Fish-oil supplementation enhances the effects of strength training in elderly women

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ABSTRACT

Background: Muscle force and functional capacity generally decrease with aging in the older population, although this effect can be reversed, attenuated, or both through strength training. Fish oil (FO), which is rich in n–3 (omega-3) PUFAs, has been shown to play a role in the plasma membrane and cell function of muscles, which may enhance the benefits of training. The effect of strength training and FO supplementation on the neuromuscular system of the elderly has not been investigated.

Objective: The objective was to investigate the chronic effect of FO supplementation and strength training on the neuromuscular system (muscle strength and functional capacity) of older women.

Design: Forty-five women (aged 64 ± 1.4 y) were randomly assigned to 3 groups. One group performed strength training only (ST group) for 90 d, whereas the others performed the same strength-training program and received FO supplementation (2 g/d) for 90 d (ST90 group) or for 150 d (ST150 group; supplemented 60 d before training). Muscle strength and functional capacity were assessed before and after the training period.

Results: No differences in the pretraining period were found between groups for any of the variables. The peak torque and rate of torque development for all muscles (knee flexor and extensor, plantar and dorsiflexor) increased from pre- to posttraining in all groups. However, the effect was greater in the ST90 and ST150 groups than in the ST group. The activation level and electromechanical delay of the muscles changed from pre- to posttraining only for the ST90 and ST150 groups. Chair-rising performance in the FO groups was higher (ST150 group) or for 150 d (ST150 group; supplemented 60 d before training). Muscle strength and functional capacity were assessed before and after the training period.


INTRODUCTION

The ability of skeletal muscles to generate torque and the rate at which this torque is developed are reduced by aging (1). Such a phenomena occurs due to changes in the neuromuscular system, including morphologic and phenotypic changes, change in size of muscle fibers, and loss of muscle mass (2); neural degenerative disorders of the central and/or peripheral nervous system (3); low physical activity level; and nutritional changes (4). Therefore, different strategies to attenuate or reverse the decline of the neuromuscular system in the elderly are advised. Indeed, it has been shown that strength training is able to attenuate and/or partially reverse the functional capacity reduction of the neuromuscular system ability in the elderly (5).

Some studies report that strength training increases peak torque and RTD (5, 6), as well as functional capacity (7). In addition, the neural excitability is improved after a strength-training program, which decreases the EMD—ie, the time between the electrical stimulation and the mechanical response of muscle (8). This suggests that strength training can induce neuromuscular adjustment in older individuals, leading to improvements in the quality of life.

Western diets are high in n–6 and low in n–3 PUFAs, which compete for incorporation into the labile second position of phospholipids in the cell membranes. n–6 PUFA, mainly linoleic acid, is a precursor of arachidonic acid, which is a substrate of cyclooxygenase and lipoxygenase enzymes that leads to a net proinflammatory environment that will cause damage in several tissues, including muscles. On the other hand, n–3 PUFAs exert pleiotropic actions on many tissues, particularly in the cardiovascular and central nervous systems, that might be protective against age-related diseases. The central nervous system has a high concentration of complex lipids, which determine the structural and functional properties of its cellular and subcellular membranes (9–11). FO supplementation, which is rich in n–3 PUFAs, has been shown to increase nerve conduction velocity in the elderly (12), sarcolemma ion channel modulation (13), and improved heart contractile activity (14). Thus, because FO supplementation improves both cardiac muscle contractility (15) and nerve conduction velocity, it is reasonable to hypothesize that it may potentiate strength-training effects on skeletal muscles.

There is a dearth of studies that report the effects of FO supple-

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2 There was no funding source in this study. Fish oil was kindly donated by Herbarium Foundation for Health and research, Curitiba, Paraná, Brazil.

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4 Abbreviations used: EMD, electromechanical delay; FO, fish oil; RMS, root mean square; RTD, rate of torque development; ST group, strength-training group; ST90 group, strength-training group with 90 d of FO supplementation; ST150 group, strength-training group with 150 d of FO supplementation; IRM, one-repetition maximal test.

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mentation on neuromuscular function in the elderly and a lack of information regarding the length of supplementation and dose.

This study aimed to investigate the effect of FO supplementation associated with a strength-training program on the neuromuscular system (muscle strength and functional capacity) in elderly women. In addition, it also investigated whether the duration of FO supplementation modifies the effect. It was hypothesized that FO supplementation associated with strength training would potentiate neuromuscular function.

