The muscle typology of elite and world-class swimmers

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Submission type: Original investigation

Acknowledgments

The authors have no financial relationships relevant to this article that need to be disclosed and no other conflicts of interest to disclose. The results presented in this study are without fabrication. This project was partially funded by the QAS Sport Performance Innovation and Knowledge Excellence (SPIKE) unit.

Word count: 3091 Number of figures: 5 Number of tables: 1

ABSTRACT

Purpose: We aimed to examine whether the muscle typology of elite and world-class swimmers could discriminate between their best distance event, swimming stroke-style or performance level. **Methodology:** The muscle carnosine content of 43 male (860 ± 76 FINA points) and 30 female (881 ± 63 FINA points) swimmers was measured in the soleus and gastrocnemius by proton magnetic resonance spectroscopy and expressed as a carnosine aggregate Z-score (CAZ-score) to estimate muscle typology. A higher CAZ-score is associated with a higher estimated proportion of type II fibres. Swimmers were categorized by their best stroke, distance category (sprinters; 50-100 m, middle-distance; 200-400 m, or long-distance; 800 m–open water) and performance level (world-class; world top-10 or elite; world top-100 swimmers outside of the world top-10). **Results:** There was no significant difference in the CAZ-score of sprint- (-0.08±0.55), middle- (-0.17±0.70) or long-distance swimmers (-0.30±0.75,p=0.693). World-class sprint swimmers (all strokes included) had a significantly higher CAZ-score (0.37±0.70) when compared to elite sprint swimmers (-0.25±0.61,p=0.024,*d*=0.94). Breaststroke swimmers (0.69±0.73) had a significantly higher CAZ-score compared to freestyle (-0.24±0.54,p<0.001,*d*=1.46), backstroke (-0.16±0.47,p=0.006,*d*=1.42) and butterfly swimmers (-0.39±0.53,p<0.001,*d*=1.70). Furthermore, within the cohort of breaststroke swimmers there was a significant positive correlation between FINA points and CAZ-score (r=0.728, p=0.011); however, this association was not evident in other strokes. **Conclusion:** While there was no clear association between muscle typology and event distance specialisation, world-class sprint swimmers possess a greater estimated proportion of type II fibres compared to elite sprint swimmers, as well as breaststroke swimmers compared to freestyle, backstroke and butterfly swimmers.

Keywords: CARNOSINE, MUSCLE FIBRE TYPE COMPOSITION, SWIMMING, SPECTROSCOPY

INTRODUCTION

Muscle fibres have been traditionally been classified by analyses of their myosin heavy chain (MHC) isoforms revealing three major fibre types that can be identified as type I, IIA and IIX fibres[1]. These skeletal muscle fibre types show a large diversity in their physiological and mechanical characteristics. Compared to type II muscle fibres, type I fibres produce force relatively slowly[2] but possess superior fatigue resistance[1], while the metabolic characteristics vary considerably[3]. Considering this diversity, the heterogeneity in muscle fibre type composition (i.e., muscle typology) between individuals is thought to be associated with the inter-individual variation in exercise performance[4].

During the 1970's and 1980's, it was popular to determine the muscle typology of athletes from different sports events[5-10]. In the landmark work from Costill et al.[5], it was demonstrated that international-level distance runners possessed a significantly greater percentage of type I fibres (mean; range: 69; 63-74%) in the gastrocnemius compared to middle-distance (61; 44-73%) and sprint-distance runners (27; 27-28%). Costill et al.[6] subsequently reported that elite distance runners possessed a higher percentage of type I fibres (mean ± SD: 79 ± 3.5%) in the gastrocnemius compared to their lesser trained counterparts (well-trained distance runners; 62 ± 2.9% type I fibres) and untrained men (58 ± 2.5% type I fibres). As such, the belief that muscle typology was deterministic in event specialization and in training status gained credibility. In swimming, the relationship between muscle typology and distance event specialization seems to be less coherent. Gerard et al.[7] did not report clear differences in the vastus lateralis muscle typology of male or female swimmers categorized as long-, middle- and sprint-distance swimmers. Other research has reported that swimmers (University club standard) possess ~60% type I fibres in the gastrocnemius and deltoid[8], while Danish national-level female swimmers possessed 60% and 50% type I fibres in the deltoid and vastus lateralis, respectively[9]. Moreover, Gollnick et al.[10] reported that "trained" swimmers possessed 74% and

