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Muscle Fiber Typology and Its Association With Start and Turn Performance in Elite Swimmers

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Purpose: To determine the association between estimated muscle fiber typology and the start and turn phases of elite swimmers during competition. ***Methods:*** International and national competition racing performance was analyzed from 21 female (FINA points = 894 ± 39: 104.5 ± 1.8% world record ratio [WRR]) and 25 male (FINA points = 885 ± 54: 104.8 ± 2.1% WRR) elite swimmers. The start, turn, and turn out times were determined from each of the swimmers' career best performance times (FINA points = 889 ± 48: 104.7 ± 2.0% WRR). Muscle carnosine concentration was quantified by proton magnetic resonance spectroscopy in the gastrocnemius and soleus and was expressed as a carnosine aggregate *z* score relative to an age- and gender-matched nonathlete control group to estimate muscle fiber typology. Linear mixed models were employed to determine the association between muscle fiber typology and the start and turn times. ***Results:*** While there was no significant influence of carnosine aggregate *z* score on the start and turn times when all strokes and distance events were entered into the model, the swimmers with a higher carnosine aggregate *z* score (ie, faster muscle typology) had a significantly faster start time in 100-m events compared with the swimmers with a lower carnosine aggregate *z* score ($P = .02$, $F = 5.825$). The start and turn times were significantly faster in the male compared with the female swimmers in the 100-m events compared with other distances, and between the 4 different swimming strokes ($P < .001$). ***Conclusion:*** This study suggests that start times in sprint events are partly determined (and limited) by muscle fiber typology, which is highly relevant when ~12% of the overall performance time is determined from the start time.

Keywords: carnosine, swim start, swim turn, world-class swimmers, muscle fiber composition

In order to analyze competitive swimming performances, races can be segmented into different phases: (1) swim time: the total time taken to swim the entire distance of the race, (2) splits: the time taken to swim each 50-m lap of the race, (3) start time (StT): the time taken to complete the first 15 m, (4) turn time (TnT): the total time taken to complete the last 5 m (approach) and first 7.5 to 15 m (departure) of consecutive laps, (5) turn out time (ToT): the time taken from the initial touch on the wall within the turn phase to the 7.5- to 15-m point on the subsequent lap, and (6) free swim time: the swim time during the free-swimming segments of the race.[1–3] Analyzing swimming races in this way indicates that successful performance relies heavily on the StT and TnT, as the combination of these segments can equate to >25% of the overall performance time (ie, ~20% in 50-m events or ~28% in 1500-m events). Given that swimming events at the Olympic Games and World Championships can be won or lost by margins of 0.01 second,[4] understanding the determinants of StT and TnT is warranted.

It is well established that several biological systems must be optimized for superior athletic performance and that the measurement of physiological, biomechanical, and psychological characteristics can be used to understand the limiting factors of performance.[5,6] However, most previous studies that demonstrate strong associations between swimming performance and physical attributes examine characteristics that change with maturation, training, and/or other factors.[7–10] For example, elite swimmers demonstrate higher maximum muscle strength of the shoulder muscles compared with recreational swimmers,[7] which may be a result of training, while the enhanced "mental toughness" evident in elite swimmers has also been found to change with training.[8,11] Therefore, research that examines genetically determined physical characteristics may offer promising explanations of aspects of performance that cannot be solely explained by training.[8] One key physical characteristic that is principally genetically determined is skeletal muscle fiber typology.[12,13] Indeed, muscle fiber typology seems to be resistant to changes in response to prolonged training and detraining, given that young talented, active elite, and retired ex-elite athletes competing in sprint and endurance disciplines have polarized muscle fiber typology.[14,15]

The muscle fiber typology of human skeletal muscle is the degree to which the muscle is made up of type I and type II fibers, often referred to as slow twitch and fast twitch, respectively. Type I and type II fibers show great variation in their respective mechanical and physiological characteristics, which, in turn, dictates the performance characteristics of the muscle.[16,17] The maximal shortening velocity of type II muscle fibers is substantially greater than type I muscle fibers, contributing to the superior maximal power output of these fibers.[18] Furthermore, type II fibers are characterized by a greater ATPase activity, creatine phosphate, and glycogen content, and shorter excitation times when compared with type I fibers.[16,17] As such, these characteristics are thought to be important for activities that are limited by maximal muscular power output and rate of force development (eg, jumping and sprinting).[19] Therefore, it could be suggested that muscle fiber typology may be important for swimming performance parameters that require a high level of muscular power output, such as the StT, TnT, and ToT. For example,

