.55	34.04 ± 4.63	0.445	34.37 ± 4.58	33.91 ± 4.87	0.167	34.30 ± 4.36	34.11 ± 4.38	0.106
BMC (kg)	2.14 ± 0.33	2.14 ± 0.32	0.823	2.13 ± 0.32	2.12 ± 0.32	0.431	2.14 ± 0.33	2.10 ± 0.41	0.317
Total mass (kg)	55.80 ± 9.11	55.75 ± 9.09	0.162	56.03 ± 9.16	55.88 ± 9.13	0.0001	56.02 ± 9.05	55.82 ± 9.08	0.0001

Note: BMC = Bone mineral content.

Table 2 Summary statistical significance for the ANOVA model. The conditions are the three experimental sessions and the measurements are assessments before and after the specific session. The interaction term refers to the combination effects of conditions and measurements. Explained variance is presented as partial eta-squared (η_p^2) and is interpreted as small (0.01), medium (0.06), and large (0.14) (Cohen, 1988).

Variable	Source of variance					
	Conditions (A)		Measurements (B)		Interaction (A × B)	
	p ≤	η_p^2 =	p ≤	η_p^2 =	p ≤	η_p^2 =
Arms						
Tissue fat (%)	0.004	0.18	0.747	0.00	0.0001	0.26
Region fat (%)	0.004	0.17	0.870	0.00	0.0001	0.25
Tissue (kg)	0.0001	0.27	0.0001	0.52	0.0001	0.42
Fat mass (kg)	0.734	0.01	0.004	0.26	0.371	0.03
Lean mass (kg)	0.0001	0.37	0.0001	0.53	0.0001	0.58
BMC (kg)	0.635	0.02	0.020	0.17	0.499	0.02
Total mass (kg)	0.0001	0.28	0.0001	0.54	0.0001	0.40
Legs						
Tissue fat (%)	0.279	0.04	0.251	0.05	0.036	0.11
Region fat (%)	0.229	0.05	0.181	0.06	0.032	0.11
Tissue (kg)	0.154	0.06	0.585	0.01	0.031	0.11
Fat mass (kg)	0.453	0.03	0.399	0.03	0.173	0.06
Lean mass (kg)	0.086	0.08	0.275	0.04	0.024	0.12
BMC (kg)	0.855	0.01	0.997	0.00	0.179	0.06
Total mass (kg)	0.141	0.07	0.554	0.01	0.038	0.11
Total body						
Tissue fat (%)	0.321	0.04	0.149	0.07	0.994	0.00
Region fat (%)	0.384	0.03	0.134	0.08	0.998	0.00
Tissue (kg)	0.238	0.05	0.0001	0.62	0.003	0.18
Fat mass (kg)	0.354	0.04	0.327	0.03	0.369	0.03
Lean mass (kg)	0.761	0.01	0.064	0.11	0.370	0.03
BMC (kg)	0.483	0.03	0.276	0.04	0.442	0.03
Total mass (kg)	0.333	0.04	0.0001	0.65	0.004	0.17

Note: BMC= Bone mineral content.

For the arms region, significant interactions were observed on fat tissue, fat region, tissue, lean mass, and total mass (Table 2). Post-hoc analyses for fat tissue showed significant mean differences for NEC of 0.56 ± 0.20% ($CI95\%_{diff}$ = 0.15 to 0.97%) and for UBE of 0.68 ± 0.18% ($CI95\%_{diff}$ = 0.29 to 1.04%). Post-hoc analyses for fat region showed significant mean differences for NEC of 0.54 ± 0.19% ($CI95\%_{diff}$ = 0.16 to 0.92%) and for UBE of 0.59 ± 0.17% ($CI95\%_{diff}$ = 0.24 to 0.93%). Post-hoc analyses for

