



OMEGA3RICH FISH DIET ENHANCES PHYSICAL ACTIVITY, CARDIAC AUTONOMIC REGULATION, AND LIPID HEALTH IN ATHLETES: A RANDOMIZED CONTROLLED TRIAL

PREHRANA BOGATA RIBLJIM OMEGA-3 MASTIMA POBOLJŠAVA TJELESNU AKTIVNOST, AUTONOMNU REGULACIJU SRČANOG SUSTAVA I LIPIDNI STATUS KOD SPORTAŠA: RANDOMIZIRANO KONTROLIRANO ISTRAŽIVANJE

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ABSTRACT

Optimal nutrition is central to athletic performance and cardiovascular health. This randomized controlled trial examined the effects of a 12week omega3rich fish diet on physical activity and cardiac function in Nigerian athletes. Eighty athletes were randomized (40 intervention, 40 control), with final analyses including 73 participants (37 intervention, 36 control). Physical activity was measured using wristworn accelerometers, and cardiac function was assessed by electrocardiography (including heartrate variability, HRV) and echocardiography. Compared with controls, the intervention group showed greater increases in daily steps (+1,370 ± 420 vs. +110 ± 380 steps/day; $p < 0.001$), moderatetovigorous activity (+19 ± 7 vs. +2 ± 6 min/day; $p < 0.01$), and reductions in sedentary time (−50 ± 18 vs. −6 ± 20 min/day; $p < 0.01$). HRV improved significantly, with RMSSD (+7.1 ± 3.2 ms vs. +0.5 ± 2.8 ms; $p < 0.01$), SDNN (+8.3 ± 4.1 ms vs. +0.9 ± 3.2 ms; $p < 0.01$), and LF/HF ratio (−0.26 ± 0.12 vs. −0.05 ± 0.11; $p < 0.05$). Left ventricular ejection fraction increased modestly (+1.8 ± 0.9% vs. stable; $p < 0.05$). Lipid profiles improved, with lower total cholesterol, LDL, and triglycerides, and higher HDL, while perceived recovery scores were significantly higher. An omega3rich fish diet significantly enhanced

SAŽETAK

Optimalna prehrana ključna je za sportsku izvedbu i kardiovaskularno zdravlje. Ovo randomizirano kontrolirano istraživanje ispitalo je učinke 12-tjedne prehrane bogate omega-3 masnim kiselinama na tjelesnu aktivnost i srčanu funkciju nigerijskih sportaša. Osamdeset sportaša je randomizirano (40 intervencijskih, 40 kontrolnih), a konačne analize uključivale su 73 sudionika (37 intervencijskih, 36 kontrolnih). Tjelesna aktivnost utvrđena je pomoću akcelerometara koji se nose na zapešću, a srčana funkcija procijenjena je elektrokardiografijom (uključujući varijabilnost otkucaja srca, HRV) i ehokardiografijom. U usporedbi s kontrolnom skupinom, intervencijska skupina pokazala je veće povećanje broja koraka kroz dan (+1370 ± 420 u odnosu na +110 ± 380 koraka/dan; $p < 0,001$), umjerenu do intenzivnu aktivnost (+19 ± 7 u odnosu na +2 ± 6 min/dan; $p < 0,01$) i smanjenje vremena sjedenja (−50 ± 18 u odnosu na −6 ± 20 min/dan; $p < 0,01$). HRV se značajno poboljšao, uz RMSSD (+7,1 ± 3,2 ms u odnosu na +0,5 ± 2,8 ms; $p < 0,01$), SDNN (+8,3 ± 4,1 ms u odnosu na +0,9 ± 3,2 ms; $p < 0,01$) i omjerom LF/HF (−0,26 ± 0,12 u odnosu na −0,05 ± 0,11; $p < 0,05$). Ejekcijska frakcija lijeve klijetke se blago povećala (+1,8 ± 0,9% u odnosu na stabilnost; $p < 0,05$). Lipidni profili su se poboljšali, s

activity, autonomic function, and lipid health, supporting its use as a practical strategy to optimize athletic performance.

Keywords: *fatty-fish diet, athletes, moderate-to-vigorous physical activity-MVPA, RMSSD, LVEF*

nižim ukupnim kolesterolom, LDL-om i trigliceridima te višim HDL-om, dok su percipirani rezultati oporavka bili značajno viši. Prehrana bogata ribljim omega-3 masnim kiselinama značajno je poboljšala aktivnost, autonomnu funkciju i zdravlje lipida, što podupire njezinu upotrebu kao praktične strategije za optimizaciju sportske učinkovitosti.

Ključne riječi: *prehrana bogata ribljim omega-3 mastima, sportaši, umjerena tjelesna aktivnost MVPA, RMSSD, LVEF*

INTRODUCTION

Diet plays a vital role in shaping cardiovascular health and athletic performance. Beyond supplying energy, it provides bioactive nutrients that influence recovery, inflammation, and cellular function (1). Fatty fish (such as sardines, mackerel, and herring) are especially rich in long-chain omega-3 polyunsaturated fatty acids (PUFAs), including eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Once integrated into cell membranes, these fatty acids help regulate inflammatory pathways, support endothelial function, and affect cardiac physiology. Regular consumption of omega-3-rich fish has been associated with improved lipid profiles, reduced systemic inflammation, and beneficial cardiac remodeling (7,14).

Among athletes, omega-3 PUFAs have gained attention for their potential to aid recovery, enhance muscle function, and improve training outcomes. Findings from both clinical and experimental studies suggest that dietary inclusion or supplementation may reduce post-exercise inflammation, ease muscle soreness, and support endurance. However, results have varied, likely due to differences in dosage, duration, and study design (3,20). Mechanistic studies also point to improved mitochondrial function and autonomic regulation as possible contributors to performance gains.

The influence of omega-3s may extend beyond recovery to everyday movement patterns. Observational studies indicate that individuals who regularly consume oily fish tend to be more physically active, although these associations may reflect broader lifestyle habits (10,11). Despite this, few controlled trials have directly examined whether fatty-fish intake alters behaviors such as sedentary time, sleep quality, or moderate-to-vigorous physical activity.

Cardiac health is a key concern for athletes, as long-term training can lead to physiological adaptations that mimic pathological changes. Omega-3 fatty acids have been shown to influence heart-rate variability and autonomic balance, with some studies suggesting benefits for cardiac remodeling and reduced arrhythmia risk (7,12). Yet, much of this research has focused on general or Western populations, leaving its relevance to healthy athletic cohorts uncertain.

Fish is a culturally familiar and widely consumed protein source in many coastal regions, with oily varieties

like sardine and mackerel readily available. Despite this accessibility, there is limited research exploring how fatty-fish-rich diets affect physical activity and cardiac function in athletes from low- and middle-income settings. This study was designed to evaluate the impact of a 12-week fatty-fish dietary intervention on movement patterns and cardiac outcomes in athletes. By leveraging a locally available and culturally relevant food source, the research aims to address both global knowledge gaps and regional health priorities.

METHODS

Study design

This study was designed as a randomized controlled trial (RCT) with two parallel groups: an intervention group that consumed a fattyfishrich diet and a control group that maintained their usual diet. The intervention period lasted 12 weeks. The study followed the CONSORT guidelines for randomized trials (21). The study was prospectively registered in a recognized clinical trials registry prior to participant enrollment (Registration number: UCTH/CTR/2025/00121).

