Effects of Exercise Sessions on DXA Measurements of Body Composition in Active People

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ABSTRACT

NANA, A., G. J. SLATER, W. G. HOPKINS, and L. M. BURKE. Effects of Exercise Sessions on DXA Measurements of Body Composition in Active People. *Med. Sci. Sports Exerc.*, Vol. 45, No. 1, pp. 178–185, 2013. **Purpose**: Dual-energy x-ray absorptiometry (DXA) is rapidly becoming more accessible and popular as a technique to monitor body composition, especially in athletic populations. This study investigates the reliability of DXA in measuring body composition of active individuals, specifically to ascertain biological variability associated with two different types of exercise under free-living conditions in active individuals. **Methods**: Well-trained individuals (27 strength-trained male subjects, 14 female cyclists, and 14 male cyclists) underwent three whole-body DXA scans over a 1-d period: in the morning after an overnight fast, approximately 5 min later after repositioning on the scanning bed, and shortly after a self-chosen exercise session (resistance training or cycling). Subjects were allowed to consume food and fluid *ad libitum* before and during exercise as per their usual practices. Magnitude of typical (standard) errors of measurement and changes in the mean of DXA measures were assessed by standardization. **Results**: Exercise and its related practices of fluid and food intake are associated with changes in the mean estimates of total and regional body composition that range from trivial to small but substantial. An exercise session also increases the typical error of measurement of these characteristics by approximately 10%. **Conclusion**: The easiest and most practical way to minimize the biological "noise" associated with undertaking a DXA scan is to have subjects fasted and rested before measurement. Until sufficient data on the smallest important effect are available, both biological and technical "noises" should be minimized so that any small but potentially "real" changes can be confidently detected. **Key Words:** RELIABILITY, ATHLETES, DUAL-ENERGY X-RAY ABSORPTIOMETRY, LEAN MASS, BODY FAT

Dual-energy x-ray absorptiometry (DXA) is rapidly becoming more accessible and popular as a technique to monitor body composition, especially in athletic populations (5,15,17,20,21,23). Although traditionally used in a clinical setting to measure bone mineral content and bone mineral density, DXA has become recognized as a rapid and nonintrusive technique to estimate fat and lean mass plus bone mineral content for total body as well as regional body composition assessment (1,22). Although DXA exposes subjects to radiation (approximately 0.5 μSv per one whole-body scan), this is considerably less than those received from 7-h airplane flights (50 μSv) and well below the typical radiation dose of a chest x-ray (40 μSv) (2).

An assumption that underpins any type of physique assessment is that the technique is valid and reliable. Invalid or unreliable techniques compromise the integrity of research findings or other interventions. We have previously noted that a strict protocol regarding subject positioning and presentation is required to minimize the technical error of measurement associated with DXA (4,7,8,10,12). Indeed, we found that the consumption of food and fluid (biological variation) substantially altered the reliability of DXA estimates of lean mass and regional body composition in active populations (12). Consequently, we recommended that any subject who is undergoing a DXA scan to assess body composition should ideally be presented in a fasted state to reduce the associated biological variability. However, the practical implication of such recommendations is that the period of the day in which DXA can be used to collect reliable measurements of whole-body composition of subjects is limited.

A further complication of work involving athletes is that undertaking exercise may also interfere with DXA measurements of physique. Exercise or substantial physical activity may affect the reliability of DXA estimates because of expansion or reduction of body fluid compartments as a result of dehydration and/or increased blood flow and capillary dilation

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(3,9,16). The intake of fluid and/or food before and/or during exercise, which is often an integral or recommended part of the session (13,16), would further affect (biological variation) estimates of body composition. Differences in the type, duration, and intensity of the exercise session might influence these direct and indirect effects of physical activity on the reliability of DXA estimates of whole and regional body composition. This issue has not been systematically examined either from first principles (i.e., the effect of a standard exercise bout on DXA measurements) or from a real-life perspective (i.e., the total effects of *ad libitum* exercise and its related nutrition practices on DXA measurements). In setting guidelines for clinical practice, it is important to understand the range in variability that is likely to occur from a session of exercise in a free-living athletic population.

Accordingly, the purposes of this study are as follows: 1) to establish reliability of DXA in measuring body composition of trained individuals and 2) to ascertain specific biological variability associated with two different types of exercise (cycling and resistance training) under free-living conditions in active individuals. The outcomes of this study could be used to develop protocols to guide the real-life use of DXA-derived estimates of body composition in athletic populations.

