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Neuromuscular determinants of explosive torque: Differences among strength-trained and untrained young and older men

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This study compared the differences in neural and muscular mechanisms related to explosive torque in chronically strength-trained young and older men (>5 years). Fifty-four participants were allocated into four groups according to age and strength training level: older untrained (n = 14; 65.6 ± 2.9 years), older trained (n = 12; 63.6 ± 3.8 years), young untrained (n = 14; 26.2 ± 3.7 years), and young trained (n = 14; 26.7 ± 3.4 years). Knee extension isometric voluntary explosive torque (absolute and normalized as a percentage of maximal voluntary torque) was assessed at the beginning of the contraction (ie, 50, 100, and 150 ms—T50, T100, and T150, respectively), and surface electromyogram (sEMG) amplitude (normalized as a percentage of sEMG recorded during maximal voluntary isometric contraction) at 0-50, 50-100, and 100-150 time windows. Supramaximal electrically evoked T50 was assessed with octet trains delivered to the femoral nerve (8 pulses at 300 Hz). Voluntary T50, T100, and T150 were higher for trained than untrained in absolute ($P < 0.001$) and normalized ($P < 0.030$) terms, accompanied by higher sEMG at 0-50, 50-100, and 100-150 ms ($P < 0.001$), and voluntary T50/octet T50 ratio for trained. Greater octet T50 was observed for the young trained ($P < 0.001$) but not for the older trained ($P = 0.273$) compared to their untrained counterparts. Age effect was observed for voluntary T50, T100, and T150 ($P < 0.050$), but normalization removed these differences ($P > 0.417$). Chronically strength-trained young and older men presented a greater explosive torque than their untrained pairs. In young trained, the greater explosive performance was attributed to enhanced muscular and neural mechanisms, while in older trained to neural mechanisms only.

KEYWORDS
aging, geriatrics, rapid force, rate of force development, resistance training

1 | INTRODUCTION

The seemingly unavoidable declines in musculoskeletal tissue and neural performance that occur during aging can reduce movement capacity,[1] and increase dependence,[2] hospitalization, nursing care, fall events (~40%-50% of results in death),[3] and personal and governmental healthcare costs.[4,5] The decline in neuromuscular performance with aging results from an impaired capacity from the nervous system to generate a motor command (input) and transform it into trains of action potentials (output) to activate the muscle fibers, which are also weakened by aging.[1] Because of these neuromuscular changes, aging individuals commonly experience decreased capacity to rapidly produce large forces in short periods at the beginning of a voluntary contraction,[1,6] also referred to as explosive force/torque.[7] Appropriate explosive torque capacity during aging is associated with enhanced static and dynamic postural control[8-10] and general functional capacity,[11] improving functional independence and reducing the risk of falls.[2,8,9,12] Identifying optimal interventions to maintain or recover explosive torque generation capacity in elders can lead to improved physical independence and overall quality of life.

Explosive torque is determined by neural (eg, the ability of the motor neurons to quickly discharge in higher frequencies) and muscular (eg, the ability of the muscle intrinsic properties to perform fast and strong contractions) mechanisms.[13,14] Neural and muscular mechanisms are known to be negatively influenced by aging[1,15-17] and positively influenced by strength training interventions.[18-20] The decline of explosive torque with aging is mainly attributed to decreases in the maximal motor unit discharge rate at the beginning of torque production, and a slowing and weakness of the contractile properties of the muscle fibers.[17,21,22] To improve explosive torque in young adults, short-term strength training (6 weeks) has been shown effective due to increases in motor unit discharge rates at the beginning of muscle contraction.[19] In older adults, short-term strength training (4-16 weeks) has been shown to improve explosive torque, especially when adopting higher training intensities or fast contraction velocity[18,20,23,24] and cross-sectional studies have shown that chronically strength-trained older adults produce greater explosive torque than their untrained counterparts.[25] However, there is a gap in the literature regarding the understanding of neuromuscular mechanisms underpinning the enhanced explosive torque following strength training in older adults. For example, it is unclear the extent to which neural and muscular mechanisms contribute to improvements in explosive torque in "chronically" strength-trained (eg, >2 years) older adults. The present cross-sectional study was designed to address this gap by comparing the effects of chronic strength training (ie, >5 years) on explosive torque and the neural and muscular determinants of explosive torque in trained and untrained young and older adults.