**SUBJECTS AND METHODS**

**Participants**

Forty-five healthy white women (aged 64 ± 1.4 y) volunteered to participate in this study (Table 1). They were screened by a physician and were deemed in good health to perform strength training. The participants were neither receiving hormone replacement therapy nor engaged in any other regular physical activity program during the 12 mo before the present study. Positive University’s ethics committee granted approval for the experimental procedures, and participants signed an informed consent form before starting the procedures. The study commenced in March 2008.

In the first session, participants answered the International Physical Activity Questionnaire (16), and no differences in physical activity level were identified between groups. In an attempt to obtain 3 homogeneous groups, participants were randomly assigned to 1 of the 3 experimental groups, after being classified in quartiles according to their relative knee extension strength (one repetition maximal/body weight) (5). One group performed only the strength training (ST group; n = 15). The ST90 group (n = 15) was supplemented with FO throughout the 90 d of strength training. Finally, the ST150 group (n = 15) started the FO supplementation 60 d before commencing the strength training. The FO supplement contained 180 g EPA and 120 g DHA/kg. All participants in the supplemented groups received 2 g/d of FO (one capsule during each main meal), which provided ~0.4 g EPA and 0.3 g DHA/d.

The participants were asked to maintain their normal eating habits and physical activity level throughout the study (Table 1). The strength-training program was designed to improve lower limb muscle strength. The program included supervised resistance-training exercises performed 3 times/wk, for 12 wk, for a total of 36 training sessions. Diet was monitored by using food-frequency questionnaires completed before and after training to ensure that there was no change in dietary intake. Neuromuscular (first session) and functional capacity (second session) assessments were performed before (pre-) and after (post-) the training period for the ST and ST90 groups. The ST150 group participants were evaluated at 3 different times: presupplementation (base, collected 60 d before initiating pretraining period), pretraining (at 60th day to coincide with pre-), and posttraining (at 150th day to coincide with post-). Special care was taken so that the participants involved in this study did not come into contact with other groups during training or blood collection to minimize the chances of psychological effects. In addition, the ST group trained on different days of the week (ie, Tuesdays, Thursdays, and Saturdays) from the supplemented groups (ST90 and ST150; ie, Mondays, Wednesdays, and Fridays). The participants received specially worded consent forms to ensure that they were unaware of the existence of other experimental groups. A placebo was not provided because 1) there was no contact between groups and 2) there was no suitable placebo available to the experimenters for FO supplementation. Providing any other oil could cause its incorporation into the cell membranes and increase oil consumption, which has been associated with the development of chronic diseases (17). All participants concluded the experimental procedures.

**Fatty acid composition of plasma and of the FO capsule**

The fatty acid composition of the FO capsules as well of the plasma of the participants was assessed by HPLC (Varian ProStar). Total lipids were extracted from the FO capsules and plasma of volunteers by using chloroform-methanol (2:1 vol:vol). Fatty acids were derivatized with 4-bromomethyl-7-coumarin and then separated by using an octadecylsilica column (25 cm × 4.6 mm internal diameter; particle size: 5 μm). Fatty acids were resolved isocratically by using a mobile phase of acetonitrile-water (gradient from 77:23 to 90:10 vol:vol) at a flow rate of 1 mL/min. Fatty acid derivatives were detected by fluorescence (325-nm excitation, 395-nm emission), as previously described (18). The analysis showed the presence of the following fatty acids in the

### TABLE 1

| Physical characteristics and dietary habits of the participants in the ST, ST90, and ST150 groups before and after traininga |
|---|---|---|---|---|---|---|---|
| | ST (n = 15) | ST90 (n = 15) | ST150 (n = 15) |
| Age (y) | 64.9 ± 1.0 | 63.8 ± 1.4 | 63.3 ± 2.0 |
| Height (m) | 1.60 ± 0.04 | 1.61 ± 0.01 | 1.62 ± 0.02 |
| Body mass (kg) | 65.9 ± 1.0 | 65.1 ± 1.3 | 66.8 ± 1.4 |
| BMI (kg/m²) | 25.4 ± 1.6 | 25.7 ± 1.7 | 27.7 ± 1.3 |
| Total energy (kcal) | 1470 ± 380 | 1480 ± 395 | 1490 ± 412 |
| Carbohydrate (g) | 174 ± 47 | 183 ± 52 | 176 ± 45 |
| Protein (g) | 52 ± 21 | 57 ± 20 | 54 ± 19 |
| Lipids (g) | 63 ± 20 | 61 ± 21 | 63 ± 18 |

