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Detecting meaningful body composition changes in athletes using dual-energy X-ray absorptiometry

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Short title: Detecting meaningful body composition changes in athletes using DXA

Abstract

Dual-energy X-ray absorptiometry (DXA) imaging is considered to provide a valid and reliable estimation of body composition when stringent scanning protocols are adopted. However, applied practitioners are not always able to achieve this level of control and the subsequent impact on measurement precision is not always taken into account when evaluating longitudinal body composition changes. The primary aim of this study was to establish the reliability of DXA in an applied elite sport setting to investigate whether real body composition changes can be detected. Additionally, the performance implications of these changes during the training year were investigated. Forty-eight well-trained athletes (from four diverse sports) underwent two DXA scans using a ‘real-world’ approach (with limited pre-scan controls), typically within 48 h, to quantify typical error of measurement (TEM). Twenty-five athletes underwent further scans, before and after specific training and competition blocks. ‘True’ body composition changes were evaluated using $2 \times \text{TEM}$

thresholds. Twelve bob skeleton athletes also performed countermovement jump and leg press tests at each time point. Many ‘true’ body composition changes were detected and coincided with the primary training emphases (e.g., lean mass gains during hypertrophy-based training). Clear relationships ($r \pm 90\%$ CI) were observed between performance changes (countermovement jump and leg press) and changes in lean mass (0.53 ± 0.26 and 0.35 ± 0.28 , respectively) and fat mass (-0.44 ± 0.27 and -0.37 ± 0.28 , respectively). DXA was able to detect real body composition changes without the use of stringent scanning controls. Associations between changes in body composition and performance demonstrated the potential influence of these changes on strength and power indices.

Key Words: DXA, fat mass, lean mass, performance, reliability, scanning

1. Introduction

Change in body composition are important to monitor in athletic populations due to its influence on the crucial power-to-body mass ratio that underlies many sporting movements (Cronin and Hansen 2005). Consequently, dual-energy X-ray absorptiometry (DXA) scans are being increasingly used to characterise physique (Sutton *et al* 2009a, Sutton *et al* 2009b) and body composition changes (Harley *et al* 2011, Santos *et al* 2010, Silva *et al* 2012) in athletes. However, the reliability of these measurements in applied sport settings can often be overlooked and the measurement errors inherent in DXA are seldom considered when evaluating body composition changes.

Biological variation, including differences in food or fluid intake and the short-term effects of exercise, is known to inflate DXA measurement errors (Nana *et al* 2012, 2013, Pietrobelli *et al* 1998). This may, in turn, influence the ability of DXA to detect ‘true’ body composition changes across time (Nana *et al* 2014). Thus, a meticulous scanning protocol has been outlined (Nana *et al* 2012, 2013) in order to minimize the errors in DXA body composition estimates amongst athletic populations. This requires athletes to be fasted, rested, euhydrated and carefully positioned on the scanning bed using custom-made blocks. However, this level of control is not always achieved in reality, partly due to

complex training programmes, inflexible dietary regimes and behavioural variation. Thus, the precision of DXA estimates might be reduced in the applied setting and practitioners may have difficulty differentiating body composition changes from the measurement error.

In the context of elite sport, performance is often the primary outcome measure. Typically, a broad range of athletes' characteristics are monitored longitudinally with the overarching aim to better understand athlete development and how performance can be enhanced. Thus, in order for DXA-estimated body composition changes to be truly meaningful in this setting they should relate to an athlete's ability to perform. Strength and conditioning programmes can result in considerable body composition changes (Burke *et al* 1986, Gabbett 2005, Legaz and Eston 2005), which may have important implications for athletic performance. Indeed, decreases in lower limb skinfold measurements have previously been associated with improvements in sprint performance (Legaz and Eston 2005). However, the association between DXA-estimated body composition changes and changes in elite physical performance are relatively unexplored. Thus, the aims of this study were: (1) to establish the reliability of DXA in an applied setting, by quantifying the measurement errors when athletes from diverse sports are scanned using a practical DXA protocol, and (2) to use the measurement errors to evaluate body composition changes exhibited across a season by two different athletic groups (bob skeleton athletes and elite rugby union players) with unique virtues and training emphases. Further, in order to better understand the performance implications of these changes, the associations between body composition and lower limb strength and power measures were also investigated in bob skeleton athletes.

2. Methods

2.1. DXA protocols and reliability

Body composition was estimated using a DXA system (Hologic Discovery W, Bedford, MA; QDR software version 12.4.2) by differentiating the fat, bone, and non-bone non-fat (lean) masses. All scans were undertaken at a similar time of day (typically within 90 minutes). A quality control scan using a phantom spine was performed before all scanning sessions in accordance with the

manufacturer's guidelines. A body composition phantom was not available for this study, however, monitoring the performance of DXA using a bone mineral density phantom was still considered a valuable quality control to assess the stability of measurements. A local NHS Research Ethics Committee provided ethical approval for this study and each participant provided written informed consent prior the first scan. Participants were asked to wear light clothing (males: cycling shorts; females: cycling shorts and unwired sports bra) and remove all metal objects before each scan. Participants were then carefully positioned in a supine position on the scanning bed which enabled body regions to be easily partitioned and were asked to remain in this position for the duration of the scan (approximately seven minutes). Immediately after the scan, operational procedures were followed by a trained technician to identify anatomical landmarks and manually place boundaries around discrete anatomical regions (left arm, right arm, trunk, left leg, right leg, and head) within the software, before the system calculated regional masses and composition. Consistency of the regional partitioning was retrospectively verified by one researcher before data were pooled for analysis. Whole body measurements were calculated as the sum of all region masses.