METHODS

Subjects. Fifty-five subjects were recruited from a local pool of well-trained individuals. Subjects were classified as trained cyclists if they were members of the Australian National Cycling Team, had a training load of ≥250 km·wk^{-1} for greater than 2 yr, and/or competed at the Australian National Championship. Subjects were classified as strength trained if they had a history of resistance training of ≥2 yr currently undertaking two or more strength training sessions per week. All subjects signed a consent form approved by the Human Ethics Committee of the Australian Institute of Sport (AIS) and RMIT University Human Research Ethics Committee before participating in this study. Subjects were excluded from the study if they were more than 190 cm tall (i.e., taller than the active scanning area of the DXA machine). Subject characteristics are presented in Table 1.

Study overview. Each subject underwent three whole-body DXA scans for a 1-d period (Fig. 1). Each subject undertook measurements 1 and 2 under standardized baseline conditions (early morning, overnight fasted, and standardized body positioning on the scanning bed), with repositioning between measurements.

Shortly after measurement 2, subjects were allowed to consume food and fluid *ad libitum* in accordance with their usual preexercise and during-exercise nutrition practices. Measurement 3 was undertaken immediately after a self-selected, sport-specific exercise session with standardized positioning on the scanning bed. Strength-trained subjects undertook their exercise session at the AIS Strength and Conditioning gymnasium, whereas the cyclists completed their exercise session on the roads around the Canberra region during Australian summer and autumn. Comparison of measurements 1 and 2 enabled calculation of the technical error of measurement, whereas measurement 3 enabled calculation of the biological variation introduced by exercise and *ad libitum* food and fluid consumption before and during the exercise session.

Standardized baseline conditions. Subjects were overnight fasted and had not undertaken any exercise on the morning of measurements 1 and 2. They were asked to wear light clothing, and all jewelry and metal objects were removed before each scan. Subjects were bladder voided before each scan, with a midstream sample collected for later analysis of specific gravity using a digital refractometer (UG-1; ATAGO Co. Ltd., Japan).

DXA instrument. Body composition was measured from a whole-body scan using a narrowed fan-beam DXA (Lunar Prodigy; GE Healthcare, Madison, WI) with analysis performed using GE Encore 12.30 software (GE). The DXA was calibrated with phantoms as per manufacturer's guidelines each day before measurement. The scanning mode was automatically chosen by the DXA machine, with all subjects scanned in the standard mode. The scans were analyzed automatically by the software, but regions of interest were subsequently confirmed by the technician.

Standardized DXA operational protocol. All scans were performed and analyzed by one trained technician. All DXA scans were undertaken according to the AIS whole-body DXA protocol (12). In brief, the protocol emphasized the consistency in the positioning of subjects on the scanning bed. Subjects were centrally aligned with their feet and hands placed in custom-made foam blocks to maintain a constant distance between the feet (15 cm) and between the palms and trunk (3 cm). The custom-made blocks were made of Styrofoam and were transparent under DXA. Subjects were asked to record details of their exercise session, the duration, particular details (e.g., distance, heart rate, intensity, and type of exercise), as well as the amount of food and fluid consumed before and during the exercise session. Duration of the exercise session (mean ± SD) for cyclists was 110 ± 42 min for males and 79 ± 53 min for females, whereas the strength session was 62 ± 10 min (Table 1).

Statistical analysis We derived measures of reliability separately for each body compartment, each tissue component, each type of exercise session, and each gender with a mixed linear model realized with Proc Mixed in the Statistical Analysis System (Version 9.2; SAS Institute, Cary, NC). The measurements were log transformed before analysis and then back transformed after analysis to express the effects and errors in percent units. The only fixed effect in the model, the identity of the measurement trial (three levels), provided estimates of the means and of changes in the mean between measurements. The random effects were the identity of the subjects (representing consistent difference between subjects), the residual error (representing within-subject short-term test-to-test variability), and a term representing additional error in the postexercise measurement. The errors were combined to provide estimates of

TABLE 1. Subject characteristics.

