Monitoring Changes in Lean Mass of Elite Male and Female Swimmers

David B. Pyne, Megan E. Anderson, Will G. Hopkins

Purpose: To characterize within-subject changes in anthropometric characteristics of elite swimmers within and between seasons. Methods: The subjects were 77 elite swimmers (31 females, 46 males, age 15 to 30 years) monitored over 0.4 to 9.2 years. One anthropometrist recorded their body mass (M) and sum of 7 skinfold thicknesses (S) on 2042 occasions over 14 years from phase to phase within a season and over consecutive seasons. We estimated change in lean mass using a newly derived index (LMI) that tracked changes in M controlled for changes in S. Results: The LMI is M/Sx, where x = 0.16 ± 0.04 for females and 0.15 ± 0.05 for males (mean ± SD). The LMI of males increased 1.1% (95% confidence limits ± 0.2%) between preseason and taper phases, almost twice as much as that of females (0.6% ± 0.3%). During the same period, M and S fell by ~1% and ~11%, respectively. From season to season LMI increased by 0.9% (0.8% to 1.0%) for males and 0.5% (0.3% to 0.7%) for females. All these within-subject effects on LMI were well defined (±~0.3%). The typical variation (SD) of an individual’s LMI was 1.2% for assessments within a season and 1.9% between seasons, with a short-term technical error of measurement of ~0.5%. Conclusion: Coaches and conditioners should typically expect a twofold greater increase in lean mass in male swimmers within and between seasons than in females. An LMI of the form M/Sx should be useful for monitoring individual swimmers and athletes in other sports in which body composition affects performance. Key Words: body composition, fat mass, sum of skinfolds, swimming, taper, training

Developing and maintaining lean body or fat-free mass is generally considered important in sports in which speed, power, and strength are associated with performance. Coaches and athletes are interested in achieving an optimal balance between lean mass, fat mass, and total body mass appropriate for their particular sport. A higher total body mass can be an advantage in strength-dependent sports (eg, weight lifting, football, and basketball), particularly if additional mass is lean rather than fat. Conversely, a number of experimental studies have shown that added mass has an adverse effect on performance in a diverse range of sports including running, cycling, swimming, triathlon, and ice hockey. Accurately and reliably assessing the various components of body composition will help coaches and athletes address these issues in their sport.
Monitoring Lean-Mass Changes in Swimmers

Traditional methods of evaluating body composition include measurement of skinfold thicknesses, densitometry (underwater weighing), bioelectrical impedance, and dual-X-ray absorptiometry, although the estimates are not directly comparable and cannot be easily interchanged.\textsuperscript{8,9} The most common method for elite athletes is measurement of skinfold thicknesses, for reasons of timeliness and practicality.\textsuperscript{10} Indirect assessment of body fat using skinfolds yields a 2-compartment model of body composition: fat mass estimated from sum of skinfolds and fat-free or lean body mass by subtracting fat mass from total mass. For almost 50 years this approach has formed the basis of evaluating mass and lean body mass in clinical and sporting populations.\textsuperscript{11} The equations used to evaluate skinfold measurements have been derived from differences in fat mass (and also lean mass) between subjects, however, and their ability to track changes in fat and lean mass in individuals in an athletic setting has not been investigated.

Existing methods of calculating lean body mass depend on the assumptions implicit in equations evaluating skinfold thickness, body density, and body fat. Given the long-standing concerns of the suitability of these equations for specific athletic populations,\textsuperscript{12,13} our main aim was to examine the utility of a newly described index\textsuperscript{14} that tracks changes in lean mass using only body mass and skinfold thicknesses. Despite the relative ease of skinfold measurement, most studies have focused on between-subjects differences\textsuperscript{15} rather than within-subject seasonal and long-term changes in athletes. In swimming there is only limited published information on morphological changes associated with training.\textsuperscript{16} An additional aim was therefore to characterize within- and between-seasons changes in sum of skinfolds, total body mass, and lean mass in elite male and female swimmers.

Methods

Subjects

The subjects were 77 elite swimmers (31 females, 46 males, age range 15 to 30 years) who had been residing at the Australian Institute of Sport for 0.4 to 9.2 years. All swimmers had represented Australia at either the junior or the senior level. Body-composition measurements were taken as part of routine testing in accordance with the requirements of the coach and the athletes’ training and competition program. All athletes provided written informed consent for scientific and medical testing at the commencement of their scholarship. The swimmers generally trained 44 to 48 weeks each year, with pool and dry-land training typically reaching a total of 20 h/wk. Dry-land training typically involved 3 gymnasium sessions per week consisting of traditional resistance training, circuits, and swimming-specific exercises. The resistance training generally comprised strength- and power-oriented exercises for upper and lower body regions using 3 to 5 sets of 3 to 10 repetitions, depending on the phase of season. Male and female swimmers were in mixed training groups and essentially completed the same training programs.