To assess the reliability of the DXA scanning protocol, 48 participants underwent two whole body DXA scans typically within 48 hours. Athletes across four sports (12 bob skeleton, 8 rugby union, 14 swimming, and 14 athletics sports men and women) participated in this part of the study. Descriptive characteristics for these 48 athletes (and 5 further rugby players, see below) including baseline body composition information are presented in table 1. The second scan for rugby players typically occurred 4-6 days after the first due to training schedules. The exact food and fluid consumption in the rugby, athletics or swimming sub-groups in the immediate pre-scan period was not controlled due to the inflexibility of their dietary regimes during training seasons. More controls were possible for the bob skeleton athletes as the body composition assessments formed part of a more extensive, controlled testing battery. Scans for the bob skeleton sub-group were always undertaken between 0730 and 0845 and athletes were asked to consume 500 ml of fluid in the morning before each scan. Breakfast intake was not controlled, however, bob skeleton athletes were asked to consume similar amounts and types of food and fluid prior to each scan.

Table 1. Participant characteristics (mean $\pm$ SD) at baseline (first scan).

	Rugby	Bob skeleton		Athletics		Swimming		All participants (n = 53)	All males (n = 34)	All females (n = 19)
	13 male	7 male	5 female	7 male	7 female	7 male	7 female			
Age (yr)	28 $\pm$ 4	25 $\pm$ 1	24 $\pm$ 1	21 $\pm$ 2	20 $\pm$ 2	21 $\pm$ 3	20 $\pm$ 1	23 $\pm$ 4	24.1 $\pm$ 4	21.0 $\pm$ 2.2
Height (m)	1.86 $\pm$ 0.08	1.76 $\pm$ 0.07	1.68 $\pm$ 0.05	1.83 $\pm$ 0.04	1.68 $\pm$ 0.05	1.87 $\pm$ 0.05	1.71 $\pm$ 0.06	1.78 $\pm$ 0.10	1.83 $\pm$ 0.76	1.69 $\pm$ 0.57
Body mass (kg)	112.7 $\pm$ 9.0	77.5 $\pm$ 7.5	65.6 $\pm$ 6.5	76.4 $\pm$ 6.1	59.9 $\pm$ 6.3	80.2 $\pm$ 4.5	66.2 $\pm$ 5.4	79.1 $\pm$ 18.9	89.0 $\pm$ 17.7	64.1 $\pm$ 6.9
Lean mass (kg)	85.0 $\pm$ 7.2	64.9 $\pm$ 6.7	50.7 $\pm$ 5.5	66.8 $\pm$ 5.1	45.2 $\pm$ 4.3	68.6 $\pm$ 3.8	48.6 $\pm$ 4.4	62.4 $\pm$ 14.5	71.9 $\pm$ 10.2	47.9 $\pm$ 5.2
Fat mass (kg)	23.1 $\pm$ 5.1	9.5 $\pm$ 1.5	11.9 $\pm$ 1.6	6.3 $\pm$ 2.0	12.0 $\pm$ 3.5	8.4 $\pm$ 1.4	15.3 $\pm$ 2.6	12.5 $\pm$ 6.2	12.3 $\pm$ 7.6	13.0 $\pm$ 3.2
Body fat %	20.5 $\pm$ 3.8	12.2 $\pm$ 1.9	18.2 $\pm$ 1.9	8.2 $\pm$ 2.4	19.8 $\pm$ 4.5	10.5 $\pm$ 1.5	23.0 $\pm$ 3.4	16.0 $\pm$ 6.1	13.2 $\pm$ 5.5	20.3 $\pm$ 4.0

2.2. Body composition changes

Body composition changes across the training and competition seasons were characterised for the aforementioned 12 bob skeleton athletes and 8 (plus an additional 5) rugby players. Bob skeleton athletes underwent three (elite squad athletes) or two (talent squad athletes) further whole body DXA scans, each at the end of a training or competition block (figure 1). For the elite squad, this represented two training blocks (each 12 weeks) and the competition season (approximately 24 weeks). The emphasis of the first training block (block 1) was hypertrophy, whereas the second training block (block 2) involved higher velocity, sprint based exercises. The season for the talent squad bob skeleton athletes consisted of one 24 week training block and the competition season (approximately 17 weeks).

Rugby players were scanned at three further time points, the first of which coincided with the end of a 12 week pre-season training block (emphasis on fat mass reduction), and the second and third coinciding with the middle and end of a 32-week playing season, respectively. Two rugby players dropped out before the final time point (figure 1). Elite squad bob skeleton athletes ($n = 7$) ranged from international level of competitors to a World Cup winner. Talent squad bob skeleton athletes ($n = 5$) were preparing for their first competitive season on the developmental level circuit. The 13 rugby union players were all professional players and were competing in the top tier of rugby union in England. Overall, the longest period between the first and last scan on an individual was 48 weeks. The quality control of the test phantom scans revealed that the error was within the manufacturer's recommended limits across the whole data collection period demonstrating the stability of the system.