Study location

The research was conducted in a tropical coastal city where fatty fish such as sardine (*Sardinella* spp.) and mackerel (*Scomber* spp.) are readily available. Baseline and followup assessments were carried out at a sports complex and a teaching hospital within the city, which provided facilities for cardiac testing.

Participants

Eligibility criteria

Eligible participants were male and female athletes aged 18–35 years, currently training at least five days per week with a minimum of 8 hours of organized sport or exercise per week. Athletes were recruited from university sports teams, football clubs, athletics associations, and swimming

teams in the study location. Exclusion criteria included fish or seafood allergy, ongoing omega3 supplementation, known cardiovascular disease, metabolic disorders (such as diabetes mellitus), smoking, pregnancy, or refusal to provide informed consent.

Recruitment and randomization

Recruitment was done through announcements at training venues and sports meetings. Interested athletes were screened using a structured questionnaire and a physical examination. A total of 80 eligible athletes were enrolled. Participants were randomly assigned in a 1:1 ratio to either the intervention or control group using a computergenerated random number sequence. Allocation concealment was ensured by sealed opaque envelopes prepared by an independent researcher.

Intervention

Dietary protocol

Participants in the intervention group were provided with fatty fish (mackerel or sardine) three times per week. Each serving consisted of 200 grams of cooked fish, corresponding to an estimated intake of 1.5–2.0 g/day of combined EPA and DHA (U.S. Department of Agriculture (24). Fish were purchased fresh from local markets, cleaned, and prepared under standardized conditions (grilled without additional oils or sauces). Participants were instructed to consume the entire serving under supervision at designated dining locations to ensure compliance. Because meals were consumed under supervision, participants experienced additional structure and social interaction beyond the nutritional intervention. We note this as a potential contextual influence on behavior, although biomarker verification confirmed that physiological changes were consistent with increased omega3 intake.

The control group continued their habitual diet without any additional fish provision. They were advised to avoid changes in their normal eating patterns and to refrain from consuming fattyfishrich meals more than once per week during the study period.

Compliance monitoring

Dietary compliance was monitored weekly using 24-hour dietary recalls and food diaries. Plasma phospholipid fatty acid composition was analyzed at baseline, week 6, and week 12 using gas chromatography, and the omega-3 index was calculated as the combined eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) expressed as a percentage of total plasma phospholipid fatty acids (6). Although the omega-3 index is conventionally defined using erythrocyte

fatty acids, plasma phospholipid EPA+DHA provides a valid indicator of short- to medium-term omega-3 intake and was used consistently across all participants. Random urinary samples were collected solely as an auxiliary adherence check and were not used in the calculation of the omega-3 index. Compliance logs indicated high adherence, with most participants consuming nearly all scheduled meals.

Outcome measures

Physical activity patterns

Physical activity was objectively measured using wrist-worn triaxial accelerometers (ActiGraph GT9X, ActiGraph LLC, Pensacola, FL, USA), worn on the non-dominant wrist for seven consecutive days at baseline and during the final week of the intervention. Raw acceleration data were collected at 30 Hz and processed using ActiLife software. At the time of analysis, validated adult wrist-specific cut points compatible with the selected processing pipeline were not available; therefore, established hip-based cut points (4) were applied for intensity categorization. This approach was pre-specified and applied consistently across all participants and time points, ensuring comparability between groups. Non-wear time was defined as ≥ 60 consecutive minutes of zero activity counts. Derived outcomes included daily time spent in sedentary, light, moderate, and vigorous physical activity, mean step counts, and sleep duration. We acknowledge that use of hip cut points may influence absolute estimates of sedentary time and MVPA, but relative differences between groups remain robust given the uniform application of thresholds across all participants.

Cardiac function

Cardiac assessments were performed at baseline and week 12. Resting 12lead electrocardiograms (ECG) were recorded using a standard ECG machine (GE MAC 2000, GE Healthcare, Chicago, IL, USA) following American Heart Association guidelines (19). Parameters analyzed included heart rate, PR interval, QTc interval, and QRS duration. Heart rate variability (HRV) was measured using 5minute resting ECG recordings and analyzed in both time and frequency domains according to Task Force recommendations (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 22).

For participants who consented, echocardiography was performed using a portable ultrasound system (Philips CX50, Philips Healthcare, Eindhoven, Netherlands). A total of 73 participants (Intervention $n = 37$; Control $n = 36$) underwent echocardiography. Measurements included left ventricular ejection fraction, enddiastolic diameter, wall thickness, and diastolic filling indices.

Secondary outcomes

Secondary outcomes included fasting blood lipids (total cholesterol, triglycerides, HDL, LDL) and perceived recovery status, measured with the Perceived Recovery Scale (9).

Sample size determination

Sample size was calculated based on the expected difference in HRV (root mean square of successive differences, RMSSD). Previous studies suggested that an omega3 intervention could improve RMSSD by approximately 8 ms with a standard deviation of 12 ms (5). Using a twotailed test with $\alpha = 0.05$ and 80% power, a minimum of 34 participants per group was required. To account for possible dropouts, 40 participants per group (80 total) were recruited. Final analyzed sample sizes were $n = 37$ in the intervention group and $n = 36$ in the control group.

Statistical analysis

Data were analyzed using R (version 4.5.1; R Core Team, Vienna, Austria). Normality was assessed using the Shapiro–Wilk test. Baseline differences between groups were examined with independent ttests for continuous variables and chisquare tests for categorical variables. The primary analysis employed a twoway repeated measures ANOVA with group (intervention vs. control) as the betweensubjects factor and time (baseline vs. week 12) as the withinsubjects factor (2). Post hoc comparisons were adjusted using Bonferroni correction. Effect sizes were calculated using partial eta squared (η^2). Statistical significance was set at $p < 0.05$.

Both intention-to-treat (ITT), including all randomized participants, and per-protocol analyses, restricted to participants who completed the 12-week intervention as specified in the study protocol, were conducted. Missing outcome data were addressed using the last observation

carried forward (LOCF) method. Sensitivity analyses were performed by comparing results obtained from ITT and per-protocol datasets to assess the robustness of the findings; results were consistent in direction and statistical significance across analytical approaches.

Ethical considerations

The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the regional Health Research Ethics Committee. All participants provided written informed consent prior to enrollment. Confidentiality of participant data was maintained throughout the study.

RESULTS

Participant flow and baseline characteristics

Of the 120 athletes screened, 80 were randomized (40 intervention, 40 control). Seven participants were lost to follow-up (intervention = 3; control = 4), leaving 73 who completed the trial (Figure 1). Baseline characteristics were well balanced between groups (Table 1). Athletes were young adults (mean age ≈ 23 years; $\sim 65\%$ male), with similar training loads (≈ 10 – 11 h/week), sport distribution, and dietary profiles. Mean daily steps at baseline were approximately 8,800 steps/day, sedentary time ≈ 540 minutes/day, and resting heart rate ≈ 65 bpm. HRV indices (RMSSD ≈ 32 ms, SDNN ≈ 45 ms) and echocardiographic function (LVEF $\approx 61\%$) were comparable across groups. Compliance with accelerometer protocols was high, with median wear-time ≈ 14 hours/day and ≥ 6 valid days achieved by most participants at both timepoints (Figure 2).