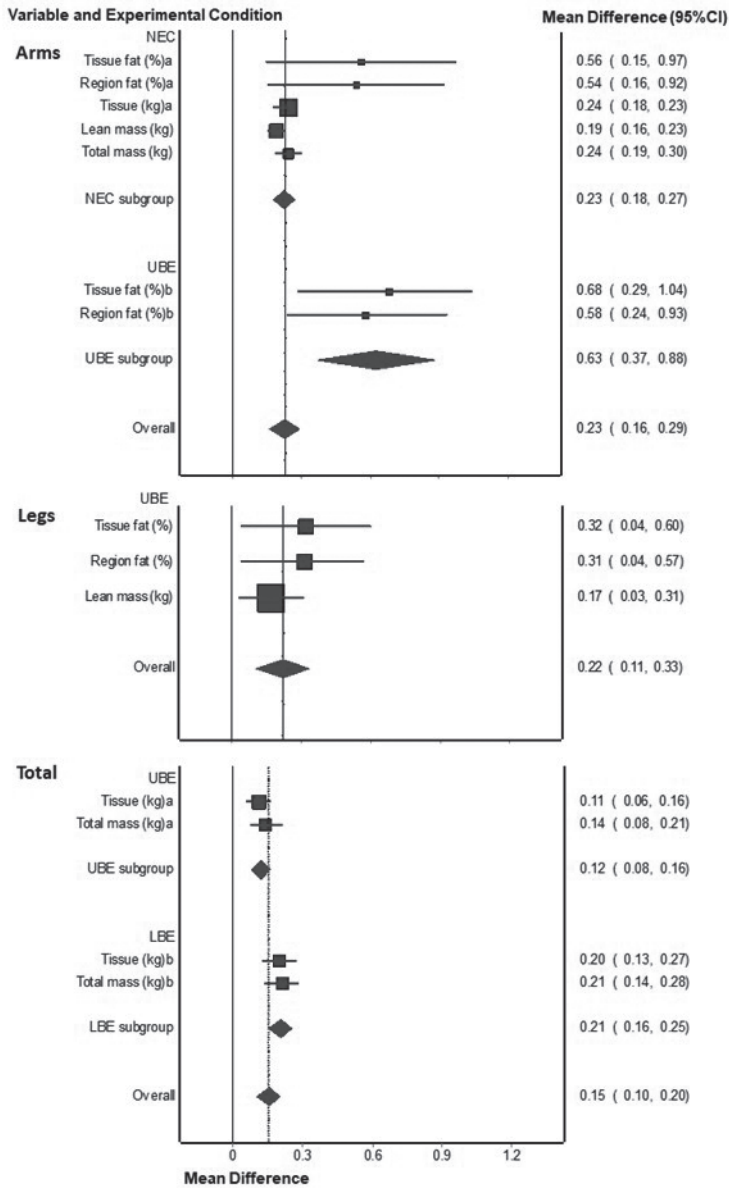

Figure 1 Forest plot of arms, legs, and total body region changes in body composition scores among females completing three experimental conditions: NEC: non-exercise control; UBE: upper-body exercise; LBE: lower-body exercise (n = 30).

Table 3 Absolute reliability (TEM, CV%) and smallest worthwhile change (SWC) of regional body composition scores of college-females completing three experimental sessions (n = 30). TEM and SWC are shown in the original measurement units, and CV is interpreted as small if ≤ 10% (Currell & Jeukendrup, 2008).