	Cycling		Strength
	14 M	14 F	27 M
Age (yr)	27.4 ± 8.4	25.6 ± 4.3	30.2 ± 6.1
Height (cm)	180.1 ± 4.6	169.6 ± 6.6	178.6 ± 6.0
Urine specific gravity	1.0204 ± 0.007	1.0163 ± 0.004	1.0223 ± 0.005
DXA estimates			
Total mass (kg)	75.4 ± 5.7	64.6 ± 8.0	80.6 ± 10.2
Total lean mass (kg)	64.0 ± 4.1	48.8 ± 5.5	64.3 ± 7.4
Total fat mass (kg)	8.2 ± 5.6	13.1 ± 5.3	12.8 ± 4.4
Total bone mineral content (kg)	3.1 ± 0.3	2.7 ± 0.5	3.5 ± 0.6
Duration of exercise session (min)	110 ± 42	79 ± 53	62 ± 10
Time between DXA 2 and DXA 3 (min)	197 ± 57	163 ± 77	101 ± 13

Data are expressed as mean ± SD.
M, male; F, female.

the typical (standard) errors of measurement and intraclass correlation coefficients expected when a morning DXA measurement performed after an overnight fast is followed by another measurement performed either immediately with no intervening meal or activity, and later after an intervening exercise session (strength training or cycling) with *ad libitum* food and fluid. All analyses were repeated with an additional fixed effect in the model representing the duration of the exercise session as a simple numeric predictor (covariate). This predictor allowed estimation of changes in the mean per hour of exercise with an additional additive constant representing the change with an exercise session of zero duration; errors derived from these analyses represented errors with the duration of exercise adjusted to the same arbitrary value for all subjects.

Uncertainty in estimates of changes in the mean and errors of measurement was provided by the model and expressed as 90% confidence limits. Inferences about the true magnitudes of changes in the mean and differences in errors were mechanistic. That is, they were deemed unclear if the confidence intervals included substantial positive and negative values; effects were otherwise clear, and their magnitudes were interpreted probabilistically (6). The typical error of the immediate reassessment was classified as technical error of measurement (variation caused by the DXA machine and/or repositioning of the subject on the scanning bed), whereas the typical errors of the reassessment after exercise included technical error and the effect of the exercise session (inclusive of food and fluid intake).

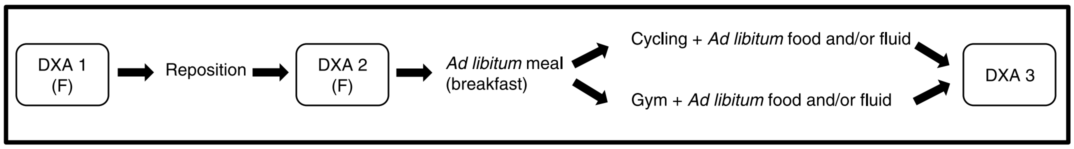
The magnitudes of changes in the mean and of typical errors were interpreted after these were standardized by dividing the between-subject SD in the fasting state by one third. This factor of one third (Δmean/(1/3 × SD)) was used because the between-subject SD of body measurements in our study population was approximately three times greater than those previously found in a study with athletic populations (19). To our knowledge, there are no published data on the smallest worthwhile effects of whole and regional body composition; therefore standardization with an appropriate between-subject SD was the appropriate default approach. Magnitude of standardized effects was assessed using the following scale: <0.2, trivial; <0.60, small; <1.20, moderate; and <2.0, large (6). Changes in the mean were classified as substantial when the standardized value reached the threshold for small (≥0.2). To interpret the magnitude of the errors, we halved the smallest important effects before assessing it on the above-mentioned scale (6,18).

A combine/compare effects spreadsheet from the Sportscience web site (http://sportsci.org) was used to derive relevant statistics (difference and inference) for the differences in body composition estimates postexercise between male and female cyclists and between strength-trained subjects and male cyclists.

RESULTS

The percentage change in the mean and the corresponding smallest important effect, as well as the typical error of measurement (TEM) for total and regional body composition estimates of the immediate reassessment and after an exercise session, are presented in Table 2 (strength) and Table 3 (cycling). In each case, results are presented as percentage change and raw units (g).

Total mass. For both strength-trained subjects and cyclists, the percentage change in the mean after the immediate reassessment (or the technical error of measurement)



F = fasted

FIGURE 1—The study design.

was trivial for total and regional mass estimates (Tables 2 and 3). However, when taking into account the uncertainty represented by the confidence limits, changes in the immediate reassessment of some regional mass estimates in cyclists could be small in effect size but substantial in terms of the smallest important effect. When the typical errors were doubled to interpret their magnitude, most of the errors of the immediate reassessment for total and regional mass estimates for both types of exercise were substantial but small in effect size.