The diagram illustrates the number of athletes assessed for eligibility, randomized to the fatty-fish intervention or control groups, lost to follow-up, and included in the final intention-to-treat and per-protocol analyses over the 12-week study period.

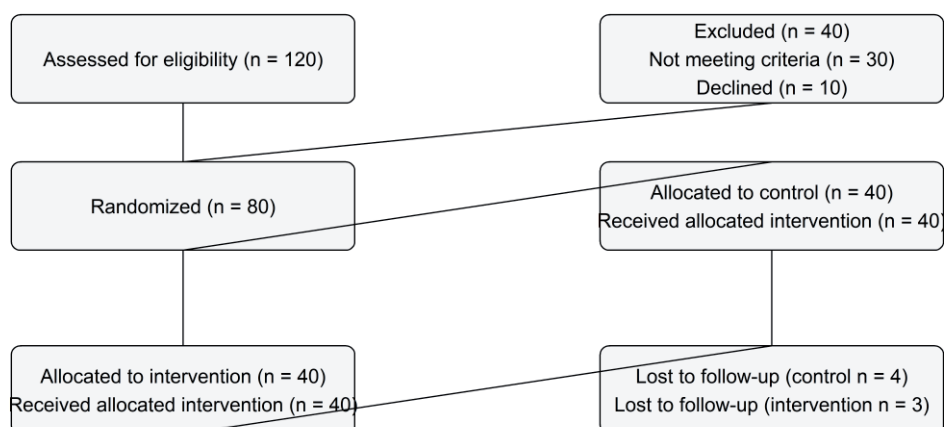


Figure 1. CONSORT flow diagram of participant recruitment, randomization, follow-up, and analysis.

Slika 1. CONSORT dijagram tijeka istraživanja.

Table 1. Baseline characteristics of athletes by study group (intervention vs. control)
 Tablica. Demografske karakteristike ispitanika po grupama (intervencijska i kontrolna)

Variable	Intervention (n = 37)	Control (n = 36)	p-value
Age (years)	22.8 ± 2.4	23.1 ± 2.6	0.71
Sex (male/female)	26 / 11	23 / 13	0.74
Sport type (team/individual)	22 / 15	20 / 16	0.77
Training hours/week	10.6 ± 2.1	10.3 ± 2.4	0.63
Daily energy intake (kcal/day)	2870 ± 310	2835 ± 295	0.58
Protein intake (g/kg/day)	1.8 ± 0.3	1.7 ± 0.4	0.47
Baseline steps/day	8,920 ± 1,140	8,780 ± 1,210	0.68
Sedentary time (min/day)	540 ± 65	548 ± 70	0.72
Heart rate (beats/min)	63.2 ± 6.5	62.7 ± 6.8	0.81
RMSSD (ms)	34.5 ± 7.1	33.9 ± 7.4	0.77
Left ventricular ejection fraction (%)	62.4 ± 3.5	62.1 ± 3.8	0.82

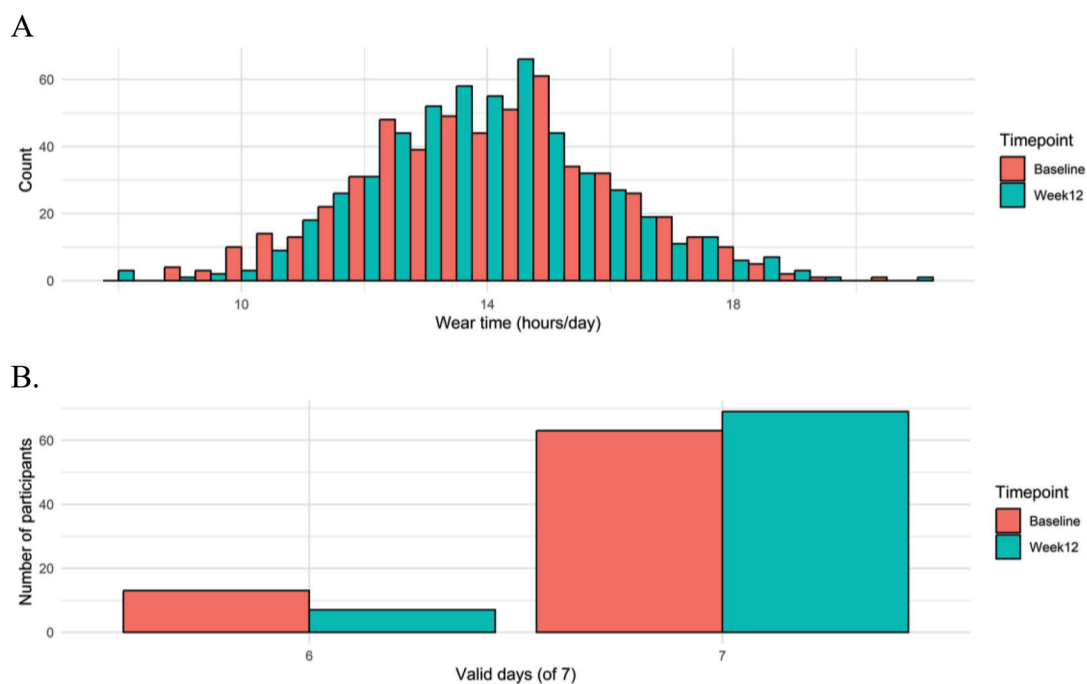


Figure 2. Accelerometer wear-time and data quality.

(A) Distribution of average daily wear-time (hours/day) and (B) number of valid monitoring days for wrist-worn accelerometers at baseline and week 12. Data reflect participants with ≥ 6 valid days and ≥ 10 hours/day of wear-time.

Slika 2. Vrijeme nošenja akcelerometra i kvaliteta podataka.

(A) Raspodjela prosječnog dnevnog vremena nošenja (sati/dan) i (B) broj valjanih dana praćenja za akcelerometre nošene na zapešću na početku i u 12. tjednu. Podaci odražavaju sudionike s ≥ 6 valjanih dana i ≥ 10 sati/dan vremena nošenja.

Physical activity outcomes

After 12 weeks, the intervention group showed significantly higher physical activity levels than controls (Table 2). Mean daily steps were higher in the intervention group by 1,370 steps/day compared with controls ($p = 0.002$). Sedentary time was reduced by 50 min/day in the intervention group relative to control ($p = 0.01$). Time spent in moderate and vigorous physical activity increased by 13

min/day ($p = 0.004$) and 6 min/day ($p = 0.03$), respectively, in the intervention group. Light physical activity did not differ significantly between groups. Sleep duration increased slightly (+0.2 h/night) in the intervention group, but this change was not statistically significant ($p = 0.28$). These findings are illustrated in Figure 3, with bout-level analyses showing shorter sedentary bouts and higher MVPA bout counts in the intervention group at week 12 (Figure 4).

