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Muscle Typology of World-Class Cyclists across Various Disciplines and Events

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Abstract

Purpose. Classical track-and-field studies demonstrated that elite endurance athletes exhibit a slow muscle typology, while elite sprint athletes have a predominant fast muscle typology. In elite cycling, conclusive data on muscle typology are scarce, which may be due to the invasive nature of muscle biopsies. The non-invasive estimation of muscle typology through the measurement of muscle carnosine enabled to explore the muscle typology of 80 world-class cyclists of different disciplines. *Methods.* The muscle carnosine content of 80 cyclists (4 bicycle motor cross racing (BMX), 33 track, 8 cyclo-cross, 24 road and 11 mountain bike) was measured in the soleus and gastrocnemius by proton magnetic resonance spectroscopy and expressed as a z-score relative to a reference population. Track cyclists were divided into track sprint and endurance cyclists based on their UCI-ranking. Moreover, road cyclists were further characterized based on the percentage of UCI points earned during either single- and multi-stage races. *Results.* BMX cyclists (carnosine aggregate z-score of 1.33) are characterized by a faster muscle typology than track, cyclo-cross, road and mountain bike cyclists (carnosine aggregate z-score of -0.08, -0.76, -0.96 and -1.02, respectively: $P < 0.05$). Track cyclists also possess a faster muscle typology compared to mountain bikers ($P = 0.033$) and road cyclists ($P = 0.005$). Moreover, track sprinters show a significant faster muscle typology (carnosine aggregate z-score of 0.87) compared to track endurance cyclists (carnosine aggregate z-score of -0.44) ($P < 0.001$). In road cyclists, the higher the carnosine aggregate z-score, the higher the percentage of UCI points gained during single-stage races ($r = 0.517$, $P = 0.010$). *Conclusions.* Prominent differences in the non-invasively determined muscle typology exist between elite cyclists of various disciplines, which opens opportunities for application in talent orientation and transfer. **Key Words:** Cycling, muscle fiber type composition, elite, carnosine, spectroscopy

1 Introduction

The Union Cycliste Internationale (UCI) governs five main cycling disciplines: bicycle motor cross racing (BMX), track, road, mountain bike and cyclo-cross (1). Both track and road races can be further subdivided in specific events (sprint, keirin, 500m-1km time trial, individual pursuit, scratch, points race and omnium for track and single-stage, multi-stage and time trial for road, respectively). Some events are classified as sprint events (e.g. BMX, sprint, 500m-1km time trial and keirin) or as endurance events (e.g. scratch, multi-stage), while others are allocated in between, as they are endurance based but require repeated sprints during the performance (e.g. points race) (2).

Decisive determinants across these events are either maximal power generation capacity, muscle endurance, or a mixture of both (3). Maximal power generation during cycling is mainly determined by a large muscle volume, long muscle fibers and a high percentage of fast-twitch fibers (2, 3). These fast-twitch fibers have a two (Type IIa) to four fold (Type IIx) higher maximal shortening velocity and consequently generate higher peak power as compared to slow-twitch fibers (4). Therefore, a high proportion of fast fibers is essential in sprint events, like BMX racing in which a fast start is crucial for the final ranking (5), but also for road sprinters who produce a very high intensity burst of speed at the finish of the race (6). On the other hand, physiological markers found to be predictive of success in endurance cycling include a high maximal aerobic power (VO_2max), high gross mechanical efficiency, high lactate threshold and a high proportion of slow-twitch muscle fibers (6–8). Slow-twitch fibers are characterized by a high resistance to fatigue, enabling the maintenance of high power outputs for long periods as well as a high gross mechanical efficiency (3, 6, 7). Considering that an across-muscle

phenotype exist, with respect to the muscle fiber type composition (in which some individuals display generally faster/slower muscles when compared to others (9, 10)), this muscle typology is mostly genetically determined (11) and crucial to both ends of the cycling spectrum, it can be considered as an important factor for predicting performance success, and thus for talent identification and transfer possibilities.

Classic biopsy studies determining the muscle typology in humans revealed a muscle fiber continuum ranging from 15% to 85% slow-twitch fibers in the vastus lateralis (12). In track-and-field, international caliber sprinters can be found at the fast side of the continuum, demonstrating a low percentage of slow-twitch fibers (21-28% slow-twitch fibers in the gastrocnemius), middle-distance runners occupy the center, showing a mix between both fibers (41-73% slow-twitch fibers in the gastrocnemius), while distance runners can be located at the slow side of the continuum (63-74% slow-twitch fibers in the gastrocnemius) (13). Literature on the muscle typology of cyclists is less conclusive, as “well-trained” road cyclists span the full range of 17 to 85% slow-twitch fibers in the vastus lateralis (3, 7, 14–17). However, it is still unclear if part of this range can be explained by differences in athlete level and specialization (single vs multi-stage oriented cyclists). Research on national and international elite track sprint athletes showed a distribution of 58 to 61% slow-twitch fibers in the vastus lateralis (3, 18). It is uncertain if this muscle typology is generalizable to world-class track sprint cyclists. Conclusive data on the muscle typology of professional road and track cyclists are scarce and to the best of our knowledge no data is available on the muscle typology of BMX, cross-country mountain bike or cyclo-cross athletes.