58% type I fibres in the deltoid and vastus lateralis, respectively. However, few of these studies[7-10] provided information on the specialist event of the swimmers that were studied, while their training status and competitive level were less described. As such, contemporary information on the most accomplished swimmers is scarce.

Baguet et al.[11] developed a non-invasive method to estimate muscle typology, based on the proton magnetic resonance spectroscopy (^{1}H-MRS) measurement of muscle carnosine. This technique clearly discriminated the muscle typology of different athletes by confirming that all explosive athletes had the highest carnosine levels and thus, a greater estimated proportion of type II fibres, compared to endurance athletes, with intermediate athletes always situated between these two groups[12]. More recently[13], we demonstrated prominent differences in the muscle typology of elite and world-class cyclists competing in various disciplines. Interestingly, we did not observe such prominent differences in the muscle typology in a cohort of 11 trained swimmers[12]. Nonetheless, the sample size and performance level of these swimmers was not sufficient to make firm conclusions as to the importance of muscle typology for discipline specialisation in swimming. As such, based on historic[7-10] and contemporary evidence[12] it remains to be elucidated whether muscle typology is equally deterministic for event specialization in swimming as in other sports such as running and cycling[12-15]. To this end, the present study aimed to compare the estimated muscle typology of elite sprint-, middle- and long-distance swimmers to determine whether; i) muscle typology is associated with the specialist distance event category of each swimmer; ii) swimming stroke-style is associated to muscle typology, and; iii) whether the muscle typology of world-class (i.e., world top-10) sprint- or long-distance swimmers would display a more extreme value than elite (i.e., world top-100 swimmers outside of the world top-10) swimmers within the same distance categorization. Given the inconclusive findings of previous research [7,12], we hypothesized that muscle typology may not demonstrate such prominent differences between swimmers specialising in different distance events.

METHODOLOGY

Participants

Forty-three male (24.1 ± 3.5 years, 184.8 ± 6.5 cm, 79.6 ± 8.01 kg) and thirty female (24.1 ± 3.2 years, 173.2 ± 5.5 cm, 66.4 ± 7.1 kg) swimmers volunteered to participate in this cross-sectional study. The swimmer's specialist event was classified based on their best swimming performance according to the International Swimming Federation (FINA) point scoring system. The FINA classification allows intra- and inter-individual comparisons of performance obtained in different events by ascribing a point score (range, 0 - 1100) to each swimmer according to their best time in her or his main event. The swimmers were categorized as sprint-distance (specialists in 50 - 100 m), middle-distance (specialists in 200 - 400 m), or long-distance (specialists in 800 m - open water; OW) swimmers according to the distance of their specialist event. We also classified swimmers as world-class (i.e., world top-10) or elite (i.e., world top-100 swimmers outside of the world top-10). Of the swimmers in the current study, 33 had been ranked in the world top-10, 24 ranked between world top-10 to 50, while the remaining 16 swimmers had been ranked between world top-50 to 100 within 2 years before or after the ^{1}H-MRS measurements in the present study. Swimmers were also categorized into groups based on their specialist stroke-style of the event in which the swimmer achieved their highest FINA point score. From this categorization, 39 swimmers specialised in freestyle, 12 in butterfly, 11 in backstroke and 11 in breaststroke. These swimmer categories are presented in table 1.