After approximately 1 h of strength training, there were trivial changes in total and most regional mass estimates. An exception was for arm mass, where there was a small but substantial increase. There was also a possibility of small but substantial changes in other regions (trunk and leg masses). Cycling generally produced trivial changes in mean total and regional body masses in females, whereas in males, there were small but substantial changes in mean total, trunk, and arm masses. Both types of exercise increased the TEM slightly, but all were still small in magnitude.

Lean mass. Changes in the immediate reassessment of total and regional lean mass were similar to those found in total mass. That is, there were trivial changes in the immediate reassessment for total and regional lean mass estimates for both strength-trained subjects and cyclists. However, when taking into account the uncertainty represented by the confidence limits, changes in lean mass in the immediate reassessment in all cyclists could be substantial in relation to the smallest important effect but small in effect size. The typical errors for all lean mass estimates were small but substantial for both strength-trained subjects and cyclists.

Changes in total and regional lean masses after a strength or a cycling session were similar to changes in total masses. After a strength session, there were trivial changes in total and most regional lean masses, with the exception for arm lean mass where there was a small but substantial increase. However, when taking into account the uncertainty represented by the confidence limits, changes in trunk and leg lean masses in strength-trained subjects could be substantial. Similar changes in lean masses were also observed in cyclists. A cycling session by females produced trivial changes for all lean masses. There were small but substantial changes in male cyclists for lean mass regions. Both types of exercise increased the TEM slightly, but all were still small in magnitude.

Fat mass. There were trivial changes in the immediate reassessment for total and regional fat mass estimates in both strength-trained subjects and cyclists. However, when taking into account the uncertainty represented by the confidence limits, the changes in the immediate reassessment for trunk and arm fat could be substantial but small in cyclists. The TEM in the immediate reassessment in both types of exercise was mostly small in effect size but substantial in comparison with the smallest important effects.

After a strength exercise or a cycling session, there were trivial changes in total and regional fat masses. However, many of the changes in fat mass in both types of exercise could be substantial but small in effect size. The TEM of fat mass increased slightly after both types of exercise, although values were small in magnitude.

Bone mineral content. Both strength training and cycling exercise produced trivial changes in the immediate reassessment for total and regional bone mineral content. However, when taking into account the uncertainty represented by the confidence limits, changes in the immediate reassessment for trunk and arm bone mineral content could be substantial in male subjects. Typical errors of measurement

TABLE 2. Change in the mean (Δmean) and TEM for DXA measurements of total mass, lean mass, fat mass and bone mineral content in 27 strength-trained subjects

				Immediate Reassessment						Reassessment After Exercise					
		Smallest Important Effect^a		Δmean	±CL	TEM	×/÷CL	Δmean	TEM	Δmean	±CL	TEM	×/÷CL	Δmean	TEM
	Mean ± SD^b	Pct.	Grams	Pct.				Grams		Pct.				Grams	
Total mass	80.6 kg ± 13%	0.9	690	0.0	0.1	0.1	1.26	10	90	0.4	0.2	0.4	1.26	290	320
Trunk mass	37.3 kg ± 13%	0.9	320	0.2	0.3	0.7	1.26	60	260	0.8	0.5	1.2	1.27	300	450
Leg mass	27.4 kg ± 14%	1.0	270	−0.3	0.4	0.8	1.26	−80	230	−0.8	0.4	1.0	1.32	−220	280
Arm mass	10.8 kg ± 15%	1.1	110	0.3	0.7	1.4	1.18	30	150	2.0^c	0.6	1.4	1.18	220	150
Total lean	64.2 kg ± 12%	0.8	520	0.0	0.3	0.6	1.26	10	390	0.4	0.3	0.7	1.36	270	430
Trunk lean	29.3 kg ± 11%	0.8	230	0.1	0.6	1.2	1.27	30	360	0.7	0.7	1.5	1.32	210	450
Leg lean	21.6 kg ± 13%	0.9	200	−0.2	0.5	1.0	1.26	−50	220	−0.8	0.5	1.2	1.34	−160	250
Arm lean	9.2 kg ± 15%	1.1	100	0.4	0.6	1.4	1.18	30	130	2.6^c	0.6	1.4	1.18	240	130
Total fat	12.9 kg ± 35%	2.4	300	0.1	1.1	2.5	1.18	10	320	0.2	1.0	2.5	1.18	20	320
Trunk fat	6.9 kg ± 38%	2.6	180	0.8	1.8	4.0	1.18	60	270	1.4	1.6	4.0	1.18	100	270
Leg fat	4.5 kg ± 37%	2.6	120	−0.8	1.1	2.5	1.18	−40	110	−1.0	0.9	2.5	1.18	−50	110
Arm fat	1.1 kg ± 40%	2.9	30	−0.6	2.0	4.4	1.18	−10	50	−2.1	1.7	4.4	1.18	−20	50
Total BMC	3.5 kg ± 16%	1.0	36	0.0	0.4	1.0	1.18	−1	34	0.0	0.4	1.0	1.18	0	34
Trunk BMC	1.1 kg ± 22%	1.4	16	0.2	1.2	2.7	1.18	2	30	0.4	1.0	2.7	1.18	5	30
Leg BMC	1.3 kg ± 16%	1.1	14	−0.1	0.3	0.7	1.26	−1	10	−0.4	0.3	0.8	1.37	−5	11
Arm BMC	0.5 kg ± 17%	1.1	8	−0.3	0.7	1.6	1.18	−1	8	−0.1	0.6	1.6	1.18	0	8