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the ability to rapidly produce force and power in lower-body limbs has been shown to influence the StT in swimming.[20–22]

A previous study has developed a noninvasive methodology to estimate the muscle fiber typology based on the proton magnetic resonance spectroscopy (^{1}H-MRS)-derived measurement of intramuscular carnosine.[15] Carnosine is a stable dipeptide that has a 2-fold higher concentration in type II fibers[23,24] and is associated with the muscle-biopsy-determined percentage area occupied by type II fibers ($P < .01$ and $r = .71$).[15] Bex et al[25] demonstrated the construct validity of this technique by confirming that explosive sprint athletes had the highest carnosine z scores and endurance athletes had the lowest, while middle-distance athletes were typically situated within these extreme disciplines. This study aimed to use this noninvasive technique to assess the influence that muscle fiber typology has on the StT and TnT of elite and world-class swimmers. It is hypothesized that swimmers with higher carnosine z score values would have a faster StT, TnT, and ToT.

Methodology

Subjects

A total of 21 female and 25 male elite swimmers volunteered to participate in this study. The characteristics of the swimmers are presented in Table 1. All swimmers had been ranked in the world top-100 in their best swimming event (highest FINA points scoring event) within 4 years of the ^{1}H-MRS measurement in this study. No swimmer was vegan or vegetarian or had consumed β-alanine supplementation in the 3 months prior to the study to restrict unnatural influences to muscle carnosine concentration. Previous research has shown decreases in carnosine concentrations to be "very low or even nonexistent" from adulthood to older age[26] and relatively stable over a period of 3 months.[27] The study was approved by the Griffith University Human Ethics Committee, and the subjects gave their written informed consent to participate.

Research Design

An observational research design was employed for this study. The subjects attended a radiology clinic on one occasion to have their muscle fiber typology estimated using ^{1}H-MRS to measure the carnosine content of the gastrocnemius and soleus. The subject's career best race performances were analyzed, and linear mixed models were employed to determine the association between muscle fiber typology and StT and TnT.

Muscle Fiber Typology

Muscle carnosine content was measured by ^{1}H-MRS in the soleus and gastrocnemius medialis muscle of each subject's right limb to estimate the muscle fiber type composition. ^{1}H-MRS measurements were performed on a 3-T whole-body magnetic resonance imaging scanner (Philips Medical Systems, Best, The Netherlands). The subjects were lying in a supine position, while their lower leg was fixed in a spherical knee coil. All the spectra were acquired using single-voxel point-resolved spectroscopy with the following parameters: repetition time of 2000 milliseconds, echo time of ~40 milliseconds, number of excitations was 128 (carnosine) and 16 (water), spectral bandwidth was 2048 Hz, and a total acquisition time of 4 minutes and 16 seconds (carnosine) and 32 seconds (water). The voxel size was 40 mm × 15 mm × 20 mm. Spectral data analysis was carried out using jMRUI (version 6.0), with carnosine peaks fitted and expressed relative to the internal water signal. The carnosine content (in millimolars) was calculated using the following formula:

$$\mathrm{Cm} = \frac{(\mathrm{C_s})}{(\mathrm{H_2O_s})} \cdot \frac{(\mathrm{H_2O_{T1r}})}{(\mathrm{CT_{1r}})} \cdot \frac{(\mathrm{H_2O_{T2r}})}{(\mathrm{CT_{2r}})} \cdot \mathrm{H_2O_{muscle}} \cdot \mathrm{H_2O_{protons}},$$