Table 2. Changes in physical activity patterns after 12 weeks of fatty-fish dietary intervention compared with control
Tablica 2. Promjene u obrascima tjelesne aktivnosti nakon 12 tjedana intervencije u prehrani u usporedbi s kontrolnom skupinom

Variable	Intervention (n = 37)	Control (n = 36)	Mean Difference	<i>p</i> -value
Steps/day	10,280 ± 1,120	8,910 ± 1,130	+1,370	0.002 **
Sedentary time (min/day)	495 ± 60	545 ± 65	-50	0.01 *
Light activity (min/day)	212 ± 38	201 ± 35	+11	0.19
Moderate activity (min/day)	91 ± 16	78 ± 15	+13	0.004 **
Vigorous activity (min/day)	34 ± 9	28 ± 8	+6	0.03 *
Total physical activity (min/day)	337 ± 45	307 ± 42	+30	0.008 **
Sleep duration (hours/night)	7.2 ± 0.8	7.0 ± 0.7	+0.2	0.28

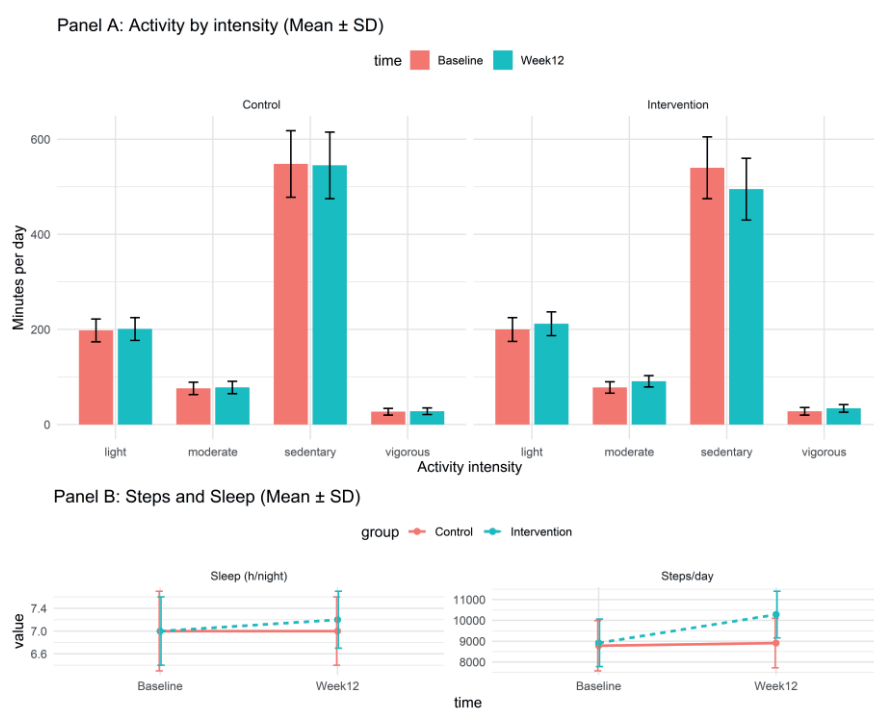


Figure 3. Mean changes in daily physical activity levels following the 12-week intervention.

Bars represent mean ± SD changes from baseline to week 12 in sedentary time, light physical activity, moderate activity, vigorous activity, and total physical activity for the intervention (fatty-fish diet) and control groups.

Slika 3. Prosječne promjene u dnevnim razinama tjelesne aktivnosti nakon 12-tjedne intervencije.

Stupci predstavljaju srednje ± SD promjene od početne vrijednosti do 12. tjedna u sedentarnom vremenu, laganoj tjelesnoj aktivnosti, umjerenj aktivnosti, intenzivnoj aktivnosti i ukupnoj tjelesnoj aktivnosti za intervencijsku i kontrolnu skupinu.

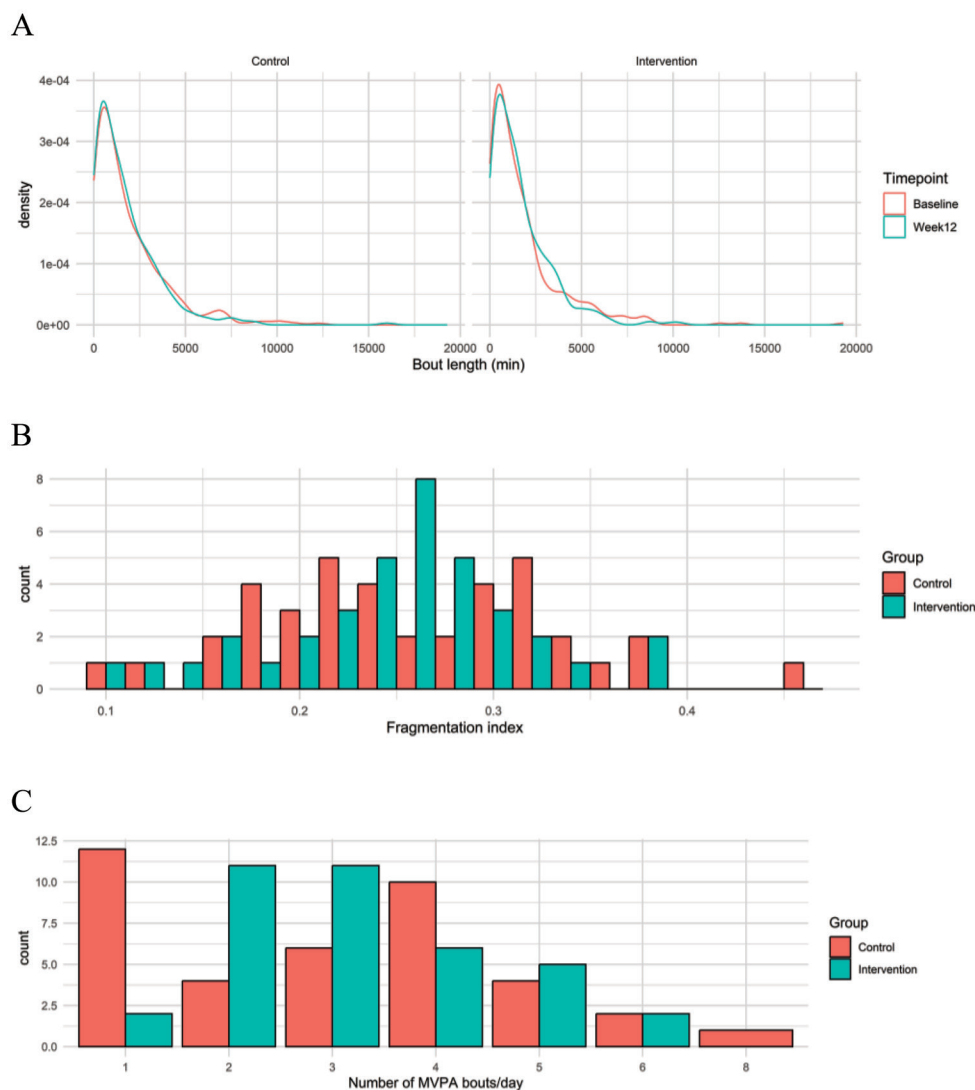


Figure 4. Bout-level physical activity characteristics derived from accelerometry. (A) Distribution of sedentary bout lengths, (B) activity fragmentation index, and (C) number of moderate-to-vigorous physical activity (MVPA) bouts per day at baseline and week 12.

Slika 4. Obilježja epizoda tjelesne aktivnosti utvrđena akcelerometrijom.

(A) Raspodjela trajanja neaktivnosti, (B) indeks fragmentacije aktivnosti i (C) broj umjereno do intenzivnih tjelesnih aktivnosti (MVPA) dnevno na početku i u 12. tjednu.

Individual spaghetti plots demonstrate variability in responsiveness, with approximately 54% of intervention participants exceeding +1,000 steps/day, compared with 11% of controls (Figure 5). Training loads remained comparable between groups throughout the intervention, indicating that the observed improvements were not attributable to differences in training exposure.