Data are shown for immediate reassessment in the rested state and for reassessment after an exercise session.

The intraclass correlation coefficient that corresponds to these TEM ranged from 0.85 to 0.99.

[a] Values shown are smallest important values for Δmean. The smallest important values for the TEM are one half of these.

[b] Between-subject SD expressed as a coefficient of variation (%).

[c] Small important values.

CL, 90% confidence limits in ± or ×/÷ form; BMC, bone mineral content.

TABLE 3. Change in the mean (Δmean) and TEM for DXA measurements of total mass, lean mass, fat mass, and bone mineral content in 14 female and 14 male cyclists.

			Smallest Important Effect		Immediate Reassessment						Reassessment After Exercise					
					Δmean	±CL	TEM	×/÷CL	Δmean	TEM	Δmean	±CL	TEM	×/÷CL	Δmean	TEM
		Mean ± SD[a]	Pct.	Grams	Pct.				Grams		Pct.				Grams	
Total mass	F	64.7 kg ± 13%	0.8	550	0.2	0.3	0.4	1.40	150	280	0.0	0.4	0.6	1.44	−10	390
	M	75.4 kg ± 8%	0.5	390	0.0	0.1	0.2	1.40	10	150	−0.7[c]	0.3	0.5	1.39	−490	340
Trunk mass	F	29.1 kg ± 12%	0.8	240	0.4	0.3	0.5	1.40	130	150	0.1	0.6	1.0	1.39	30	280
	M	34.4 kg ± 7%	0.5	170	0.2	0.8	1.2	1.38	50	420	−1.7[c]	0.8	1.3	1.56	−580	450
Leg mass	F	23.9 kg ± 14%	1.0	240	−0.1	0.6	0.9	1.26	20	210	−0.1	0.5	0.9	1.26	−20	210
	M	26.9 kg ± 10%	0.7	180	−0.2	0.7	1.2	1.26	−50	310	0.1	0.6	1.2	1.26	20	310
Arm mass	F	7.3 kg ± 15%	1.0	70	0.6	1.0	1.5	1.26	40	110	−0.3	0.8	1.5	1.26	−30	110
	M	9.0 kg ± 10%	0.7	60	0.0	1.0	1.5	1.42	0	140	1.0	1.3	2.1	1.45	90	190
Total lean	F	48.9 kg ± 11%	0.7	370	0.3	0.5	0.8	1.39	170	380	0.0	0.6	1.0	1.45	20	500
	M	64.0 kg ± 6%	0.4	290	−0.1	0.3	0.5	1.26	−50	330	−0.4[c]	0.3	0.5	1.26	−280	330
Trunk lean	F	22.9 kg ± 10%	0.7	160	0.7[c]	0.7	1.0	1.39	170	220	0.1	1.1	1.7	1.40	20	390
	M	29.6 kg ± 7%	0.5	140	−0.1	0.6	1.0	1.40	−20	290	−1.5[c]	0.7	1.2	1.48	−450	360
Leg lean	F	16.9 kg ± 13%	0.9	150	−0.2	0.7	1.1	1.26	−30	190	0.0	0.6	1.1	1.26	0	190
	M	22.4 kg ± 7%	0.5	110	−0.1	0.8	1.3	1.26	−30	290	0.5	0.7	1.3	1.26	100	290
Arm lean	F	5.7 kg ± 16%	1.1	60	0.5	1.0	1.6	1.26	30	90	−0.1	0.9	1.6	1.26	0	90
	M	7.9 kg ± 8%	0.6	50	−0.1	0.9	1.4	1.41	−10	110	1.0[c]	1.4	2.2	1.43	80	170
Total fat	F	13.1 kg ± 40%	2.9	390	−0.1	1.3	1.9	1.39	−20	250	−0.8	1.2	2.1	1.57	−100	270