Region variable	Non-Exercise Control			Upper-Body Exercise			Lower-Body Exercise		
	TEM	CV (%)	SWC	TEM	CV (%)	SWC	TEM	CV (%)	SWC
Arms									
Tissue fat (%)	0.77	2.43	0.22	0.70	2.26	0.20	0.74	2.36	0.21
Region fat (%)	0.73	2.40	0.21	0.66	2.20	0.19	0.71	2.35	0.20
Tissue (kg)	0.11	2.17	0.03	0.11	2.01	0.03	0.11	2.12	0.03
Fat mass (kg)	0.06	3.50	0.02	0.06	3.85	0.02	0.06	3.76	0.20
Lean mass (kg)	0.08	2.19	0.02	0.07	1.85	0.02	0.07	2.04	0.02
BMC (kg)	0.00	1.90	0.00	0.00	2.23	0.00	0.00	2.00	0.00
Total mass (kg)	0.11	2.13	0.03	0.11	1.99	0.03	0.11	2.10	0.03
Legs									
Tissue fat (%)	0.51	1.27	0.14	0.53	1.34	0.15	0.48	1.22	0.14
Region fat (%)	0.45	1.17	0.13	0.51	1.32	0.14	0.44	1.16	0.13
Tissue (kg)	0.30	1.61	0.09	0.38	2.02	0.11	0.38	1.93	0.10
Fat mass (kg)	0.19	2.50	0.05	0.17	2.22	0.05	1.05	13.89	0.30
Lean mass (kg)	0.16	1.43	0.05	0.27	2.37	0.08	0.26	2.33	0.07
BMC (kg)	0.00	1.19	0.00	0.00	1.13	0.00	0.01	1.30	0.00
Total mass (kg)	0.31	1.59	0.09	0.38	1.95	0.11	0.38	1.94	0.11
Total body									
Tissue fat (%)	0.51	1.44	0.15	0.50	1.40	0.14	0.62	1.73	0.17
Region fat (%)	0.46	1.34	0.13	0.45	1.30	0.13	0.58	1.68	0.16

Region variable	Non-Exercise Control			Upper-Body Exercise			Lower-Body Exercise		
	TEM	CV (%)	SWC	TEM	CV (%)	SWC	TEM	CV (%)	SWC
Tissue (kg)	0.13	0.24	0.04	0.09	0.17	0.03	0.13	0.24	0.04
Fat mass (kg)	0.27	1.39	0.08	3.06	15.97	0.86	0.37	1.88	0.10
Lean mass (kg)	0.34	1.00	0.10	1.25	3.65	0.35	0.43	1.26	0.12
BMC (kg)	0.04	1.64	0.01	0.03	1.48	0.01	0.13	6.31	0.04
Total mass (kg)	0.12	0.22	0.04	0.12	0.21	0.03	0.13	0.24	0.04

Note: BMC – Bone mineral content; TEM – typical error of the measurement; SWC – smallest worthwhile change; CV – coefficient of variability.

UBE showed significant mean differences for tissue of 0.24 ± 0.03 kg ($CI95\%_{diff}$ = 0.18 to 0.23 kg), lean mass of 0.19 ± 0.02 kg ($CI95\%_{diff}$ = 0.16 to 0.23 kg), and total mass of 0.24 ± 0.03 kg ($CI95\%_{diff}$ = 0.19 to 0.30 kg) (Table 1, Figure 1).

For the legs region, significant interactions were observed on fat tissue, fat region, tissue, lean mass, and total mass. Post-hoc analyses for UBE showed significant mean differences for fat tissue of 0.32 ± 0.14% ($CI95\%_{diff}$ = 0.04 to 0.60%), fat region of 0.31 ± 0.13% ($CI95\%_{diff}$ = 0.04 to 0.57%), and lean mass of 0.17 ± 0.07 kg ($CI95\%_{diff}$ = 0.03 to 0.31 kg). Post-hoc analyses for NEC and UBE on total mass pre vs. post were insignificant in spite of the significant interaction. The interaction was explained by the differences in pre-test total mass scores between NEC and UBE (M_{diff} = 0.26 ± 0.01 kg; $CI95\%_{diff}$ = 0.04 to 0.48 kg), and NEC and LBE (M_{diff} = 0.27 ± 0.01 kg; $CI95\%_{diff}$ = 0.06 to 0.47 kg). Also, the post-hoc analyses for NEC and UBE on tissue pre vs. post were insignificant in spite of the significant interaction. The interaction was explained by the differences in pre-test tissue scores between NEC and UBE (M_{diff} = 0.25 ± 0.11 kg; $CI95\%_{diff}$ = 0.04 to 0.47 kg), and NEC and LBE (M_{diff} = 0.27 ± 0.10 kg; $CI95\%_{diff}$ = 0.07 to 0.47 kg) (Table 1, Figure 1).