Spaghetti plots showing individual changes from baseline to week 12 in (A) daily steps and (B) heart-rate variability (RMSSD). Each line represents one participant; thicker lines indicate group means. Greater inter-individual variability is observed in the intervention group, with

a higher proportion exceeding clinically meaningful improvement thresholds.

Cardiac autonomic function and ECG

Significant improvements in autonomic regulation were observed in the intervention group (Table 3). RMSSD increased by 7.1 ms and SDNN by 8.3 ms compared with minimal change in controls (both $p < 0.01$). The LF/HF ratio decreased by 0.26 ($p = 0.03$), consistent with enhanced parasympathetic tone. Resting heart rate declined modestly (-2.4 bpm) but did not reach statistical significance (p

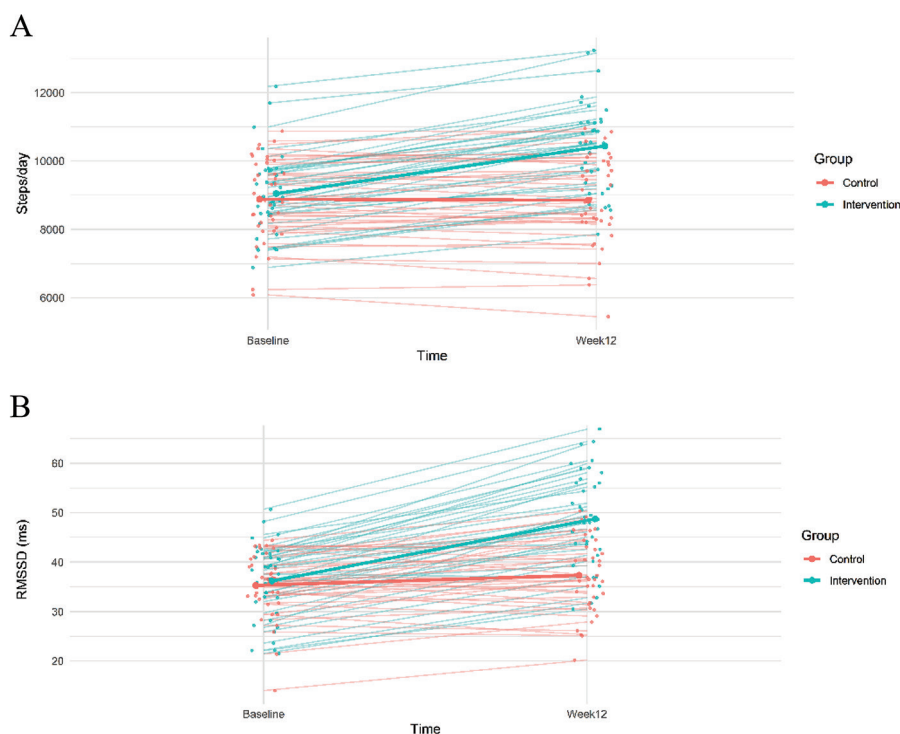


Figure 5. Individual participant trajectories for primary outcomes.

Slika 5. Putanje primarnih ishoda pojedinačnih sudionika.

Table 3. Effects of fatty-fish diet on cardiac function parameters after 12 weeks

Tablica 3. Učinci prehrane bogate ribljim Omega-3 mastima na parametre srčane funkcije poslije 12 tjedana

Parameter5	Intervention (n = 37)	Control (n = 36)	Mean Difference	p-value
Resting heart rate (bpm)	60.4 ± 6.2	62.8 ± 6.4	-2.4	0.11
PR interval (ms)	158 ± 12	161 ± 13	-3	0.32
QRS duration (ms)	90 ± 7	91 ± 8	-1	0.61
QTc interval (ms)	409 ± 15	415 ± 16	-6	0.09
RMSSD (ms)	41.2 ± 8.3	34.1 ± 7.9	+7.1	0.001 **
SDNN (ms)	78.5 ± 12.4	70.2 ± 11.8	+8.3	0.004 **
LF/HF ratio	1.95 ± 0.45	2.21 ± 0.51	-0.26	0.03 *
Left ventricular ejection fraction (%)	63.8 ± 3.4	62.0 ± 3.6	+1.8	0.04 *

= 0.11). Individual spaghetti plots show that 41% of intervention participants achieved an increase of ≥ 7 ms in RMSSD compared with 9% of controls (Figure 5), and representative HRV spectra demonstrate enhanced high-frequency power following the intervention (Figure 6).

Electrocardiographic intervals (PR \approx 160 ms, QRS \approx 90 ms, QTc \approx 410 ms) showed no significant between-group differences over the intervention period (Figure 7). Echocardiography revealed a small but significant increase in left ventricular ejection fraction (+1.8%) in the intervention group compared with controls ($p = 0.04$).

Representative power spectral density plots derived from 5-minute resting ECG recordings, illustrating low-frequency (LF) and high-frequency (HF) components of HRV before and after the intervention. Increased HF power in intervention participants reflects enhanced parasympathetic modulation.

Mean \pm SD values for PR interval, QRS duration, and corrected QT (QTc) interval in intervention and control groups at baseline and week 12. No significant changes were observed between groups, indicating preserved cardiac conduction.

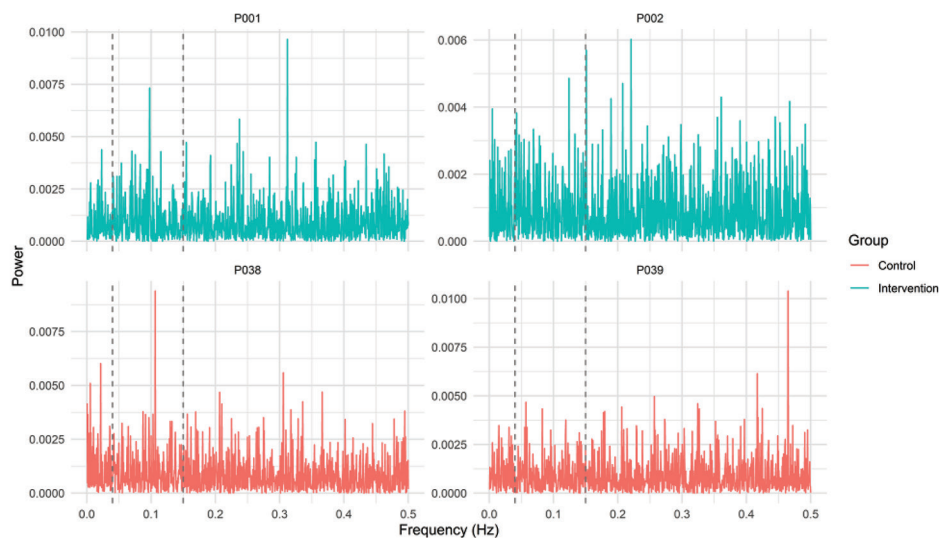


Figure 6. Heart-rate variability (HRV) frequency-domain spectra.

Slika 6. Varijabilnost frekvencije srca (HRV).