Experimental Design and Procedures

One anthropometrist recorded the body mass and sum of 7 skinfold thicknesses during 2042 assessments over 14 years. Measurements of body mass and sum of
skinfolds were generally taken between 8:00 and 9:00 a.m. with the swimmers presenting in a fasted state. The 7 sites used to calculate the sum of skinfolds were triceps, subscapular, biceps, supraspinale, abdomen, thigh, and calf, in accordance with prescribed methods. Harpenden skinfold calipers (Model HSK-BI, Baty International, West Sussex, UK) were calibrated in accordance with protocols established by the Laboratory Standards Assistance Scheme of the Australian Institute of Sport. Body mass was measured to the nearest 0.1 kg on digital standing scales (Model DS-410, Teraoka Seiko, Tokyo, Japan). The anthropometrist’s typical error of measurement for the sum of 7 skinfold thicknesses was 1.5 mm (2.8%), and the typical (instrument) error for body mass was <0.2%. Unfortunately, the height of the swimmers was not measured systematically in parallel with mass and skinfolds, and therefore it is not possible to report changes in stature or body-mass index (BMI).

**LMI Index**

We have recently proposed and validated a new method for analyzing the relationship between changes in log-transformed mass and sum of skinfolds using repeated-measures multiple linear regression. Briefly, back transformation yielded a function of mass and sum of skinfolds of the form \( M/S^x \), where \( M \) = body mass, \( S \) = sum of skinfold thicknesses, and \( x \) is a constant estimated from the analysis. We interpreted this function as a lean-mass index (LMI), because statistically it tracks changes in mass controlled for changes in skinfold thickness. Although the terms lean body mass and fat-free mass or weight are often used interchangeably, lean body mass includes an essential amount of lipid necessary for membrane and nerve functioning, whereas fat-free mass technically excludes all lipids. For the purpose of the present study we adopted lean body mass as the preferred terminology in this athletic setting.

**Analysis**

To determine the time course of short-term changes in body composition, we divided each training season into discrete phases based on the time remaining to the subsequent major competition: preseason (>16 weeks before competition), early season (10 to 16 weeks to competition), midseason (4 to 10 weeks to competition), and late season (<4 weeks to competition). We modeled longer term within-athlete changes as the effect of time the athlete had been in the swimming program. We also analyzed for the effects of calendar year and swimmer’s age at commencement of the program.

We used the mixed linear-modeling procedure (Proc Mixed) in the Statistical Analysis Software (Version 8.02, SAS Institute, Cary, NC) to estimate fixed effects (changes and differences in means) and random effects (within- and between-subjects variances). The fixed-effects model was Phase, Time, Time × Time, Age, Time × Age, Age × Age, Year, Year × Year. Phase was a nominal within-subject effect with values pre, early, mid, and late representing training phase at the time of each assessment. Time was a numeric within-subject effect representing the time (in years) the swimmer had been in the program at the time of each assessment. Age and year were numeric between-subjects effects representing age and calendar year.
at commencement of the program. This choice of variables eliminated confounding of within- and between-subjects effects that arose in initial analyses when we used the age of the swimmer at the time of each assessment.

The random effects were athlete, Athlete × Season, and residual variation. Athlete and season were nominal effects representing identity of the athlete and identity of each 6-month swimming season (“prep”) respectively. Expressed as standard deviations, the values of athlete and residual represent respectively pure between-subjects variation and error of measurement between assessments within a season. The variance of Athlete × Season added to that of the residual and expressed as a standard deviation represents within-subject random error for assessments between seasons. This variance added to the athlete variance and expressed as a standard deviation represents the expected value of the observed SD between athletes in any given assessment.