For the total body, significant interactions were observed on tissue and total mass. Post-hoc analyses of tissue for UBE showed mean differences of 0.11 ± 0.02 kg ($CI95\%_{diff}$ = 0.06 to 0.16 kg) and for LBE of 0.20 ± 0.03 kg ($CI95\%_{diff}$ = 0.13 to 0.27 kg). Post-hoc analyses of total mass for UBE showed mean differences of 0.14 ± 0.03 kg ($CI95\%_{diff}$ = 0.08 to 0.21 kg) and for LBE of 0.21 ± 0.03 kg ($CI95\%_{diff}$ = 0.14 to 0.28 kg) (Table 1, Figure 1).

Reliability estimates

The consistency of the body composition scores as computed by the CV (%) was high across experimental conditions (inconsistency is determined when CV ≥ 10%) (Currell & Jeukendrup, 2008). For the NEC condition, the absolute reliability was high for the arms region (Min = 1.90, Max = 3.50%), the legs region (Min = 1.17, Max = 2.50%), and total body (Min = 0.22, Max = 1.64%). For the UBE condition, the absolute reliability was high for the arms region (Min = 1.85%, Max = 3.85%), and the legs region (Min = 1.13%, Max = 2.37%); however, for the total body the reliability scores were mostly high (Min = 0.17%, Max = 3.65%), with only one score > 10% (i.e., fat mass in kg = 15.97%). Finally, for the LBE condition, the reliability was high for the arms region (Min = 2.00%, Max = 3.76%), for the total body (Min = 0.24%, Max = 6.31%), and mostly for the legs region (Min = 1.16%, Max = 2.33%), with only one score > 10% (i.e., fat mass in kg = 13.89%) (Table 3).

Regardless of the experimental condition, the relative (i.e., %) SWC for tissue fat and region fat for the arms, legs, and total body was between 0.13% and 0.22%. Also, regardless of the experimental condition, the SWC in kg for tissue, fat mass, lean mass, BMC, and total mass was between 0.00 kg and 0.86 kg (Table 3).

DISCUSSION

The study aimed to determine changes in DXA body composition scores in females following exercise-induced body fluid redistribution. We predicted changes in body composition scores following acute exercise, and our main findings were that

body composition scores acutely changed following the three experimental conditions; the scores were highly reliable, and the SWC was small for each outcome.

We did not expect body composition scores changes following the seated NEC, yet the small change was detected by the DXA device, a value that reached the expected SWC. We expected relevant changes in body composition scores only following the two exercise experimental conditions (i.e., UBE, LBE) since working muscles redistribute more body fluids than a seated NEC. Indeed, both exercise conditions elicited significantly higher fluid losses (i.e., UBE ~143 g, LBE ~206 g), as determined by the change in total body mass following the respective experimental condition, compared to NEC (~50 g). The changes in body mass were explained by losses in body water occurring by the sweating response elicited to control the increased body temperature resulting from the intense muscle work (~70% HRR) during exercise (Périard et al., 2021; Trangmar & González-Alonso, 2019). Thus, an increased sweat production implies body fluid redistribution occurred during the exercise conditions to maintain the heat balance.

In the present study, we found that brief acute exercise (30-min) did not immediately affect BMC. This is because bones respond more to long-term, chronic mechanical loading rather than acute stressors. It takes weeks to months for actual mineralization of bone to become evident through changes in BMC (Gillies & Lieber, 2011). Additionally, changes in bone turnover markers induced by acute exercise may not be large enough to result in detectable alterations in BMC in the short term (Kohrt et al., 2004). In our study, we aimed to detect changes in highly dependent body fluid tissues (i.e., muscle mass) and their possible influence on DXA body composition scores. As such, BMC was not expected to change beyond measurement error.