The lack of data on the muscle typology in professional and world-class cyclists may be due to the invasive nature of muscle biopsies, which is required for the traditional evaluation of the muscle fiber type composition. Therefore, the application of a non-invasive estimation of muscle typology might yield further insight. Baguet et al. developed a non-invasive estimation based on calf muscle carnosine quantification with proton magnetic resonance spectroscopy (19). Carnosine is a muscle pH buffer, that has a twofold higher concentration in fast-twitch fibers compared to slow-twitch fibers (20) and is associated with the muscle biopsy determined area of fast-twitch fibers (19). Moreover, the validity of this technique is already demonstrated in track-and-field (19, 21). In an initial report (21), we documented data on 14 professional cyclists, comparing them to runners, kayakers and swimmers, but it lacked the power to compare the numerous disciplines of cycling. Therefore, the current study aimed to compare the muscle typology of a large group of world-class cyclists spanning the entire range of cycling disciplines and events.

2 Methods

Participants

In total, 80 professional cyclists (57 men and 23 women) from six nationalities (Belgium, Australia, UK, the Netherlands, New Zealand and Germany) volunteered to participate in this cross-sectional study conducted at two scan sites in Belgium and Australia (table 1). To classify a cyclist into his/her specialist discipline and event, the UCI ranking was consulted, as this ranking allowed intra- and inter-individual comparison of performance between different disciplines and events (1). A cyclist was allocated to the discipline/event in which he/she obtained the best UCI ranking during his/her career. Only professional BMX cyclists (n=4), track

cyclists (n=33), cyclo-crossers (n=8) and cross-country mountain bikers (n=11) competing at major international cycling events such as continental or world championships were included in this study. Road cyclists needed to be part of a professional World Tour (n=18) or Pro Continental team (n=6). If they were part of the latter, they also needed to have obtained at least a mean of 100 UCI points over the past 3 years, in order to make sure they participated regularly and successfully in professional races (22). Moreover, athletes were only scanned if they did not use beta-alanine in the 3 months before the scan, as beta-alanine supplementation has been shown to increase muscle carnosine and would therefore disrupt the relation between the carnosine concentration and the muscle fiber typology. In total, this cohort consisted of 4 Olympic medalists and 24 World Championship medalists. Moreover, 26 of the 80 athletes in this study were classified as world top 10 athletes, 35 athletes were ranked between place 11 and 100 and the remaining 19 athletes had not (yet) reached a world top 100 ranking during their career.

Ethical approval

Written informed consent was obtained from all individual participants included in the study. This study was performed in accordance with the standards of ethics outlined in the Declaration of Helsinki and was approved by the local ethics committees (Ghent University Hospital, B67020097348 and Griffith University Human Ethics Committee, 2017/344).

Muscle typology screening

Muscle carnosine content was measured by proton magnetic resonance spectroscopy (^1H -MRS) on a 3-T whole body MRI scanner in the soleus and the gastrocnemius of all subjects. Fifty-four

athletes were scanned in Belgium (Siemens Healthineers AG, Erlangen, Germany) and 26 were scanned in Australia (Philips Medical Systems, Best, The Netherlands). The subjects were lying in a supine position and the lower leg was fixed in a spherical knee coil. Single-voxel point-resolved spectroscopy sequence with the following parameters was used: repetition time (TR) of 2000ms, echo time (TE) of 30ms (Belgium) and of ~40ms (Australia), 128 excitations (carnosine), 1024 data points, spectral bandwidth of 1200Hz (Belgium) and 2048Hz (Australia), total acquisition time of 4min16s (carnosine) and 32s (water), and a voxel size of 40mm x 12mm x 30mm (Belgium) and 40mm x 15mm x 20mm (Australia). The absolute carnosine content (mM) in Belgium was calculated as described by Baguet et al. (4) using the phantom replacement technique. In Australia, peaks were fitted and expressed relative to the internal water signal. Carnosine content (mM) was calculated using following formula:

$$C_m = \frac{(C_s)}{(H_2O_s)} \cdot \frac{(H_2O_{T1r})}{(CT_{1r})} \cdot \frac{(H_2O_{T2r})}{(CT_{2r})} \cdot H_2O_{\text{muscle}} \cdot H_2O_{\text{protons}} \quad [1]$$

where C_m is the carnosine concentration, C_s is the carnosine signal, H_2O_s is the water signal, CT_{1r} , CT_{2r} , H_2O_{T1r} and H_2O_{T2r} are the relaxation correction factors for carnosine (earlier described by Baguet et al. (23)) and water (described by Macmillan et al. (24)), H_2O_{muscle} is the concentration of water in muscle, which was deducted from the molar concentration of water (55 000mM) and the approximate water content of skeletal muscle tissue (0.7L/kg wet weight of tissue) (25). H_2O_{proton} is the number of protons in water. In both sites, the carnosine concentration of each muscle was converted to a sex-specific z-score relative to an age-matched control population of active, healthy non-athletes, consisting of 163 men and 112 women in Belgium and 38 men and 30 women in Australia. The mean of the carnosine z-scores of the

gastrocnemius and the soleus was then calculated, and this carnosine aggregate z-score was used for all analyses. The carnosine aggregate z-score was used for two reasons: 1) both muscles showed comparable differences in the carnosine z-score between the cycling disciplines and events, 2) using the average of both muscles attenuated the effect of possible methodological errors.

Data analysis

Road:

Road cyclists were further characterized into two different subclasses using ProCyclingStats (26). On the one hand we classified a cyclist to be a single-stage, time trial or multi-stage cyclist. For this purpose, the UCI points obtained by the cyclist during his/her whole career were subdivided in either single-stage, time trial or multi-stage, depending on the characteristics of the race in which the UCI points were obtained. The category in which they obtained the most UCI points determined the cyclist's classification. Moreover, we summated the points obtained during single-stages and multi-stages and calculated the percentage share of both events to further analyze correlations with the muscle typology.