where Cm is the carnosine concentration; C_S is the carnosine signal; H_2O_S is the water signal; C_{T1r}, C_{T2r}, H_2O_{T1r}, and H_2O_{T2r} are the relaxation correction factors for carnosine (previously described by Baguet et al[15]) and water (previously described by MacMillan et al[28]); H_2O_{muscle} is the concentration of water in muscle, which was deducted from the molar concentration of water (55,000 mM) and the approximate water content of skeletal muscle tissue (0.7 L/kg wet weight of tissue); and H_2O_{proton} is the number of protons in water. The coefficient of variation (CV) for test–retest interday carnosine measurements (~7 d apart) in our laboratory was 3.5% (soleus) and 4.3% (gastrocnemius; n = 15 subjects). The carnosine concentration of the soleus and gastrocnemius was converted to a sex-specific carnosine z score relative to a control population of active, healthy nonathletes (males: n = 38; females: n = 30). A carnosine aggregate z score was then derived by taking the average of the 2 muscle-specific carnosine z score values and was used for all analyses.

Race Performance Analysis

Although the participants had to be ranked in the world top-100 within the past 4 years of this study, races between 2010 and 2019 were analyzed for each participant with their career best performance used for the final analysis. Nonetheless, all career best performances were achieved within 2 years of the ^{1}H-MRS measurement. The races were analyzed from the following competitions: Australian National Open Championships 2010–2019; the Olympic Games—Rio de Janeiro, Brazil, 2016 and London, United Kingdom, 2012; the World Championships—Barcelona, Spain, 2013, Kazan, Russia, 2015, and Budapest, Hungary, 2017; the Commonwealth Games—Glasgow, United Kingdom, 2014

Table 1 Subject Characteristics

		FINA points		World record rank, %		Age, y		Height, cm		Body mass, kg	
	n (F:M)	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
Backstroke	7 (4:3)	919 (43)	898 (74)	104.1 (1.5)	103.7 (2.4)	23.8 (2.8)	24.8 (2.7)	175.3 (4.7)	180.0 (4.9)	66.0 (4.7)	74.0 (1.4)
Breaststroke	9 (5:4)	902 (16)	865 (32)	104.2 (1.0)	106.4 (1.6)	24.1 (2.1)	23.0 (2.3)	170.8 (6.8)	187.5 (3.0)	62.6 (6.8)	80.0 (3.9)
Butterfly	9 (3:5)	883 (65)	859 (39)	105.6 (2.4)	106.2 (1.9)	21.9 (2.2)	23.9 (3.7)	174.3 (7.8)	188.0 (4.1)	62.0 (8.3)	82.6 (6.3)
Freestyle	21 (9:13)	881 (25)	898 (53)	104.4 (1.8)	104.1 (1.8)	23.6 (3.7)	23.0 (2.6)	171.2 (3.5)	187.7 (5.7)	69.3 (5.5)	82.0 (8.0)

Abbreviations: F, female; M, male. Note: Data are presented as mean (SD).

and Gold Coast, Australia, 2018; the Pan Pacific Championships—Gold Coast, Australia, 2014 and Tokyo, Japan, 2018. Video footage and analysis were acquired from Swimming Australia Ltd (SAL, Melbourne, Australia); all race analyses were performed by Swimming Australia Ltd sports science practitioners (intratester 95% confidence interval [CI]; StT: ±0.11 s, TnT: ±0.26 s, and ToT: ±0.15 s). The StT was defined as the time from the starting signal until the crown of the swimmers' head crossed the 15-m mark; the TnT was defined as the time from the crown of the swimmer's head passing the 5-m line prior to contact with the wall to the crown of the head reaching the 10-m line from the wall on the subsequent lap, while ToT was identified as the time from initial contact with the wall during the turn segment to the crown of the head passing 10 m on the subsequent lap. To integrate the data into a single analysis including both male and female, as well as all strokes and race distances, a reference database (ie, control population) of 220 races (FINA points = 950 ± 22) was compiled. Ten swimming performances from each gender, stroke, and distance were analyzed, and the StT, TnT, and ToT were calculated. The mean (SD) for each performance parameter in every event in the reference database was determined, from which the individual subject performance parameter *z* scores were calculated to allow for an integrated analysis of swimmers across different events.