The contribution of muscular and neural components to explosive torque can be quantified using different techniques. Torque produced during electrically evoked contractions, as opposed to voluntary contractions, specifically indicates the ability of the muscle-tendon unit to develop force. When electrical stimulation is delivered to produce maximal contractions, torque is generated by recruiting all of the motor axons innervating a given muscle or muscle group, thus mostly bypassing the central nervous system and its contribution to torque production.[13,26,27] For this reason, torque produced by maximal trains of electrical stimulation ("octet trains"; 8 pulses at 300 Hz) has been used to gain insight into the muscle-tendon unit's ability to produce explosive force, especially when torque is assessed within a short time after the onset of contraction (eg, 50 ms).[13,27] The contribution of neural mechanisms to explosive torque can be quantified by comparing torque during voluntary and supramaximal electrically evoked explosive contractions (voluntary/octet torque at 50 ms),[28] as well as by quantifying the total surface electromyogram (sEMG) amplitude at the beginning of a voluntary contraction (~0-50 ms).[7,13,14,27,29] A greater voluntary/octet torque ratio at 50 ms combined with larger voluntary sEMG amplitude is thought to indicate higher motor unit recruitment and discharge rates, eliciting near maximum performance of the muscular contractile properties. Lower voluntary/octet torque at 50 ms ratio, combined with lower sEMG amplitude, indicates that neural components may be limiting the explosive torque production.[13,27]

To reduce the gap in literature regarding the effects of chronic strength training on explosive torque during aging, we compared the neural and muscular determinants of explosive torque in chronically trained (>5 years) and untrained young and older men. As described above, neural mechanisms were investigated by comparing torque during voluntary and involuntary electrically evoked contractions and using voluntary sEMG. Muscular mechanisms were investigated by comparing torque at the onset of electrically evoked contractions. We hypothesized that chronic resistance training would result in greater explosive torque in both young and older adults and that this would be associated with enhanced neural and muscular determinants in both groups. Thus, we predicted that older and young trained participants would produce more torque during voluntary and involuntary contractions, and more voluntary sEMG during explosive contractions compared to their untrained pairs. The results of these experiments contribute to our understanding of the influence of chronic strength training programs on the neuromuscular system of older adults.

2 | MATERIALS AND METHODS

2.1 | Study participants

Participants were allocated into four groups: (a) untrained older men (older untrained), (b) older men practicing strength training (older trained), (c) untrained young men (young untrained), and (d) young men practicing strength training (young trained). To be included in the study participants had to be between 20-35 (young men) or 60-75 (older men) years old, male and be free of neuromusculoskeletal disorders in the lower limbs and cardiovascular disease (except untrained led hypertension). Participants were excluded if they answered "yes" to at least one question on the Physical Activity Readiness Questionnaire (PAR-Q) or were participating in hormone replacement therapy and/or using anabolic steroids. The inclusion criteria for the strength-trained participants were as follows: (a) more than 5 years of strength training experience; (b) no pauses in training of longer than 1 month per year in the last 5 years; (c) training frequency for the lower limbs of ≥2 d/wk; (d) no combined regular practice of explosive exercises and sports (eg, involving kicking, sprinting, and jumping); (e) trained participants reported to have not been performing explosive-type contractions in their training routine; and (f) strength training prescribed and supervised by a certified instructor. Participants with no previous or recent (last 10 years) experience in strength training and explosive exercises or sports were allocated to the untrained groups. Participants who did not tolerate the electrical stimulation were excluded from the study. This study was approved by the ethical committee of the Federal University of Santa Catarina and conducted according to the Declaration of Helsinki. All the participants signed the written informed consent.