The natural logarithms of body mass ($M$) and sum of skinfolds ($S$) were the dependent variables in separate analyses using the described model. To derive the exponent $x$ in the LMI ($M/S^x$), the analysis of body mass was also performed with log $S$ as an additional numeric fixed effect and Athlete × log $S$ as an additional random effect. The coefficient of log $S$ represented the mean value of $x$ for all swimmers, and the SD derived from Athlete × log $S$ represented individual differences in $x$. This analysis was performed with log $S$ normalized to a mean of zero for each swimmer to eliminate any effect of the between-subjects relationship between $M$ and $S$ on the within-subject effect $x$. The natural logarithm of the LMI was then calculated for every assessment of every subject and analyzed using the same fixed- and random-effects models as for $M$ and $S$. All analyses were performed for males and females separately; comparison of effects between females and males was limited to a qualitative assessment of the overlap of confidence limits.

Uniformity of the modeling was investigated by examining plots of random effects against predicted values and against within-subject fixed effects. The plots were individual values of residuals against individual values of predicteds and individual values of time in the program; the SD of residuals in each quintile of predicteds and in each quintile of time in the program; the SD of residuals against phase; and the SD of Athlete × Time against the number of seasons in the program. We identified outliers as observations with residuals of magnitude greater than 5 SDs. After checking and correcting any obvious errors in data entry, we deleted 6 outliers with residuals greater than 7 SDs (all of one athlete’s 4 observations and 2 observations of another athlete) before performing the analyses.

**Results**

**Subject Characteristics**

The mean number of anthropometric tests per swimmer, mean age, age at commencement, and length of time on scholarship are shown for both male and female swimmers in Table 1. The mean age was ~20 years for females and ~21 years for males. The anthropometric characteristics of the swimmers were assessed approximately 8 times per year in the program. A number of long-term scholarship holders were tested more than 100 times over a 9-year period.
Derivation of LMI Exponent \( x \)

Mean values of \( x \) were 0.16 (95% confidence limits 0.14 to 0.19) for females and 0.15 (0.13 to 0.17) for males. Individual differences in \( x \), represented by SDs, were 0.04 (0.02 to 0.08) for females and 0.05 (0.03 to 0.07) for males.

Uniformity of Modeling

Plots of individual values of residuals showed no obvious systematic nonuniformity, which was more apparent in the plots of SDs of the residuals and of Athlete \( \times \) Time. The SD varied typically by 10% between quintiles of predicted values or between levels of fixed effects, usually in a nonsystematic manner that presumably reflected sampling variation. Against this background, the residuals for \( S \) for males increased by ~10% for each quintile of predicted values, and the SD for the highest quintile was twice that of the lowest quintile. Residuals for LMI showed only a small increase with increasing quintile of predicted values (lowest to highest quintile, ~20%). The residuals were substantially greater (up to 40% for males) in the pre and taper phases than in the early phase and midphase for \( M \) and \( S \), but there was little effect of phase on the residuals for the LMI. There was also a trend toward smaller residuals the longer a swimmer had been in the program (overall decline ~20%), although this effect was not apparent for LMI for males. The SD of Athlete \( \times \) Time for each of the dependent variables changed little with increasing number of seasons the swimmers had been in the program.

Within-Subject Changes

The female swimmers had a mean reduction of ~1.4% (~1.8 to ~1.0), or ~0.9 kg for the typical mass of 65 kg, through the season (preseason phase to taper phase). The male swimmers had a similar loss of ~0.8% (~1.0 to ~0.6), or ~0.7 kg for the typical mass of 82 kg. These pure within-season changes between different phases were superimposed on within-subject between-seasons increases in total body mass: 0.9% (0.8 to 1.0) per season for male swimmers and 0.4% (0.2 to 0.7) per season for female swimmers. The overall combined effect of the within- and between-seasons changes on total body mass during each phase of a season relative to the preseason level is presented in Figure 1 (upper panel). The typical random

---

**Table 1 Descriptive Statistics for the Participants**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Females (n = 31)</th>
<th>Males (n = 46)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Number of tests</td>
<td>24 ± 27</td>
<td>3–106</td>
</tr>
<tr>
<td>Starting age (y)</td>
<td>18.2 ± 2.7</td>
<td>14.7–25.5</td>
</tr>
<tr>
<td>Time in program (y)</td>
<td>3.0 ± 2.5</td>
<td>0.2–9.2</td>
</tr>
<tr>
<td>Mean mass (kg)</td>
<td>64.9 ± 9.0</td>
<td>51.4–78.1</td>
</tr>
<tr>
<td>Mean skinfolds (mm)</td>
<td>67.6 ± 12.0</td>
<td>49.9–100.5</td>
</tr>
<tr>
<td>Mean lean-mass index</td>
<td>32.8 ± 2.8</td>
<td>26.5–37.7</td>
</tr>
</tbody>
</table>
variation in an individual swimmer’s body mass was 1.6% between tests during a season and 3.4% between tests in different seasons. There were minimal quadratic effects for within-subject between-seasons changes in $M$, $S$, and LMI: All magnitudes were less than 0.2%/y$^2$.