Statistical Analysis

All values are presented as mean (SD). The participants in this study were divided into 2 groups based on their carnosine aggregate *z* score. The participants were assigned to the high or low carnosine aggregate *z*-score group if their score was above or below the median value of all subjects. A linear mixed model was then used to determine the effect of the carnosine aggregate *z*-score group (ie, high or low) on StT, TnT, and ToT. To determine if the race distance influenced the performance parameters, a linear mixed model was employed with the absolute (ie, minutes:seconds: milliseconds) StT, TnT, and ToT values. Finally, as the relative importance of the start and turn to overall performance is greater in 100-m events compared to events of greater distance, we used a linear mixed model to determine the effect of carnosine aggregate Z-score group on the race performance parameter. When a significant *F* value for an interaction or main effect was identified, pairwise comparisons were performed with Bonferroni adjustments, where "differences" were detected. The effect size (*d*) was calculated to assess the magnitude of difference between the high and low carnosine aggregate *z* score groups. All statistical analyses were performed on IBM SPSS Statistics (version 25, Armonk, NY), and significance was accepted at $P < .05$. We used an Excel spreadsheet[29] to determine the mean performance differences between the positive and negative carnosine aggregate *z* score groups for each event. The analyses were performed separately for the male and female athletes and only for events with at least 2 observations in each group. The mean effects for male and female athletes were combined using a separate Excel spreadsheet.[30] CIs are approximate with our small sample size.

Results

The carnosine aggregate *z* score for the high and low groups was 0.60 ± 0.52 and −0.57 ± 0.33, respectively ($d = 2.69$). When the high and low carnosine aggregate *z* score groups were compared, there was no influence of the carnosine aggregate *z* score on the StT ($F = 3.20$, $P = .08$), TnT ($F = 0.97$, $P = .33$), and ToT ($F = 1.06$, $P = .31$) *z* scores (Table 2). There were no significant interactions between gender, stroke, and distance on the absolute StT and TnT, but there were significant main effects for gender (StT, $F = 235.67$; TnT, $F = 135.22$; ToT, $F = 102.25$, $P < .001$), stroke (StT, $F = 70.56$; TnT, $F = 178.56$; ToT, $F = 307.00$, $P < .001$), and distance (StT, $F = 39.84$; TnT, $F = 74.31$; ToT, $F = 44.56$, $P < .001$).

Absolute 100-m StT, TnT, and ToT were significantly faster when compared with 200-m StT ($P < .01$), TnT ($P < .001$), and ToT ($P < .001$), as well as 800/1500-m StT and TnT ($P < .001$; Table 3). When the 100-m event performance parameters' *z* scores were independently entered into a linear mixed model, the high carnosine aggregate *z*-score group had a significantly lower StT *z* score (high StT = 0.75 ± 1.15; low StT = 1.81 ± 1.51; $F = 5.825$, $P = .02$), but there were no significant differences in the TnT or ToT *z* scores between the 2 carnosine aggregate *z* score groups (TnT, $F = 2.56$, $P = .12$; ToT, $F = 2.60$, $P = .116$) (Figure 1).

In the 100-m freestyle events, the females in the high carnosine aggregate *z*-score group were substantially faster in both the StT (absolute difference ± 90% CI; 0.48 ± 0.25 s) and TnT (0.43 ± 0.39 s) compared with the low carnosine aggregate *z*-score group, but there was no clear difference in ToT (0.28 ± 0.31 s). Substantial performance differences between the carnosine aggregate *z*-score groups were not observed in the male 100-m freestyle swimmers: StT (0.02 ± 0.28), TnT (0.08 ± 0.74), and ToT (0.01 ± 0.31).