Two hundred and one males (112 young and 89 older men) volunteered to participate. After the initial screening, 32 young and 35 older men were selected according to the study criteria, received a detailed description of the study procedures, signed an informed consent form, and started the testing procedures. During the assessments and data analysis, participants were excluded if they did not complete the neuromuscular tests (n = 5) or if they had a low tolerance to electrical stimulation (n = 8). Thus, 54 participants (Older untrained, n = 14; Older trained, n = 12; Young untrained, n = 14; and Young trained, n = 14) completed all the procedures and were included in the data analysis.

2.2 | Study design

Participants visited the Biomechanics laboratory from the Federal University of Santa Catarina (Brazil) on three occasions. In the first visit, they were familiarized with the procedures to reduce the influence of learning on performance and to assess the participants' tolerance to the electrically evoked contraction intensity. After 7 days, data were collected during the neuromuscular tests. Participants were requested to avoid lower limb exercises for 96 hours and any exercise 24 hours before this session. The order in which familiarization and testing were performed was the same on both days: (a) warm-up; (b) electrically evoked contractions intensity determination; (c) knee extension maximum voluntary isometric contraction (MVIC); (d) explosive voluntary contractions; and (e) electrically evoked contractions. Body composition was assessed on a third visit.

2.3 | Neuromuscular tests

2.3.1 | Warm-up

Participants performed a general warm-up on a cycle ergometer with a 50 W load for 5 minutes, followed by submaximal knee isokinetic extension/flexion contractions (10 repetitions, concentric, 120°/s) and two knee isometric extension/flexion contractions (5-second at 70°) as warm-up in the dynamometer.

2.3.2 | Torque acquisitions

Knee extension torque from the preferred limb was recorded using a dynamometer (Biodex System 4, Biodex Medical Systems). Participants were seated in the dynamometer chair and firmly secured by straps over the trunk, hips, thighs, and ankle. Isometric knee extension contractions were performed at a knee angle of 70° (0° = knee full extension and hip in neutral position) and hip angle of 85°.[11] Torque signals were recorded using an analog-to-digital converter system (MioTec Biomedical) at a sampling frequency of 2000 Hz.

2.3.3 | Maximum voluntary isometric contractions

Participants performed two isometric knee extension MVICs of ~5 seconds and 2-minute rest. A third was recorded if the maximum voluntary torque (MVT) of the two contractions varied by more than 6%. Before each MVIC, participants were instructed to contract as hard as possible and they performed the MVIC while receiving strong verbal encouragement to achieve maximal torque production. After each contraction, participants received visual (torque trace visualization) and verbal feedback to maximize performance for each contraction.

2.3.4 | Explosive voluntary contractions

Five minutes after the MVICs, participants performed 10 explosive isometric knee extension contractions that lasted ~1 second, each separated by a 20-second rest. Before each contraction, participants were instructed to remain relaxed and avoid any pre-activation or countermovement, and to contract "as fast and hard as possible" with emphasis on "fast," after a luminous signal. Visual and verbal feedback was provided after each trial. Attempts where torque did not reach at least 80% of the MVT or with a observed countermovement were discarded and thus, if necessary, up to three additional contractions were recorded.[7,13]

2.3.5 | Electrically evoked contractions

Knee extension isometric torque was also generated by delivering electrical stimulation (monophasic rectangular pulses of 100 μs) octet trains (8 pulses at 300 Hz) using a constant-current stimulator (Digitimer DS7AH)[27] and two adhesive gel electrodes (ValuTrode, Axelgaard). The circular cathode (3.2 cm of diameter and 5 cm^2) was placed and pressed over the femoral nerve region in the femoral triangle by an experienced researcher. The cathode placement was determined by delivering submaximal stimulation pulses in different positions over the femoral nerve to find the location at which the greatest torque was evoked at the lowest stimulation intensity. The rectangular anode (13 × 7.5 cm and 97.5 cm^2) was placed under the gluteal fold.

Stimulation intensity was determined by delivering octet trains with stepwise increments in current, separated by ~10 seconds until a plateau in torque was reached. The current was then increased by 20% to ensure that the stimulation was supramaximal. Three supramaximal octet contractions were recorded (~10 seconds of rest between stimulations).

