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Olympic lightweight and open-class rowers possess distinctive physical and proportionality characteristics

D. A. KERR[1], W. D. ROSS[2], K. NORTON[3], P. HUME[4], M. KAGAWA[1], & T. R. ACKLAND[5]

[1]*Curtin University of Technology, Perth, WA, Australia,* [2]*Western Washington University, Bellingham, WA, USA,* [3]*University of South Australia, Adelaide, SA, Australia,* [4]*Auckland University of Technology, Auckland, New Zealand and* [5]*The University of Western Australia, Perth, WA, Australia*

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Abstract

Rowers competing at the 2000 Olympic Games were measured for 38 anthropometric dimensions. The aim was to identify common physical characteristics that could provide a competitive advantage. The participants included 140 male open-class rowers, 69 female open-class rowers, 50 male lightweight rowers, and 14 female lightweight rowers. Body mass, stature, and sitting height were different ($P < 0.01$) between the open-class and lightweight rowers, as well as a comparison group of healthy young adults ("non-rowers", 42 males, 71 females), for both sexes. After scaling for stature, the open-class rowers remained proportionally heavier than the non-rowers, with greater proportional chest, waist, and thigh dimensions ($P < 0.01$). Rowers across all categories possessed a proportionally smaller hip girth than the non-rowers ($P < 0.01$), which suggested the equipment places some constraints on this dimension. Top-ranked male open-class rowers were significantly taller and heavier and had a greater sitting height ($P < 0.01$) than their lower-ranked counterparts. They were also more muscular in the upper body, as indicated by a larger relaxed arm girth and forearm girth ($P < 0.01$). For the male lightweight rowers, only proportional thigh length was greater in the best competitors ($P < 0.01$). In the female open-class rowers, skinfold thicknesses were lower in the more highly placed competitors ($P < 0.01$). In conclusion, the rowers in this sample demonstrated distinctive physical characteristics that distinguish them from non-rowers and other sports performers.

Keywords: *Anthropometry, body composition, Olympic rowers, proportionality*

Introduction

The quality of Olympic athletes arises from a unique combination of inherited traits and capacities developed through training. Identifying such factors as physical size and structure, which may result in the best performance, can assist exercise scientists and coaches when selecting and developing talented athletes (Ackland, 2005). In rowing, talent identification programmes have tried to identify potential young athletes using various performance variables, including several anthropometric measurements (Hahn, 1990). However, few anthropometric data have been collected at World Championships or Olympic Games to facilitate this talent identification approach.

The last comprehensive anthropometric survey of rowers was the Montreal Olympic Games Project (MOGAP) conducted at the1976 Games (Carter, 1982). Seventy-one male and 51 female rowers were included in this sample, but lightweight rowing was not an Olympic event in 1976. Since 1976, there have been many developments in training methods and rules for participation. It is possible that these factors have resulted in changes to the optimum athletic physique required for rowing events.

A unique opportunity to gather this information was presented in August and September 2000, during the Sydney Olympic Games. With the official support of the international rowing governing body, and funding from the IOC Medical Commission, 38 anthropometric measurements were obtained from 273 rowing competitors. Of these rowers, 74% were ranked in the top 10 Olympic finalists, making this the most current and comprehensive survey of elite rowers.

Correspondence: D. Kerr, School of Public Health, Curtin University of Technology, GPO Box U1987, Perth, WA 6845, Australia.
E-mail: d.kerr@curtin.edu.au

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The aim of this study was to analyse the anthropometric characteristics of Olympic rowers to determine whether they possess unique physical characteristics that provide an advantage for their sport and distinguish them from the general population. In addition, the proportional differences in physique between lightweight and open-class rowers were examined. This information can be used most effectively for talent identification and development programmes (Ackland, 2005).

Methods

Participants

In total, 190 male and 83 female rowers were measured on 38 anthropometric dimensions in the 15 days before the start of Olympic competition (Ackland *et al.*, 2001). Rowers from 30 countries competed in 14 events from single sculls to eight-person crews. Normative samples of randomly selected, healthy young adult males [$n = 42$ (Kagawa, 2005)] and females [$n = 71$ (Kerr, 1996)] were also included as representative groups for comparison. These "non-rowers" were all Caucasian and varied in how active they were, but none were elite athletes.

While the initial contact was made through team officials, rowers were invited to take part in this study on an individual basis. All participants read and signed a consent form before measurement and were recruited under the patronage of the Human Rights Committee of The University of Western Australia.

Data collection

Before data collection, inter-tester technical errors of measurement for each of the participating anthropometrists (ISAK level 2 or 3) compared with the criterion anthropometrist (ISAK level 4) were calculated for every variable (Norton & Olds, 1996). For inclusion on the measurement team, the anthropometrists were required to demonstrate inter-tester technical errors of measurement of less than 5% for skinfolds and less than 1% for segment lengths, breadths, and girths. Further assistants were recruited to act as data recorders and marshals during the test phase.

A mobile laboratory was despatched to accommodation venues for each of the teams so that rowers could be measured in a single session during a rest period within their training schedule. Before being measured, each rower completed demographic and crew position information.