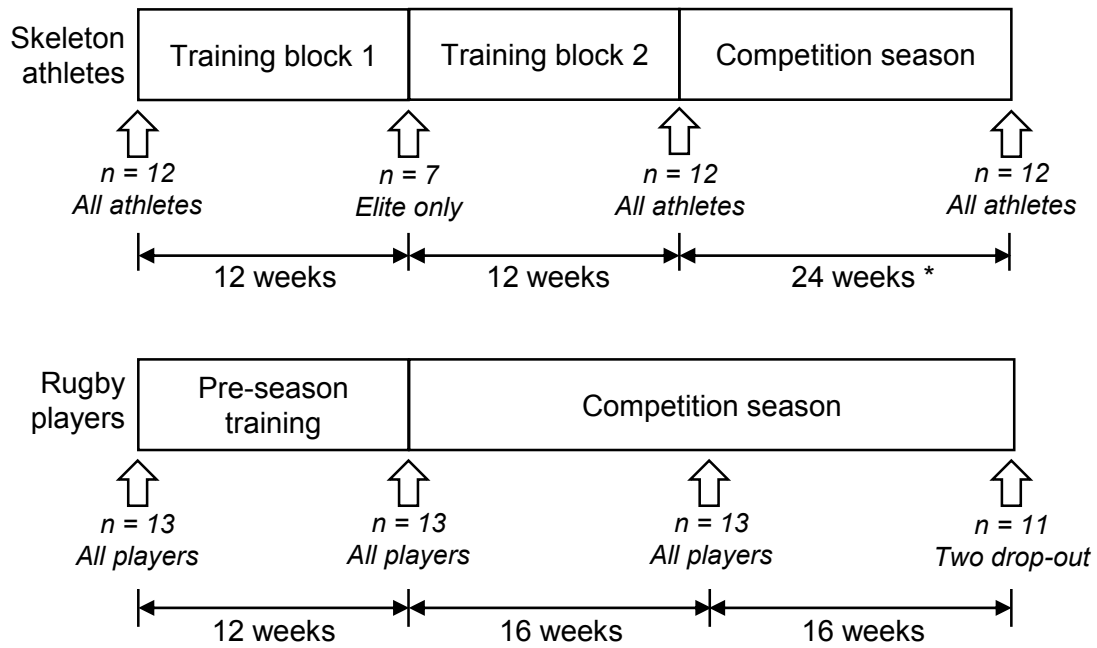


Figure 1. A schematic illustrating the timings of the DXA scans (block arrows) used to assess body composition changes across training and competition blocks in bob skeleton athletes and rugby players. *N.B. 17-week competition season for talent squad bob skeleton athletes.

2.3. Associations between body composition and lower limb strength-power indices

In order to assess the association between body composition and relevant physical strength-power characteristics, the skeleton athlete group underwent further physical tests. Within one week of each DXA scan, all bob skeleton athletes completed countermovement jump and leg press testing. These were considered to reflect lower limb power and strength which have previously been shown to be important physical attributes for bob skeleton athletes to possess (Sands *et al* 2005). Jump tests were performed on a force plate (Fi-tech; Skye, Australia) which sampled vertical ground reaction force at 600 Hz. Force data were filtered (82 Hz cut-off frequency) using a low-pass second-order recursive Butterworth filter before maximum centre of mass displacement was calculated using the impulse-momentum relationship. Athletes performed three maximal effort unloaded jumps and the average jump height was calculated. Leg press testing was conducted on a Keiser A420 pneumatic leg press (Keiser Sport, Fresno, CA). This consisted of an incremental test consisting of ten repetitions, starting from a low resistance in the initial repetitions and reaching an estimated maximum resistance

on the tenth repetition. Resistance was incrementally increased until failure and athletes were sometimes able to continue beyond the prescribed maximum. The Keiser system (sampling frequency at 400 Hz) provided force and velocity (and thus power) data for each effort. A second order polynomial was then plotted through the force-power data, allowing peak power and the force at which an athlete attained peak power to be calculated.

2.4. Statistical analysis

Means and standard deviations for body composition measures were calculated for each athlete sub-group. These included total mass, lean mass, and fat mass for the whole body, as well as for the trunk, leg and arm regions. Data from repeated scans were used to calculate change in the mean (the mean difference between the repeated scan results), typical error of the measurements (TEMs; standard deviation of the difference scores of all athletes in the group divided by $\sqrt{2}$, in grams and %) and intraclass correlation coefficients (ICCs) for all body composition measures, using a published spreadsheet (Hopkins 2000b). To ensure normality of the sampling distribution, each of these measurements were firstly log transformed before analysis and back transformed after analysis, as recommended by Hopkins (2000a). TEMs were derived for the whole cohort, for each sub-group of athletes (each sport separated by gender; $n = 7$) and for male and females. To test whether the TEMs differed by height, weight or body fat percentage, TEMs were computed for the first and fourth quartiles when athletes were ranked according to each of these descriptors. Uncertainty in the TEM estimates were expressed as 90% confidence limits (CL). The typical error differences between the two groups for each demographic (gender, height, weight and body fat percentage) were considered clear, if the 90% confidence intervals (CI) of the groups did not overlap. Additionally, Pearson correlation coefficients were used to assess the relationship between the mean fat masses and the fat mass TEMs of the associated body regions.