Design

An observational research design was employed for this study. The subjects attended a radiology clinic on one occasion to have their muscle typology estimated using ^{1}H-MRS to measure the carnosine content of the gastrocnemius and soleus. Subjects were categorized into groups according to their best event and performance level and comparisons were made between groups.

Muscle carnosine quantification by ^{1}H-MRS

Muscle carnosine content was measured by ^{1}H-MRS in the gastrocnemius medialis and soleus muscle of each participants right limb to estimate muscle typology[11]. ^{1}H-MRS measurements were performed on a 3-T whole body MRI scanner (Philips Medical Systems Best, The Netherlands) as previously described[13,16]. The carnosine concentration of each muscle was converted to a sex-specific Z-score relative to an age- and sex-matched control population of active, healthy non-athletes, consisting of 40 men and 33 women. The mean of the carnosine Z-scores of the gastrocnemius and the soleus was then calculated (i.e., carnosine aggregate Z-score; CAZ-score), and this CAZ-score was used for all analyses. A higher CAZ-score is associated with a higher estimated proportion of type II fibres.

Statistical analysis

A one-way ANOVA was performed to compare the CAZ-score of the different categorical groups with Tukey post-hoc comparisons applied when appropriate. Differences between groups were also interpreted using Cohen's *d* effect sizes. Pearson correlations were used to examine the associations between CAZ-score and FINA point score of swimmers specialising in each stroke. All analyses were done with SPSS statistical software (SPSS 21, Chicago, Illinois, USA). All values are reported as mean ± SD and statistical significance was set at $P < 0.05$.

RESULTS

There was no significant difference in the CAZ-score of the sprint- (n = 29, 0.05 ± 0.74), middle- (n = 29, -0.11 ± 0.64), or long-distance swimmers (n = 15, -0.29 ± 0.75; all strokes included) compared to the male (n = 40, 0.00 ± 0.94) and female (n = 33, 0.00 ± 0.96) non-athlete control groups (Figure 1).

When all freestyle swimmers were grouped according to their best event by distance categorization, there was no difference in the CAZ-score of sprint- (n = 11, -0.08 ± 0.55), middle- (n = 13, -0.17 ± 0.70) and long-distance freestyle swimmers (n = 15, -0.29 ± 0.75, p = 0.732) (Figure 2A). Furthermore, when this categorization only included world-class freestyle swimmers, there was no significant differences between the CAZ-score of the freestyle groups (sprint-distance: n = 4, 0.20 ± 0.42; middle-distance: n = 5, 0.18 ± 0.98; long-distance: n = 8, -0.31 ± 0.83, p = 0.468) (Figure 2B).

When swimmers specialising in sprint-distance events (50- and 100-m events) were grouped together, world-class sprint swimmers had a significantly higher CAZ-score (n = 14, 0.40 ± 0.79) compared to elite sprint swimmers (n = 15, -0.27 ± 0.54, p = 0.012, *d* = 1.01) (Figure 3A). When swimmers specialising in long-distance events (800 m - OW freestyle) were grouped together, there was no difference in the CAZ-scores of world-class (n = 8, -0.31 ± 0.83) and elite long-distance swimmers (n = 7, -0.28 ± 0.71, p = 0.939, *d* = 0.04) (Figure 3B).

When all swimmers specialising in 50 - 200-m events were grouped according to the stroke-style of their best event, breaststroke swimmers (n = 11, 0.70 ± 0.73) had a significantly higher CAZ-score compared to freestyle (n = 17, -0.23 ± 0.54, p < 0.001, *d* = 1.46), backstroke (n = 11, -0.16 ± 0.47, p = 0.005, *d* = 1.43) and butterfly swimmers (n = 12, -0.38 ± 0.53, p < 0.001, *d* = 1.70) (Figure 4). Furthermore, within the cohort of breaststroke swimmers there was a significant positive correlation between FINA point score and CAZ-score (r = 0.728, p = 0.011) (Figure 5); however, this association was not evident in other strokes.