On the other hand, we identified each cyclist's "specialization" into flat terrain, all terrain or uphill terrain. In this analysis every race was categorized in either being a flat or an uphill race, based on a profile score of that race. When computing this profile score, the steepness and length of the climbs and the position of the climbs from the finish were reviewed: $((\text{steepness}(\%)/2)^2 \times \text{length (km)} \times \text{position of the climb})$ (26), in which the position of the climb was 1; 0.8; 0.6; 0.4; 0.2 depending on the distance of the climb to the finish, respectively 10km, 25km, 50km, 75km

or >75km. Races were classified as flat races if the ProfileScore was 50 or lower and the ProfileScore of the final 20km was 25 or lower, while races were classified as uphill races if the ProfileScore was 50 or higher or the ProfileScore of the final 20km was 25 or higher. All points that were obtained in flat and uphill races were summed and a cyclist was classified as being a flat terrain specialist if he/she obtained >66% of his points during flat terrain races, as an all terrain specialist if he/she did not show a specific specialization and as an uphill terrain specialist if he/she obtained >66% of his points during uphill races. Moreover, these percentage shares were used to further analyze correlations with the muscle typology.

Track:

In order to analyze transfer possibilities and combinability in between all individual track events, it was analyzed if medalists on a specific event during the World Championships of 2009 to 2020 were able to obtain a medal in another event during these Championships (sprint, keirin, 500m-1km time trial, individual pursuit, scratch, points race and omnium). First, the percentage of athletes having no successful combinations with another event were determined. The remaining percentage was further subdivided based on the distribution of the successful combinations.

Statistical analysis

Shapiro-Wilk tests were performed to check the normality of the data. A one-way ANOVA was used to compare the carnosine aggregate z-scores of the different disciplines. Pearson correlations were performed to examine associations between the carnosine aggregate z-score and the percentage share of single/multi-stage and flat/uphill terrain points. An independent t-test and one-way ANOVA was performed to analyze the difference in carnosine aggregate z-score

between track sprint and endurance athletes and between different levels of athletes (world top 10; top 100; >top 100). All statistical analyses were performed using SPSS 26.0 (SPSS Inc, Chicago, IL, USA), with statistical significance accepted as $P \leq 0.05$.

3 Results

BMX cyclists (carnosine aggregate z-score of 1.33; range: 0.21 to 2.43) are characterized by a higher carnosine aggregate z-score, which indicates a faster muscle typology compared to track cyclists (carnosine aggregate z-score of -0.08; range: -1.41 to 3.62), cyclo-crossers (carnosine aggregate z-score of -0.76; range: -1.45 to -0.10), road cyclists (carnosine aggregate z-score of -0.96; range: -2.22 to 0.63) and mountain bikers (carnosine aggregate z-score of -1.02; range: -1.94 to -0.06). Track cyclists also express a higher carnosine aggregate z-score compared to road cyclists ($P=0.005$) and mountain bikers ($P=0.033$) (Fig.1).

The broadest range in the carnosine aggregate z-score was found in the road and the track cyclists (width of range of 2.85 and 5.03, respectively). These disciplines consist of different type of races and were therefore further divided into specific events. The road cyclists were classified as being a time trial, single-stage or multi-stage specialist (Fig. 2A). No significant differences in carnosine aggregate z-score were found between these groups, neither between the world top 100 nor the >top 100 cyclists in these events ($P>0.05$). However, the percentage share of single/multi-stage UCI points was significantly correlated to the carnosine aggregate z-score in all subjects ($r=0.517$, $P=0.010$; Fig. 2B), and even more strongly when only the world top 100 athletes were considered ($r=0.688$, $P=0.019$).

When investigating the specialisation into flat terrain, all terrain or uphill terrain, no significant differences were found in carnosine aggregate z-score between the categories (Fig.2C). However, cyclists ranked in the world top 100 of the flat terrain group showed higher carnosine aggregate z-scores (-0.31 ± 0.62) in comparison to the athletes who did not reach the top 100 (-1.14 ± 0.72 ; $P=0.031$). Moreover, the percentage share of flat/uphill points significantly correlated to the carnosine aggregate z-score in all subjects ($r=0.426$, $P=0.038$; Fig. 2D), and also when only the world top 100 athletes were considered ($r=0.596$, $P=0.053$).

Track cyclists were further divided into sprint (sprint, keirin and 500m-1km time trial) and endurance events (individual pursuit, scratch, points race and omnium). The sprint group had significantly higher carnosine aggregate z-scores than the endurance group ($P=0.001$, Fig. 3A&B). Moreover, 89% of the sprint group had a positive carnosine aggregate z-score, while 71% of the endurance group had a negative carnosine aggregate z-score. When looking into the successful combinability of events in these athletes, defined as having a world top 100 ranking in more than 1 event (Fig. 3C), most track sprint athletes are able to combine their main event (black circle) with other sprint events (gray arrows). The same is valid for the endurance group, in which most successful combinations are present within endurance events. The only event in which combinations were seen between sprint and endurance events is the 500m-1km time trial group.

