Effects of 12 weeks of omega-3 fatty acid supplementation in long-distance runners

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Purpose

To investigate the effects of 12 weeks of omega-3 fatty acid supplementation during endurance training on Omega-3 index (O3I) and indicators of running performance in amateur long-distance runners.

Methods

26 amateur male long-distance runners aged ≥ 29 years supplemented omega-3 fatty acid capsules (OMEGA group, n=14; 2234 mg of EPA and 916 mg of DHA daily) or medium chain triglycerides capsules as placebo (MCT group, n=12; 4000 mg of MCT daily) during 12-week of endurance training. Before and after intervention, blood samples were collected for O3I assessment and an incremental test to exhaustion and 1500-m run trial were performed.

Results

O3I was significantly increased in the OMEGA group (from 5.8% to 11.6%, $P < 0.0001$). A significant increase in VO_{2peak} was observed in the OMEGA group (from 53.6 ± 4.4 $ml^{*}kg^{-1*}min^{-1}$ to 56.0 ± 3.7 $ml^{*}kg^{-1*}min^{-1}$, $P = 0.0219$) without such change in MCT group (from 54.7 ± 6.8 $ml^{*}kg^{-1*}min^{-1}$ to 56.4 ± 5.9 $ml^{*}kg^{-1*}min^{-1}$, $P = 0.1308$). A positive correlation between the change in O3I and change in running economy was observed when data of participants from both groups were combined (-0.1808 ± 1.917, $P = 0.0020$), without such an effect in OMEGA group alone ($P = 0.1741$). No effect of omega-3 supplementation on 1500-m run results was observed.

Conclusions

12 weeks of omega-3 fatty acid supplementation at a dose of 2234 mg of EPA and 916 mg of DHA daily during endurance training resulted in improvement of O3I and running economy and increased VO_{2peak} without improvement in the 1500-m run trial time in amateur runners.

Clinical registry

The study was registered at https://www.clinicaltrials.gov/ with identifier NCT04780451

Runing title

Omega-3 index and physical performance indicators in amateur runners

Key words

Omega-3 index (O3I), polyunsaturated fatty acids, running performance, endurance training, running economy

Abbreviations

AA, arachidonic acid

ALA, α-linolenic acid

CRP, C-reactive protein

DHA, docosahexaenoic acid

EPA, eicosapentaenoic acid

HR, heart rate

HRR, heart rate reserve

LT, lactate threshold

MCT, medium-chain triglycerides

O3I, omega-3 index

PUFA, polyunsaturated fatty acids

RE, running economy

RER, respiratory exchange ratio

V_e, pulmonary ventilation

VO_2, volume of oxygen uptake

VCO_2, volume of carbon dioxide

VO_{2peak}, peak oxygen uptake

VT1, first ventilatory threshold

VAT, ventilatory anaerobic threshold

INTRODUCTION

Omega-3 fatty acids include α-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), characterized by the first double bond on the third carbon atom from the methyl end of the fatty acyl chain. There is growing evidence that synthesis de novo of EPA and in particular DHA is limited in the human body and sources of preformed EPA and DHA e.g. seafood, especially fatty fish or supplements should be consumed (1,2). Despite this, athlete's intake of sources of omega-3 fatty acids is often inadequate (3,4). Harris and von Schacky proposed the so-called omega-3 index (O3I) as a valid indicator of omega-3 PUFA status, reflecting both intake of these fatty acids and their biological and health effects (5). O3I is the sum of EPA and DHA expressed as a percent of total fatty acids in erythrocytes. It is proposed that values > 8% are associated with the greatest cardioprotection, whereas values < 4% are associated with the least (5). O3I has been recognized as the best marker of omega-3 PUFA status associated with many health indicators and outcomes in the general population (6); however it's relation with physical performance indicators in athletes is poorly understood. Observations on amateur and competitive athletes confirm low O3I values. For example, in 106 German elite winter endurance athletes, only one had an O3I in the target range of >8% and the average O3I value of the others was 4.97 ± 1.19% (7). Analysis conducted on collegiate athletes, professional basketball players and trained, but not professional, endurance athletes confirm low values of the O3I and its increase after supplementation with omega-3 PUFAs (8,4,9). A recent systematic review summarizing randomized placebo-controlled trials in athletes revealed that omega-3 PUFA supplementation improved cognitive function (e.g. reduction of reaction time and improvement of mood state), promoted skeletal muscle recovery and attenuated proinflammatory cell responses (10).