Anatomical landmarks were located and marked by the criterion anthropometrist, before the rower was directed to one of five stations for the measurement of 38 anthropometric dimensions (9 skinfolds, 10 direct lengths, 12 segment girths, 6 breadth measurements, and body mass). All variables were measured on the right side of the body in duplicate (when time permitted) and the mean value was recorded. On occasions when the time available was restricted, single measures for length and breadth variables were recorded. The standard procedures for each measurement, as defined by the International Society for the Advancement of Kinanthropometry (ISAK) and reported in Bloomfield, Ackland and Elliott (1994) and Norton and Olds (1996), were followed at all times. The nine skinfold sites measured were the triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, medial calf, and mid-axilla skinfolds. Upper arm length was recorded as the distance between the acromiale and radiale landmark, while forearm length was the distance between the radiale and stylion landmark. Thigh length was recorded as the distance between the trochanterion and tibiale laterale, and lower leg length was the distance between the tibiale laterale and the floor. Shoulder breadth was defined as the distance between the most lateral points on the acromion processes, and hip breadth was the most lateral points on the iliac crests. Arm, chest, waist, mid-thigh, and calf girth were all corrected for the skinfold at the site using the following formula: corrected girth = girth − ($\pi \times$ skinfold thickness). Using this formula, arm girth was corrected for triceps skinfold, chest girth corrected for subscapular skinfold, waist girth corrected for abdominal skinfold, mid-thigh girth corrected for front thigh skinfold, and calf girth was corrected for medial calf skinfold. The corrected girth provides a better indicator of musculoskeletal size at each site (Martin, Spenst, Drinkwater, & Clarys, 1990).

Data analysis

Absolute body size statistics were calculated for all Olympic lightweight and open-class competitors. The measurement sites used to calculate the sum of eight skinfolds were triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh, and medial calf. Information about relative size was gained through calculation of Phantom Z-scores (Z_p) (Ackland & Bloomfield, 1995; Ross & Marfell-Jones, 1991). Phantom Z-scores indicate the relative magnitude of a physical characteristic with respect to the individual's stature. The somatotypes were calculated using the method of Carter and Heath (1990).

Absolute and relative size differences were compared between the three groups (open-class rowers, lightweight rowers, and non-rowers). As the assumption for homogeneity of variance was violated in this sample, a non-parametric test (Kruskal-Wallis test)

for K independent samples was applied. Statistical significance was set at $P < 0.01$ to take account of multiple comparisons. The sample of open-class and lightweight rowers was then stratified for comparison of those males ranked in the top seven (Best) places (including sweep and scull rowers in events from one to eight crew members) with the remaining competitors (Rest). While both the open-class and lightweight male rowers were included, the analysis was only performed for open-class female rowers due to the small number of lightweight female rowers. A series of univariate analyses of variance was used for this comparison, with separate analyses being performed for male and female rowers. *Post-hoc* comparisons were made using Tukey's HSD test. For these multiple comparisons, a full Bonferroni correction was not applied as this method is known to be conservative. Instead, statistical significance was set at $P < 0.01$ (i.e. $0.05 \div 5$) and considered a good compromise between accounting for multiple comparisons with a moderate sample size, without increasing the risk of Type II errors. Statistical power was calculated for each analysis.

Results

Absolute body size and somatotype

Mean values and the results of the analyses of variance for the anthropometric variables are shown in Table I. There were significant differences in body mass, stature, and sitting height (all $P < 0.01$) between the open-class and lightweight rowers for both male and female competitors, with open-class rowers being taller and heavier. The male and female lightweight rowers were closer in stature to the non-rowers than to the lightweight rowers. Nevertheless, the standard deviations in stature and body mass were smaller for the rowers, especially the lightweight rowers, than the non-rowers (Figures 1 and 2). Furthermore, when compared with athletes from other sports, the standard deviations in stature and body mass were also much lower for both male and female lightweight rowers.

No arm span data were available for the non-rowers, so this parameter is not included in Table I. However, mean arm span was 200.3 ($s = 6.2$) cm for

Table I. Absolute size characteristics of Olympic lightweight and open-class rowers and a comparison groups of non-rowers[†].