Table 2 The Mean (SD) StT, TnT, and ToT z Score for High and Low Carnosine Aggregate z-Score Groups for Each Distance (100, 200, 400, and 800/1500 m)

		Mean performance parameter z score		
		All strokes		
Event distance, m	Carnosine aggregate z-score group	Start	Turn	Turn out
100	High	0.75 (1.15)	1.66 (2.57)	0.86 (2.26)
	Low	1.81 (1.51)	3.15 (2.65)	2.46 (2.23)
200	High	0.04 (1.34)	1.56 (1.74)	0.96 (1.53)
	Low	0.91 (1.22)	1.75 (1.56)	0.85 (1.11)
400	High	0.16 (1.74)	2.48 (0.34)	1.17 (0.12)
	Low	0.03 (1.76)	1.39 (2.15)	1.18 (1.15)
800/1500	High	0.85 (0.66)	2.18 (1.53)	1.09 (0.33)
	Low	−0.23 (1.30)	1.94 (3.14)	1.11 (2.10)

Abbreviations: StT, start time; TnT, turn time; ToT, turn out time. Note: Data are presented as mean (SD).

Table 3 Absolute Start, Turn, and Turn Out Times (in Seconds)

		Times, s											
		Freestyle			Backstroke			Breaststroke			Butterfly		
Distance, m	Gender	StT	TnT	ToT	StT	TnT	ToT	StT	TnT	ToT	StT	TnT	ToT
100	Male	5.72 (0.15)	7.01 (0.26)	4.30 (0.15)	6.29 (0.04)	7.31 (0.27)	4.37 (0.19)	6.67 (0.23)	9.11 (0.19)	6.16 (0.16)	5.67 (0.29)	7.67 (0.32)	5.10 (0.32)
	Female	6.50 (0.25)	7.98 (0.25)	4.86 (0.18)	7.38 (0.28)	8.29 (0.15)	4.99 (0.11)	7.68 (0.27)	9.82 (0.13)	6.56 (0.13)	6.70 (0.26)	8.64 (0.38)	5.75 (0.26)
200	Male	5.96 (0.17)	7.51 (0.15)	4.50 (0.11)	6.64 (0.36)	8.20 (0.45)	4.90 (0.33)	6.90 (0.05)	9.51 (0.08)	6.27 (0.05)	6.05 (0.22)	8.64 (0.15)	5.62 (0.15)
	Female	6.72 (0.28)	8.37 (0.10)	5.05 (0.12)	7.58 (0.18)	8.79 (0.27)	5.16 (0.14)	7.85 (0.05)	10.52 (0.06)	6.90 (0.11)	6.73 (0.12)	9.38 (0.25)	6.19 (0.24)
400 m	Male	6.16 (0.19)	7.91 (0.18)	4.82 (0.16)									
	Female	7.34 (0.10)	8.82 (0.17)	5.38 (0.04)									
800/1500	Male	6.58 (0.28)	8.44 (0.37)	5.09 (0.21)									
	Female	7.56 (0.17)	9.03 (0.19)	5.46 (0.09)									

Abbreviations: StT, start time; TnT, turn time; ToT, turn out time. Note: Data are presented as mean (SD).