The effect of omega-3 fatty acid supplementation on exercise performance is unclear, although several studies show positive effects on oxygen kinetics: cycling efficiency or maximal oxygen uptake (10). To date, the longest study where physical performance parameters were analyzed lasted 10 weeks with the applied dose of 1.60 g of EPA and 1.04 g of DHA daily (11). The length and dose of omega-3 fatty acid supplementation seem to be crucial due to the incorporation of EPA + DHA into target tissues, which would be reflected in erythrocyte membranes and O3I. Maximal incorporation of EPA and DHA into erythrocytes is related to erythrocyte turnover: in a twelve-month controlled intervention trial conducted on healthy individuals, Browning and co-authors revealed that it takes 55 and 136 days for EPA and DHA respectively, to achieve peak incorporation into erythrocytes in the case of a supplementation dose of 3.27 g of EPA + DHA for 4 days a week (12).

Given the paucity of long-term studies using omega-3 fatty acid supplements in athletes showing relation between O3I values and physical performance indicators, there is a need for further work in this area. Accordingly, we determined the effects of 12 weeks of EPA+DHA supplementation (2234 mg and 916 mg a day respectively) compared with medium-chain triglycerides (MCT) as placebo in dose 4000 mg a day during endurance training on O3I and physical performance indicators in amateur runners. We hypothesize that this duration and dosage of omega-3 PUFAs will result in significant incorporation of EPA and DHA into erythrocytes membranes and increase O3I to values considered as a target range (i.e. > 8%). Moreover, using the longest duration and the highest dose of supplementation of the studies conducted so far, we hypothesize that this will increase VO_{2peak} and improved running economy (RE) to a degree that will translate into better running performance.

METHODS

Ethical approval

The study was approved by the Bioethical Committee of Regional Medical Society in Gdańsk (NKBBN/628/2019) and conducted according to the Declaration of Helsinki. After comprehensive details of the study protocol were explained orally and in writing, all participants provided their written informed consent.

Participants

40 amateur male long-distance runners were recruited through advertisements on the internet. Inclusion criteria included age between 29 and 42 years, and completion of an official 10 km race over the 2016 and 2020 time period with a time result between 37 and 57 min. The exclusion criteria included chronic diseases, cigarette smoking, or use of prescribed medications or dietary supplements, including omega-3 fatty acids. On the day of familiarization with the laboratory conditions and the treadmill test, participants were allocated sequential numbers that were then used as the identifiable characteristic. Assignment to each group (OMEGA or MCT) using an online randomizer (http://www.randomizer.org) took place on the first day of the actual exercise tests. All participants agreed to carry out only the training courses included in the programme and were instructed to continue with their habitual dietary patterns for the duration of the intervention.

Overview of study design

The trial was conducted in the Laboratory of Physical Exercise and Department of Biochemistry of the Academy of Physical Education and Sport in Gdansk. After inclusion, participants were randomly assigned to one of the two groups: OMEGA or MCT providing either omega-3 fatty acids or MCTs. All participants completed a progressive endurance training supervised by a track and field coach. The paralell, randomized trial consisted of 3 four-week phases, for a total of 12 weeks together with simultaneous supplementation. A graded exercise test to exhaustion with assesement of $VO_{2\ peak}$, running economy and a 1500-m run trial were carried out before and after completion of the exercise training programme. Each test was preceded by a standardized breakfast for all participants consumed 1 hour before the test began. Blood collection and weight assessment were performed when participants were in a fasting state. Fig. 1 outlines the experimental protocol.