DISCUSSION

The results from the present study demonstrate that there is a large variation in the estimated muscle typology of elite and world-class freestyle swimmers when grouped according to their specialist event category (i.e., sprint-, middle- or long-distance). As such, there was no clear association between muscle typology and distance specialisation. However, there was some evidence to suggest that world-class (i.e., world top 10) sprint-distance swimmers (50 – 100 m events) possess a higher estimated proportion of type II fibres (i.e., higher CAZ-score) compared to elite sprint-distance swimmers (i.e., world top-100 swimmers outside of the world top-10). Furthermore, breaststroke swimmers had a significantly higher CAZ-score compared to freestyle, backstroke and butterfly swimmers.

The data from the present study demonstrate that when elite and world-class swimmers were grouped according to their best event by distance categorization, there was no difference in the CAZ-score of sprint-, middle- or long-distance swimmers. As such, in our large cohort of elite and world-class swimmers, there appears to be no clear association between muscle typology and distance event specialisation. In agreement, classical studies have been unsuccessful in identifying a clear association between muscle typology and distance event categorisation in swimmers or with training status within a cohort of swimmers[7-10]. Previous research employing ^{1}H-MRS to estimate[11-13] or muscle biopsies[5,6,15] to directly measure the muscle typology of elite athletes demonstrate that within different sports, endurance-type athletes possess a greater proportion of type I fibres (i.e., lower CAZ-score) compared to sprint-type athletes, with intermediate-type athletes always situated in between. Previous research has also demonstrated that muscle typology may be deterministic for performance level within a specific event category. Costill et al.[6] reported that elite distance runners possessed a higher percentage of type I fibres compared to their lesser trained counterparts (well-trained distance runners and untrained men). Furthermore, Bex et al.[12] reported that superior track sprinters (IAAF scores above 1050) possessed a higher CAZ-score than lower level track sprint athletes. In the present study, we also compared the CAZ-score of truly world-class swimmers (i.e., world top-10) with their elite counterparts (world top-100 swimmers outside of the world top-10) who compete in the same distance event category (i.e., sprint- or long-distance). There were no differences in the CAZ-score of world-class and elite level long-distance swimmers; however, world-class sprint-distance swimmers (50- to100-m event speciality) had a significantly higher CAZ-score than their elite counterparts. These findings are supported by previous research where we demonstrated that elite and world-class 100 m swimmers with a higher CAZ-score had a significantly faster start time during their career best race performances compared with swimmers with a lower CAZ score[17]. It is likely that possessing a greater proportion of type II muscle fibres lends an advantage to the swim start which, when performed maximally, is an explosive movement of the lower-body musculature. Taken together, these findings suggest that possessing a greater proportion of type II fibres may contribute to an increased likelihood of an elite sprint swimmer becoming world-class. Nonetheless, muscle typology may not be as such a deterministic trait for distance event specialisation in swimming as it is in other sports such as running and cycling[5,6,11-15].