**Figure 1** — Within-subject percentage changes relative to the preseason level in body mass, sum of skinfolds and lean mass in male and female swimmers during the early, mid, late, and taper phases. Values are the overall combined effect of the within- and between-seasons changes.
Both male (–11.6%, –12.8% to –10.4%) and female (–11.5%, –13.0% to –9.9%) swimmers showed a relatively linear within-subject decrease in $S$ from the preseason to the taper phase. This magnitude of change equated to a mean loss of ~5 mm in $S$ (7 sites) for the typical male and ~7 mm over the same period for females. Although there were substantial changes within each season in $S$, only trivial changes were observed for each additional year in the program (between-season changes) of –1.0% (–3.4% to 1.5%) for females and –0.4% (–1.9% to 1.1%) for males. The overall combined effect of the within-season and between-seasons changes in $S$ is shown in Figure 1 (middle panel). The typical random variation in an individual’s sum of skinfolds was 7.2% between tests during a season and 15% between tests in different seasons.

The increase in LMI from the pre to the taper phase during a season for males (1.1%, 0.8% to 1.3%) was approximately twice that for females (0.6%, 0.3% to 0.9%). Early in the season, the males increased their LMI by 0.4%, in contrast to the females, who exhibited a slight reduction of –0.2%. During the midseason and taper phases, both males and females exhibited a continuing increase in lean mass. The substantial increase in LMI for each additional year in the program was almost twice as large for males 0.9% (0.8% to 1.0%) as for females (0.5%, 0.3% to 0.7%). The overall combined effect for both within- and between-seasons changes in LMI are shown in Figure 1 (bottom panel). Superimposed on these changes in mean LMI were typical variations in an individual’s LMI of 1.2% between tests during a season and 1.9% between tests in different seasons. These variations represented mainly real changes in the individual’s LMI rather than technical error of measurement, which was only ~0.5% (based on typical errors of <0.2% for $M$ and 2.8% for $S$).

**Between-Subjects Differences**

Figure 2 shows some representative plots of individual values for annual trend (adjusted for age) in changes in $M$, $S$, and LMI for male swimmers. There was little evidence of any substantial linear or quadratic between-subjects secular changes (annual trend) in $M$, $S$, and LMI in both male and female swimmers over the study period. The observed between-subjects variations for measurements in any given assessment were ~10% for $M$, ~24% for $S$, and ~10% for LMI. There was some evidence that female swimmers were lighter in $M$, $S$, and LMI in more recent years. The cohort of females in the final year of the study period, in comparison with 10 years earlier, were marginally lower in $M$ (–7.1% ± 12.1%), $S$ (–7.1% ± 23.0%), and LMI (–6.1% ± 11.3%), although the uncertainty in these estimates highlights the need for further investigation. In contrast, there was evidence of small increases in these measures in the cohort of male swimmers: $M$ 4.7% ± 12.4%, $S$ 10.5% ± 23.8%, and LMI 3.3% ± 11.7% over the same period.

We also examined the effect of starting age on $M$, $S$, and LMI. There was some evidence that older male swimmers had a higher total body mass (18.0% ± 12.3% at age 24 years compared with age 19 years) and LMI (19.8% ± 15.0%), but a lower sum of skinfolds (–10.3% ± 17.1%). In females there was little effect of starting age: higher body mass (6.3% ± 14.3% at age 24 years compared with age 19 years), sum of skinfolds (–1.3% ± 24.6%), and LMI (6.7% ± 13.5%). There was minimal interaction between the linear effect of years in the program and age, because all values were less than 0.2%/y².
Figure 2 — Scatter plots for the modeling of between-subjects secular trend in body mass, sum of skinfolds, and lean mass for male swimmers for the period 1993 to 2003. The fitted trend line for males and females represents the combined linear-quadratic effects model showing marginal increases for body mass (linear), skinfolds (linear), and sum of skinfolds (curvilinear).
Discussion

In this study we examined the utility of a new measure of body composition, the LMI, to track changes in lean mass in a group of elite swimmers over an extended period. The subcutaneous region is a primary site of body fat, and changes in sum of skinfolds are widely used to infer changes in storage of body fat, so it is logical to identify the new measure as an index for tracking changes in nonfat or lean mass. The results of this study show that the rate of increase in the LMI for male swimmers was almost twice that for females, both from phase to phase within a season and from season to season. There was considerable individual variation around these mean changes, however, so coaches and swimmers will need to account for individual responses in the management of training programs and dietary practices.