Omega-3 PUFA supplementation

Throughout the study all participants took 4 identical-looking capsules each day (2 in the morning and 2 in the evening) containing either omega-3 fatty acids or MCTs. The omega-3 capsules provided 2234 mg of EPA and 916 mg of DHA daily (Omega-3 double plus, NAMED SPORT, Italy), whereas the MCT capsules contained 4000 mg of MCTs (MCT Oil, Now Foods, USA). The dose of omega-3 fatty acids is consistent with the dosage applied in the study of Browning and co-authors (12). To maintain certainty of the amount of each fatty acid and the general quality of the supplements containing omega-3 fatty acids, an International Fish Oil Standard (IFOS) certified product was selected. The IFOS programme verifies the amount of each fatty acid and the content of heavy metals, dioxins and rate of oxidation. A publicly available batch report of the supplements used in the study indicated that the amounts of individual acids were in accordance with the manufacturer's claims, and content of heavy metals, dioxins and rate of oxidation did not exceed accepted standards. Moreover, both supplements were certified by the informed-sport programme, under which products are tested for substances banned by the World Anti-Doping Agency. To avoid a potential recognition of supplements, participants were informed that they were all taking omega-3 fatty acids in one of two chemical forms. On the day of arrival at the laboratory, 1 hour prior to the graded exercise test and the 1500-m run trial, participants consumed the same standarized breakfast. Breakfast was a replication of a typical pre-start meal and consisted of wheat roll with butter and jam and half a banana.

Total energy value and amount of carbohydrate, protein and fat was 290 kcal, 49 g, 5 g and 8 g, respectively. Dietary intake over 3 days (2 days from week and 1 day from weekend) was recorded in the first and the last week of the programme. Participants used the MyFitnessPal mobile application to record the meals they consumed. Before using the app for the first time, the basic functions were demonstrated to all participants. Moreover, the website ilewazy.pl was presented to participants, so they could more easily estimate the portions they consumed when kitchen scales were not available. If recorded meals were not precise, participants were asked to clarify the information. Collected dietary records where then analysed using nutrition analysis software (Kcalmar.pro, Poland). Every food item in meals, with the consumed amount, was entered to the nutrition analysis software and total dietary energy, carbohydrate, protein and fat content was calculated.

Exercise testing

Before (week 0) and after completion (week 13) of the exercise training programme, participants were submitted to a graded exercise test to exhaustion on a motorized treadmill (h/p Cosmos, Saturn, Germany) to determine whether omega-3 fatty acids combined with endurance training might positively affect the endurance potential of runners. Prior to the intervention, the participant’s body weight and height were measured (analyzer InBody 720 and stadiometer Seca 213 respectively), then they were familiarized with the laboratory conditions and the treadmill test.

First, participants stood on the treadmill for 2 minutes to make sure the measuring equipment was ready and to measure the resting values. Thereafter, runners walked for 5 min at 5 km/h speed and with a 1.5% inclination as a warm-up prior to starting the test. Every next stage lasted 3 min aimed to reach steady-state VO_2 (13), and the treadmill belt was accelerated starting from 8 km/h by 1 km/h per stage up to 12 km/h. Then, the inclination of the treadmill was increased to 5%, 10% and 15% at 12 km/h speed until volitional exhaustion. During both tests, heart rate (HR) was monitored (Polar RS400 Kempele, Finland) to define the highest value (HRmax) during each test. Pulmonary ventilation (V_e), oxygen uptake (VO_2), carbon dioxide output (VCO_2) and respiratory exchange ratio (RER) were continuously measured using a breath-by-breath analyzer (Oxycon Pro, Jaeger, Germany) which was calibrated before each test following the manufacturer's recommendations. Measurements were averaged in 10-second intervals. VO_{2peak} was obtained as the highest 30 s mean value recorded during the test. Running economy was measured as an oxygen cost from last 50 seconds of each stage to 12 km/h speed and was expressed as $ml^{*}kg^{-1*}min^{-1}$ (14), and RE analysis was performed up to RER <1. All measurements were performed at similar time of day ± 2 h and constant environmental conditions (18-20°C and humidity 40-45%). Additionally, participants were informed to avoid strenuous exercise for 24 h before and caffeine and alcohol consumption for 12 h before laboratory tests. 1 week after the graded exercise test, participants took part in a 1500-m run time trial on an indoor 200-m track. The time was recorded with a handheld stopwatch to the nearest 0.1 s. During both tests, participants received strong verbal encouragement.