Furthermore, successful combinability of events during the World Championships of 2009 to 2020 was investigated in a separate medal analysis. If a medalist on a specific event was able to obtain a medal in another event during these championships, this combination was determined as

successful (Fig. 3D). Combinations between sprint events seem to be the most common as 56.7 to 62.6% of the track sprint medals were combined with a second medal in another sprint event. However, the overall combinability seems to be lower in the track endurance events, as only 29.9 to 31.3% of the scratch, points race and omnium medals were combined with a second medal in another endurance event. Individual pursuit seems to harbor the most specificity as this was only combined with other endurance events in 13% of the cases. Combinations between track endurance and track sprint events were less common (0 to 3.73%) and the highest possibility to combine sprint and endurance successfully was found in the 500m-1km time trial group (3.73%).

In the overarching view of all cycling disciplines (Fig. 4), a fast muscle typology predominates in sprint events, such as keirin, BMX, sprint and 500m-1km time trial, while an intermediate typology is found in time trial, points race, scratch and omnium, and a slow typology is detectable in individual pursuit, single-stage, cyclo-cross, mountain bike and multi-stage. Moreover, this trend does not seem to be influenced by sex, nor by the level of the professional athlete (world top 10, top 100, >top 100).

4 Discussion

This is the first study investigating the muscle typology in a large group of elite cyclists, allowing the examination of different cycling disciplines and events. A large heterogeneity in the non-invasively estimated muscle typology was found, indicating that all muscle typologies are present amongst elite cyclists. Nevertheless, when grouping the cyclists according to their main discipline, clear patterns in muscle typology emerged, in which both BMX cyclists and track

cyclists possessed a faster typology when compared to cyclo-cross, road and mountain bike cyclists.

We determined a predominantly fast typology in BMX cyclists, which matches the performance-determining factors of this discipline. BMX racing can be defined as an all-out sprint discipline with race times not exceeding 45s at the elite level. In order to optimize performance a fast start is needed, in which a maximal power output (higher than 2000W) should be reached in 1-2s (27, 28). BMX cyclists use a relatively low fixed gear ratio, to induce a small inertial load during the stationary start. The latter allows a fast start and implies that high power should be generated at high cadences (28). As it has been established that the optimal pedaling rate is positively correlated with the percentage area of fast fibers in the vastus lateralis, possessing a high percentage of fast fibers will be crucial in this discipline (29).

The track sprint cyclists possessed a carnosine aggregate z-score of 0.87, corresponding to a fast muscle typology. This is in contrast to the current literature reporting higher amounts of slow versus fast fibers in this population (61.3 ± 7.8 % slow-twitch fibers in the vastus lateralis in the research of Van Der Zwaard et al., (3) and $58.0 \pm 10.8\%$ slow-twitch fibers in the vastus lateralis in the research of Mackova et al. (18)). This discrepancy could be attributed to the level of the athletes. The current investigation included world-class track sprint athletes (5 of the 9 track cyclists were medalists at the World Champions, and 8 out of 9 were world top 100 athletes) (30), which was not the case in the previous investigations. In the study of Mackova, the Czechoslovakian National team had a mean personal best which was 22-24% slower than the current world record and the track sprint athletes in the study of Van Der Zwaard had a lower

peak power output (18.5W/kg) compared to what is normally established in elite athletes (19.3-20.8W/kg), and could therefore not be classified as world-class. This might suggest that a fast typology is favorable to become a world-class track sprint athlete. As track sprint cycling is performed with fixed gears, the fast fibers are needed to produce a high pedaling frequency (mean pedaling frequency of around 150 revolutions per minute (rpm) during 200m sprint) and consequently high peak power outputs (up to 2000W in 200m sprint) (31, 32). Cyclists excelling in the track endurance events (individual pursuit, scratch, points race and omnium) expressed an intermediate muscle typology (mean z-score of -0.44), which is in line with the physiological needs, as both a high aerobic and anaerobic power are needed to be successful in these events (33).

An interesting finding from the present study was the relationship between the combinability of events in track cycling and the muscle typology. Combinations between track sprint events (sprint, keirin and 500m-1km time trial) occur regularly, and might be related to the fast typology. Fast fibers and muscle volume explain 65% of sprint performances (3) and might therefore be an important, innate quality of a purebred sprinter. In track endurance events, less combinations occurred compared to track sprint events. This might be related to the fact that next to the muscle typology, many other factors determine track endurance performance such as high maximal aerobic power ($\text{VO}_{2\text{max}}$), lactate threshold, gross mechanical efficiency, muscle oxygenation and tactical decisions (8). Lastly, of the few combinations that were present between sprint and endurance events, most combinations were seen with the 500m-1km time trial. Interestingly, this was also the event with the highest range in muscle typology (carnosine aggregate z-scores from -1.39 to 2.31) and seems to be the only event in which the aerobic and

the anaerobic energy system equally contribute to energy delivery (5-20% anaerobic alactic, 40-47% anaerobic lactic and 35-50% aerobic energy production), in comparison to sprint which is mostly anaerobically based (95-100%) and in individual pursuit and points race which is mostly aerobically based (84-94%) (30, 34).