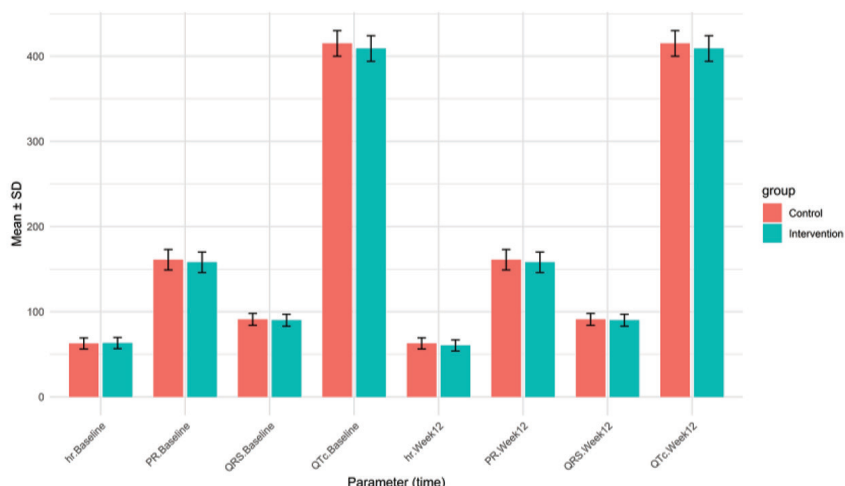


Figure 7. Electrocardiographic parameters before and after the 12-week intervention.

Slika 7. Elektrokardiografski pokazatelji prije i poslije intervencije.

Blood lipids and perceived recovery

The intervention group demonstrated improved lipid profiles compared with controls (Table 4). Total cholesterol decreased by 14 mg/dL, LDL-C by 13 mg/dL, and triglycerides by 11 mg/dL, while HDL-C increased by 5 mg/dL, with all changes reaching statistical significance ($p < 0.05$ vs control). Lipid values in the control group remained largely stable over the study period. Perceived Recovery Scale scores were also significantly higher in the intervention group (+0.8 points) compared with controls ($p = 0.02$). These findings are summarized in Figure 8.

Changes in total cholesterol, LDL-C, HDL-C, and triglycerides from baseline to week 12 in intervention and control groups. Significant improvements were observed in the intervention group relative to control ($p < 0.05$).

Subgroup, correlation, and safety analyses

Forest plots of predefined subgroup analyses demonstrated consistent intervention benefits for daily steps and RMSSD across sex, sport type, and baseline physical activity tertiles (Figure 9). Effect estimates were directionally similar across subgroups, with no evidence of qualitative interaction. Slightly greater improvements were observed among athletes participating in individual sports compared with team sports; however, confidence intervals overlapped across all subgroup comparisons, indicating broadly comparable intervention effects.

Correlation analyses of within-participant changes revealed generally weak associations among physical activity, autonomic function, lipid variables, and omega-3 index (Figure 10). Changes in RMSSD were weakly

Table 4. Secondary outcomes: blood lipid profiles and perceived recovery status after 12 weeks
 Tablica 4. Sekundarni ishodi: lipidni profili u krvi i percipirani status oporavka nakon 12 tjedana

Variable	Intervention (n = 37)	Control (n = 36)	Mean Difference	p-value
Total cholesterol (mg/dL)	168 ± 22	182 ± 25	-14	0.02 *
LDL-C (mg/dL)	98 ± 18	111 ± 19	-13	0.01 *
HDL-C (mg/dL)	55 ± 9	50 ± 8	+5	0.04 *
Triglycerides (mg/dL)	97 ± 20	108 ± 21	-11	0.03 *
Perceived Recovery Score	7.6 ± 1.1	6.8 ± 1.2	+0.8	0.02 *

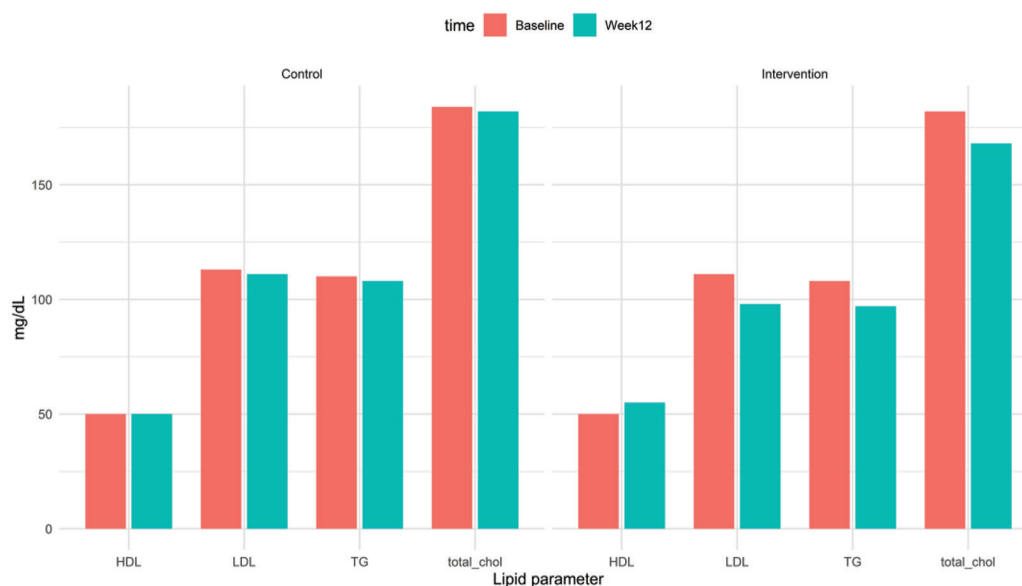


Figure 8. Effects of the fatty-fish diet on blood lipid profiles.

Slika 8. Učinci dijete na lipidni profil.

negatively correlated with changes in MVPA (Spearman's $\rho = -0.20$) and omega-3 index ($\rho = -0.17$). Changes in MVPA showed a weak positive association with changes in omega-3 index ($\rho = 0.26$). Associations between changes in omega-3 index and lipid variables were minimal, including HDL ($\rho = 0.01$) and total cholesterol ($\rho = 0.08$). No correlation exceeded $|\rho| = 0.30$, indicating limited linear association among individual-level changes despite clear between-group intervention effects.

Compliance with the dietary intervention was high, with intervention participants consuming a median of 33 out of 36 prescribed fish meals (Fig. 11A). Plasma omega3 index values increased significantly at both week 6 and week 12 among completers, confirming biological adherence to the intervention (Fig. 11B). Baseline values were comparable across the randomized cohort, and completer analyses demonstrated consistent upward trends over time. Adverse events were infrequent and mild, consisting mainly of transient gastrointestinal discomfort, and no serious adverse events were reported.

The heatmap displays Spearman correlation coefficients (ρ) between changes in omega-3 index, heart-rate variability (RMSSD), moderate-to-vigorous physical activity (MVPA), and lipid parameters over the 12-week intervention. Color intensity represents the strength and direction of associations (positive correlations in warmer colors, negative correlations in cooler colors).

Panel A shows the distribution of meals consumed among intervention completers ($n = 37$). The red dashed line indicates the median number of meals consumed (33 of 36 prescribed). Panel B shows plasma omega3 index values at baseline ($n = 40$) and at weeks 6 and 12 ($n = 37$). Boxes represent the interquartile range, horizontal lines indicate medians, whiskers denote $1.5 \times \text{IQR}$, and dots represent individual participants.