Training Protocol

The training protocol lasted 12 weeks and was built based on undulatory load manipulation 3:1 which was suggested to be effective to prevent overtraining and stress due to oscillations between volume/intensity according to Costa et al. (15) with slight modifications. Hence, participants performed endurance training 3 times per week. One additional training per week aimed to strengthen core muscles to reduce the risk of lower extremity injuries was also included in protocol (16). Training intensity was prescribed according to the first ventilatory threshold and ventilatory anaerobic threshold (VT1 and VAT) respectively and their associated HR values obtained during the laboratory testing. The threshold-based method was described as better than the heart rate reserve (HRR)-based method to design more individualized exercise prescriptions that will enhance training efficacy and limit training unresponsiveness (17). Consequently, participants trained in three HR zones: [Z1: ≤HR@VT1+5 bpm; Z2: (>HR@VT1+5 bpm) to (≤HR@VAT-5 bpm); Z3: >HR@VAT-5 bpm] and their average training times spent in every mesocycle were (~80%-15%-5%) in zones (Z1-Z2-Z3) respectively, accordingly to previous authors (18) with slight modifications. On the last, 12th week, the tapering procedure was performed, whereby the training load was reduced to 70% from the volume obtained in the 11th week to reduce accumulated fatigue. Participant’s training activity - training volume, intensity and energy expenditure were monitored by a Polar M430 wristwatch and a H9 heart rate chest sensor. All running tests and training procedures were supervised by a track and field coach.

Erythrocyte fatty acid analysis

Fasting blood samples were collected from participants by a nurse into 4 mL sodium citrate vacutainer tubes (BD Vacutainer®, Franklin Lakes, NJ, USA) and centrifuged at 4°C (4000 x g for 10 min). After centrifugation, erythrocytes were collected with a disposable pasteur pipette and transferred into eppendorfs, which were stored in a −80°C freezer until further analysis. Erythrocyte EPA and DHA were assesed using gas chromatography as described elsewhere (19). Briefly, erythrocyte lipids were extracted into chloroform:methanol and fatty acid methyl esters (representing the erythrocyte fatty acids) were formed by heating the lipid extract with methanolic sulphuric acid. The fatty acid methyl esters were separated by gas chromatography on a Hewlett Packard 6890 gas chromatograph fitted with a BPX-70 column using the settings and run conditions described elsewhere (19). Fatty acid methyl esters were identified by comparison with run times of authentic standards. Data are expressed as weight % of total fatty acids. O3I was calculated by summing the percentages of EPA and DHA according to Harris and von Schacky (5).

Statistical analysis

The sample size calculation was based on changes in oxygen consumption during graded exercise test to exhaustion assessed as VO_{2peak}, as this was the primary outcome of the study. A typical value for VO_{2peak} in population of recreational long-distance runners is about 54 $ml*kg^{-1}*min^{-1}$ with a SD of about 5 (20).

It is considered that a 8% increase in VO_{2peak} is meaningful in amateur runners (21). A sample size of 18 participants per group (i.e. 36 participants in total) would give 70% power to detect this difference as significant with alpha = 0.05. In order to account for a dropout rate of 10%, 40 participants were recruited. Statistical analysis was performed using the tools of GraphPad Prism 7. Arithmetic means, standard deviation (SD), and significance levels of differences between means were calculated. Two-way analysis of variance (ANOVA), with repeated measures, was used to investigate the significance of differences between groups and time. Significant main effects were further analyzed using the Bonferroni corrected post hoc test. Changes (delta) in both groups were compared using an independent samples t-test. Correlations between variables were evaluated using the Pearson correlation coefficient. All analyses used a significance level of $P < 0.05$.

RESULTS

Participant flow through the study

Participants excluded from the final analysis completed insufficient (<80%) training sessions (n=3) or withdrew from the study for health (n=9) or personal reasons (n=1). Moreover, one participant from MCT group increase intake of omega-3 fatty acids during study, therefore he was also excluded from statistics. Participant flow through the study is presented in Figure 2. From the 40 participants enrolled, 26 completed the entire study and their characteristic is shown in Table 1.