	Males				Females			
Variable	F-ratio	Non-rowers ($n = 42$)	Lightweight ($n = 50$)	Open-class ($n = 140$)	F-ratio	Non-rowers ($n = 71$)	Lightweight ($n = 14$)	Open ($n = 69$)
Age (years)	17.3*	$22.6 \pm 5.3^{a,b}$	27.1 ± 4.1^{c}	26.4 ± 3.6	12.6*	$30.5 \pm 3.3^{a,b}$	26.0 ± 2.9	27.8 ± 4.4
Body mass (kg)	316.8*	74.5 ± 9.6^{a}	72.5 ± 1.8^{c}	94.3 ± 5.9	56.2*	64.5 ± 10.2^{a}	58.5 ± 1.5^{c}	76.6 ± 5.2
Sum 8 skinfolds (mm)[#]	41.4*	$83.0 \pm 34.6^{a,b}$	44.7 ± 8.1^{c}	65.3 ± 17.3	39.9*	$138.3 \pm 51.5^{a,b}$	59.7 ± 12.4^{c}	89.0 ± 23.6
Stature (m)	1.43*	1.80 ± 0.08^{a}	1.82 ± 0.04^{c}	1.94 ± 0.05	90.1*	1.68 ± 0.07^{a}	1.69 ± 0.05^{c}	1.81 ± 0.05
Sitting height (cm)	58.8*	94.7 ± 4.2^{a}	94.6 ± 2.7^{c}	99.2 ± 2.9	36.9*	88.8 ± 3.7^{a}	89.5 ± 3.5^{c}	93.7 ± 3.1
Upper arm length (cm)	112.6*	34.2 ± 1.8^{a}	35.1 ± 1.6^{c}	37.8 ± 1.5	36.8*	32.7 ± 1.7^{a}	32.3 ± 1.5^{c}	34.9 ± 1.5
Forearm length (cm)	58.0*	26.6 ± 2.1^{a}	26.9 ± 1.0^{c}	28.8 ± 1.3	38.5*	24.4 ± 1.3^{a}	24.0 ± 0.9^{c}	26.1 ± 1.2
Thigh length (cm)	43.9*	47.1 ± 2.8^{a}	46.6 ± 2.0^{c}	50.1 ± 2.7	48.2*	43.5 ± 2.3^{a}	43.9 ± 1.8^{c}	47.4 ± 2.5
Lower leg length (cm)	132.3*	$47.8 \pm 2.4^{a,b}$	49.1 ± 2.0^{c}	53.1 ± 2.0	76.7*	44.2 ± 2.3^{a}	44.7 ± 1.9^{c}	48.4 ± 1.9
Shoulder breadth (cm)	82.4*	$39.9 \pm 2.0^{a,b}$	41.4 ± 1.5^{c}	43.7 ± 1.9	53.2*	36.6 ± 2.0^{a}	37.2 ± 1.5^{c}	39.4 ± 1.2
Chest depth (cm)	40.9*	$19.6 \pm 3.5^{a,b}$	20.1 ± 1.3^{c}	22.2 ± 1.4	9.2*	19.2 ± 1.8^{b}	17.5 ± 0.6^{c}	19.5 ± 1.5
Hip breadth (cm)	75.8*	28.3 ± 1.6^{a}	28.5 ± 1.2^{c}	30.8 ± 1.4	7.7*	29.6 ± 2.3^{b}	27.5 ± 1.0^{c}	30.0 ± 1.9
Corrected arm girth (cm)	74.2*	28.3 ± 2.6^{a}	27.8 ± 1.2^{c}	31.1 ± 1.9	60.7*	22.5 ± 2.0^{a}	23.5 ± 1.5^{c}	25.7 ± 1.5
Flexed arm girth (cm)	118.6*	33.2 ± 2.6^{a}	32.4 ± 1.2^{c}	36.5 ± 1.8	29.1*	29.1 ± 2.6^{a}	28.2 ± 1.1^{c}	31.4 ± 1.5
Forearm girth (cm)	133.8*	28.2 ± 1.6^{a}	28.2 ± 0.8^{c}	31.0 ± 1.3	57.6*	24.8 ± 1.5^{a}	24.5 ± 0.8^{c}	27.0 ± 1.0
Corrected chest girth (cm)	145.4*	94.9 ± 5.3^{a}	97.4 ± 3.2^{c}	105.9 ± 4.3	87.5*	83.3 ± 4.9^{a}	85.0 ± 2.4^{c}	92.2 ± 3.3
Corrected waist girth (cm)	196.0*	74.2 ± 4.2^{a}	75.4 ± 3.4^{c}	83.8 ± 3.1	63.4*	65.0 ± 5.2^{a}	66.8 ± 2.1^{c}	72.9 ± 3.3
Hip girth (cm)	121.2*	$97.6 \pm 6.0^{a,b}$	92.9 ± 2.3^{c}	102.4 ± 3.3	19.7*	99.5 ± 7.1^{b}	90.5 ± 2.4^{c}	100.8 ± 3.5
Corrected mid-thigh girth (cm)	166.3*	$48.4 \pm 3.1^{a,b}$	50.6 ± 1.5^{c}	55.8 ± 2.7	104.6*	$43.2 \pm 3.3^{a,b}$	46.1 ± 1.6^{c}	50.6 ± 3.0
Corrected calf girth (cm)	55.8*	34.2 ± 2.1^{a}	34.7 ± 1.6^{c}	37.3 ± 2.1	29.7*	31.5 ± 2.2^{a}	31.8 ± 2.4^{c}	34.1 ± 1.8

[a]Non-rowers significantly different from open-class rowers ($P < 0.01$). [b]Non-rowers significantly different from lightweight rowers ($P < 0.01$). [c]Lightweight rowers significantly different from open-class rowers ($P < 0.01$).

[†]Non-parametric test (Kruskal-Wallis test) for K independent samples was applied to the sample to test significance. A non-parametric test for two independent samples was used to identify which groups were significantly different.

[#]Sum of 8 skinfolds = triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medical calf. *$P < 0.01$.

