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Posted Date: 2 October 2024

doi: 10.20944/preprints202410.0132.v1

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Article

Effects of Explosive vs. Strength Resistance Training on Plantar Flexor Neuromuscular and Functional Capacities in Institutionalized Older Adults: A Randomized Controlled Trial.

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Abstract: Objectives: To compare the effects of explosive resistance training (RT) to strength RT on neuromuscular and functional parameters and to analyze the relationship between changes in walking speed and improvements in plantar flexor (PF) neuromuscular parameters following interventions. **Methods:** 40 participants were randomly assigned to either an explosive RT group (EXG, $n = 18$; age = 80.41 ± 10.12 years; BMI = 22.89 ± 2.77 kg/m²) or a strength RT group (STG, $n = 22$; age = 82.89 ± 5.32 years; BMI = 23.81 ± 3.45 kg/m²). Both groups participated in the same PF RT regimen (3 sessions per week for 12 weeks), engaging in identical exercises. However, the EXG performed 3 to 5 sets of 12 to 14 repetitions at 40% to 45% of 1RM with a rapid concentric phase and a 3-second eccentric phase, while the STG performed 3 to 4 sets of 6 to 7 repetitions at 80% to 85% of 1RM, with both phases lasting approximately 3 seconds. Before and after the interventions, gait speed (m/s) was assessed using a 10-meter walking test, and relative maximal force (Relative F max, N/kg) was evaluated during maximal voluntary isometric contraction of PF. From the force-time curve, early (0 – 50 ms) and late (100 – 200 ms) rates of force development (RFD) were extracted from the linear slopes (Δ force / Δ time). **Results:** Gait speed significantly improved in both groups ($p < 0.05$). However, the improvement was more pronounced in the EXG compared to the STG ($p < 0.05$). Relative Fmax showed a more significant increase in the STG than in the EXG ($p < 0.05$). Moreover, a significant 10% increase in early RFD in the STG and a 20.1% increase in the EXG were observed ($p < 0.05$). The improvement in early RFD was greater in the EXG ($p < 0.05$). Additionally, late RFD improved significantly only in the EXG (+20.4%, $p < 0.05$). **Conclusion:** Explosive RT appears particularly effective in improving the ability to rapidly generate force, which is essential for many daily activities requiring explosive movements and quick responses.

Keywords: gait; maximal strength; explosivity; resistance training; functional capacities; seniors

1. Introduction

Sarcopenia, characterized by the progressive loss of muscle mass and strength, significantly impacts the quality of life in older adults [1]. The associated decline in muscle force production capacity is a crucial factor in the functional deterioration and onset of frailty in this population [2]. These neuromuscular alterations are strong predictors of adverse outcomes such as falls [3], hospitalizations [4], loss of independence [5], institutionalization, and ultimately, a reduction in life expectancy [6]. Consequently, it is essential to optimize interventions, particularly targeting the neuromuscular system, to reduce dependency and prevent falls in older adults [7].

Several studies have highlighted a significant correlation between decreased ankle plantar flexor (PF) force production capacities and functional abilities [8–10]. For instance, Cattagni et al. [10] observed that within a group of 30 older adults, maximal torque of the PF was negatively correlated with the displacement of the center of pressure during static postural balance ($r = -0.77$). Furthermore, they demonstrated that 90% of individuals with maximal PF torque less than 3.1 Nm/kg had previously experienced falls, whereas 85% of those exceeding this value had not. Therefore, maximal PF force production capacity could be considered a predictive parameter for fall risk [11]. However, the ability to avoid a fall depends not only on maximal force production capacity but also on motor response time, which reflects the speed to generate submaximal force, also known as the rate of force development (RFD) [12,13].

RFD, defined as the increase in force per unit of time, is calculated from the slope of the force-time curve ($\Delta \text{force} / \Delta \text{time}$) [12,14]. RFD evaluations typically consider different phases of muscle contraction, including the early phase (0 – 50 ms) and the late phase (100 – 200 ms) [13]. The early phase is largely related to the initiation of motor unit activation and their firing sequences, as well as intrinsic muscle characteristics, such as fiber composition and calcium dynamics [15]. In contrast, the late phase relies on the ability to transmit the force produced by the contractile component through the parallel and series elastic components [16]. Several studies consider RFD as a crucial predictor of functional capacities in older adults [12,17]. For example, Hester et al. [12] demonstrated that RFD was the sole predictor of Timed Up and Go test performance in older adults [18–20]. Improving RFD could therefore be a key objective in rehabilitation and training programs aimed at enhancing walking ability and reducing fall risks in older adults [8].