2.3.6 | Surface electromyography

sEMG was used to measure the myoelectric activity at the MVIC and beginning of each voluntary explosive contraction[13,30] using a 8-channel system (MioTec Biomedical), at a sampling rate of 2000 Hz per channel, with common rejection mode of 110 dB, impedance input of 1 TΩ, and resolution of 14-bit. After skin preparation (shaving, light abrasion, and cleaning with 70% ethanol), bipolar electrodes (Kendall, Meditrace) were placed over the rectus femoris, vastus lateralis, and vastus medialis following the expected muscle fiber direction. Electrode impedance was lower than 5 kΩ for all participants (rectus femoris, 1.49 ± 1.08 kΩ, vastus lateralis 1.52 ± 0.94 kΩ, and vastus medialis 1.56 ± 1.06 kΩ.).

2.4 | Data analysis

Torque and sEMG signals were stored on a personal computer and processed offline using custom-written MATLAB® R2018 scripts (MathWorks). Torque data were filtered and gravity-corrected. Signal processing included a recursive fourth-order Butterworth low-pass filter and a cutoff frequency of 500 Hz.[28,31] The torque onset of explosive voluntary and electrically evoked contractions was identified visually when the torque increased above baseline, following recommendations by Tillin et al.[32,33] See Supplementary Material 1 for a torque trace data example.

MVT was determined as the highest torque obtained during the MVICs and was used to normalize explosive and octet torque data. Torques recorded during the three voluntary explosive contractions with the highest torque at 100 ms were averaged together and quantified at time points relative to torque onset (T50, T100, and T150 ms).[13] Torque recorded during the three electrically evoked octet contractions was analyzed at 50 ms after the onset.[7,13] Both voluntary and octet torque data are reported in absolute values (N·m) and normalized as a percentage of MVT or octet peak torque, respectively.

sEMG signals recorded during the MVIC were smoothed using a recursive fifth-order band-pass Butterworth digital filter with a frequency range set between 10 and 500 Hz and quantified over a 500-ms window centered at the peak torque, and the root mean square (RMS) was calculated. RMS obtained during the explosive contractions was calculated over 0-50, 50-100, and 100-150 ms after contraction onset and then normalized to the sEMG RMS of the MVIC.[13] After normalizing the RMS values for each muscle, they were averaged to represent the sEMG of the quadriceps muscle group. sEMG onsets were determined visually for each muscle, and the first to activate was determined as the common onset (time zero) for all muscle sEMG recordings.[13]

2.5 | Body composition

A Dual-energy X-ray absorptiometry (DXA) (Lunar Prodigy Advance, GE Medical System Lunar) and the Prodigy Software were used to assess lean and fat mass. The total body measurement was performed according to the manufacturer recommendations, and skeletal muscle index (skeletal muscle mass/height^2) was estimated.[34]

2.6 | Statistical analysis

All data are presented as mean and 95% confidence interval (CI). Quantile-quantile plots and Shapiro-Wilk tests confirmed normality of data, and Levene's tests confirmed between-groups homogeneity of variances. Two-way ANOVAs (training level vs age) were used to compare participant's characteristics, voluntary and octet torque, and sEMG variables. Bonferroni post hoc analyses were conducted when appropriate. Statistical significance was set at $\alpha = 0.05$ for all tests.

3 | RESULTS

3.1 | Participant characteristics

Young participants were taller than older participants ($P = 0.002$). The skeletal muscle index and MVT were greater in trained participants than untrained ($P < 0.001$) and in young than older participants ($P < 0.001$). In addition, trained participants presented lower body fat than untrained participants ($P = 0.021$), and young presented lower body fat than older participants ($P = 0.001$) (Table 1). See Supplementary Material 2 for detailed statistics results.

3.2 | Voluntary explosive contractions

The absolute voluntary T50, T100, and T150 were greater for trained than untrained participants ($P < 0.001$), and for young than older participants ($P < 0.050$), with no interaction ($P > 0.435$) (Figure 1A). When absolute voluntary torque was normalized as a percentage of MVT, T50, T100, and T150 were greater for trained than untrained ($P < 0.030$), and there was no effect of age ($P > 0.417$) and no interaction ($P > 0.277$) (Figure 1B).