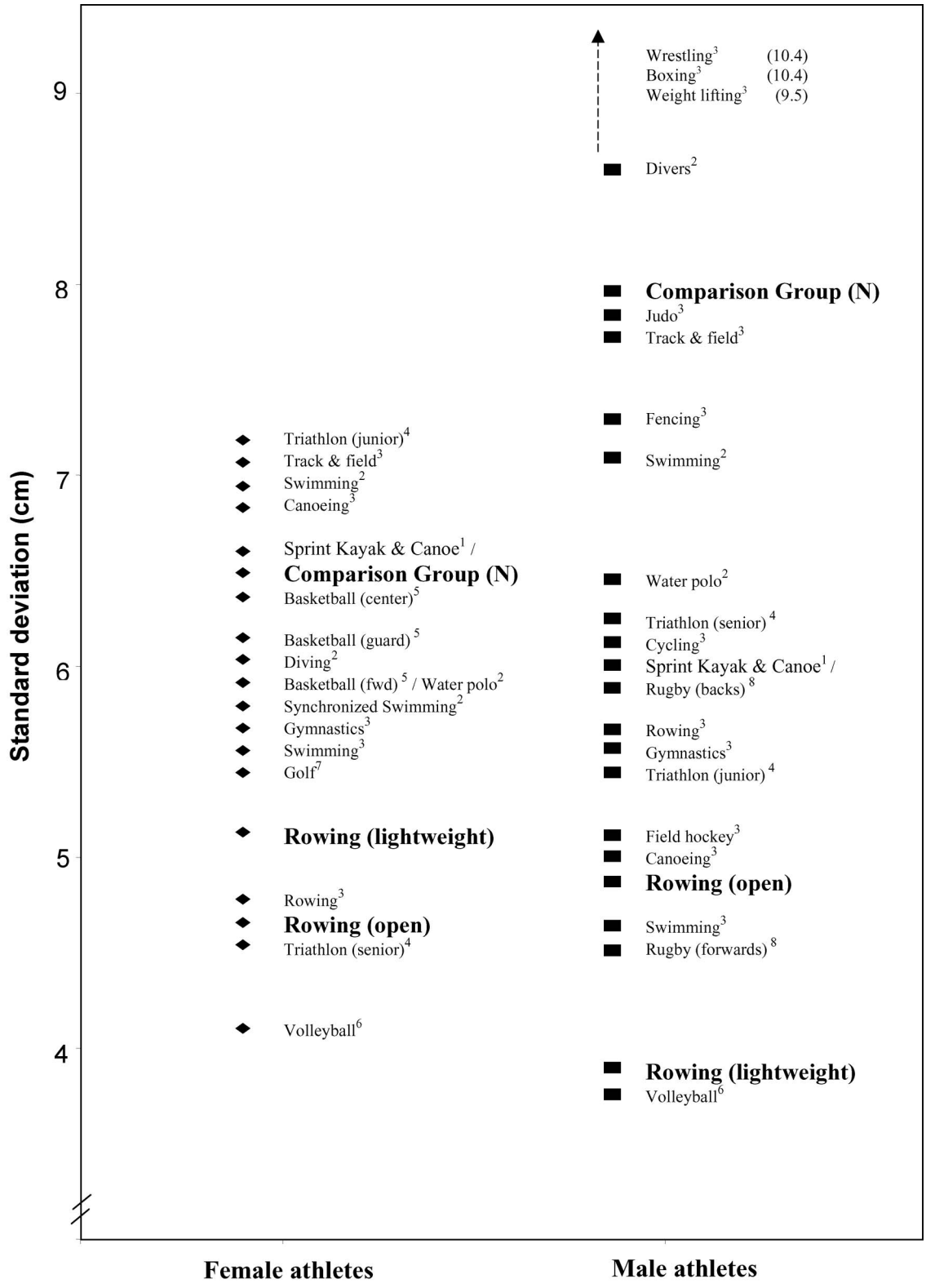

Figure 1. Standard deviation in stature of Olympic rowers in relation to elite athletes in other sports and the comparison groups of non-rowers. [1]Ackland *et al.* (2001), [2]Carter and Ackland (1994), [3]Carter (1982), [4]Landers *et al.* (2000), [5]Ackland *et al.* (1997), [6]Puhl *et al.* (1982), [7]Crews *et al.* (1984), [8]Dacres-Manning (2000).

the male open-class rowers and 187.6 ($s = 4.9$) cm for the male lightweight rowers ($P < 0.001$). Mean arm span was 183.8 ($s = 5.2$) cm for the female open-class rowers and 170.5 ($s = 4.3$) cm for the female lightweight rowers ($P < 0.001$). For all rowers, arm span was greater than their height.

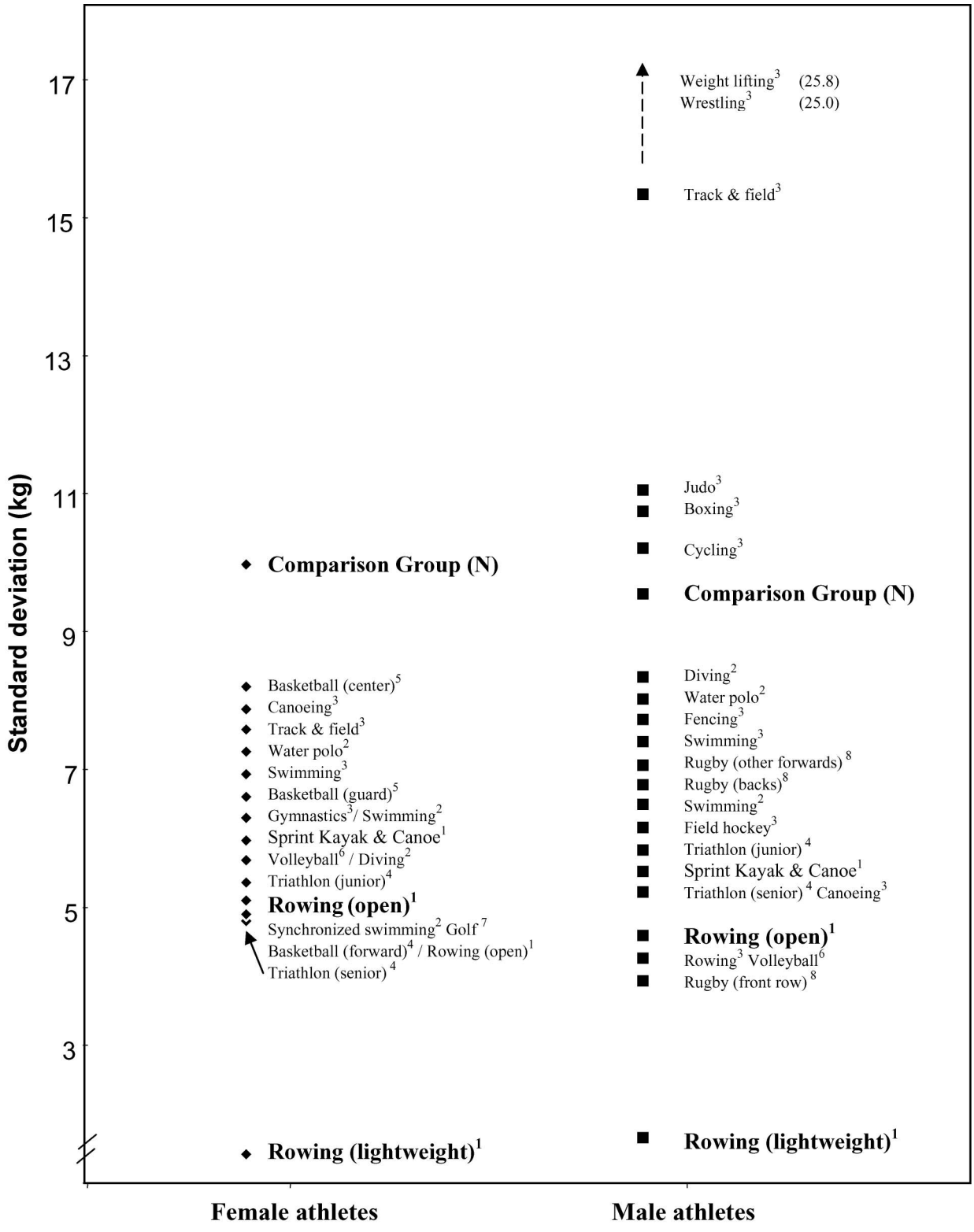

Figure 2. Standard deviation in body mass of Olympic rowers in relation to elite athletes in other sports and the comparison groups of non-rowers. [1]Ackland *et al.* (2001), [2]Carter and Ackland (1994), [3]Carter (1982), [4]Landers *et al.* (2000), [5]Ackland *et al.* (1997), [6]Puhl *et al.* (1982), [7]Crews *et al.* (1984), [8]Dacres-Manning (2000).