According to Hopkins (2000a), the TEM (which represents the error in both directions) should be multiplied by a factor of 1.5 to 2 before interpreting longitudinal changes. Thus, TEMs were doubled to provide a conservative ‘TEM threshold’ above which changes were considered likely (92%

probability) to be ‘true’ changes. Data from the first scans were used as an estimate of baseline body composition. For the follow-up DXA scans, percentage changes (from baseline and between time points) in three whole body composition measures (total body mass, lean mass and fat mass) were calculated for all bob skeleton athletes and rugby players at each time point. Additionally, for the bob skeleton athletes only, percentage changes in leg lean mass were calculated at each time point as the emphasis of training was lower limb hypertrophy. The percentage changes in total lean mass, leg lean mass, and physical test scores across all testing blocks were then pooled for the bob skeleton athletes. Pearson correlation coefficients were used to assess the relationships between the percentage changes in body composition and the physical test scores. The smallest worthwhile effect was set at $r = 0.1$ for all Pearson correlation coefficients, with 90% confidence intervals (CI) calculated and magnitude-based inferences derived as previously suggested (Batterham and Hopkins 2006).

3. Results

3.1. Reliability of DXA protocol

The typical errors and ICCs associated with repeated DXA measurements are provided in table 2. Regional TEMs (%) were larger than those associated with whole body measures. Fat mass TEMs (%) were consistently larger than the total mass and lean mass TEMs of the same body region. There were no clear gender differences in the TEMs for whole body mass, lean mass and fat mass. Additionally, there did not appear to be a difference in these TEMs between the first and fourth quartiles for both height and weight. However, there was a clear TEM difference (90% CI did not overlap) between the first and fourth quartile for body fat percentage, where higher fat mass errors were exhibited for leaner individuals (first quartile; 3.2%, 90% CI = 1.7 to 6.2%) compared with those who had greater body fat percentage (fourth quartile; 0.5%, 90% CI = 0.3 to 0.9%).

Table 2. Reliability statistics for DXA estimated body composition measures (n = 48).

		Change in the mean (g)	Typical error of the measurement			ICC
			(g)	(%)	CL ^a	
Whole	Total mass	75	506	0.6	1.2	1.00
	Lean mass	179	549	0.9	1.2	1.00
	Fat mass	-85	359	3.9	1.2	0.99
Legs	Total mass	89	313	1.0	1.2	1.00
	Lean mass	118	290	1.2	1.2	1.00
	Fat mass	-26	185	4.5	1.2	0.99
Arms	Total mass	9	143	1.6	1.2	1.00
	Lean mass	20	156	2.3	1.2	1.00
	Fat mass	-10	63	7.7	1.2	1.00
Trunk	Total mass	22	496	1.4	1.2	1.00
	Lean mass	70	510	1.8	1.2	1.00
	Fat mass	-41	298	8.0	1.2	0.98

^a 90% confidence limits (CL) in $\times/\div$ form.

ICC = intraclass correlation coefficient

Total fat mass errors also varied across the seven athlete sub-groups and were typically greater in the leaner athlete populations. Correlation coefficients for the relationships between absolute fat mass and absolute fat mass TEMs are illustrated in figure 2. The relationships between total and trunk fat masses and the associated TEMs were substantially negative. Unclear relationships were found between arm fat mass and arm fat mass TEMs, and between leg fat mass and leg fat mass TEMs.

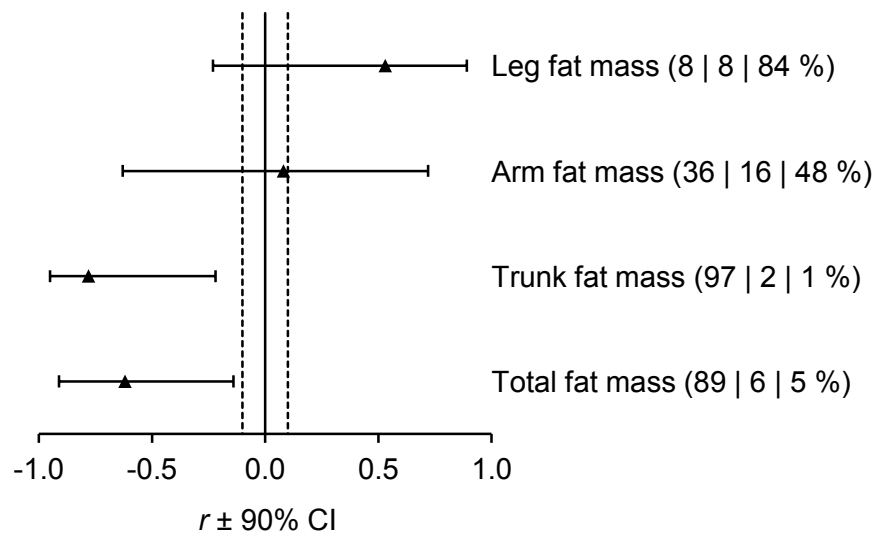


Figure 2. Correlation coefficients for the relationships between mean fat masses and absolute typical error of the measurements for seven sub-groups, at a whole body and region level. Bars represent 90% confidence intervals (CI). Percentages in brackets represent the likelihoods that the relationships are negative | trivial | positive.