The exponent $x$ in the formula for the LMI ($M/S^x$) represents body fat as a fraction of body mass. The mean value of $x$ for the females (0.16, or 16%) is similar to typical estimates for percentage body fat in highly trained female swimmers from application of standard equations, whereas for males the mean value (0.15, or 15%) is somewhat greater than the corresponding estimates of ~9% to 12%\textsuperscript{5,20,21}. Two violations of the assumptions of the LMI can account for this discrepancy in the index for male swimmers. First, the assumption that percentage changes in skinfold thickness equal percentage changes in body fat requires that the entire thickness of skinfolds consist of fat, which is clearly not possible. If we assume that a fraction $f$ of the skinfold is fat, then for small changes, the percentage change in body fat will equal $1/f$ times the percentage change in skinfold thickness. The observed exponent $x$ will therefore represent the fractional fat mass inflated by a factor $1/f$. This factor must be only slightly greater than 1.0 for females, but it could be large enough in males to make $x$ similar to that for females. Second, the observed value of the exponent $x$ will be inflated if changes in skinfold thickness are accompanied not only by equivalent changes in fat mass but also by substantial changes in nonfat mass (such as body-fluid volumes or muscle mass). The observed value of the exponent $x$ represents the total fraction of body mass that changes whenever skinfolds change, so any changes in body mass additional to those attributable directly to fat mass in skinfolds will make the value of $x$ larger than the fraction of fat in the body. Any such changes would have to be substantial in males but not in females.

It is important to understand that discrepancies between theoretical and observed magnitudes of the exponent $x$ do not diminish the practical value of the LMI, which is simply an empirical measure for tracking percentage changes in body mass that do not normally accompany percentage changes in skinfolds in individual swimmers. Our results show that individual differences in the LMI are sufficiently small that the LMI computed using the group mean value for $x$ should be valid for most individuals. Further investigations are required, however, to determine the impact of using the mean exponent with individuals, especially those whose exponent is several SDs smaller or larger than the mean. If there are substantial effects on the ability of the LMI to track nonfat mass in such individuals, we will need to identify subject characteristics that predict individual values of the exponent. Alternatively, we could estimate an individual’s exponent by tracking his or her body mass and skinfold sum for several years, but by then the individual might be ready to retire from elite sport. One theoretical limitation of the LMI is that the...
index will not track changes in lean mass that accompany changes in skinfolds. Serial monitoring of a given individual athlete’s body-composition characteristics including \( M \), \( S \), and the LMI within and between seasons should nonetheless provide a useful tool for practitioners.

We have labeled the LMI as an index by analogy with another measure of body composition, the BMI (mass/height\(^2\)). The BMI is an index of body mass adjusted for between-subjects differences in height. In contrast, the LMI is an index of body mass adjusted for within-subject changes in fat (skinfolds). Although the exponent for height in the BMI is 2, a better value would be found by linear modeling of log-transformed mass and height with a representative sample of a given population. Similarly, our exponent for skinfolds in the LMI is appropriate for the population of athletes we analyzed, elite swimmers. Inasmuch as the exponent is related to the proportion of body mass represented by fat in these athletes, there are likely to be substantial differences from athletes in other sports. Further research is needed to establish the values of the exponent in other sports and to determine whether a single value for the exponent can be applied across a range of sports without compromising the validity of the LMI. One shortcoming of the retrospective data in this study is the absence of height. We recommend that future anthropometric investigations of adolescent and young-adult athletes measure height, \( M \), and \( S \) in parallel to better track changes in growth, maturation, and the BMI.

From the preseason to the taper phase there were mean losses of \(~1\%\) in \( M \) and more than \(10\%\) in \( S \). These effects are biased to some extent by nonuniformity of random effects. For example, in spite of log transformation, larger \( S \) in males was associated with larger residuals, so the effects on \( S \) will tend to apply more to males with larger \( S \). On the other hand, the mean increase in the LMI of \(~1\%\) over the same period applies without substantial bias to the range of swimmers in our study, because the random effects for the LMI showed little nonuniformity.