In terms of eight skinfolds, the open-class and lightweight rowers were leaner than the non-rowers for both males and females. The male lightweight rowers were leaner than their open-class counterparts ($P = 0.01$), but for the females rowers there was a trend only ($P = 0.05$).

The differences in stature and body mass described above were also displayed in several measures of limb lengths and girths respectively. Limb lengths were similar for the lightweight rowers and non-rowers, reflecting similar overall skeletal size (Table I). Both male and female open-class rowers had longer segments than the lightweight rowers and non-rowers at all sites.

Among the male lightweight rowers there was little difference in corrected girths and other absolute girth measures compared with the non-rowers, except for the corrected mid-thigh girth, indicating greater muscularity at this site. Both male and female lightweight rowers had a smaller hip girth than the non-rowers and open-class rowers, possibly indicating less adiposity and a smaller physical structure of the hips. For males, the non-rowers had a significantly smaller shoulder breadth than the lightweight and open-class rowers, whereas for females, the lightweight rowers had significantly narrower hips than the non-rowers and open-class rowers, suggesting a more linear physique for the lightweight rowers.

Relative body size

The male open-class rowers were more endomorphic and mesomorphic and less ectomorphic than the male lightweight rowers (open-class: 1.9 – 5.0 – 2.5; lightweight: 1.4 – 4.4 – 3.4). Similar differences were observed for the female rowers (open-class: 2.8 – 3.8 – 2.6; lightweight: 2.0 – 3.5 – 3.3), reflecting the requirements of a weight category event. The somatotypes of the non-rowers were 2.7 – 5.0 – 2.8 for males and 4.7 – 4.0 – 2.1 for females.

Given the significant absolute size differences between open-class rowers and the other groups, further analysis was performed to expose any differences in body segment proportions. These proportionality characteristics (Z_p) of male and female rowers are presented in Table II, while Figures 3 and 4 display the proportionality differences between the two groups of rowers and the non-rowers for males and females respectively.

Table II shows that the open-class rowers possessed markedly higher proportional body mass (Z_p body mass) than the lightweight rowers and non-rowers ($P < 0.01$). Thus, not only are open-class rowers heavier in absolute terms, male and female open-class rowers are almost 1.5 and 1.0 Z_p-scores above the non-rowers respectively, when scaled to a common stature (Figures 3 and 4). Female lightweight rowers are more than 0.5 standard scores below the non-rowers. Since these groups were of similar stature, this result confirms the need for female lightweight rowers to minimize adiposity, yet maximize lean tissue within the weight limits imposed by the sport.

With the exception of the Z_p body mass parameter, male open-class and lightweight rowers demonstrate a similar pattern of segment proportions, in contrast

Table II. Relative size characteristics calculated from Z_p-scores of Olympic lightweight and open-class rowers and a comparison group of non-rowers[†].

	Males				Females			
Proportionality variable	*F*-ratio	Non-rowers ($n = 42$)	Lightweight ($n = 50$)	Open-class ($n = 140$)	*F*-ratio	Non-rowers ($n = 71$)	Lightweight ($n = 14$)	Open-class ($n = 69$)
Z Body mass	238.6*	0.67[a]	0.37[c]	2.14	30.3*	0.06[a,b]	−0.66[c]	0.88
Z Sitting height	19.9*	−0.08[a]	−0.33[c]	−0.57	10.8*	−0.02	0.04	−0.37
Z Upper arm length	15.0*	−0.13[a]	0.16	0.40	2.0	0.31	0.00	0.16
Z Forearm length	1.2	0.39	0.45	0.59	2.6	0.10	−0.34	0.03
Z Thigh length	3.7	1.28[b]	0.89	1.09	2.1	1.07	1.14	1.31
Z Lower leg length	26.6*	0.14[a]	0.42[c]	0.74	10.3*	−0.06[a]	0.07	0.31
Z Shoulder breadth	4.3	−0.15[a,b]	0.32	0.24	0.5	−0.54	−0.29	−0.49
Z Chest depth	6.9*	0.74[a]	0.94[c]	1.50	12.2*	1.39[a,b]	0.06	0.64
Z Hip breadth	3.1	−1.17	−1.23[c]	−0.98	18.3*	0.64[a,b]	−0.65	−0.36
Z Corrected arm girth	10.4*	−0.06	−0.37[c]	0.23	12.6*	−1.78[a]	−1.38	−1.14
Z Flexed arm girth	18.6*	0.85[b]	0.38[c]	1.16	1.8	0.01	−0.42	0.08
Z Forearm girth	11.1*	1.08	0.86[c]	1.53	2.2	−0.03	−0.29	0.20
Z Corrected chest girth	12.4*	0.37[a]	0.62[c]	1.05	7.5*	−0.70[a]	−0.44	−0.19
Z Corrected waist girth	28.9*	−0.38[a]	−0.32[c]	0.43	8.8*	−1.39[a]	−1.04	−0.72
Z Hip girth	29.4*	−0.42[a,b]	−1.40[c]	−0.81	29.8*	1.08[a,b]	−0.62[c]	0.06
Z Corrected mid-thigh girth	28.9*	−2.36[b]	−2.01[c]	−1.58	30.7*	−2.87[a,b]	−2.21	−1.92
Z Corrected calf girth	1.3	−1.26	−1.22	−1.06	0.4	−1.47	−1.42	−1.35

[a]Non-rowers significantly different from open-class rowers ($P < 0.01$). [b]Non-rowers significantly different from lightweight rowers at $P < 0.01$. [c]Lightweight rowers significantly different from open-class rowers ($P < 0.01$).