Higher sEMG amplitudes were observed for trained than the untrained participants ($P < 0.001$) at all the time windows, and for older than younger participants at 50-100 ms ($P = 0.039$), with no age effect for sEMG in 0-50 and 100-150 windows ($P = 0.095$ and 0.197, respectively), and with no interaction ($P > 0.530$) (Figure 2). See Supplementary Material 2 for detailed statistics results.

3.3 | Octet contractions

Absolute octet T50 was higher for young trained than older trained ($P < 0.001$), for young untrained than older untrained ($P = 0.007$), and for young trained than young untrained ($P < 0.001$), while older trained were not different than older untrained ($P = 0.190$) (training level vs age interaction, $P = 0.014$) (Figure 3A). When octet T50 was normalized to octet peak torque (%), it was higher in trained than untrained participants ($P = 0.026$), and greater in older than younger participants ($P = 0.011$), with no interaction ($P = 0.566$) (Figure 3B). Octet peak torque was greater for trained than untrained ($P = 0.009$) and for young than older participants ($P < 0.001$), with no interaction ($P = 0.095$) (Figure 3C). Greater voluntary T50/octet T50 ratio was observed for trained than untrained participants ($P = 0.001$) with no age effect ($P = 0.144$) and no interaction ($P = 0.141$) (Figure 3D). See Supplementary Material 2 for detailed statistics results.

4 | DISCUSSION

Our cross-sectional study was designed to investigate the neuromuscular determinants that underlie the differences in explosive torque in untrained and chronically strength-trained young and older men. The main findings suggest that strength-trained participants presented greater levels of explosive torque accompanied by superior neural drive to the muscle for both young and older participants. Enhanced neural drive to the muscle is evidenced by the larger voluntary T50/octet T50 ratio, sEMG amplitude, and T50, T100, and T150 (%MVT) during explosive voluntary contractions[7,13,35] in trained participants. However, our results suggest that older trained presented a weaker muscle compared to young trained. The larger octet T50 observed for young trained than the other groups highlights the positive influence of muscular mechanisms on a higher explosive performance. Also, T50 octet was not different between older trained and untrained individuals, which could indicate lower muscle plasticity in older adults independent of training level. These results highlight the fact that explosive torque is higher in chronically strength-trained participants, independent of age. These results indicate potential preservation of voluntary explosive torque during aging mainly explained by enhanced neural drive to the muscle in chronically strength-trained older men.

TABLE 1 Participant characteristics

Groups	Older untrained	Older trained	Young untrained	Young trained
Age (y)	65.6 (63.7, 67.4)	63.6 (61.2, 66.0)	26.2 (24.1, 28.3)	26.7 (24.7, 28.7)
Body mass (kg)	78.5 (69.0, 86.9)	79.0 (70.1, 87.4)	73.7 (65.1, 82.2)	82.9 (77.3, 88.6)
Height (m)	1.71 a (1.67, 1.75)	1.72 a (1.68, 1.77)	1.77 b (1.73, 1.82)	1.80 b (1.75, 1.85)
Body fat (%)	29.0 Aa (24.3, 32.7)	23.6 Ba (18.9, 28.4)	21.2 Ab (16.1, 26.3)	16.9 Bb (13.07, 20.69)
Skeletal muscle index (kg/m^2)	9.0 Aa (8.5, 9.7)	10.0a Ba (9.2, 10.9)	9.3b Ab (8.7, 9.8)	11.5b Bb (11.1, 11.9)
MVT (N·m)	213 Aa (189, 236)	245a Ba (213, 277)	290b Ab (258, 321)	357b Bb (319, 397)

Note: Data are presented as mean and 95% confidence interval (lower limit, upper limit). MVT, maximum voluntary torque. Different upper-case letters (A and B) denote effect of training level differences; different lower-case letters (a and b) denote effect of age differences ($P < 0.05$).