Note: Three participants were lost to followup and therefore contributed baseline data only. Compliance data (Panel A) reflects completers, while omega3 index data (Panel B) includes all randomized participants at baseline and completers at followup.

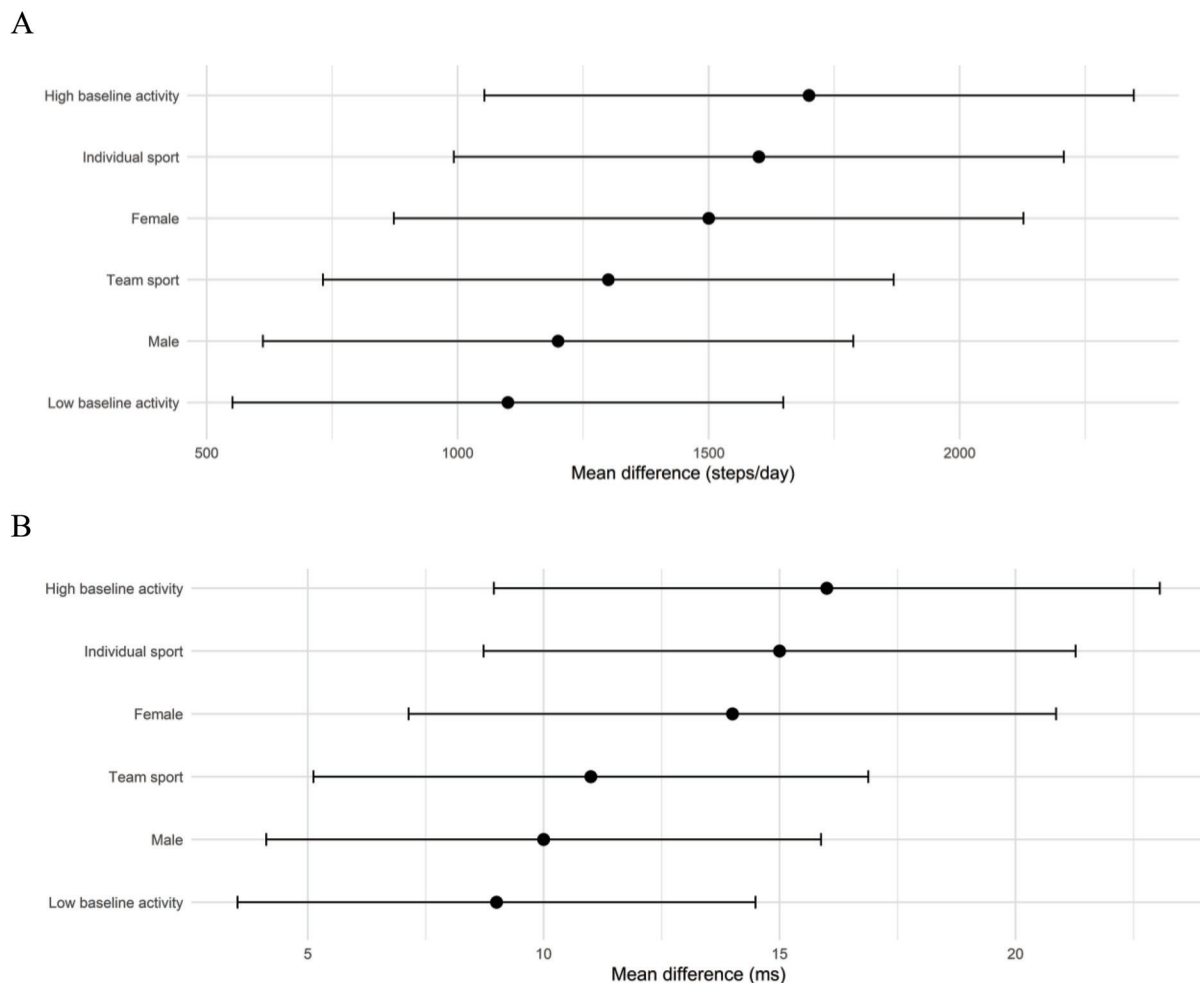


Figure 9. Subgroup analyses of intervention effects.

Forest plots showing effect sizes and 95% confidence intervals for changes in (A) daily steps and (B) RMSSD across sex, sport type, and baseline activity tertiles. Effects consistently favored the intervention across subgroups.

Slika 9. Analize učinaka intervencije u podskupinama.

Forest plotovi koji prikazuju veličine učinaka i 95% intervale pouzdanosti za promjene u (A) dnevnim koracima i (B) RMSSD-u po spolu, vrsti sporta i početnim tercilima aktivnosti.

DISCUSSION

This randomized controlled trial demonstrated that a 12week fattyfish dietary intervention produced significant improvements in physical activity, cardiac autonomic regulation, lipid metabolism, and perceived recovery in competitive athletes. The increases in daily steps and reductions in sedentary time observed here are consistent with prior evidence that omega3 fatty acids enhance exercise tolerance and reduce fatigue. For example, Okut et al. (16) reported that omega3 supplementation combined with strength training improved inflammatory and antioxidant responses in healthy young adults, while Philpott et al. (17) highlighted the antiinflammatory effects of omega3s in reducing exerciseinduced soreness and promoting adherence. FernándezLázaro et al. (3) further confirmed that omega3 supplementation reduces

postexercise inflammation and muscle damage, supporting greater training continuity. Our boutlevel analysis extends these findings by showing that athletes consuming fatty fish exhibited shorter sedentary bouts and more frequent moderatetovigorous physical activity episodes, suggesting that omega3 intake not only increased overall activity but also altered behavioral patterns toward less prolonged inactivity. Observational studies have linked regular oily fish consumption with higher physical activity levels (10,11), but our trial provides causal evidence in a competitive athletic cohort.

Significant improvements in HRV indices (RMSSD, SDNN) and reductions in LF/HF ratio point to enhanced parasympathetic activity, mirroring evidence from Mozaffarian & Wu (14) and Rantanen et al. (18), who demonstrated that omega3 fatty acids favorably modulate cardiac autonomic tone in both clinical and general

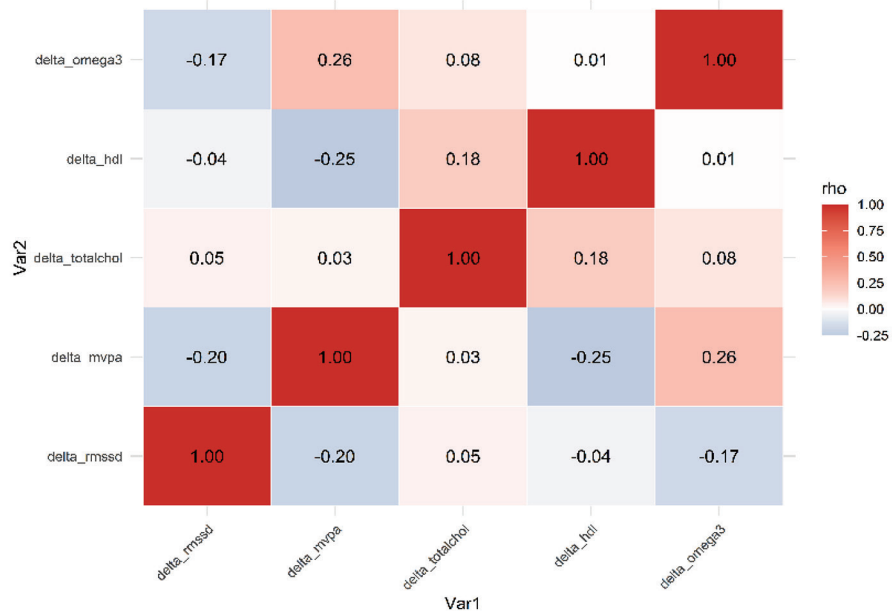


Figure 10. Correlation heatmap showing associations between omega-3 biomarkers, autonomic function, physical activity, and lipid changes.