a All values are means ± SDs. P values refer to interaction effects by using a 2-factor ANOVA. No time (Pre to Post differences) or group (ST, ST90, and ST150) effects were observed (P > 0.05). Post, posttraining (refers to the data collected after the end of the training program); Pre, pretraining (refers to the data collected immediately before starting the training program); ST, strength-training group; ST90, strength-training group supplemented with fish oil during 90 d; ST150, strength-training group supplemented with fish oil during 150 d.
capsules provided to the participants (mean ± SD): lauric (12:0), 7.0 ± 0.1%; miristic (14:0), amount not determined; palmitic (16:0), 14.2 ± 1.9%; stearic (18:0), 1.4 ± 0.4%; palmitoleic (16:1n–7), amount not determined; oleic (18:1n–9), 10.6 ± 1.1%; linoleic (18:2n–6), 3.3 ± 0.3%; α-linolenic (18:3n–3), amount not determined; arachidonic (20:4n–6), 13.7 ± 0.8%; EPA (22:5n–3), 29.5 ± 0.7%; DHA (22:6n–3), 23.6 ± 0.2%.

Strength-training program

After warming up, a 1RM was performed in the first training session. The participants were familiarized with the strength-training exercises for 6 sessions (2 wk) by performing 3 sets of 8 repetitions at 50% of their 1RM load. After the familiarization period, 12 wk of strength training were introduced. The first training week included 3 sets of 8 repetitions at 70% of 1RM. Training load was increased in the second week to 80% of 1RM and was adjusted on a weekly basis (every 3 sessions) from the third to the last week of training. Similar procedures have been used in previous studies of muscle strength in the elderly (19). The sessions were performed under the supervision of one researcher and under the guidance of 2 qualified instructors.

The following exercises were performed: bilateral knee flexion and extension, bilateral hip adduction and abduction, unilateral hip extension and flexion, bilateral horizontal leg press, and bilateral plantar flexion. Exercises were performed that included concentric and eccentric phases using pulley-type machines (Athletic). Verbal encouragement was provided during each exercise series. The load for each exercise was recorded throughout the experimental period to quantify load improvements.

Peak torque and RTD

Maximal voluntary isometric contraction was used to determine the peak torque, defined as the best performance from 3 trials. It was calculated by multiplying the force, measured by a strain gauge (model CZC500; Kratos), by the distance from its attachment point to the segment joint center. The lead (steel cable) of the strain gauge was firmly secured on the distal portion of the dominant segment by an adjustable Velcro strap (5, 20). One minute of rest was allowed between each trial. The participants were asked to exert a maximum effort (ie, to push as hard and fast as possible) with the dominant segment positioned at ~90°/C176. Maximal voluntary isometric contraction, the RTD was calculated as possible) with the dominant segment positioned at ~90°/C176.

Muscle activation and EMD

A surface electromyography device (model Telemyo 900; Noraxon) was used to evaluate the muscle activation and EMD during the maximal voluntary isometric contractions. The electromyography of the rectus femoris, vastus lateralis, biceps femoris, tibialis anteriorius, gastrocnemius, and soleus muscles were recorded synchronically with force traces by using a common pulse marker. The electrodes were placed with an interelectrode distance of 1.5 cm on the largest muscle bulk, following the orientation of muscle fibers. To ensure the same placement of electrodes pre- and posttraining, a transparent plastic sheet was used to identify the exact electrode sites in relation to anatomic points, scars, and marks on the skin. The acquisition frequency of the electromyography was set at 1000 Hz, and band pass filters with cutoff frequencies of 20 and 500 Hz were applied to the raw data. The muscle activation level was determined by calculating the RMS, 500 ms around the peak torque, with the use of specific software (model Telemyo 900; Noraxon). The EMD was determined by the time lag between the beginning of the electromyographic activity and the beginning of the mechanical response (torque increase). The beginning of the electromyographic activity was determined as an increase in the muscle activation of >2 SDs from resting values. The initiation of torque was determined by the force trace increasing to 2 SDs from resting values.