Within-subject changes in the LMI within a season (~1%) and between seasons (~1% to 2%) represented mainly real changes in an individual’s LMI, given a technical error of measurement of ~0.5%. Are such small changes important for the individual swimmer, though? In the Cohen approach to magnitudes they are not, because the smallest worthwhile change in the LMI is ~2% (0.2 of the between-subjects SD of ~10%). Changes in the LMI on the order of 1% would be important, however, if they track similar changes in competitive performance over a season, and gradual changes in LMI over several seasons can be even larger. Studies directly examining relationships between changes in body composition and changes in performance of competitive swimmers are required.

The changes in body-composition measures from phase to phase during the season suggest a gradual response to the effects of training and diet. It appears that the physical preparation of elite swimmers for competition is characterized by marked reductions in body fat accompanied by modest changes in total body mass and lean mass. Within-subject variations in these changes were typically larger than the changes in the means (for example, ~1% within season and ~2% between seasons in an individual’s LMI). A key question is whether changes of this magnitude in lean mass have a substantial impact on performance. Future studies will address this issue.

Only a small number of studies have detailed changes in body composition of highly trained swimmers during a season. In a study of 15 elite female swimmers
monitored at 3 points during a competitive season, there were substantial changes only during the early part of the season: Losses in body fat were observed in parallel with gains in lean body mass. A case study with 2 male swimmers showed a variable pattern of responses, with one athlete losing lean body mass and body fat, whereas the other increased lean mass while reducing body fat. More recently, a study of 21 intercollegiate swimmers showed declines in fat mass during the season for female but not male swimmers. Our study is the first to quantify within-subject changes in total mass, lean mass, and skinfolds through consecutive phases of a competitive season. Our results show similar direction and magnitude of within-season changes for males and females, underlining the potential utility of the LMI for tracking changes in body composition for both sexes.

An important aspect of the present analysis was a fixed-effects model that distinguished between the within-subject effect of time in the program and the between-subjects effect of starting age. The adolescent growth spurt typically occurs between the ages of 12 and 15 years for females and 14 and 17 years for males. Full skeletal maturation is normally reached by 16 to 20 years of age. The swimmers in the present study ranged in age from 15 to 30 years, so for the most part normal growth and maturation would have been completed. Supporting evidence for the physical maturity of swimmers was the observation of only modest between-subjects effects for starting age on body composition, so within-subject effects for subsequent years in the program are more likely a result of the training than of age. To further address this issue we also modeled the interaction between age and years in the program (data not shown). The small magnitude of the interaction supports the conclusion that age had a much smaller effect than time did in the program on the observed changes in body composition.

Practical Applications

Parallel measurement of skinfolds and body mass and application of the LMI to estimate changes in body fat and lean body mass provide a basis for monitoring the effectiveness of training and dietary interventions. In particular, we see the LMI being useful for monitoring athletes undertaking specific weight-gain or weight-loss programs. It is apparent that heavier athletes with more body fat tend to lose fat mass rather than lean mass during programs designed to reduce body mass, whereas leaner athletes with lower levels of body fat reportedly lose ~0.5 kg of lean mass for every 1 kg of weight lost despite a well-planned exercise program. The latter observation suggests that lean athletes with low levels of body fat should recognize the difficulty in conserving lean mass in the face of significant weight loss. Our results with the LMI (Figure 2) show that individual athletes aiming to gain lean mass can do so while maintaining stability in overall body mass coupled with a reduction in body fat. In contrast, heavier athletes aiming to reduce body fat would expect a reduction in the sum of skinfolds, maintenance of lean body mass, and a variable change in total body mass, depending on the magnitude of changes in the 2 constituent compartments. Given these applications, the LMI should also be useful in characterizing the body composition of individual athletes in a range of sports.
Conclusions

A measure of body composition of the form $M/S^x$ should be a useful index of lean mass for monitoring individual athletes in sports in which body composition affects performance. Given a relatively small technical error of measurement, we have shown the LMI to be sufficiently reliable to monitor practically important long-term changes in the body composition of highly trained swimmers. Coaches and conditioners should typically expect a 2-fold greater increase in lean mass in male swimmers within and between seasons than in females. The observation of small individual differences in the LMI implies that the index should be valid for most individual swimmers. Further investigations are required to determine the impact of using the mean value of the exponent $x$ for individual athletes with atypical body composition and whether changes in LMI track changes in competitive swimming performance.

Acknowledgments

The authors gratefully acknowledge the conceptual contributions provided by Hamilton Lee, Department of Physiology, Australian Institute of Sport, and Gennadi Touretski, Swimming Program, Australian Institute of Sport.

References