Erythrocyte EPA, DHA and O3I

The percentage values of erythrocyte EPA, DHA and O3I pre- and post-intervention in the OMEGA and MCT groups are presented in Figs. 3 and 4. There was no difference in baseline values of either omega-3 PUFA or O3I between the groups (OMEGA group: 1.1% EPA, 4.7% DHA, 5.8% O3I; MCT group: 1.2% EPA, 4.4% DHA, 5.6% O3I, all $P > 0.9999$). 12 weeks of omega-3 fatty acid supplementation during endurance training increased both omega-3 PUFAs and O3I in the OMEGA group (to 4.9 ± 1.1% EPA, 6.7 ± 0.8% DHA, 11.6 ± 1.7% O3I, all $P < 0.0001$) without significant changes in the MCT group (to 1.1% EPA, 4.5% DHA, 5.6% O3I, all $P > 0.9999$). At the end of the intervention period EPA, DHA and O3I were significantly higher in OMEGA group than in MCT group (all $P < 0.0001$).

VO_{2peak}, running economy and 1500-m run trial

There was no significant difference between groups in change in VO_{2peak} over the 12-week intervention period ($P = 0.6764$) (Fig. 5B). However, a significant increase in VO_{2peak} from pre- to post-intervention in OMEGA group was observed (from 53.6 ± 4.4 $ml^{*}kg^{-1*}min^{-1}$ to 56.0 ± 3.7 $ml^{*}kg^{-1*}min^{-1}$, $P = 0.0219$) with no significant change in MCT group (from 54.7 ± 6.8 $ml^{*}kg^{-1*}min^{-1}$ to 56.4 ± 5.9 $ml^{*}kg^{-1*}min^{-1}$, $P = 0.1308$) (Fig. 5A). Increase in $VO_{2\ peak}$ was seen in 13 out of 14 (93%) participants in the OMEGA group while in the MCT group improvements were visible in 9 out of 12 (75%) runners.

Moreover, oxygen uptake at 12 km/h changed in both groups: the running economy increased significantly in the OMEGA group (from 47.6 ± 1.8 to 46.5 ± 2.4 $ml^{*}kg^{-1*}min^{-1}$, *P* = 0.0295), while it decreased in the MCT group (from 47.7 ± 3.3 to 48.7 ± 2.9 $ml^{*}kg^{-1*}min^{-1}$, *P* = 0.1127) (Fig. 5C). The change in oxygen uptake over the 12-week intervention period was significantly different between groups (*P* = 0.0033) (Fig. 5D). When results pre- and post- 12-week intervention from all participants were combined, correlation highlighted the relationship between O3I and oxygen cost of submaximal running (Fig. 6A, *P* = 0.0338 and Fig. 6 B, *P* = 0.0020). There was significant improvement in completion of the 1500-m run trial in both groups from pre- to post-intervention, however, results did not differ between groups over the study period (OMEGA group from 356.3s to 344.9s, *P* = 0.0002 and MCT group from 362.1s to 347.3s, *P* < 0.0001; post- to post- between groups, *P* > 0.9999).

Physiological and nutritional variables

Table 2 summarises physiological and nutritional variables obtained from the participants at the beginnning and after completing the intervention programme. There was no difference in weekly training volume (*P* = 0.7399), energy expenditure (*P* = 0.1828) and HRmax (*P* = 0.4624) between the groups. However, in both groups there was a significant increase in HR max at VAT [%] post-intervention compared to pre-intervention (OMEGA group from 91.7 ± 2.6 to 93.9 ± 2.8, *P* = 0.0331 and MCT group from 90.8 ± 3.9 to 95.2 ± 3.7, *P* = 0.0001). Total energy (kcal/d), carbohydrate and protein ($g^{*}kg^{-1*}day^{-1}$) intake did not differ pre- to post-intervention within either group (OMEGA group *P* > 0.9999, *P* = 0.5442, *P* = 0.5777; MCT group *P* =0.1973, *P* > 0.9999, *P* = 0.7721 respectively).

There was a statistically significant difference in fat intake between the two groups with a significantly higher fat intake in the OMEGA group (from 83.4 ± 25.9 to 91.9 ± 25.9 g, P = 0.0321) and lower, however not significant fat intake in the MCT group (P = 0.0943). Moreover, a significant decrease in body mass during the study was observed in the MCT group (-1.225 kg; P = 0.0265).