Functional capacity

Functional capacity was determined in the second assessment session and included the following tests: “foot up and go,” “sit and reach,” “chair rising,” and 6-min walk. Tests were performed with an interval of 20 min between each and are described in detail elsewhere (21, 22).

Statistical analysis

After confirming data normality and variance homogeneity, a number of analyses of variance (2-factor ANOVA), with group (ST, ST90, and ST150) and time (pre- and posttraining) as factors, were conducted with the last factor treated as a repeated measure. A dependent-sample t test was used for ST150 group data to compare the dependent variables before the supplementation period (baseline) with the pretest data (pretest), and no significant differences were observed. Hence, the baseline data of the ST150 group were not emphasized in the analysis. The EMD data were analyzed by using an ANCOVA, with the pretraining data as a covariate and group as a factor. The Bonferroni-corrected t test was applied to identify where differences occurred. Statistical analyses were performed by using Statistica software (version 7.0; Statsoft Inc). The significance level was set at P < 0.05.

RESULTS

Body mass, BMI, and eating habits for all groups in the pre- and posttraining periods are shown in Table 1. Body mass and dietary habits remained unchanged from pre- to posttraining in all groups (P > 0.05). The total mean energy, carbohydrate, protein, and lipid intake were similar between groups (group effect; P > 0.05) and did not change after the training period (time effect; P > 0.05).

Plasma lipid profiles for all groups are shown in Table 2. The ST group showed no change in EPA and DHA (P > 0.05). The ST90 group experienced significant increases (P < 0.05) in EPA and DHA concentrations in the plasma after FO supplementation (posttraining) of 45% and 20%, respectively. The ST150 group also showed significant mean increases in EPA and DHA concentrations in the plasma after FO supplementation (from baseline to pretraining) of 112% and 50%, respectively. No changes were observed in EPA and DHA in the ST150 group from pre- to posttraining (P > 0.05).

Peak torque and RTD

Peak torque values in the muscles analyzed pre- and posttraining in the ST, ST90, and ST150 groups are presented in
after training in the ST (n = 15), ST90 (n = 15), and ST150 (n = 15) groups

<table>
<thead>
<tr>
<th>Fatty acids</th>
<th>Pre (n = 15)</th>
<th>Post</th>
<th>Pre (n = 15)</th>
<th>Post</th>
<th>Pre (n = 15)</th>
<th>Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPA (20:5n–3)</td>
<td>1.7 ± 0.2</td>
<td>1.1</td>
<td>± 0.4</td>
<td>1.1</td>
<td>± 0.2</td>
<td>1.6</td>
</tr>
<tr>
<td>DHA (22:6n–3)</td>
<td>6.1 ± 1.3</td>
<td>5.3</td>
<td>± 1.5</td>
<td>6.5</td>
<td>± 1.1</td>
<td>7.8</td>
</tr>
<tr>
<td>Arachidonic (20:4n–6)</td>
<td>3.1 ± 0.1</td>
<td>2.9</td>
<td>± 0.1</td>
<td>2.8</td>
<td>± 0.2</td>
<td>2.5</td>
</tr>
<tr>
<td>α-Linolenic (18:3n–3)</td>
<td>0.7 ± 0.2</td>
<td>1.0</td>
<td>± 0.8</td>
<td>0.8</td>
<td>± 0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Linoleic (18:2n–6)</td>
<td>23.0 ± 1.5</td>
<td>22.4</td>
<td>± 1.1</td>
<td>22.6</td>
<td>± 1.0</td>
<td>21.5</td>
</tr>
<tr>
<td>Oleic (18:1n–9)</td>
<td>20.4 ± 2.8</td>
<td>19.2</td>
<td>± 2.1</td>
<td>20.3</td>
<td>± 2.1</td>
<td>20.2</td>
</tr>
<tr>
<td>Stearic (18:0)</td>
<td>2.7 ± 0.4</td>
<td>2.5</td>
<td>± 1.3</td>
<td>2.8</td>
<td>± 0.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Palmitoleic (16:1n–7)</td>
<td>1.2 ± 0.5</td>
<td>0.9</td>
<td>± 0.3</td>
<td>1.4</td>
<td>± 0.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Palmitic (16:0)</td>
<td>13.9 ± 0.2</td>
<td>13.0</td>
<td>± 1.3</td>
<td>12.7</td>
<td>± 1.2</td>
<td>12.6</td>
</tr>
<tr>
<td>Mirtistic (14:0)</td>
<td>4.1 ± 2.7</td>
<td>6.2</td>
<td>± 2.1</td>
<td>5.1</td>
<td>± 1.6</td>
<td>6.1</td>
</tr>
<tr>
<td>Lauric (12:0)</td>
<td>25.2 ± 4.4</td>
<td>25.5</td>
<td>± 3.8</td>
<td>26.1</td>
<td>± 4.1</td>
<td>24.9</td>
</tr>
</tbody>
</table>