In the present study, we reported the TEM since it assumes that errors occur from random events instead of a systematic error (i.e., biological variation) when measuring body composition variables (Adão Perini et al., 2005; Lucas & Henneberg, 2017). The arms region analyses showed significant mean differences in selected body composition outcomes; some changes were smaller than the estimated TEM (Table 3). For example, the TEM for fat tissue (%) was higher than the observed mean difference in the NEC and UBE experimental conditions. Also, the TEM was higher for the fat region (%) than the observed mean difference in the NEC and UBE experimental conditions. On the contrary, the TEM was smaller than the observed mean differences in the UBE experimental condition for tissue, lean mass, and total mass. The legs region analyses also showed significant mean differences in the UBE experimental condition smaller than the TEM for tissue fat and region fat but for lean mass, which was higher than the TEM. Finally, the total body region analyses showed significant mean differences in the UBE and LEB experimental conditions on tissue and total mass higher than the TEM. From a practical perspective, the TEM can be quantified and controlled with proper instructions to the individual being assessed and by careful positioning in the DXA by the responsible technician. For instance, in the present study, two researchers responsible for the DXA assessments underwent a precision study, and their computed coefficients of variation were below 0.4% for body composition variables, a precision error judged acceptable by the International Society for Clinical Densitometry (2019). Nevertheless, the random error affecting TEM will always be present.

Taken together, the present study's findings suggest that, as opposed to LBE, UBE exerted a meaningful impact on selected body composition scores following exercise. Likely, the increased metabolic demand of the small muscles of the forearm (primarily responsible for the UBE experimental condition) caused a hyperemic transient state that might have remained during the post-DXA scan assessment (Dulaney et al., 2023; Joyner & Casey, 2015). Consequently, the DXA software detected changes in some body composition outcomes. The precise interaction between software programming (i.e., X-ray attenuation) and true physiological changes resulting from exercise and the impact on body composition scores deserves further examination. Therefore, from a practical point of view, it is recommended that individuals undergoing DXA assessment avoid engaging in acute exercise at least 30-min prior to the measurement session. This can minimize any noise during scanning and ensure accurate results.

High reliability was found in the DXA body composition scores in the three experimental conditions. Only one score in the UBE and LBE experimental conditions was moderate (i.e., CV ≥ 10%). Our results are similar to those reported by others (Rose et al., 2021), with CV (%) smaller than 2% for lean mass and 3% for fat mass; precision figures accepted by the International Society for Clinical Densitometry (2019). The SWC calculated for all body composition variables was small in relative and absolute units, which may be explained by the low variability of scores (i.e., TEM) (Hopkins, 2000). Therefore, in the present study, the values recorded were within the expected range, giving technicians the confidence that they were accurate, regardless of the experimental condition. However, it is essential to note that reaching the SWC is necessary to determine any meaningful changes in body composition scores; and in this particular study, the recorded values remained stable.

Study strengths and limitations

This study has strengths and limitations. First, we used a repeated measures design where all participants completed the experimental sessions; therefore, we reduced between-subject variability. Secondly, we performed a successful precision study as the International Society for Clinical Densitometry (2019) recommended. Third, we assessed initial hydration status and provided instructions to reduce physical activity the day before testing occurred. Potential limitations included the lack of control of the participant's diet (i.e., food and fluid intake); however, the potential influence of diet was controlled by the random assignment of the participants to the experimental conditions and by requiring participants to arrive to the assessment sessions in a 10-h fasting state. In addition, we could not assess total body water immediately following the experimental conditions since DXA assessment was our priority, and fluid redistribution might have caused bias in BIA measures. Finally, we did not collect information on the individuals' menstrual cycle. However, experimental and meta-analytical evidence (Gould et al., 2021) indicates that DXA body composition scores are not affected beyond measurement error as a result of compartmental changes elicited by the menstrual cycle. Furthermore, we only performed DXA scans on euhydrated individuals. Thus, despite not controlling the menstrual cycle, no differences in weight loss elicited by sweat evaporation from the thermoregulatory response were expected.

CONCLUSION

This study found that exercise-induced body fluid redistribution in young college females elicited small changes in body composition scores. Small changes can be considered practically and clinically meaningless. Most small changes were observed following the UBE experimental condition and might have resulted from transient hyperemia in the forearm muscles, which might have impacted DXA's X-ray attenuation. The majority of body composition scores recorded were reliable in the three experimental conditions, and the SWC reported were small due to the low TEM. Therefore, to reduce random variation and record accurate scores, DXA technicians should control the previous physical activity of participants undergoing DXA scanning.

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