Resistance training (RT) has been shown to improve muscle force production capacity in older adults [21]. For instance, Walker et al. [22] demonstrated improvements in maximal strength and quadriceps mass when exercises were performed at slow and controlled cadences. These results justify the feasibility [23,24] and necessity of integrating resistance exercises for older adults [25,26]. However, most interventions have advocated for strength resistance exercises, consisting of 1 to 4 sets of about 8 to 15 repetitions at moderate to high loads, performed at least twice a week, in line with previous international recommendations [27]. Recent studies and meta-analyses indicate that RT, including explosive training elements, is more effective for enhancing functional abilities compared to strength RT [28,29]. Explosive RT involves performing the concentric muscle contraction of each exercise repetition as quickly as possible, demonstrating notable improvements in morphological and neural adaptations as well as functional performance capacities [30]. For example, Cadore et al. [23] showed significant improvements in muscle power production, strength, muscle cross-sectional area, and dual-task performance in frail institutionalized older adults after 12 weeks of explosive RT. While the benefits of explosive RT in developing muscle strength are generally recognized, no study, to our knowledge, has yet thoroughly examined the specific effects of explosive RT on improving both early and late RFD of PF in institutionalized older adults. These investigations could potentially provide crucial insights into the underlying mechanisms of muscle explosivity enhancement in this specific population and, by extension, the influence of these adaptations on walking speed, an essential parameter of physical function.

The main objective of this study was to compare the effects of explosive versus strength RT on maximal strength, early and late RFD of PF, and gait speed. We hypothesize that explosive RT results in greater improvements in PF neuromuscular and functional parameters compared to strength RT.

2. Materials and Methods

2.1. Study Design

This study was a prospective, controlled, single-blinded, randomized trial, with participants randomly assigned to either an explosive resistance training group (EXG) or a strength resistance training group (STG). Both groups underwent the same assessments before and after the intervention, which consisted of 3 sessions per week for 12 weeks. While both groups performed identical PF resistance exercises, the execution parameters differed significantly in both cadence and stimuli. The EXG performed 3 to 5 sets of 12 to 14 repetitions at 40% to 45% of 1RM, focusing on a rapid concentric phase followed by a 3-second eccentric phase. In contrast, the STG performed 3 to 4 sets of 6 to 7 repetitions at 80% to 85% of 1RM, with both the concentric and eccentric phases lasting approximately 3 seconds each. This distinction in cadence and load was intended to differentiate between explosive and maximal strength training stimuli. The study adhered to the ethical principles outlined in the Helsinki Declaration, and approval for the study protocol, patient information letter, and informed consent form was obtained from the local ethics committee of the Intercommunal Health Center of Sarthe et Loir.

2.2. Recruitment

The recruitment process consisted of a three-week recruitment period, followed by a one-week screening phase (**Figure 1**). Participants were recruited from a retirement home located in Sablé-sur-Sarthe (France) between January 15 and February 15, 2024. To be eligible, individuals had to be older than 65 years or, capable of walking without technical assistance (e.g., canes, walkers) from another person, and able to communicate verbally effectively with the research team. Individuals with neurological or cognitive disorders, severe cardiovascular diseases, significant musculoskeletal issues in the lower limbs, or those taking medications that could affect the tests were excluded. The eligibility of each participant was meticulously verified by the medical staff. Then, participants were randomized into one of two groups: the EXG and STG. The randomization list was generated using a computer algorithm by an independent statistician. At the end of the screening process, the investigator, who was blinded to the treatment assignment, obtained a unique randomization number for each participant.