All values are mean ± SD percentages. Two-factor ANOVA for repeated measures was used to identify differences between factors (group and time), and the Bonferroni-corrected t test was applied to determine where differences occurred. A t test for independent samples was applied to compare Base and Pre values of the ST150 group. *Differences between Pre and Post (P < 0.05). †Differences compared with Pre (P < 0.05). Base, baseline (refers to the data collected 60 d before initiating the training period); Post, posttraining (refers to the data collected after the end of the training program); Pre, pretraining (refers to the data collected immediately before starting the training program); ST, strength-training group; ST90, strength-training group supplemented with fish oil during 90 d; ST150, strength-training group supplemented with fish oil during 150 d.

Figure 1. There were no differences between groups in peak torque pretraining (P > 0.05). Peak torque in the knee flexor and extensor, plantar and dorsiflexor muscles increased from pre- to posttraining in all groups (time effect; P < 0.05). However, FO supplementation resulted in significantly higher peak torque posttraining than in the ST group for all muscles assessed (P < 0.05). A longer supplementation period (ST150) did not cause any additive effect, and results were similar to those for the

![Figure 1](https://academic.oup.com/ajcn/article-figures/95/2/428/4576792)

**Figure 1.** Mean (±SD) peak torque of lower limb joints [knee flexor (A), knee extensor (B), plantar flexor (C), and dorsiflexor (D) muscles] before and after training in the ST (n = 15), ST90 (n = 15), and ST150 (n = 15) groups. *P < 0.01 compared with pretraining. Two-factor ANOVA for repeated measures was used to identify differences between factors (group and time), and the Bonferroni-corrected t test was applied to determine where differences occurred. The t test for repeated measurements showed no differences (P > 0.05) between baseline (presupplementation) and pretest in the ST150 group. BASE, baseline (refers to the data collected 60 d before initiating the training period); POST, posttraining (refers to the data collected after the end of the training program); PRE, pretraining (refers to the data collected immediately before starting the training program); ST, strength-training group; ST90, strength-training group supplemented with fish oil during 90 d; ST150, strength-training group supplemented with fish oil during 150 d.
The RTDs in the muscles analyzed pre- and posttraining in the ST, ST90, and ST150 groups are presented in Figure 2. There were no differences in RTD pretraining between groups \((P > 0.05)\). RTD in the knee flexor and extensor, plantar, and dorsiflexor muscles increased from pre- to posttraining in all groups (time effect; \(P < 0.05\)). However, FO supplementation resulted in significantly higher RTD posttraining than in the ST group for all muscles assessed \((P < 0.05)\). A longer supplementation period (ST150) did not cause an additive effect, and results were similar to those for the ST90 group \((P > 0.05)\) but were higher than for the ST group \((P < 0.05)\).

Electromyography and EMD

The muscle activation level was determined by calculating the RMS for the muscles analyzed pre- and posttraining (Figure 3). Pretraining RMS values were similar between groups \((P > 0.05)\). RMS increased from pre- to posttraining in all groups \((P < 0.05 \text{ compared with pretraining})\). When FO supplementation was included, the RMS of the vastus lateralis, rectus femoris, biceps femoris, tibialis anterioris, and soleus in the ST90 and ST150 groups increased significantly when compared with the ST group \((P < 0.05)\). A longer supplementation period (ST150) did not cause an additive effect, and results were similar to those for the ST90 group \((P > 0.05)\) but were higher than for the ST group \((P < 0.05)\).