[†]Non-parametric test (Kruskal-Wallis test) for *K* independent samples was applied to the sample to test significance. A non-parametric test for two independent samples was used to identify which groups were significantly different. *$P < 0.01$.

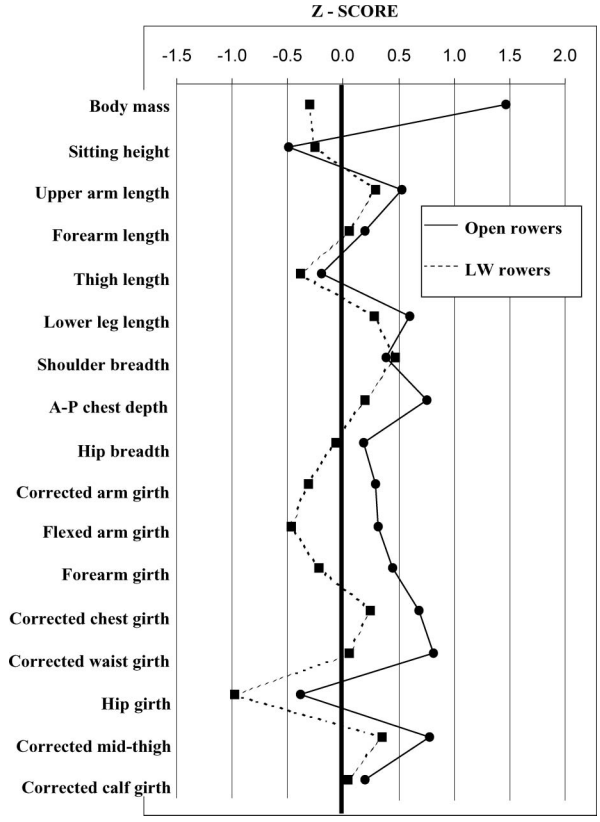

Figure 3. Proportionality (Z_p-scores) of male rowers comparing lightweight and open-class rowers.

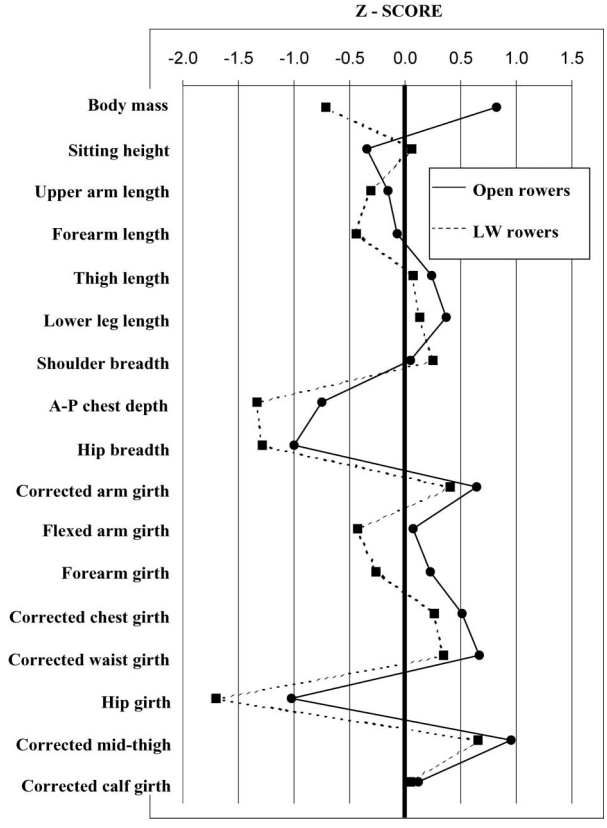

Figure 4. Proportionality (Z_p-scores) of female rowers comparing lightweight and open-class rowers.

to the non-rowers (Figure 3), although the open-class rowers are more distinct from the non-rowers in several features. Open-class rowers are more than 0.5 standard scores higher than the non-rowers on measures of proportional upper arm and lower leg lengths, proportional chest depth, and corrected chest, waist, and mid-thigh girths. Yet, despite a greater absolute hip girth, open-class rowers possess a lower Z_p hip girth than the non-rowers ($P < 0.01$). Similarly, the open-class rowers possess a shorter Z_p sitting height than the non-rowers, even though this variable is greater in absolute terms.

Figure 4 shows a similar pattern of segment proportions between the females open-class and lightweight rowers. The open-class rowers were more than 0.5 Z_p-scores above the non-rowers in measures of proportional limb girths (corrected arm, chest, waist, and mid-thigh girths). Clearly, the open-class rowers possess significantly smaller proportional scores for chest depth, hip breadth, and hip girth, despite being larger than the non-rowers in absolute size. The female lightweight rowers showed similar traits for these variables, with Z_p-scores at least 1.0 standard scores below the non-rowers.

Best versus rest

As shown in Table III, the higher placed male open-class rowers were taller and heavier, and had a greater sitting height (all $P < 0.01$), than the rest. They were also more muscular, as indicated by larger relaxed arm and forearm girths (both $P < 0.01$). For the male lightweight rowers, only proportional thigh length was greater in the best competitors ($P < 0.01$). For the female open-class rowers, the sum of eight skinfolds was lower ($P < 0.01$) for the more highly placed competitors than the rest.