3.2. Body composition changes across time

The longitudinal body composition changes exhibited by bob skeleton athletes and rugby players are illustrated in figures 3 and 4, respectively. Many body composition changes above the TEM threshold (TEM doubled) between time points were observed in both bob skeleton sub-groups. For example, five out of seven elite squad bob skeleton athletes and all five talent squad bob skeleton athletes exhibited increases in both lean mass (2.3 to 6.9%) and leg lean mass (3.5 to 10.9%) between the first two scan time points (across training block 1 and the training season, respectively). Conversely, across the competition season, seven out of 13 bob skeleton athletes exhibited decreases in lean mass (-2.0 to -7.7%), and increases in fat mass (9.4 to 24.8%) were also observed in nine of the athletes across this period (i.e. from block 2 to the end of competition season). Body composition changes above the associated TEM thresholds were also observed in rugby players at several time points across the season (figure 4). For example, decreases in fat mass (-7.9 to -28.4% change from baseline) were exhibited in 12 out of 13 rugby players across the pre-season training block, which was focussed on fat reduction.

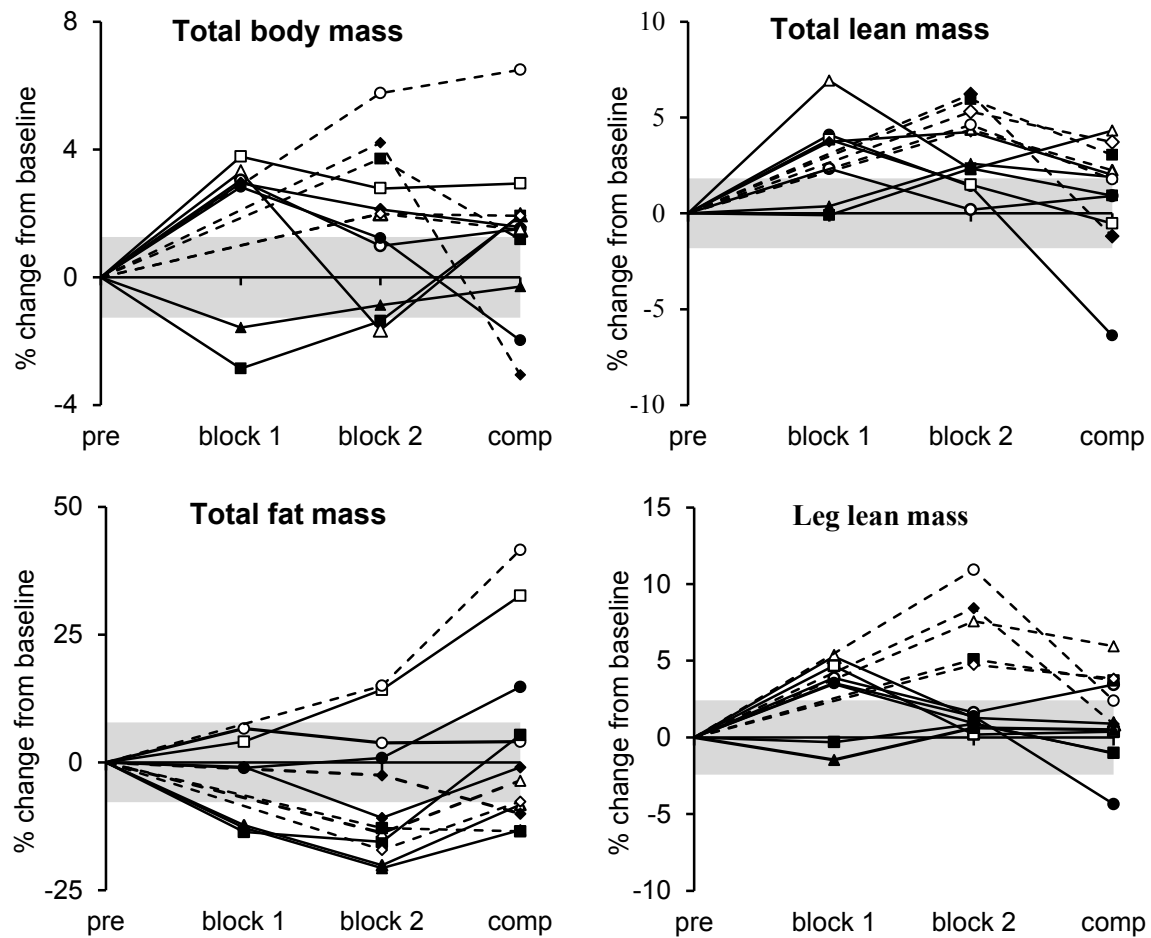


Figure 3. Longitudinal changes in body composition from baseline (pre) exhibited by individual bob skeleton athletes across two training blocks (block 1 and 2) and one competition block (comp). Shaded areas represent the typical error of the measurement (TEM) threshold (TEM doubled) for each body composition measure from baseline. Solid lines represent elite squad and dashed lines represent talent squad bob skeleton athletes. N.B. talent squad training block was 24 weeks instead of 2 times 12 weeks blocks for elite squad.