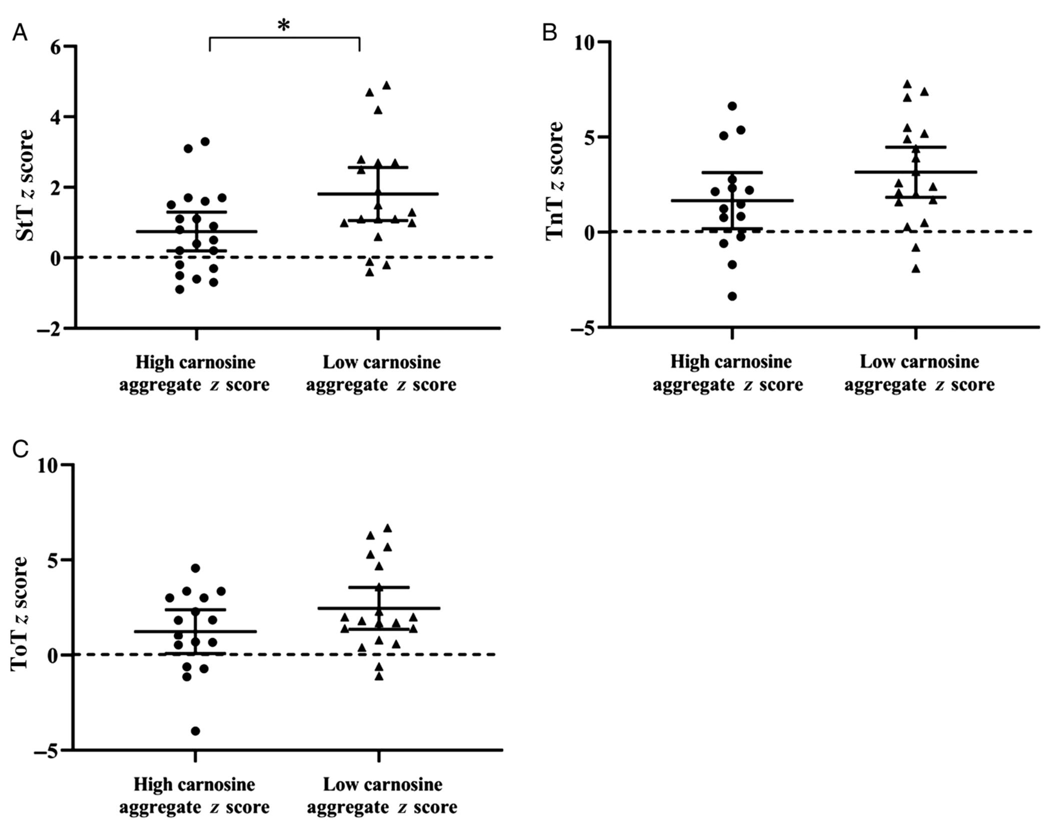

Figure 1 — Mean and 95% CI of the 100-m events: (A) StT z score, (B) TnT z score, and (C) ToT z score for the high and low carnosine aggregate z-score groups ($^{*}P = .02$). StT indicates start time; TnT, turn time; ToT, turn out time.

However, the combined male–female performance differences in the 100-m freestyle event showed clear differences between the carnosine aggregate z score groups in StT (0.25 ± 0.17 s), but not in TnT (0.20 ± 0.62) or ToT (0.01 ± 0.12 s).

Discussion

This study demonstrated that the degree to which MFT influences performance parameters in elite swimmers depends upon the event distance. The StT and TnT were significantly faster in 100-m events compared with both 200- and 800/1500-m events. During 100-m events, the swimmers with a higher carnosine aggregate z score (ie, faster muscle typology) had a significantly faster StT compared with the swimmers with a low carnosine aggregate z score.

To date, the effect of MFT on start and turn performance in competitive swimming has not been investigated. The swim start is an explosive movement of the lower-body musculature, which maximizes the net impulse and take-off velocity to augment performance.[31] We found that the elite swimmers in 100-m events had a faster StT, TnT, and ToT than 200- and 800/1500-m events, and within 100-m events, the swimmers with higher carnosine aggregate z scores had a significantly faster StT. In contrast, we found no influence of muscle fiber typology on the performance parameters when all distances were entered into a single linear mixed model. The lack of influence of muscle fiber typology in these analyses can be explained by the substantial differences between strokes, distances, and gender, which may have diluted the influence that muscle fiber typology has on these performance parameters. We aimed to reduce the influence that these factors have by calculating StT and TnT, and the ToT z scores derived from truly world-class swimming performances (FINA points = 950 ± 22). It is clear that 100-m swimmers place a larger emphasis on the start phase than swimmers of longer distance events, which is likely because the StT contributes ~12% of the overall 100-m performance time.[2] In comparison, the StT contributes ~7% time in 200-m events, ~2.5% in 400-m events, and <1.5% in 800/1500-m events. This is in agreement with other research that has demonstrated that both the StT and TnT of 200-m events are slower than 100-m events.[1] A faster StT has also been associated with measures of lower-body power and strength, including the countermovement jump, squat jump, and 3-repetition maximum squat.[20,32–34] Specifically, West et al[20] found that lower-body peak power and predicted 1-repetition maximum were significantly related to the StT (15 m) in a cohort of international-caliber male 50-m swimmers ($r^2 = −.73$ and −.55, respectively). Furthermore, West et al[20] suggested that land-based strength programming should be included into a training program to improve the StT and continued to advise that the specific hypertrophy of type II muscle fibers and/or an individual with higher proportions of type II muscle fibers would have an advantage in sprint swimming StT performance. A recent review of strength and conditioning practices in swimming highlighted that low-volume, high-velocity training focusing on the rate of force development showed a positive transfer to swimming performance.[35] It is conceivable that this type of training may preferentially induce type II muscle fiber hypertrophy, but this requires further experimental evidence. The results of this study would confirm these suggestions, whereby 100-m swimmers with a faster muscle typology had a substantially faster StT compared with swimmers with a slower muscle typology.