	M	8.3 kg ± 67%	4.0	330	0.9	2.2	3.3	1.40	70	270	−2.4	2.1	3.7	1.57	−200	300
Trunk fat	F	5.4 kg ± 47%	3.6	200	−0.8	3.0	4.6	1.39	−40	250	−1.5	2.9	5.0	1.56	−80	270
	M	3.8 kg ± 62%	4.1	150	2.3	3.7	5.7	1.27	90	220	−3.2	3.0	5.7	1.27	−120	220
Leg fat	F	5.9 kg ± 37%	2.6	160	0.1	0.9	1.4	1.40	10	80	−0.3	1.0	1.6	1.52	−20	100
	M	3.3 kg ± 78%	4.4	150	−1.3	2.8	4.4	1.41	−40	150	−2.1	2.7	4.8	1.58	−70	160
Arm fat	F	1.3 kg ± 46%	3.7	50	1.5	2.4	3.7	1.27	20	50	−1.7	2.0	3.7	1.27	−20	50
	M	0.8 kg ± 68%	4.3	30	1.9	3.4	5.2	1.40	10	40	0.2	3.3	5.7	1.57	0	40
Total BMC	F	2.7 kg ± 19%	1.3	36	−0.1	0.5	0.8	1.26	−4	23	−0.2	0.5	0.8	1.26	−6	23
	M	3.1 kg ± 9%	0.6	18	0.0	0.5	0.8	1.42	1	24	−0.4	0.5	0.9	1.57	−12	28
Trunk BMC	F	0.8 kg ± 25%	1.9	15	−0.1	1.4	2.2	1.26	−1	18	0.3	1.2	2.2	1.26	2	18
	M	0.9 kg ± 13%	0.9	8	0.0	1.6	2.5	1.26	0	23	−1.4[c]	1.3	2.5	1.26	−13	23
Leg BMC	F	1.0 kg ± 20%	1.4	15	0.0	0.4	0.6	1.26	0	6	−0.6	0.3	0.6	1.26	−6	6
	M	1.2 kg ± 11%	0.8	10	0.3	0.3	0.5	1.39	3	6	−0.3	0.5	0.8	1.42	−3	9
Arm BMC	F	0.4 kg ± 19%	1.4	5	−0.2	1.1	1.8	1.26	−1	6	−0.5	1.0	1.8	1.26	−2	6
	M	0.5 kg ± 8%	0.6	3	−0.3	0.7	1.1	1.41	−1	5	1.1[c]	1.4	2.1	1.40	5	10

Data are shown for immediate reassessment in the rested state and for reassessment after an exercise session.

The intraclass correlation coefficient that corresponds to these TEM ranged from 0.40 to 0.99.

[a] Between-subject SD expressed as a coefficient of variation (%).

[b] Values shown are smallest important values for Δmean. The smallest important values for the TEM are one half of these.

[c] Small important values.

F, female; M, male; CL, 90% confidence limits in ± or ×/÷ form; BMC, bone mineral content.

for total and regional bone mineral content in the immediate reassessment were small in effect size but substantial in comparison with the smallest important effect.

After both strength and cycling sessions, there were trivial changes for total and regional bone mineral content. However, cycling sessions in males produced small but substantial changes in trunk and arm bone mineral content. Most of the typical errors of measurement of bone mineral content after both types of exercise increased slightly but were still small in value.