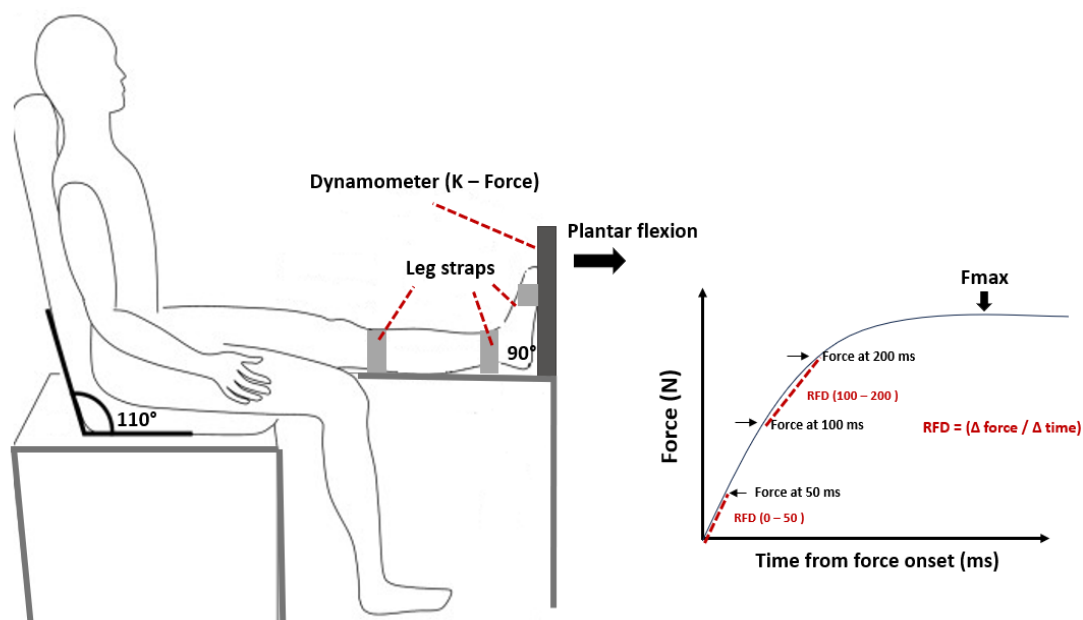


Figure 1. Setup for the maximal voluntary contraction test of the plantar flexors and parameter extraction.

2.3. Evaluation Protocol

All assessments were conducted in a clinical examination room under consistent environmental conditions, supervised by a blinded evaluator who was unaware of the group affiliation of the participants. Prior to the assessments, participants received a standardized set of verbal instructions to ensure familiarity with the procedures.

2.3.1. Anthropometric Parameters

Body mass (BM) and height (H) of the participants were precisely measured using a digital floor scale and a wall-mounted stadiometer, respectively. Body mass index (BMI, in kg/m²) was subsequently calculated. Lean body mass (LBM) was measured using bioelectrical impedance (Tanita; SC 240, Amsterdam, The Netherlands) [31]. During the measurement, participants were instructed to stand still, with their arms slightly away from their body and their legs not touching, while their feet were positioned on the electrodes of the bioelectrical impedance. All measurements were conducted in the morning, with participants fasting and having avoided any physical activity for 24 hours prior.

2.3.2. Gait Speed

Gait speed (m/s) was assessed over a 20-meter flat surface, with measurements taken between the 5th and 15th meters to exclude acceleration and deceleration phases [32]. Participants were instructed to walk at their usual pace and attempt to reach their maximum speed between the 5th and 15th meters. A stopwatch was used to measure the time required to walk the 10-meter distance. The average walking speed (m/s) was then calculated using the following formula:

Walking speed (m/s) = distance / time, (1)

2.3.3. Neuromuscular Parameters

Neuromuscular parameters of PF of the dominant leg were assessed during maximal voluntary contractions (MVC) using a dynamometer (K-Force, Kinvent, Montpellier, France). Participants were seated on a chair, ensuring contact between their back, buttocks, and thighs with the chair while keeping their leg horizontally extended (**Figure 1**). They were instructed to push with the ends of their foot against the dynamometer [31,33]. Two trials were conducted with a one-minute rest interval between them, and the maximum force of the PF (Fmax, N) from both trials was recorded. The relative maximum force (Fmax relative, N/kg) was calculated by normalizing the maximum force to the participant’s body mass. The early RFD was calculated from the onset of each MVC to 50 ms (RFD 0 – 50), and the late RFD was calculated between 100 and 200 ms (RFD 100 – 200). Both early and late RFD were derived from the linear slope of the force-time curve (Δ force / Δ time).