The estimated predominance of slow fibers in road cyclists is in agreement with the literature (3, 16) and the broadness of the muscle typology range (carnosine aggregate z-score of -2.22 to 0.63) can be explained by the specialization of the individual cyclists. We found that the lower the carnosine aggregate z-score (the slower the typology), the more the cyclists are able to collect points during multi-stages and uphill terrain races. During these multiday and mountainous races, the fatigue resistance, high gross mechanical efficiency and fast recovery of the slow fibers are indispensable (35). Further evidence of the importance of slow fibers and the optimization of their use in road cycling are the high cadences (> 90 rpm) typically used by professional cyclists. These cadences do not serve to minimize the oxygen uptake, as low cadences (50-60 rpm) are reported to be the most efficient (36), but are rather used to minimize the force per pedal stroke, and thereby reduce the recruitment of the less efficient and easily fatiguing fast fibers (37). Nevertheless, fast fibers are beneficial for road cyclists in order to win the sprint in flat terrain and single-stage races, which is supported by the positive correlation between the carnosine aggregate z-score and the performance at flat terrain/single-stage races. The objective of road sprinters is to complete a race with the least possible energy cost to be able to create high power at the finish (>1500W for the last 200m) (6). The need for fast fibers in road sprinters was already suggested by Mackova et al. (18) and Sjogaard et al. (16), as the best sprinters of both the biopsied populations possessed the highest percentage of fast fibers in the vastus lateralis. In

addition, a fast typology might contribute to reach the world top level, as world top 100 athletes specializing in flat terrain races had a faster typology than their non-top 100 counterparts. Next to the final sprint, the faster muscle typology might also be valuable during a decisive attack, which often determine a victory during these flat terrain races.

Furthermore, the muscle typology of cyclo-cross and mountain bike was comparable to road cyclists (carnosine aggregate z-score of -0.76; -1.02 and -0.96, respectively). It could have been expected that the muscle typology of cyclo-cross cyclists was somewhat faster than that of road cyclists and mountain bikers, due to the shorter duration (cyclo-cross: \pm 1h; mountain bike: \pm 1h30min-2h; road: $>$ 4h), high work rates, involving short explosive climbs and running (cyclo-cross: \pm 330W; mountain bike: \pm 220W; road 150-300W) and higher heart rates during the race (cyclo-cross: 91% of peak heart rate; mountain bike: 88% of peak heart rate and road 51.7-78.6% of peak heart rate) (30, 32, 38–40). Interestingly, the indifference between the muscle typology suggests that one could possibly transfer between these disciplines. However, it should be noted that next to muscle typology, multiple other factors like the technical skills will be important for a successful transfer. The comparable muscle typology between mountain bike and road cycling was expected as the physiological profile of mountain bike was found to be similar to uphill terrain and all terrain road cyclists (41, 42).

The present study shows that the muscle typology is related to event specialization in cycling, supporting the importance of the muscle typology in the multi-dimensional construct of talent identification. As the muscle typology was characterized non-invasively in this study, this information could be used as additive information on the anthropometrical, physical and

technical data that is currently used by cycling federations and clubs in order to identify talents. In this way, this tool could be useful to support emerging cyclists by giving additional information on their ideal discipline and event. For example, if a young talent cyclist possessed a carnosine aggregated z-score of 1, we would advise this athlete to consider BMX or a track sprint. In contrast, an athlete with a z-score of -2 would have a higher likelihood to excel in multi-stage road cycling or mountain bike. Moreover, the knowledge of the muscle typology might be of importance to established professional cyclists as it can further guide them into their most suitable events and transfer possibilities. Furthermore, this non-invasive estimation of muscle typology can be of value in individualizing training and recovery programs, as the time to recover from high-intensity cycling is shown to be dependent on the muscle typology (35).

The different study locations (Belgium and Australia) enabled to investigate a large group of professional and world-class athletes (n=80), which is a valuable asset of this study. However, it introduced the use of two different devices and quantification methods. Nevertheless, we were able to correct for possible differences in absolute carnosine concentrations by converting these concentrations into site-specific z-scores relative to a locally scanned healthy non-athlete control population.

Conclusion:

This study is the first to investigate the muscle typology of elite cyclists across the five main cycling disciplines. Based on the results of this study, keirin, BMX, sprint and 500m-1km time trial cyclists can be considered as fast typology athletes, who are in need of fast fibers to produce the highest power possible. Time trial, points race, scratch and omnium can be classified as more

intermediate typology athletes, as they need combined sprint and endurance performance. Individual pursuit, single-stage, cyclo-cross, mountain bike and multi-stage cyclists have a slow typology, as these are mostly aerobically-based disciplines. As the muscle typology correlates well with the ideal discipline and event in both male and female cyclists of all professional levels, it may be a relevant factor for talent identification and talent transfer.

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Figure captions

Figure 1. Boxplots showing the muscle typology of the five main cycling disciplines. Data are presented as median, lower quartile, upper quartile and minimum to maximum range. (* $P < 0.05$; ** $P < 0.001$)

Figure 2. Categorization of road cyclists into time trial, single-stage and multi-stage (A) and flat terrain, all terrain and uphill terrain (C). Correlations between the percentage share of single/multi-stage UCI points and carnosine aggregate z-score in all cyclists and in the world top 100 cyclists only (B). Correlations between the percentage share of flat/uphill terrain points and carnosine aggregate z-score in all cyclists and in the world top 100 cyclists only (D).

Figure 3. Subdivision of the 33 track cyclists in (A) the 3 sprint versus the 4 endurance events and (B) in each of the 7 specific events separately. Combinability of events in the athletes from this study, the black circle is the main event and the gray arrow points towards a successful combination (C). Combinability of events from medal analysis during the World Championships (D). (* $P < 0.05$)

Figure 4. Distribution of carnosine aggregate z-scores of male and female cyclists with different levels (world top 10, top 100, >top 100 ranking) in all disciplines and events.

Table:

Table 1. Number, anthropometrical details and level of athletes in the different disciplines

Data are presented as mean \pm SD. BMX, bicycle motor cross racing; MTB, mountain bike.