The findings of this study suggest that swimmers with higher carnosine aggregate z scores do not gain a significant advantage in the turn phase of swimming performance. Previous research has suggested that the technique of the turn has greater importance on overall turn performance than leg muscle power,[36,37] which supports the findings of this study. Furthermore, Nicol et al[37] assessed the influence of 21 biomechanical parameters on turn performance and determined that the largest improvements in rotation TnT (ie, FR) would result from an emphasis on the force applied to the wall and in the tuck TnT (ie, FL) by increasing the distance at which the point of surfacing occurs. The authors suggested that, because the influence of each parameter was small to moderate in effect, a "holistic" approach should be implemented to improve turn performance, with a high importance placed on the technique. Swimmers with superior dry-land force and power characteristics have also been described to have superior turn performance, which was suggested to be associated with the number of years spent undertaking dry-land training, as opposed to an underlying physiological or physical characteristic.[21] These findings highlight that, while TnT and ToT parameters are consistent with explosive movements, superior turn technique may be more influential on turning performance, rather than maximizing muscle power output. The results of this study agree with this previous research,[37] whereby swimmers with a faster muscle typology did not seem to have a superior turn performance. To improve the validity of our results, individualization of each competitor's flight, surface, and underwater profiles could be distinctly identified and considered.

Athletes who possess a greater proportion of type II muscle fibers compete in sports that require higher levels of explosive power, such as explosive track-and-field events, track cycling, and powerlifting.[14,25,38,39] Interestingly, swimmers have been characterized as typically possessing greater proportions of type I muscle fibers compared with type II muscle fibers.[14,25,40–44] Sprint-orientated swimmers have been shown to have a large variation (30%–56%) of type II muscle fibers[44] and have also been shown to have higher proportions of type I fibers, compared with other athletes of a sprint orientation.[25] Despite the few studies characterizing the MFT of swimmers, previous research has not determined the relationship between MFT and start and turn performance. Given that the previous research has alluded to type II muscle fiber hypertrophy improving swimming performance,[35] the early identification of MFT could help strength and conditioning practitioners develop individualized strength and conditioning training programs, which, in turn, maximize start and turn performance later in a swimmers' career; further research is warranted in this domain. While classical research has suggested that swimmers rarely possess a high proportion of type II fibers, this study has identified a distinct advantage for those swimmers who do possess a faster muscle typology given the faster StT of swimmers in the high carnosine aggregate z-score group within 100-m events.

Practical Applications

In light of the findings of this study, swimmers with a faster muscle typology have the potential advantage of a faster StT in sprint swimming events. The StT of a 100-m male or female freestyle swimmer with a high carnosine aggregate z score is, on average, 0.25 seconds (CI 90%, ±0.17 s) faster than a swimmer with a low carnosine aggregate z score. Coaches and sports scientists should heavily emphasize improving the technique of both the start and the turn to ensure that the most efficient skill is executed during the race. As such, a swimmer with a faster muscle typology and a superior technique will be able to take advantage of this trait during the start phase and maximize their performance in sprint swimming events. Future research could investigate the different segments of start and turn performance to identify additional parameters that may be influenced by MFT (eg, underwater or surface profiles, force application to the wall, or velocity at breakout).

Conclusion

The results of this study suggest that elite 100-m swimmers with a faster muscle typology perform the start in a faster time than swimmers with a slower muscle typology. These differences are likely to influence the overall performance time due to the substantial relative contribution that the StT contributes to the overall performance time in 100-m events and suggest that muscle fiber typology is an important characteristic for elite sprint swimmers.

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