The time lag between the beginning of the electromyographic activity and the onset of the mechanical response (EMD) is shown in Figure 4. There were no differences in EMD pretraining between groups \((P > 0.05)\). EMD of the rectus femoris and gastrocnemius muscles in the ST group decreased significantly from pre- to posttraining \((P < 0.05)\). The inclusion of FO supplementation markedly reduced the EMD of all muscles from pre- to posttraining (time effect, \(P < 0.05\)). The FO-supplemented groups (ST90 and ST150) showed a significant EMD reduction when compared with the ST group \((P < 0.05)\). No differences \((P < 0.05)\) were found between the FO-supplemented groups (ST90 and ST150).

Functional capacity

Functional capacity was determined by “foot up and go,” “sit and reach,” “chair-rising,” and “6-min walk” tests (Figure 5). There were no differences between the groups pretraining in any of these measures \((P > 0.05)\). Posttraining, the ST group showed improvement in the chair-rising test \((P < 0.05)\). FO supplementation induced a further increase in the ST90 group \((P < 0.05)\), but a longer supplementation period (ST150) did not further change functional capacity \((P > 0.05 \text{ compared with ST90})\). There were no alterations in the sit-and-reach test after strength training or FO supplementation \((P > 0.05 \text{ compared with pretest})\). The foot up and go test was performed significantly faster posttraining in all groups \((P < 0.05 \text{ compared with pretest})\).
There was a significant increase in 6-min-walk performance ($P < 0.05$) posttraining induced by exercise (ST group). The FO-supplemented groups (ST90 and ST150) showed similar results when compared with the ST group ($P > 0.05$) and did not differ between the 2 supplementation durations ($P > 0.05$).

**DISCUSSION**

The present study aimed to determine the effects on the neuromuscular system (ie, muscle strength and functional capacity) of FO supplementation when used in addition to a strength-training program in elderly women and to determine whether FO supplementation for a longer period causes further effects. The main finding was that FO supplementation along with strength training improved the response of the neuromuscular system. However, supplementation with FO for an additional period pretraining did not cause any additional effects.

Body weight remained unchanged among groups during the period of the study (Table 1). This indicated that the amount of FO provided (2 g/d) did not cause changes in body mass. Participants’ dietary habits, which remained unchanged for the duration of the study, may have also contributed to body weight stability because the amount of calories consumed was consistent across the dietary habit assessments. Thus, the stable dietary intake variations should not be seen as a confounding factor.

Strength training induced an increase in peak torque in the elderly women who were tested; the strength gains reported in the present study were higher than those reported by others. For example, Ferri et al (23) showed increased knee extensor and plantar flexor peak torques of 19% and 12%, respectively, whereas Brown and Wheir (24) observed increases of 17% for the knee extensor muscles, which are lower than those reported in the present study. The larger gains observed in the present study (~50%) may be attributed to the participants’ lower initial muscle fitness, because most participants were sedentary at baseline. The high adherence...
to the training program may have also positively influenced the results. In addition, the continuous control of the training loads (adjusted weekly) may have played a role. Regardless of the factors that mediated such gains, the strength-training effects on the neuromuscular system corroborate other studies.

The improved RTD reflects improved muscle contractility, which is an important measure for the elderly due to its contribution to several daily life tasks (20) and its relation to the ability to recover from a slip or trip, preventing a fall. Strength training has been shown to facilitate muscle protein anabolism, energy expenditure, and improved appetite and food intake in elderly people (25). Smith et al. (26) recently reported that long-chain n−3 PUFAs have anabolic properties in healthy young and middle-aged adults. Current results suggest that the same is true in our more senior population.

When FO supplementation was associated with strength training there was an additional increase in peak torque and RTD. This study is the first, to our knowledge, to show that FO supplementation is able to enhance skeletal muscle activation and force when incorporated with strength training in elderly women. Indeed, concentrations of EPA (20:5n−3) and DHA (22:6n−3) in the plasma of FO-supplemented groups (ST90 and ST150) increased and indicated the incorporation of these fatty acids in the cells, particularly in the nervous system and muscles. The uptake of fatty acids occurs from VLDL and, in the tissues, involves several isoforms of fatty acid transporter. DHA is taken up and retained in the nervous system; once in the cell membrane and in other organelles, 20-carbon fatty acids originate eicosanoids, whereas DHA produces docosanoids (neuroprostanes, maresins, neuroprotectin D1, and related 22-carbon
derivatives). n–3 PUFAs can stimulate the mitogen-activated protein kinase pathway and facilitate channel opening and gene expression due to their transcription regulator function. The investigation of the role of docosanoids and the existence of DHA-specific fatty acid receptors in the skeletal muscle tissues and neuromuscular system would be an interesting topic for future research (27).