Female–male cyclist comparison. After a cycling session, there were clear but small differences in the changes between male and female cyclists in total and regional body composition estimates. In particular, male cyclists lost more total mass (90% confidence limits ±0.5%), trunk mass (±1.0%), trunk lean mass (±1.3%), and trunk bone mineral content (±1.7%) compared with female cyclists. However, males were more likely to gain arm mass (±1.5%), arm lean (±1.6%), and arm bone mineral content (±1.7%) estimates postcycling. There were no differences in total and regional fat estimates between male and female cyclists.

There were also some small but substantial differences in the TEM between male and female cyclists. The typical errors after a cycling session were smaller in females for total lean (90% confidence limits ±0.4%) and trunk lean mass (±0.7%) estimates. Males were more likely to experience greater errors for arm mass (±0.9%), arm lean mass (±0.9%), and leg fat mass (±2.4%). However, male cyclists had lower error of measurement for arm fat mass estimates (±2.8%).

Strength-cycling exercise comparison. There were small but substantial differences in postexercise measurements between strength-trained subjects and male cyclists for total and regional body composition estimates. Male cyclists lost more total mass (90% confidence limits ±0.4%), trunk mass (±0.9%), arm mass (±1.4%), total lean mass (±0.4%), trunk lean mass (±1.0%), arm lean mass (±1.5%), trunk fat mass (±3.3%), and trunk bone mineral content (±1.6%). They were also likely to gain leg lean mass (±0.8%) and arm bone mineral content (±1.5%) compared with strength-trained subjects.

Measurements in male cyclists were likely to produce more errors than strength-trained subjects, particularly for arm mass (±0.8%), arm lean mass (±0.8%), trunk fat mass

(±1.5%), leg fat mass (±2.3%), and arm bone mineral content estimates (±0.8%).

Effect of exercise. We modeled the effect of the exercise and its related practices of food and fluid intake with a covariate to estimate change in the mean value of measurements per hour of exercise, plus a constant representing the change with an exercise session of zero duration. As expected, the model predicted the change in the dependent variable for the mean duration of exercise, but the TEM did not decrease substantially with this model (data not shown).

DISCUSSION

This is the first study in an active population to systematically examine changes in DXA body composition estimates and their typical errors of measurement associated with whole and regional body composition estimates after an exercise session that included the consumption of *ad libitum* food and fluid in accordance with the subject's usual preexercise and during-exercise nutrition practices. The sole effect of exercise on body composition estimates was not examined in this study because food and fluid intake before and during an exercise session is an integral part of everyday training of athletes and should therefore be considered in conjunction with exercise. Our main findings were that changes in the mean for many total and regional body composition estimates postexercise were trivial; however, when taking into account the uncertainty represented by the confidence limits, there was also a possibility of small but substantial change in many cases. In general, an exercise session produced a slight increase of approximately 1.10-fold (or 10%) in the TEM, although the increase in errors associated with the arm and trunk regions was slightly higher compared with other regions.

Our further findings were that after a strength session, there were trivial changes in the estimates of most total and regional body composition characteristics. Changes in the values of arm mass and arm lean mass were small in effect size but substantial in terms of the smallest important effect. The increase in value of the arm region is thought to be due to the increased blood flow and capillary dilation associated with the upper body strength exercises that formed the major part of the session (as documented in training diary). There was also a possibility of small but substantial changes in trunk and leg mass and lean mass, as well as trunk and arm fat mass after a gym session. Similarly, a cycling session by females generally produced trivial changes in total and regional mass and lean mass. However, changes in the trunk lean and trunk and arm fat mass could be substantial. A cycling session by male cyclists, on other hand, generally produced small but substantial changes in most body mass and lean mass estimates, and most changes in fat regions could be substantial when taken into account the uncertainty represented by the confidence limits. The TEM calculated from immediate reassessment, which is also classified as the technical error of measurement (often expressed as the within-subject coefficient of variation), was approximately 0.6% (approximately 370 g) for lean mass and approximately 2.5% (approximately 280 g) for fat mass. This is similar to the results from our previous study of active individuals of lower athletic caliber and training history and confirms the value of undertaking DXA measurements after a strict and standardized protocol (12).