DISCUSSION

The main finding of the study is that 12 weeks of supplementation with omega-3 fatty acids at a dose of 2234 mg of EPA and 916 mg of DHA daily shifts erythrocyte O3I to values considered as a target range for cardiovascular health. Moreover, this duration and dose of supplementation during endurance training increased VO_{2peak} and improved running economy at velocity 12 km/h with no effect on 1500-m run trial results. Insufficient values of O3I in active individuals are well described. In a study including vegan and omnivorous endurance athletes, Cradock et al. (8) showed suboptimal O3I in both groups: 4.13% in vegans and 5.40% in omnivores respectively. Similarly, O3I below the desirable values was demonstrated in German national elite winter endurance athletes (4.97 ± 1.19%), professional basketball players from NBAG-League (5.02 ± 1.19%) and collegiate athletes, representing diverse disciplines throughout the U.S. (4.33 ± 0.81%) (7,4,22). Our observations are in agreement with these reports, indicating that amateur runners had mean baseline O3I of around 5.7% (5.8% and 5.6% in OMEGA and MCT groups, respectively).

12 weeks with omega-3 fatty acid supplementation at a dose of 2234 mg of EPA and 916 mg of DHA daily during endurance training increased O3I in all but one participant in OMEGA group to mean of 11.4%, which is considered to be well within the O3I target range (5). Moreover, an increase in O3I correlated with an increase in running economy at velocity 12 km/h when results post minus pre 12-week intervention of participants from both groups were combined. Improvements in exercise economy as an effect of supplementation with omega-3 fatty acids have previously been shown in both amateur and competitive athletes (9,23,24). In an 8-week double-blind, parallel design study in well trained cyclists, Peoples et al. (23) showed that 3.2 g/day of omega-3 fatty acids reduced whole-body O_2 consumption throughout 60 minutes of sustained submaximal cycling. Contrary to our observations, peak oxygen consumption in these cyclists was not changed, which may be related to their high level of training status or quite high compared to other data (above 9%) baseline O3I values (23). Improved economy of cycling during the physiologically demanding time-trial in trained cyclists and runners was also revealed by Hingley et al. after 8 weeks of supplementation with a dose of 560 mg of DHA + 140 mg of EPA a day. Despite an elevation in O3I (from 4.7±0.2 to 6.3±0.3%) the values did not achieve the recommended O3I > 8% (9), which may be related to the low dose of EPA + DHA used. A study conducted by Kawabata et al. (24) with recreational players of American football, rugby, baseball, and basketball is consistent with other observations in trained individuals: 8-week of daily supplementation with 914 mg of EPA and 399 mg of DHA increased exercise economy during a steady-state submaximal cycloergometer test. In one cross-over study with trained cyclists, researchers observed an increase in VO2max after 3 weeks of supplementation with a daily dose of 660 mg of EPA and 440 mg of DHA (25).

In contrast to this report, an earlier study conducted by Raastad et al. (11) showed no changes in VO_{2max} and running performance in well-trained soccer players receiving 1.60 g of EPA and 1.04 g of DHA a day through 10-week period. Exercise economy together with VO_{2max}, lactate threshold and critical power are all strongly related to endurance exercise performance (26). Therefore, studies showing increased exercise economy, VO_{2max} or VO_{2peak} provide a rationale to further explore this topic together with the potential underlying mechanisms. Supplementation with omega-3 fatty acids reduces exercise-induced inflammation in athletes through decreasing in pro-inflammatory omega-6 fatty acids (27) and AA:EPA ratio (28). Given the large cross-sectional study indicating that inverse relationship between VO_2 max and C-reactive protein (CRP) is modified by omega-3 fatty acid levels (29) this may be the case. Moreover, an increase in insulin sensitivity due to unsaturation of skeletal muscle membranes (30), improved calcium handling by skeletal muscle sarcoplasmic reticulum (23) and improved endothelial function via increase in NO release (25) should be taken into account in searching for potential mechanisms of action. Of note, in the present study 13 out of 14 participants in the OMEGA group showed an improved VO_{2peak} compared to a variable response in the MCT group, in which only 9 out of 12 runners improved their results. This may suggest better adaptation to endurance training in response to omega-3 fatty acid supplementation, as has been observed with several other dietary supplements (31). Still, neither our nor previous reports support the hypothesis that long-term supplementation with omega-3 fatty acids enhances exercise performance. Duration and dose of omega-3 supplementation are crucial factors determining the amount of fatty acids incorporated into erythrocyte membranes and more than 4 months are needed to reach the highest concentration of DHA in case of a supplementation dose of 1.5 g of EPA and 1.77 g of DHA for 4 days a week (12).