Several mechanisms are involved in muscle strength improvement. Initial gains may be attributed to the neural adjustment that occurs during the first weeks of training, which are followed by enlargement in muscle cross-sectional area (28). With regard to neural adaptation (ie, muscle activation measured by electromyography), the analyzed muscle groups showed greater activation (electromyography) when FO supplementation was provided (Figure 3). One possible physiologic mechanism is that the FO may improve muscle function, changing the fluidity of the membrane and acetylcholine sensitivity. Patten et al (29) observed changes in several pharmacologic agents, such as acetylcholine, 8-iso-prostaglandins series 2, PGE₂, and F₂ and the thromboxane mimetic U-46619, which occurred in response to FO supplementation and which may have mediated contractility increases. Acetylcholine, iso-prostaglandins, and thromboxanes may act via G-protein–coupled receptor systems on the cell membrane that regulate cellular function (29). It is well established that acetylcholine is an excitatory neurotransmitter that triggers the muscle contraction process. Thus, it may assist in muscle contraction by facilitating fast synaptic transmission at the neuromuscular junction (excitatory potential action) and elicit faster muscle contraction. Moreover, changes in the lipid composition of neural membranes affect endocytosis, exocytosis, membrane fusion, neurotransmitter uptake and release, and the activities of membrane-associated enzymes (30). Better membrane fluidity and faster conduction velocity may facilitate impulse transmission (31, 32). Such neuronal adaptations, due to FO supplementation, may then explain not only the electromyographic activation level improvements but also the EMD reduction, although there was a large within-group variation in the initial EMD condition.

Improvements in functional capacity after training showed that physical activity is an important component to improving quality of life. The similarities in the flexibility (sit-and-reach test) found in all groups can be explained by the lack of a specific stretching stimulus during the training period. The chair-rising test was the only functional test that was influenced by FO supplementation. Bassey et al (35), using very elderly participants (age >85 y), found a positive correlation between leg extensor strength and chair rising, suggesting that strength and RTD improvements may influence functional capacity (36). The changes in peak torque and RTD observed around the knee joint for the ST150 group suggest that improvements in functional capacity may be viewed as a direct response to improved muscle performance.

As far as we are aware, there have been no studies investigating the effect of length of FO supplementation on the neuromuscular system. In the present study, 90 d of FO supplementation

![FIGURE 5. Mean (±SD) values for functional tests (“chair rising” (A), “sit and reach” (B), “foot up and go” (C), and “6-min walk” (D)) before and after training in the ST (n = 15), ST90 (n = 15), and ST150 (n = 15) groups. *P < 0.01. Two-factor ANOVA for repeated measures was used to identify differences between factors (group and time), and the Bonferroni-corrected t test was applied to determine where differences occurred. The t test for repeated measurements showed no differences (P > 0.05) between baseline and pretest in the ST150 group. BASE, baseline (refers to the data collected 60 d before initiating the training period); POST, posttraining (refers to the data collected after the end of the training program); PRE, pretraining (refers to the data collected immediately before starting the training program); ST, strength-training group; ST90, strength-training group supplemented with fish oil during 90 d; ST150, strength-training group supplemented with fish oil during 150 d.](https://academic.oup.com/ajcn/article/95/2/428/4576792)
potentiated the effects of an equal length of strength training, although the dose provided was below that recommended by the American Heart Association and the UK government. However, the inclusion of an additional period of 60 d of FO supplementation did not produce further effects. This indicates that the dose provided during 3 mo was sufficient to induce important physiologic changes in the neuromuscular system. These results should be viewed with caution because the participant numbers were relatively small. Other studies involving a larger sample and other combinations of training and supplementation period are required.

In conclusion, the use of FO supplementation in addition to strength training potentiates the neuromuscular system, enhancing the muscle strength and the functional capacity in elderly women. Thus, FO may be an attractive supplement for the elderly to maximize their neuromuscular responses to strength training, which is important to life quality. However, the supplementation length does not influence the strength-training effects.

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