Discussion

According to Ackland (2005), the talent identification process involves five stages, the first of which requires an understanding of the important aspects for success in competition. Thus, one must ask whether rowers demonstrate distinctiveness in physical capacities. Distinctiveness in human morphology that could lead to a competitive advantage within the sport of rowing may be demonstrated, according to Ackland (2005), by:

- homogeneity of physical structure among elite competitors;
- possession of unique physical capacities not commonly observed in the general population; and/or
- significant differences between the best athletes and competitors of a lower standard.

The data presented in this paper will be evaluated according to these three criteria in the first part of this discussion.

Do Olympic rowers exhibit homogeneity in physical structure?

Clear morphological differences exist between open-class and lightweight rowers, primarily due to the constraint on the weight of the latter group. Thus, for both male and female competitors, open-class rowers are taller, heavier, and more robust than their lightweight counterparts. Furthermore, open-class rowers accumulate more subcutaneous adipose tissue than lightweight rowers. Less body fat is commonly observed in female athletes in weight category or distance events (Brownell, Steen, & Wilmore, 1987).

When we stratify the sample according to sex and category, however, there is evidence to confirm their homogeneity in physical structure. The present sample of rowers contains competitors who vary greatly in quality, from medallists through to those who did not make the A or B finals. Yet, the variance in stature and body mass is very low for this athlete group, and among the lowest reported for similarly elite performers in other sports. This is especially the case for the lightweight rowers, who must make strict weight targets for competition, but the observation applies also to the open-class rowers.

The rules for competition require that the average crew weight (excluding any coxswain) shall not exceed 70.0 kg and 57.0 kg for male and female lightweight rowers respectively, with no individual rower exceeding 72.5 kg and 59.0 kg respectively.

Furthermore, when one considers the standard deviations for other absolute size variables of the lightweight rowers in Table I, they are consistently about half the magnitude of those of the non-rowers. This is less apparent for the open-class rowers, however, with the exception of height and weight variables, as well as corrected chest, waist, and hip girths. With respect to adiposity, all rowers display little variance in the sum of eight skinfolds compared with the non-rowers.

Therefore, the results presented here suggest that Olympic rowers do exhibit homogeneity in physical structure.

Do Olympic rowers possess unique physical characteristics?

Bloomfield (1979) described the concept of self-selection for sport as being akin to the evolutionary process, whereby athletes with appropriate traits to provide a competitive advantage survive in the sport and achieve higher ranking. This *laissez faire* approach has been overtaken with the advent of

Table III. Summary of ANOVA results and descriptive statistics (mean ± *s*) for variables that showed a significant difference ($P < 0.01$) or trend ($P < 0.05$) between highly ranked rowers (top 7 places = Best) and those ranked lower (Rest).

Measure	*F*-ratio	Best	Rest
Male open-class rowers		$n = 99$	$n = 41$
Stretch stature (m)	8.062[a]	1.94 ± 0.04	1.92 ± 0.06
Sitting height (cm)	9.473[a]	99.7 ± 2.7	98.1 ± 2.9
Body mass (kg)	10.657[a]	95.3 ± 5.4	91.9 ± 6.4
Arm girth (relaxed) (cm)	6.985[a]	33.8 ± 1.8	32.9 ± 2.0
Arm girth (flexed) (cm)	6.340[a]	36.8 ± 1.7	35.9 ± 1.9
Forearm girth (cm)	8.440[a]	31.2 ± 1.3	30.5 ± 1.3
Chest girth (cm)	4.772[b]	109.2 ± 4.0	107.5 ± 4.7
Biacromial breadth (cm)	6.103[b]	44.0 ± 1.9	43.1 ± 1.7
Z Forearm length	4.539[b]	0.509 ± 0.670	0.781 ± 0.737
Male lightweight rowers		$n = 23$	$n = 27$
Biiliocristal breadth (cm)	6.923[b]	28.1 ± 1.2	28.9 ± 1.1
Z thigh length	7.330[a]	1.155 ± 0.619	0.670 ± 0.637
Female open-class rowers		$n = 42$	$n = 27$
Sum 8 skinfolds (mm)	10.463[a]	82.1 ± 23.2	99.8 ± 20.4
Endomorphy	4.498[b]	2.62 ± 0.80	3.00 ± 0.62
Z Biiliocristal breadth	4.176[b]	−.186 ± 0.840	−.628 ± 0.927

[a]$P < 0.01$. [b]$P < 0.05$.

modern national sport systems and their emphasis on talent identification programmes (Bloomfield *et al.*, 1994). Nevertheless, sports scientists and coaches endeavour to select individuals based on these unique and identifiable physical, physiological, and psychological characteristics.

In terms of absolute size, both male and female open-class rowers are taller, heavier, and leaner than their respective non-rowing counterparts, with significant differences in most segment lengths, breadths, and girths. However, after scaling for stature, male open-class rowers are still proportionally heavier than non-rowers with greater proportional chest, waist, and thigh dimensions. Female open-class rowers are also proportionally heavier than non-rowers with greater proportional arm, chest, waist, and thigh dimensions (except proportional chest depth). These characteristics relate specifically to the muscle development and lung capacity requirements of elite rowers.

Of particular note, open-class rowers possess a proportionally smaller hip girth than non-rowers. This characteristic is common across all rower categories and suggests that the equipment they use places some constraint on this parameter. That is, boat fluid mechanics supports the design of long, narrow hull shapes for minimizing resistance to forward motion. Among the female rowers, this trait is supported by the very low proportional hip breadth in comparison to non-rowers.