Compared to previous studies in which performance indicators were assesed, our supplementation protocol (2234 mg of EPA and 916 mg of DHA daily for 12 weeks) was a higher dose over a longer supplementation period (9, 23–25). However, what values of O3I are sufficient for amateur and competitive athletes to optimize athletic performance remains a question to be answered in future studies.

Our study has some limitations that must be highlighted. Running economy is typically determined by measuring the consumption of oxygen when the steady-state of VO_2 is observed (13). We recognized steady-state conditions when runners had RER < 1 during treadmill running (13, 32); however the concentration of lactic acid was not assessed. Considering that lactate threshold (LT) is one of the indicators of disturbance in VO_2 steady-state (26,33), it should be included in future research. Animal studies showed that DHA is incorporated into the membranes of fast-oxidative glycolytic fibres (type IIA) of skeletal muscle (34). These muscle fibres have both a high oxidative and glycolytic capacity and due to their increased activation during moments of high energy demand (35) we decided to perform a 1500-m run trial. Our participants typically perform distances from 10 km to a marathon, therefore lack of experience and unfamiliarization at such a short distance as 1500-m may influence the outcome of the run trial and this must be taken into consideration when interpreting our findings. Future studies with omega-3 supplementation should also consider pre-screening, during which individuals with similar baseline omega-3 index should be selected (36).

In conclusion, 12 weeks of omega-3 fatty acid supplementation at a dose of 2234 mg of EPA and 916 mg of DHA daily during an endurance running programme increased O3I to values currently considered as a target range. This duration and dose of supplementation combined with endurance training increased peak oxygen consumption and improved running economy in amateur runners without affecting their performance.

Additional information

Competing interests

None of the authors of this paper has a competing interest.

Author contributions

Conception and design of the experiments was undertaken by M.T, Z.J, P.C.C and J.A. Collection, assembly, analysis and interpretation of data was undertaken by M.T, Z.J, M.C, R.U., H.L.F, P.C.C, M.S, J.A. Drafting the work or revising it critically for important intellectual content by M.T, Z.J, M.C, P.C.C, J.A. All authors have approved the final version of the manuscript and agree to be accountable for all aspects of the work. All persons designated as authors qualify for authorship, and all those who qualify for authorship are listed.

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The authors declare the results of this unfunded study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation and do not constitute endorsement by the American College of Sports Medicine.

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CAPTIONS FOR FIGURE

FIGURE 1. General experimental design.

FIGURE 2. Flow of participants through the study.

FIGURE 3. Effect of supplementation with omega-3 PUFAs or MCTs on individual values of O3I pre- and post-12-week intervention *$P < 0.0001$.

FIGURE 4. Effect of supplementation with omega-3 PUFAs or MCTs on erythrocyte *A*) EPA and *B*) DHA pre- and post-12-week intervention and change from baseline in *C*) EPA and *D*) DHA compared between the two groups. Data expressed as mean.
Error bars indicate ± SD, *$P < 0.0001$.

FIGURE 5. Effect of training and supplementation on *A*) peak oxygen consumption (ml*kg^{-1*}min^{-1}) pre- and post-12-week intervention *B*) change in peak oxygen consumption (ml*kg^{-1*}min^{-1}) in the two groups over the 12-week intervention *C*) oxygen utilisation (ml*kg^{-1*}min^{-1}) during submaximal treadmill running at 12 km/h pre- and post-12-week intervention and *D*) change in oxygen utilisation (ml*kg^{-1}*min^{-1}) in the two groups over the 12-week intervention Data expressed as mean. Error bars indicate ± SD, *$P < 0.05$.

FIGURE 6. Correlation between O3I and oxygen cost of submaximal running when:

A) OMEGA and MCT groups were combined pre- and post-12-week intervention

B) Results post minus pre (delta) in OMEGA and MCT groups were combined