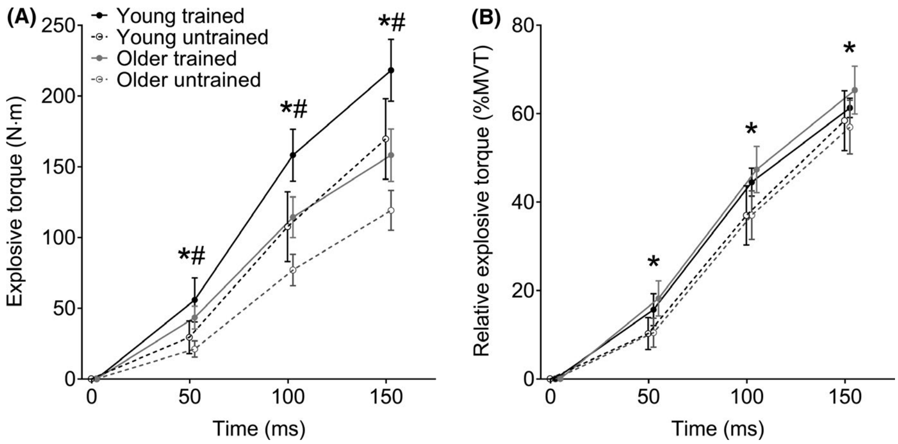

FIGURE 1 Absolute (A) and relative (B) torque during explosive voluntary contractions. *Effect of training level; #effect of age ($P < 0.05$). MVT, maximal voluntary torque

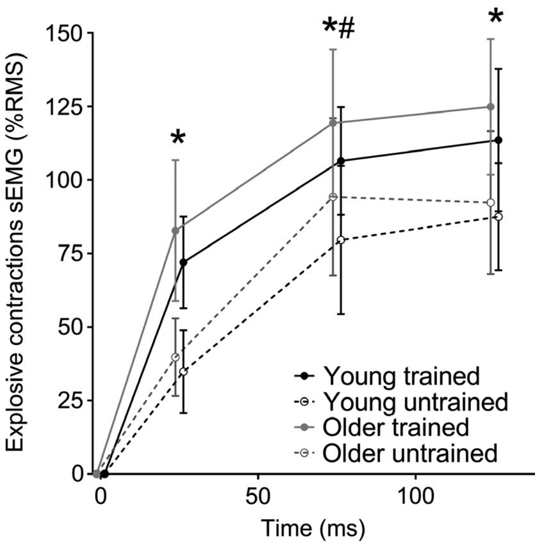

FIGURE 2 Electromyogram amplitude during explosive voluntary contractions. *Effect of training level; #effect of age ($P < 0.05$). RMS, root mean square; sEMG, surface electromyography amplitude

Voluntary explosive torque was greater for trained than untrained participants independent of age, with older trained individuals displaying similar performance when compared to the young untrained adults. A previous cross-sectional study involving older adults with extensive power-lifting training experience[25] reported that trained older adults had similar rates of torque development to untrained young participants and higher rates than their untrained older counterparts.[25] Another cross-sectional study involving young adults engaged in strength training for at least 3 years[36] found that rate of torque development was greater for trained than untrained young adults.[36] However, neither of these previous studies provided insight into the mechanisms underlying the differences in explosive torque in chronically strength-trained young and older adults, highlighting the originality of the indirect findings of the present study.

Normalizing the torque produced during explosive contractions (%MVT) is usually performed to reduce the individual influence of maximal torque and understand the influence of neural properties on explosive torque.[13] The performance at the first ~75 ms of normalized explosive torque is strongly determined by neural mechanisms.[7,13,14] Thus, the higher normalized explosive torque for trained compared to untrained participants in the present study is indicative that training may have induced relevant neural adaptations in both groups. The greater explosive torque seen in trained individuals independent of age was accompanied by greater voluntary T50/octet T50 ratio and voluntary sEMG amplitude at the 0-50-, 50-100-, and 100-150-ms windows. This torque ratio provides insights into the ability of the nervous system to recruit motor units rapidly to make use of the muscles' maximal ability to produce torque in a short period. These results, in addition to the finding of larger sEMG amplitude for young trained and older trained, may be an indicator of greater motor unit recruitment and discharge rate capacity during explosive contractions,[13,14] representing enhanced volitional neural efficiency due to chronic strength training.[7]