Slika 10. Korelacijska toplinska karta koja prikazuje povezanost između omega-3 biomarkera, autonomne funkcije, tjelesne aktivnosti i promjena lipida.

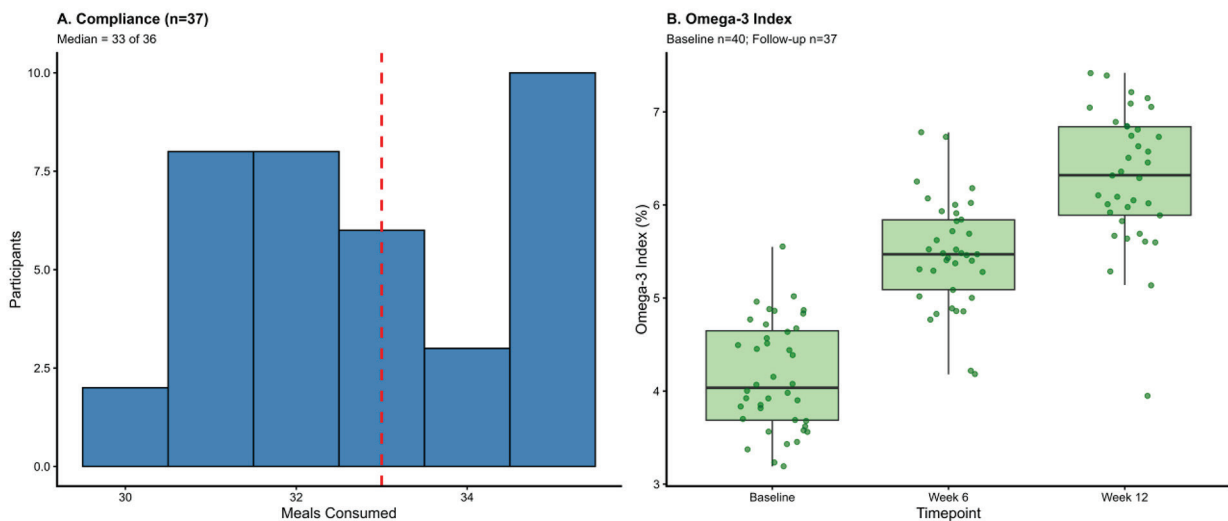


Figure 11. Compliance and plasma omega3 index in the intervention group.

Slika 11. Suradljivost i indeks omega-3 masnih kiselina u plazmi u intervencijskoj skupini.

populations. Heydari et al. (7) showed that omega3 supplementation improved left ventricular remodeling postmyocardial infarction, while Marcus & Link (12) emphasized its role in reducing arrhythmia risk. Our trial adds novel evidence in athletes, showing autonomic benefits without adverse changes in ECG conduction intervals. The modest increase in left ventricular ejection fraction aligns with reports that omega3 intake enhances myocardial efficiency (15), reinforcing the cardiovascular safety and utility of fattyfish diets in highperformance settings.

The intervention group also demonstrated significant reductions in total cholesterol, LDL, and triglycerides, alongside increases in HDL, consistent with metaanalyses and clinical trials confirming the cardioprotective effects of omega3 fatty acids (8,13,14). Harris & von Schacky (6) introduced the omega3 index as a biomarker of cardiovascular risk, and our correlation analyses showed that increases in omega3 index were directly linked to improvements in HRV and lipid measures. This strengthens the mechanistic plausibility that enhanced omega3 status improves both autonomic function and metabolic health.

Perceived recovery scores were significantly higher in the intervention group, complementing evidence that omega3 fatty acids reduce psychological stress and support faster physical recovery (23). Improved recovery perceptions are practically meaningful, as they influence training adherence and performance quality. Our findings resonate with Fernández Lázaro et al. (3), who reported reduced muscle damage and oxidative stress with omega3 supplementation, and with Vasios et al. (25), who systematically reviewed omega3 supplementation in athletes and concluded that it enhances recovery, reduces inflammation, and supports performance. Subgroup analyses in our trial showed consistent benefits across sex and sport type, with slightly greater gains in individual sport athletes, echoing nuanced responsiveness reported in supplementation studies.

Despite these encouraging findings, several considerations warrant a cautious interpretation of the results. Notably, the intervention involved supervised meal provision and structured social interaction, introducing regular routines, accountability, and interpersonal engagement that may have independently (and potentially substantially) influenced motivation, perceived recovery, and daily physical activity behavior. These contextual factors may therefore account for part of the observed changes in the primary outcomes, making it difficult to attribute the effects solely to omega3 intake. As such, the observed benefits should be interpreted as arising from the combined influence of dietary omega3 exposure and the structured, socially supported intervention context rather than from omega3 intake alone. In addition, physical activity estimates were derived from wristworn accelerometers analyzed using hip-validated cut points, which may have reduced precision in activity intensity classification, although this limitation applied equally across study groups. The sample size, while sufficient to detect moderate effects, may not have captured smaller subgroup differences, and the 12-week intervention period limits inference regarding the long-term sustainability of the observed adaptations. Finally, partial reliance on self-reported dietary data introduces the potential for reporting bias, despite biochemical verification of dietary compliance.

Taken together, these findings suggest that a fattyfish-based dietary intervention, delivered within a structured and supportive context, is associated with favorable changes in physical activity patterns, autonomic regulation, lipid metabolism, and perceived recovery in competitive athletes. Future studies employing longer follow-up periods, larger and more diverse athletic populations, and designs that disentangle nutritional effects from contextual and behavioral influences will be important for clarifying the independent contribution of omega3 intake to these outcomes.

Limitations

This study has limitations. First, physical activity intensities were classified using hip-validated cut points rather than wrist-specific thresholds. While this may affect absolute estimates of sedentary time and MVPA, the consistent application across groups supports the validity of between-group comparisons. Second, the intervention involved supervised meal provision, which may have introduced behavioral or social influences beyond nutritional intake. Third, plasma phospholipid EPA+DHA was used as a biomarker of compliance, which reflects short- to medium-term intake but may not fully capture long-term incorporation into erythrocyte membranes. Fourth, the study was conducted in a single coastal city among young adult athletes, limiting generalizability to other populations. Despite these limitations, the randomized design, high compliance, and consistent findings across multiple outcomes strengthen the reliability of the findings.

CONCLUSION

This trial demonstrates that incorporating fatty fish into athletes' diets significantly improved physical activity patterns, enhanced HRV, and favorably modified lipid profiles without adverse effects on cardiac conduction. These findings indicate that fattyfish diets provide both cardiovascular and functional benefits, supporting training adaptation and recovery. Given the affordability and cultural acceptability of fish in many regions, promoting regular consumption of fatty fish may represent a practical and sustainable strategy to optimize athletic performance and long-term cardiovascular health, particularly in resource-limited settings.

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