Previously (12), we have found small but substantial increases in values for total and regional lean mass after an acute intake of a meal. We might have expected larger perturbations in values in the present study associated with vigorous exercise. However, it is important to recognize that our exercise sessions also included the normal intake of food and fluid, and because the direction of change in values was opposite (i.e., decrease associated with exercise and increase associated with food/fluid intake), the net change was small. This may not be the case if exercise sessions are of greater duration and/or intensity, as evidenced by the observations of greater changes in our male cyclists who, by chance, undertook sessions of longer duration (male, 110 ± 42 min, vs female, 79 ± 53 min). The reduction in value for total mass and total lean observed in male cyclists is thought to be associated with dehydration. Furthermore, a cycling session can also produce fluid recompartmentalization where there is shunting of blood volume from the trunk to the periphery (11,14). A small aspect of this effect could have occurred in this study where there was a reduction in value of trunk mass in conjunction with an increase in leg and arm mass. However, this effect was not observed in female cyclists because the effect of fluid recompartmentalization on DXA values could have been compensated by food and fluid intake during a shorter cycling session.

The increase in the magnitude of TEM has an important implication for the sample size of any research study. For example, an increase of approximately 10% in the TEM postexercise as observed in this study would lead to an increase of approximately 20% in sample size of any future research involving controlled trials investigating changes in body composition over time or as a result of an intervention. Although the required increase in sample size may be small, it may lead to substantially greater financial cost (e.g., equipment and staff cost) and time burden for the researchers. Alternatively, failing to accommodate the need for an increased sample size may increase the chance of incurring a Type II error in such studies.

When the duration of the exercise session was modeled with a covariate, the model was able to predict the change in the mean of body composition estimates; however, the TEM did not substantially decrease. Therefore, we conclude that there is no advantage in adjusting for the duration of exercise using parameters derived by the crude model that included a covariate for exercise duration. If we had included measures of food intake, fluid intake, and exercise intensity, the resulting model may have resulted in a reduction in error. However, it would be impractical to adopt this approach for the small improvement in error.

Under the current AIS whole-body DXA scanning protocol (12), all subjects undergoing a whole-body DXA scan must be presented in a fasted, rested, and euhydrated state. This scanning protocol has many practical implications in the sport setting where it could interfere with the athletes' daily training schedule, potentially preventing them from undergoing a whole-body DXA scan. It is therefore tempting and potentially more convenient to scan athletes after an exercise session and use the regression equations to adjust the body composition estimates, accounting for the effect of the exercise session. However, with the increase in TEM postexercise, as well as the increased in uncertainty of body composition estimates and the lack of reduction in the TEM associated with the adjusted estimates, the regression equations should not be used.

To our knowledge, there are currently no data on the smallest important effect of body composition estimates—a magnitude of change or difference in a body composition parameter (e.g., total lean mass) that can influence performance. Having a rigorous scanning protocol will ensure that any "noise" associated with the technical and biological variability of whole-body DXA scanning is minimized. This will also increase the confidence in the observed "real" or absolute changes in body composition measurement estimates. Therefore, the most practical and easiest way to ensure best precision is to have all subjects fasted and rested, as well as have a meticulous scanning protocol (12).

In summary, exercise and its related practices of food and fluid intake are associated with changes in the mean estimates of total and regional body composition that range from trivial to small but substantial. An exercise session also increases the TEM of these characteristics by approximately 10%. Although we could potentially "adjust" for the changes in body composition estimates using regression equations, it is not recommended because of the increase in uncertainty represented by wider confidence limits. Therefore, the easiest and most practical way to minimize the biological "noise" associated with undertaking a DXA scan is to have a standardized scanning protocol with fasted and rested subjects. We have investigated the effects of two types of exercise sessions and its related nutrition practices on DXA body composition estimates. Therefore, it is not clear whether similar results apply to other types of exercise session (e.g., swimming and running) or in other environmental condition (e.g., hot condition). It is, however, speculated that a greater change in DXA measurements could occur if the exercise session is long and intensive. This will be exacerbated if a subject has limited access or opportunities to consume food and/or fluid during the session and if the session was undertaken in a hot condition where higher fluid deficit could occur. The opposite is also possible on the other extreme; for example, a subject may overdrink during a short session that is light in intensity in a cool condition. The variability and the uncertainty of outcomes confirm the benefits of standardized protocol of fasted and rested conditions. Until sufficient data on the smallest important effect are available, both biological and technical "noises" should be minimized so that any small but potentially "real" changes can be confidently detected.

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