A key question is why does muscle typology seem to be less influential for distance event specialisation in swimming compared to other sports such as running and cycling? One key consideration is the association between muscle typology and cyclic movement frequency. Bex et al.[12] demonstrated that the typical cyclic movement frequency of athletes competing in sprint, intermediate and endurance disciplines was strongly associated with muscle typology. This was most evident in runners and cyclists, but not as prominent in swimmers, which is likely due to the large disparity in cyclic movement frequencies between different distance events in running and cycling disciplines when compared to swimming. Indeed, there is a much lower discrepancy between the typical stroke rate of swimmers competing in different distance events (i.e., mean freestyle stroke rate range: ~44 to 58 cycles·min^{-1} from sprint- to long-distance events)[18,19], when compared to different distance events within both cycling (i.e., mean cadence range: ~70 to 150 rev·min^{-1})[20,21] and running (i.e., mean stride rate range: ~90 - 280 strides·min^{-1})[22,23]. It is also worth highlighting that the typical mean stroke rate of sprint swimmers (~58 cycles·min^{-1})[18] is substantially lower than the cycling stroke rate equivalent (i.e., mean cadence) of track sprint cyclists (~150 revolutions·min^{-1})[20] and the mean stride rate of track sprint runners (~280 strides·min^{-1})[22], respectively. As such, the smaller disparity in stroke rates between freestyle swimming distance events and substantially lower speed/power requirements for sprint swimming events compared to sprint events in other sports, are likely responsible for the absence of a clear association between muscle typology and distance specialisation in swimming. We also found no evidence that possessing a slow muscle typology is beneficial for long-distance swimming events. This may be due to the inherent low mechanical efficiency of swimming due to the highly resistive properties of water (i.e., hydrodynamic resistance and drag) compared to the resistive forces experienced during cycling and running (i.e., aerodynamic resistance)[24]. As such, the superseding importance of swimming technique, rather than muscle physiology, may be the most overarching determinant of a swimmer generating propulsion in the most economical manner possible (i.e., reducing active drag)[25,26]. In contrast, variation in muscle mechanical and metabolic properties arising from different fibre types may have a larger impact in other locomotor sports such as running and cycling compared to swimming.

An interesting finding from the present study was that breaststroke swimmers had a substantially higher CAZ-score compared to the freestyle, backstroke and butterfly swimmers. Furthermore, this was supported by a significant positive association between FINA point score and CAZ-score in breaststroke swimmers. The underlying mechanism supporting this association and higher CAZ-score values in breaststroke swimmers is intriguing. Classical work from Holmér et al.[27] demonstrated that energy expenditure during breaststroke and butterfly swimming is approximately twofold greater than in backstroke or freestyle swimming performed at the same submaximal relative swim velocities. In support, other research demonstrates that breaststroke is the least economic among the competitive swimming strokes[25]. In all swimming strokes, swimming velocity fluctuates during each stroke cycle, with breaststroke producing the largest intracycle velocity variability[28] given the added drag of recovering both arms under the water and in drawing the knees up to prepare for the next propulsive phase of the cycle. Furthermore, the horizontal orientation of the leg movements in breaststroke requires greater power production and generates greater propulsion than the leg kick in the other competitive swimming strokes[29]. From these findings[27-29], it could be suggested that the magnitude of muscle power required to overcome the active drag during swimming would have the highest requirements during breaststroke compared to the other swimming strokes. As such, possessing a higher proportion of type II muscle fibres may be advantageous for breaststroke swimming given the higher power generating capacity of type II compared to type I fibres[1,2], yet this hypothesis requires further investigation.

One important caveat from the present study is that we measured the carnosine content of the non-specifically trained muscles (i.e., gastrocnemius and soleus) of swimmers in contrast to some previous studies that have obtained muscle biopsies from the deltoid of swimmers[8-10]. We initially sought to include measurements of carnosine in both the deltoid and latissimus dorsi muscles, yet we encountered technical and methodological difficulties to reproducibly run the ^{1}H-MRS protocol in all swimmers, mainly due to breathing artefacts and unsatisfactory shimming quality. Nonetheless, we believe that our measurements from the gastrocnemius and soleus would still provide a valid inference as to the muscle typology of the more specifically trained upper body musculature[30]. Individuals who express a high proportion of a given fibre composition in one muscle also express a comparably high proportion of the same fibre type in other muscles[30]. We have also previously reported a significant positive association between the carnosine z-scores of the leg muscles (mean of soleus and gastrocnemius muscles) and arm muscle (deltoid) ($r = 0.81$, $p < 0.01$) in a cohort of 11 trained swimmers[12]. As such, we believe that estimating the muscle typology of the lower body musculature of swimmers would still provide valid inference as to the muscle typology of the more specifically trained upper body musculature.