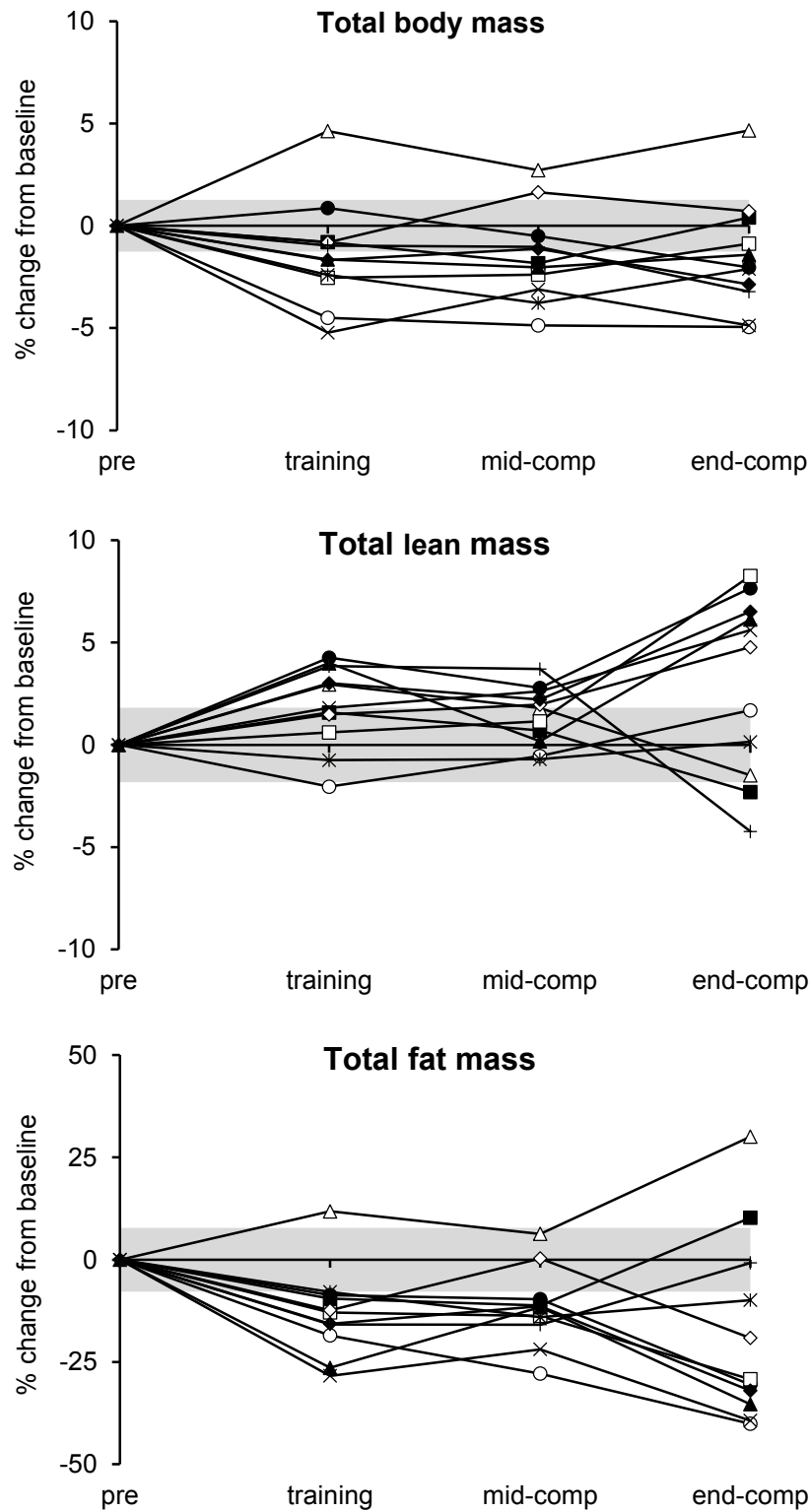


Figure 4. Longitudinal changes in body composition from baseline (pre) exhibited by individual elite rugby union players across a pre-season training block (training) and two time points across the competition season (mid-comp and end-comp). Shaded areas represent the typical error of the measurement (TEM) threshold (TEM doubled) for each body composition measure from baseline.

3.3. Associations between body composition and lower limb strength-power indices

The relationships between the changes in body composition and physical performance for bob skeleton athletes (Pearson correlation coefficients $\pm$ 90% CI and percentage likelihoods) are provided in figure 5. Relative increases in lean mass and leg lean mass were positively related to improvements in jump performance. Similarly, relative increases in lean mass were related to improvement in leg press performance. Finally, reductions in fat mass were related to improvements in both physical performance measures (figure 5).