Although the volitional neural drive to the muscle during explosive contractions seems to be similar for strength-trained young and older men, low levels of intrinsic muscle torque production can limit the final explosive torque produced.[7] Octet contractions evoke the maximum possible muscle explosive torque, with little or no influence from the central nervous system, especially at 50 ms after the torque onset.[13,27] The torque obtained from this method results from orthodromic axonal recruitment and muscle-tendon unit contractile and mechanical properties during explosive torque production (eg, stiffness, cross-sectional area, fiber type composition, and calcium release for a given level of activation).[7,13,23,35,37,38] Our data indicate an enhanced performance in young trained but not older trained individuals compared to their untrained counterparts for octet T50. This result is in agreement with a short-term strength training study that showed no improvements in twitch peak torque and rate of torque development[39] in older women. After normalization,

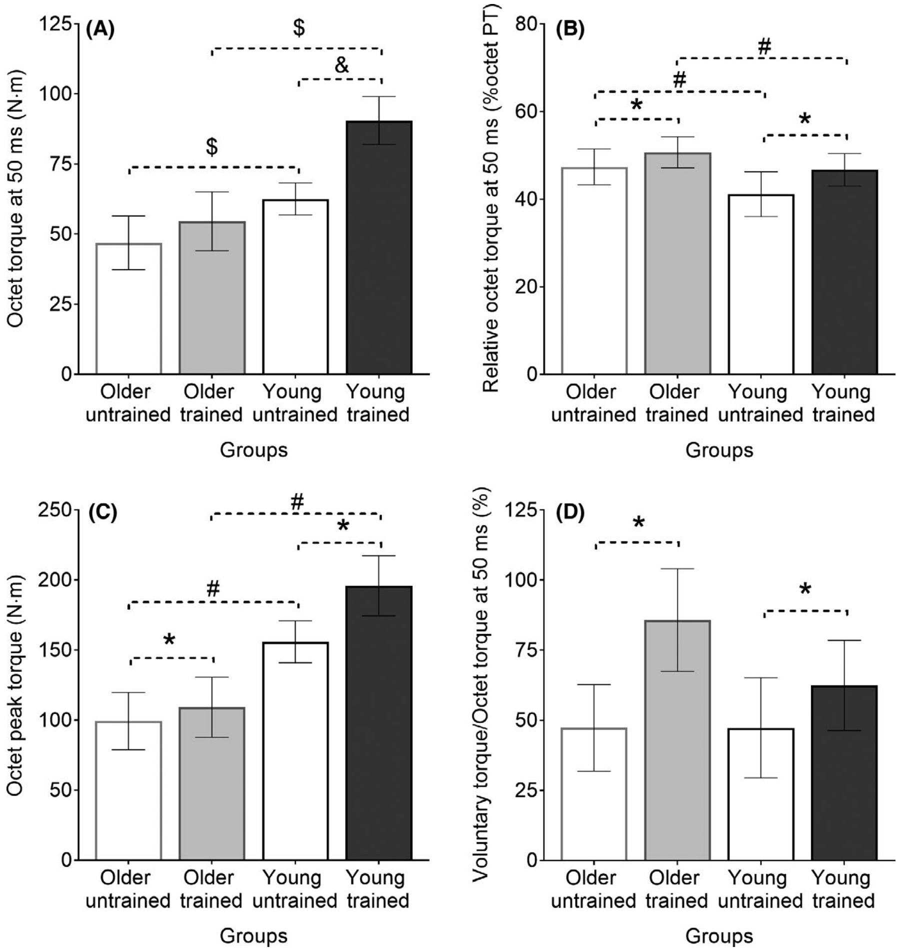

FIGURE 3 Absolute (A) and relative (B) octet torque at 50 ms, octet peak torque (C), and voluntary/octet torque ratio at 50 ms (D). Training level × age interaction interpretation at A: $young trained significantly greater than older trained and young untrained significantly greater than older untrained; and &young trained significantly greater than young untrained. There was no difference between older trained and older untrained. *Effect of training level; #effect of age ($P < 0.05$). MVT, maximal voluntary torque

we found greater T50 for trained than untrained, which is in contrast with previous findings that reported decreases in normalized octet T50 (% of octet peak torque) after short-term resistance training.[29] These results may indicate different muscle-tendon unit intrinsic contractile properties between trained older and young men. Octet T50 normalization (% octet peak torque) was performed to understand the ability to produce torque rapidly without the influence of maximal torque production and central nervous system; in other words, trained participants torque can be rapidly developed and transmitted by the muscle-tendon unit.