CONCLUSION

The results from the present study suggest that there is a large variation in the muscle typology of elite and world-class swimmers within specific groups according to their specialist event category (i.e., sprint-, middle- or long-distance). As such, there was no clear association between muscle typology and distance event specialisation. However, there was at least some evidence to suggest that world-class sprint swimmers are characterized by a greater estimated proportion of type II fibres when compared to elite sprint swimmers. Furthermore, breaststroke swimmers possess a greater estimated proportion of type II fibres compared to freestyle, backstroke and butterfly swimmers.

PRACTICAL APPLICATION

- A non-invasive methodology to estimate the muscle typology of elite and world-class swimmers using ^{1}H-MRS quantification of muscle carnosine was well received by coaches and elite athletes given that the scanning technique is not disruptive to training, painless and time efficient.
- The estimation of muscle typology employing ^{1}H-MRS could be applied to identify swimmers that may be most suited to breaststroke or sprint freestyle events.

- Given the large diversity in the muscle typology of swimmers who specialize in a given event, this information could also be used to individualise training advice but more research is required in swimmers.

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TABLES

Table 1: Participant characteristics. Swimmers were categorized by their best stroke (butterfly, breaststroke, freestyle or backstroke), distance category (sprinters; 50 - 100 m, middle-distance; 200 - 400 m, or long-distance; 800 m – open water) and performance level (world-class; world top-10 or elite; world top-100 swimmers outside of the world top-10).

*Standard deviation not provided as only one 1500 m swimmer featured in these categories. Open water swimmers are not subject to International Swimming Federation (FINA) point scoring system.

FIGURES

Figure 1: Individual carnosine aggregate Z-score (CAZ-score) values of the gastrocnemius and soleus of swimmers in the present study, as well as the non-athlete control groups (Panel A). Panel B shows the relative proportion of each cohort that are considered to have a slow muscle typology (CAZ-score: ≤ 0.5), a mixed muscle typology (CAZ-score: -0.49 – 0.49) or a fast muscle typology (CAZ-score: ≥ 0.5). The absolute carnosine concentration for each swimmers was converted to a sex- and muscle-specific Z-score relative to an age-matched control population of active, healthy male (n = 40) and female non-athletes (n = 33) and the aggregate of the carnosine Z-scores was used for all analyses.

Figure 2: The carnosine aggregate Z-score (CAZ-score) of sprint-, middle- and long-distance freestyle swimmers. Panel A includes all world-class and elite freestyle swimmers, while panel B only includes world-class freestyle swimmers. The shape of each symbol indicates those

swimmers with a slow muscle typology (CAZ-score: ≤ 0.5), a mixed muscle typology (CAZ-score: -0.49 – 0.49) or a fast muscle typology (CAZ-score: ≥ 0.5).

Figure 3: The carnosine aggregate Z-score (CAZ-score) of elite and world-class swimmers specialising in sprint-distance events (50 m and 100 m events; panel A) and long-distance events (800 m – OW freestyle; panel B). The shape of each symbol indicates those swimmers with a slow muscle typology (CAZ-score: ≤ 0.5), a mixed muscle typology (CAZ-score: -0.49 – 0.49) or a fast muscle typology (CAZ-score: ≥ 0.5).

Figure 4: The carnosine aggregate Z-score (CAZ-score) of swimmers categorized into groups based on their specialist stroke-style (50 – 200 m swimmers). The shape of each symbol indicates those swimmers with a slow muscle typology (CAZ-score: ≤ 0.5), a mixed muscle typology (CAZ-score: -0.49 – 0.49) or a fast muscle typology (CAZ-score: ≥ 0.5).

Figure 5: Association between carnosine aggregate Z-score (CAZ-score) and FINA point score in breaststroke swimmers. The shape of each symbol indicates those swimmers with a slow muscle typology (CAZ-score: ≤ 0.5), a mixed muscle typology (CAZ-score: -0.49 – 0.49) or a fast muscle typology (CAZ-score: ≥ 0.5).