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Figure 1

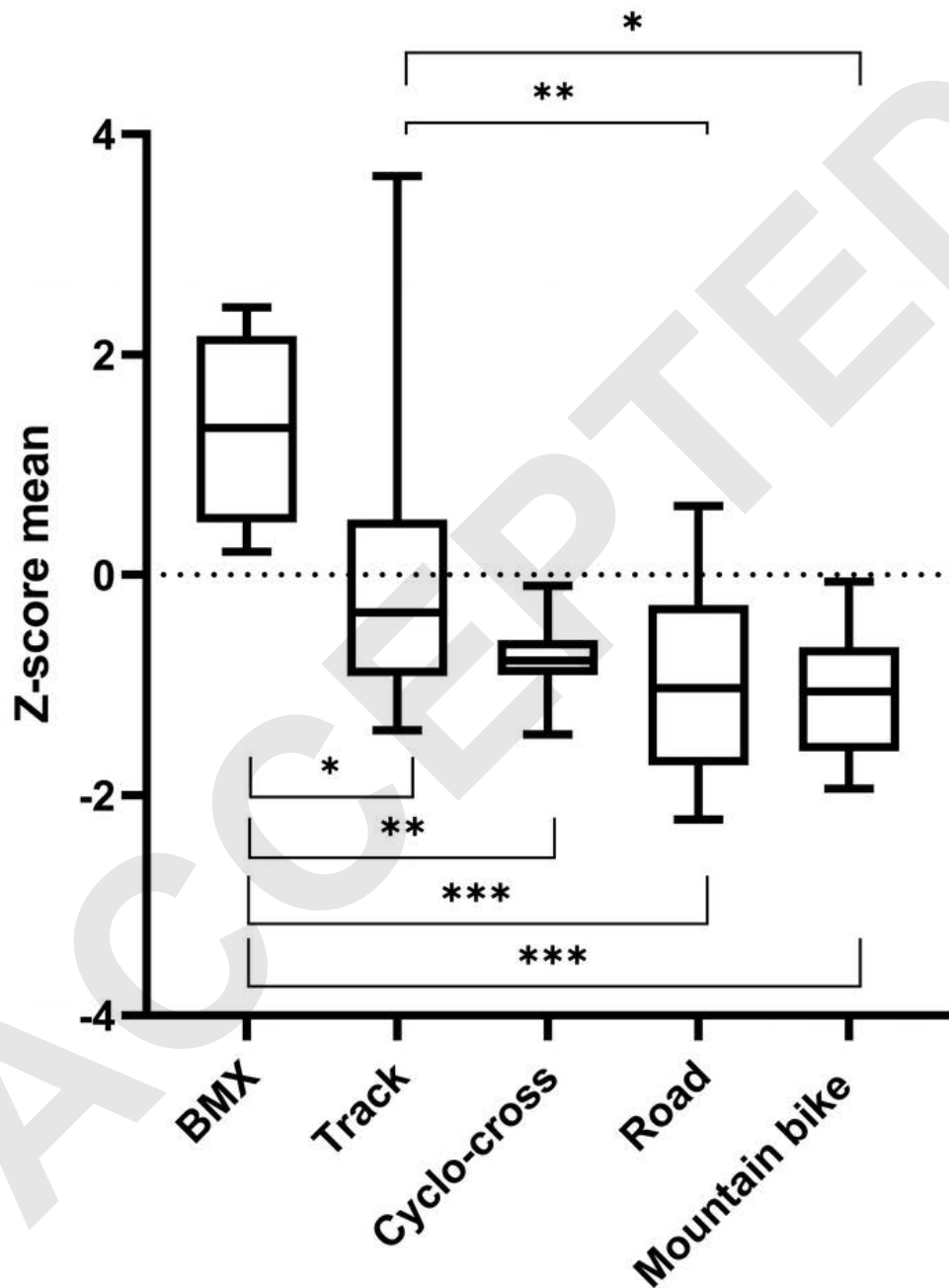


Figure 2

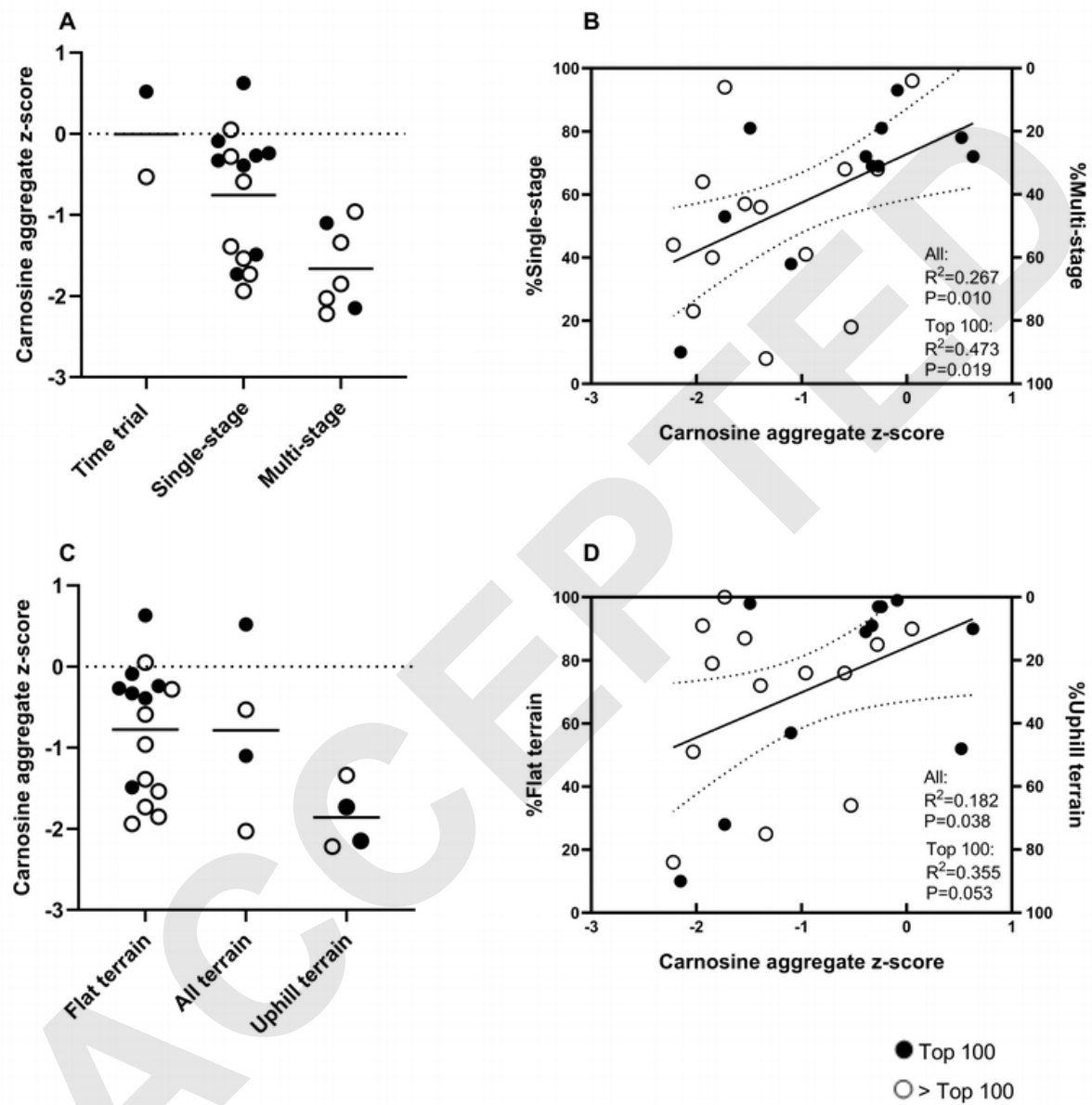


Figure 3

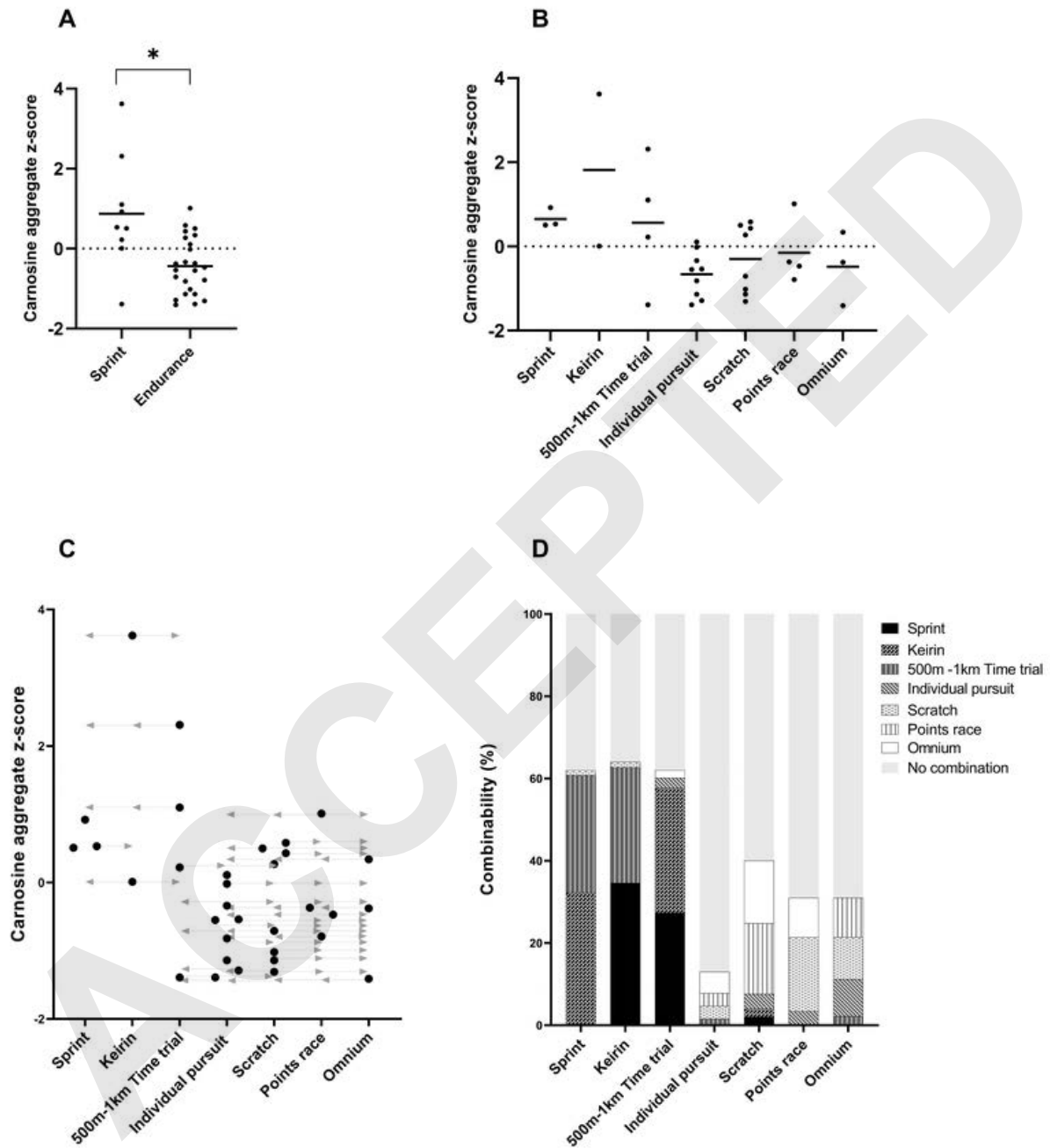


Figure 4

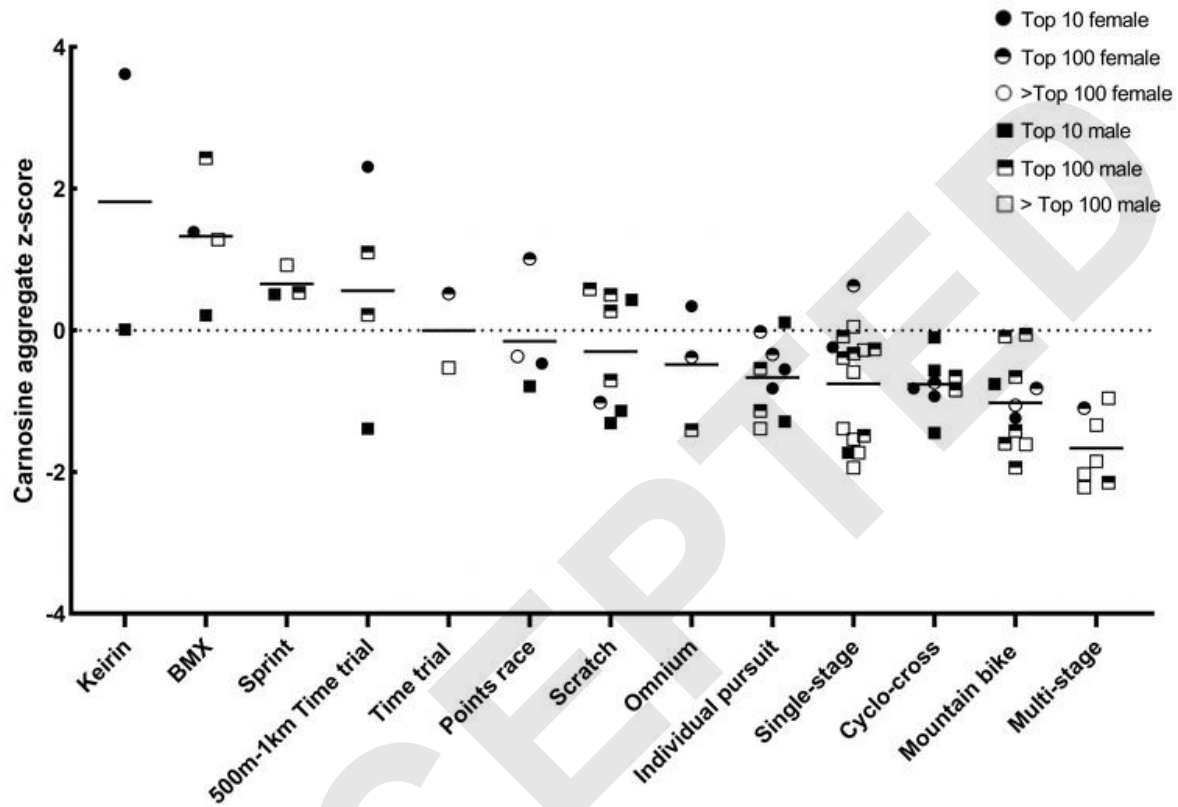


Table 1. Number, anthropometrical details and level of athletes in the different disciplines

	BMX	Track	Cyclo-Cross	Road	MTB	All cyclists