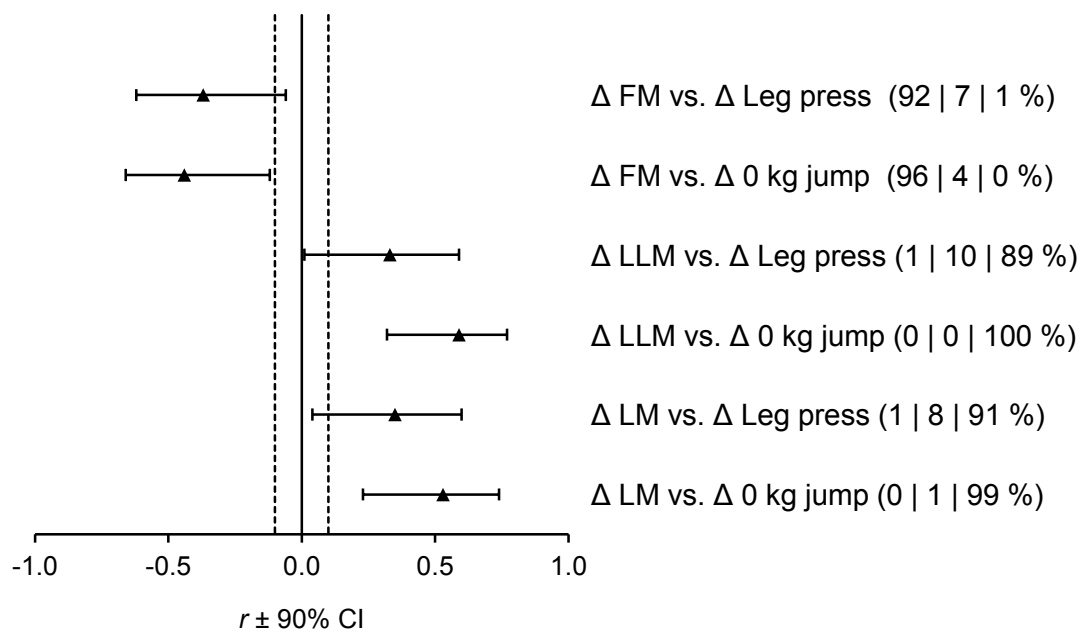


Figure 5. Correlation coefficients for the relationships between percentage changes in body composition and physical performance in 12 bob skeleton athletes. Bars represent 90% confidence intervals. Percentages in brackets represent the likelihoods that the relationships are negative | trivial | positive. FM, LLM and LM denote fat mass, leg lean mass and lean mass, respectively. Leg press denotes the force at peak power during leg press exercise and 0 kg jump denotes unloaded vertical jump height.

4. Discussion

This study investigated the reliability of DXA in a large and diverse cohort of athletes by conducting repeated scans across a short period of time, within which actual body composition changes are likely to be negligible. The two repeated scans revealed that reliable results can be obtained using DXA to estimate body composition within an applied setting, although there was some variation between the different regions of the body. The conservative approach of doubling the typical error of measurement allowed meaningful body composition changes to be detected during the training and competition season for two sub-groups of competitive athletes. There were also clear indications that the detected body composition changes are associated with changes in physical performance.

A meticulously controlled scanning protocol has previously been recommended to minimize measurement errors associated with DXA (Nana *et al* 2012, 2013). However, in reality such control can be very challenging to achieve within an applied sport setting, such as that within which this study took place. The main differences between the protocol of Nana *et al* (2012, 2013) and our approach was the level of control over food and drink consumption as well as the physical exercise conducted in the preceding 24 hours, and the use of custom-made blocks for accurate positioning of the athlete on the scanning bed. Thus, an important first step was to quantify the typical errors in the DXA measurements in a more practical applied athletic setting. Larger whole body TEMs compared to a previous study in which athletes were repositioned and immediately reassessed (Stewart and Hannan 2000). For example, Stewart and Hannan (2000) reported a lower whole body fat mass error (3.0%) compared with that of the current study (3.9%) in a group of male athletes. The introduction of biological variation (differences in hydration status, food consumption and physical activity) is likely accountable for these differences as each of these factors have been found to introduce measurement errors in the DXA estimates (Horber *et al* 1992, Nana *et al* 2012, 2013, Pietrobelli *et al* 1998).

The change in the mean (table 2) between the two repeated scans revealed that the systematic error was substantially smaller than the typical error of measurement providing confidence in

the stability of the measurement system. The observed high ICCs suggested good agreement between the DXA estimates of repeated scans for all body composition measures. However, as with any correlational measure, the strength of this relationship may have been influenced by the heterogeneous nature of the sample (Weir 2005). For example, total lean mass varied from 36.6 to 99.8 kg across the entire cohort and so the correlation between the scan results will be artificially high, as a result of the high inter-subject variability. Correlational measures also do not provide information about the magnitude of the errors and thus, as previously suggested (Hopkins 2000a), typical errors of measurements are perhaps more informative when attempting to understand the repeatability of DXA measurements.

In line with previous research (Bilsborough *et al* 2014, De Lorenzo *et al* 1997, Mazess *et al* 1990, Nana *et al* 2012, 2013), errors were higher for individual region masses (1.4, 1.0 and 1.6% for total masses of the trunk, legs, and arms, respectively) compared to at a whole body level (0.6%). This is likely to be a result of the cancelling out of regional errors to some extent when the individual region masses are summed. Fat masses appear to be more sensitive to variation than the total and lean masses (with trunk and arm fat most variable), in support of previous findings (Bilsborough *et al* 2014, Johnson and Dawson-Hughes 1991, Mazess *et al* 1990, Nana *et al* 2012, 2013). The larger errors in DXA estimated fat masses are considered to be somewhat related to variance in soft tissue water content (Horber *et al* 1992, Pietrobelli *et al* 1998). However, it has been suggested that these errors do not substantially impact the accuracy of DXA fat estimation within normal physiological ranges (Pietrobelli *et al* 1998) and other error sources (for example variation in the partitioning of body regions and data extrapolation) may be responsible for the greater variation in fat mass estimation in these body regions.