The lightweight rowers were similar to non-rowers in stature and limb lengths for both male and females. DeRose, Crawford, Kerr, Ward and Ross (1989) found male lightweight rowers from the Pan American Games to be similar to student controls with the exception of a short sitting height and a large transverse chest depth; however, this was not the case in the present study. The female lightweight rowers in the study by DeRose *et al.* were generally larger than the reference sample for most measurements with the exception of skinfold thicknesses and sitting height. In contrast, the female lightweight rowers in this study were leaner and had a smaller hip girth than the non-rowers, but there was no difference in sitting height. The present study provides data for a larger sample of more elite male lightweight rowers than that of DeRose *et al.* (1989), but both studies recruited only a small number of female lightweight rowers. The Sydney Olympic Games had only one event for female lightweight rowers, so only a few rowers were available for testing. Therefore, a larger sample of female lightweight rowers is required to identify possible unique physical characteristics.

The proportionality profile of lightweight rowers mirrors that of the open-class competitors for most variables when compared with the non-rowers (Figures 3 and 4). In general, the proportional girths and segment breadths for the lightweight competitors in these figures are shifted to the left with respect to the open-class rowers. However, there is less of a disparity with respect to proportional segment lengths. This result suggests that lightweight rowers are not simply scaled down versions of the open-class rower morphology. In summary, lightweight rowers appear to retain the advantageous segment length proportions of the open-class rowers, yet the imposition of a weight limit for lightweight competition has the effect of preferentially selecting rowers with a lean and linear physique.

In summary, the results suggest that Olympic rowers do possess unique physical characteristics compared with the general population.

Are there significant differences between Olympic rowers of varying rank?

The differences observed between higher ranked rowers and the remaining competitors were few, which supports the notion of homogeneity in physique for elite competitors in this sport. There were some significant differences, however, which serve to emphasize the critical variables for success in rowing.

Among the male open-class rowers, for example, size definitely matters. The best competitors were able to maximize segment lengths, girths and breadths, yet still conform to the performance constraints necessary to fit into the rowing shell. Therefore, the width of the boat may act as a homogenizing constraint. That is, while several adjustments to the boat rigging are possible to accommodate rowers of varying length, their hips and buttocks must fit into a seat that slides within a pre-determined boat width. This physical restriction is especially evident among female rowers, with the best performers having significantly less adiposity ($P < 0.01$) and showing a trend ($P < 0.05$) towards proportionally narrower hips.

The international governing body for rowing (FISA) does not stipulate maximum or minimum boat widths for competition, but instead publishes minimum boat weights in each event category. Thus, the manufacturer is free to design the most advantageous hull shape within this limitation, generally opting for long and narrow designs. The external width of the boats (gunwale width) varies according to the type of boat (from single scull to a full racing eight) as well as the crew location within the boat. For the boats measured at the 2000 Olympics, this dimension varied from 40.0 to 68.5 cm.

Changes in physical characteristics over time

A later stage in the talent identification process requires the compilation of a set of normative data on elite performers for comparison purposes. According to Ackland (2005), outdated normative data sets are of limited utility when the sport experiences substantial changes in rules, equipment, and athlete preparation strategies. Therefore, coaches should always seek to use the most up-to-date comparison data when creating an individual profile. The results for Olympic rowers measured at the 2000 Olympic Games will be compared with other published scores to judge the utility of the present information as a normative data set for profiling elite rowers.

The last comprehensive anthropometric survey of elite rowers was conducted at the 1976 Montreal Olympic Games (Carter, 1982). The Sydney Olympic male open-class rowers were taller (1.93 vs. 1.87 m; difference = 0.06 m) and heavier (93.6 vs. 87.2 kg; difference = 6.4 kg) than the rowers at the Montreal Olympics (Carter, 1982). Similarly, the Sydney Olympic female open-class rowers were taller (1.81 vs. 1.75 m; difference = 0.06 m) and heavier (76.6 vs. 64.5 kg; difference = 12.1 kg) than those from the Montreal Olympics.

According to Norton and Olds (1996), the secular trend in the population towards greater body size was relatively steady from the early part of the twentieth century. The mean trend for stature was reported as being 1.23 and 1.33 cm per decade for women and men respectively. Thus, we might expect differences between the Montreal and Sydney Olympic samples of approximately 3.2 cm based on the secular trend alone. Since no lightweight rowers competed at the Montreal Olympic Games, factors other than the population secular trend, such as current selection and training practices, could have influenced these differences in open-class rower morphology. Of course, there may have been some bias related to the quality of these two samples, but at Montreal (Carter, 1982) sufficient competitors were measured to minimize this effect.

Furthermore, coaches cannot simply select the largest athletes for open-class rowing competition. Clearly, there exists a contraindication for very large athletes due to the physical constraints of the rowing shell, as well as the added frontal resistance created when the boat displaces more water with a heavier crew. Thus, we suggest that the changes in open-class rower morphology over the past three decades represent "relative optimization" (optimal player size increases at a similar rate to the general population; Norton & Olds, 1996) with superimposed changes as a result of modern selection, dietary and training processes, as well as possible advances in boat and rigging design.

In contrast, the lightweight rowers must make a weight category, so they represent "absolute optimization" where a set physical characteristic is required for competition – in this case, body mass. So, despite the secular trend for taller and heavier individuals, lightweight rowers are being drawn from an ever-diminishing proportion of the population. This is one aspect of the rules that could be addressed by FISA, with a view to increasing the weight limits of lightweight crews periodically.

Conclusion

Based on several criteria, the rowers in this sample demonstrate distinctiveness in morphology that

distinguishes them from the normal population as well as other sports performers. These criteria include homogeneity in morphology within the athlete group, the possession of unique physical characteristics that set them apart from the average person, and selected differences between the best performers and the rest. Such distinctiveness in body size, composition, and proportionality could lead to a competitive advantage for rowing, and might therefore form the basis for any talent identification and development programme.

Furthermore, the data presented here may serve as useful normative or comparison data in the talent identification process. The data fulfil the utility criteria, as suggested by Ackland (2005), as being:

- relatively current;
- created using elite athletes of international calibre;
- derived from athletes who are homogeneous in morphology/capacity; and
- stratified by sex and event category.

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