N	4	33	8	24	11	80
Age (y)	22.1 ± 2.35	24.0 ± 4.48	26.8 ± 2.81	27.5 ± 2.66	26.9 ± 7.85	25.6 ± 4.70
Sex (male/female)	3/1	21/12	5/3	20/4	8/3	57/23
Length (cm)	184 ± 0.58	181 ± 4.86	177 ± 5.59	182 ± 4.63	180 ± 5.04	181 ± 4.85
					165 ±	
	163	169 ± 4.29	167 ± 5.30	165 ± 7.89	11.06	167 ± 6.13
Weight (kg)	85.8 ± 4.02	79.3 ± 9.15	71.4 ± 5.36	71.1 ± 6.30	67.8 ± 4.67	74.6 ± 8.79
	54.0	64.6 ± 5.94	57.8 ± 5.25	59.0 ± 5.65	58.1 ± 8.61	61.7 ± 6.63
Olympic medalists	0	2	0	1	1	4
World medalists	0	19	3	1	1	24
Number of top 10 athletes	2	15	5	1	3	26
Number of top 100 athletes	1	15	3	7	9	35
UCI team (Worldtour/ Pro						
Continental)	0/0	6/10	0/5	18/6	1/0	24/15
Scansite (Belgium/ Australia)	3/1	13/20	8/0	21/3	9/2	54/26

Data are presented as mean ± SD. BMX, bicycle motor cross racing; MTB, mountain bike.