The DXA system uses only a 2D image to estimate the 3D composition of the body, by determining the degree of X-ray attenuation in each image pixel (Pietrobelli *et al* 1996). Soft tissue composition can be solved only in bone-exclusive pixels and thus, algorithms within the DXA software must

extrapolate the bone-containing pixels to estimate the soft tissue that is directly above and below these pixels in the image (Pietrobelli *et al* 1996). In the trunk region, there are many bone containing pixels (i.e. spine and rib cage) and soft tissue composition estimation is more complex than other regions, primarily due to the presence of multiple organs (Stewart and Hannan 2000). Thus, a greater degree of extrapolation is required, which may somewhat explain the higher errors observed for the trunk region. Additionally, food consumption has been shown to introduce further variability in the detected composition of this region (most likely due to the presence of additional matter in the digestive system), however this appears to be dependent on both the timing and content of the meal (Nana *et al* 2012).

The repeatability of fat mass estimation by DXA appears to be related to certain individual characteristics of the athlete, with differences detected between athlete sub-groups in this study. There did not seem to be any clear gender differences in the TEMs, and height and weight did not appear to affect the reproducibility of the DXA estimates. However, total fat mass seemed to influence fat mass errors with larger whole body and trunk fat mass errors observed in the leaner athletes (figure 2). We acknowledge that statistical power will be reduced when individuals are categorised by sport or into quartiles, however, a similar effect has previously been reported in a large sample of healthy adults (van der Ploeg *et al* 2003). As whole body measures are simply the sum of regions, it appears that the variation in total fat mass is likely attributable to errors in trunk fat mass estimation. The aforementioned algorithms in-built in the DXA system software have been optimised for individuals with average adiposity and thus the stability of these equations to estimate fat masses at the extremes of this scale (e.g. obese or very lean individuals) may be compromised (Stewart and Hannan 2000). This provides an explanation for the finding that trunk fat mass errors are greater in extremely lean individuals, compared to those with greater fat mass (e.g. the rugby sub-group in this study), where adiposity may resemble the average population more closely. In fact, Stewart and Hannan (2000) reported zero fat in the trunk region in three very lean athletes, which the authors acknowledge is practically impossible given the essential lipids present in certain organs. To our knowledge, this is

the first study to explore these relationships which, especially for the trunk fat mass, warrant consideration when tracking body composition changes in very lean individuals.

Athletes and coaches can be reluctant to compromise their training schedules and/or diet. Consequently, a highly controlled DXA scanning protocol may not be achievable in this setting and a more realistic approach may be required. Many of the body composition changes exhibited by the rugby players and bob skeleton athletes in this study were shown to be greater than the measurement errors associated with the more practical scanning protocol. Thus, DXA appears to provide a sufficiently sensitive tool to detect 'true' changes in individual body composition in the applied setting. These body composition changes were typically in line with the training emphasis, with hypertrophy consistently detected across the training season in bob skeleton athletes and decreases in total fat mass observed in rugby players in response to a training block aimed towards fat reduction. Moreover, DXA revealed 'true' decreases in both lean mass and leg lean mass in seven, and 'true' increases in fat mass in nine, bob skeleton athletes across the competition season. These body composition changes are likely a detraining response (Mujika and Padilla 2001), but may also reflect changes in nutrition. Overall, DXA seems to have the potential to provide important information regarding unfavourable body composition trends across the competitive season, allowing appropriate nutritional or training interventions to be implemented.

Body composition contributes to explosive performance by influencing the crucial power-to-body mass ratio that underlies many athletic movements (Cronin and Hansen 2005). However, the impact of body composition changes on physical performance remains largely unexplored in the context of many sports. This study demonstrated that increases in both lean mass and leg lean mass were associated with increases in lower limb strength and power in bob skeleton athletes. This is likely due to the association between skeletal muscle cross-sectional area and force production (Bruce *et al* 1997, Maughan *et al* 1983). Increases in fat mass, in the absence of lean mass accrual, are likely to reduce the power-to-body mass ratio. Indeed, this study revealed negative relationships between fat mass and both physical performance measures, providing evidence that reducing fat masses could

have a positive effect on explosive performances. Thus, DXA can provide meaningful information to sports science practitioners and coaches by detecting true changes in soft tissue composition in an applied athletic setting, and importantly, these changes do appear to have implications for physical performance.

7. Conclusion

This study investigated the typical errors involved in the estimation of athletes' body composition by DXA in the applied setting. Measurement errors were higher than those previously observed when athletes were immediately reassessed and regional fat masses were found to be most variable. However, this study revealed that meaningful body composition changes in response to specific training emphases can still be detected by DXA, even when a less stringently controlled approach is adopted. Thus, this study reveals DXA as a useful tool for practitioners to obtain insight regarding the current status and development of athletes in the applied setting. Importantly, these changes in body composition were related to physical performance measures, confirming the potentially important influence of body composition on strength and power indices, and the ability of DXA to inform the training process.

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