These findings highlight the nervous system plasticity in response to resistance training and could be explained by a greater ability of trained participants' motor units to discharge at higher frequencies at the beginning of explosive contractions.[14] Trained older men can recruit their motor units rapidly and use a great amount of their muscle explosive force voluntarily. However, their explosive torque is limited by weaker muscles. On the other hand, untrained young have stronger muscles but cannot use their maximal explosive force due to inefficient motor unit recruitment. The enhanced explosive torque observed in older trained participants has important clinical relevance for the health of older men, allowing us some speculations related to using long-term strength training for health-related outcomes. First, explosive torque is related to functional capacity,[11] which is typically improved following resistance training.[40] Similarly, lower explosive torque negatively influences static and dynamic balance and the propensity for falling.[8-10] Fall events can lead to injuries (eg, fractures) and even periods of bed-rest (eg, hospitalization), both of which exacerbate the limitations on neuromuscular function [1] and lead to substantial personal and governmental healthcare costs.[4,5]

Our study has some strengths and limitations that should be highlighted. Using the same experienced evaluator and standardized procedures to perform all the neuromuscular tests gives our study high internal validity. However, the isokinetic dynamometer used in our study has greater compliance and noise than load cells attached to custom-built dynamometers. In addition, conducting a randomized clinical trial would be the optimal design to study this question; however, it is expensive and unlikely to be feasible due to the duration (>5 years). Despite the rigorous recruitment process and selection procedures to discriminate trained and untrained participants, the differences between groups cannot be attributed only to the effects of long-term strength training. Factors such as genetics, nutrition, and history of physical activity through life might also play a role in their explosive torque performance. Finally, our study did not include participants currently performing exercise involving explosive contractions which are known to enhance explosive force, and thus, our findings cannot be generalized to outcomes for this type of exercise, different muscle groups, and to women. Therefore, caution should be taken when interpreting these results and future research is needed to examine these factors.

In conclusion, chronically strength-trained young and older men (>5 years) have greater explosive torque performance compared to their untrained counterparts. In young trained, the higher explosive performance was attributed to muscular and neural mechanisms, while in older trained to neural mechanisms only. Our data also suggest similar explosive torque in older trained and young untrained individuals, indicating that long-term strength training may play an important role in the maintenance of explosive torque during aging. These findings highlight the importance of stimulating the practice of strength training throughout the lifespan to counteract or minimize the unavoidable deterioration of the neuromuscular system during aging. This aligns and strengthens the current physical exercise guidelines for young and older adults, suggesting at least 150 min/wk of moderate-to vigorous-intensity aerobic physical activity and muscle and bone-strengthening activities at least twice per week.[41] Further studies aiming to understand the influences of these differences for physical function in daily tasks and if there is a link to health outcomes are warranted.

5 | PERSPECTIVE

This study explored explosive torque and its' muscular and neural determinants in chronically strength-trained and untrained young and older adult males. We showed that young and older trained participants presented greater explosive torque than their untrained counterparts. Also, explosive torque in older trained individuals was not different from that of young untrained individuals. The increase in explosive torque in both young and older trained was accompanied by an enhanced neural drive to the muscle; however, a greater explosive torque from the muscle-tendon unit, with less influence of the nervous system, was observed mainly in young trained. These findings indicate that enhanced neural mechanisms for trained older adults play a role in the preservation of explosive torque during aging. It is reasonable to suggest that long-term strength training influenced the observed differences between age and training level groups and should be considered when aiming to delay the age-related decays of explosive torque. Further research is needed to a better understanding of which neural mechanisms might be responsible for these differences and to clarify why the muscular mechanisms were not enhanced in older trained individuals.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. No funding source is associated with the present study.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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