2.4. Resistance Training Programs

The RT comprised 36 sessions over a 12-week period, with participants in both groups completing three sessions per week. The protocol was structured based on prior studies [34–36], beginning with an initial two-week *conditioning phase*, which was followed by a *specialized training phase* tailored to the cadence and stimuli-specific focus of each group. Specific methodologies employed in each training protocol are outlined in Table 1.

Table 1. Details and methodologies employed in each training protocol.

	Explosive RT	Strength RT
Sets	3 to 5 sets	3 to 4 sets
Repetitions	12 to 14 repetitions	6 to 7 repetitions
Intensity	40% to 45% of 1 – RM	80% to 85% of 1 – RM
Concentric Phase Execution	rapidly	≈ 3 seconds
Eccentric Phase Execution	≈ 3 seconds	≈ 3 seconds
Recovery Between Repetitions	1 second	1 second

Recovery Between Sets	5 min between sets	5 min between sets
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During the *conditioning phase*, the two groups were introduced to the specific exercises they would be performing in the subsequent specialized training phase. This period was designed to familiarize participants with the correct execution of each movement, emphasizing proper technique and the controlled application of force. Using light loads, participants practiced the exercises with a focus on mastering the concentric and the eccentric phases. The EXG was instructed to perform the concentric phase rapidly, while maintaining control during the eccentric phase, whereas the STG was guided to execute both phases in a slow and controlled manner. During the final session of the conditioning phase, participants underwent a one-repetition maximum (1-RM) assessment using a seated calf raise machine. This assessment involved a progressive increase in load, with small incremental increases, until participants achieved the maximum weight they could lift with proper form. The 1-RM was defined as the heaviest load lifted with controlled execution and without any compensatory movements, and it was found to be approximately 22 kg for both groups.

To systematically increase the workload, the *specialized training phase* was organized into five micro-cycles, each spanning two weeks. To ensure that the relative load training between the EXG and STG groups was equalized, the workload was quantified using the volume load (VL) method [34]. The VL was calculated using the following equation [37]:

VL = number of sets × number of repetitions × weight lifted (kg)

(2)

Table 2 presents the predicted progression of volume-equated training loads between the two groups. The predicted VLs were established based on the first 1-RM assessment.

Table 2. Predicted progression of volume load of resistance training programs.

Week	Micro-cycle	Explosive RT	Strength RT	Volume load (kg)
1 – 2	1	conditioning phase	conditioning phase	-
3 – 4	2	4 sets x 12 reps @ 40% 1- RM (8.8 kg)	3 sets x 8 reps @ 80% 1-RM (17.6 kg)	422.4 kg each
5 – 6	3	4 sets x 13 reps @ 40% 1- RM (8.8 kg)	3 sets x 9 reps @ 80% 1-RM (17.6 kg)	457.6 kg each
7 – 8	4	4 sets x 14 reps @ 45% 1- RM (9.9 kg)	4 sets x 7 reps @ 85% 1-RM (18.7 kg)	554.4 kg each
9 – 10	5	5 sets x 12 reps @ 45% 1- RM (9.9 kg)	4 sets x 8 reps @ 85% 1-RM (18.7 kg)	594.0 kg each
11 – 12	6	5 sets x 14 reps @ 50% 1- RM (11.0 kg)	4 sets x 9 reps @ 85% 1-RM (18.7 kg)	770.0 kg each

To ensure optimal progression throughout the program, 1-RM assessments were conducted at the end of each micro-cycle [34], with VL systematically adjusted based on participants’ performance. These adjustments were made at the end of each week, following the final training session, to maintain an appropriate and challenging stimulus for continued adaptation [34,35]. Each training session began with a standardized 5-minute warm-up, consisting of light stationary cycling, rowing, or brisk walking on an ergometer or treadmill.

Throughout the 10-week of the *specialized training phase*, training load (TL) was assessed after each session using the Rate of Perceived Exertion (RPE) scale [38]. The average daily TL for each group was calculated using the following equation:

Daily TL = RPE × VL,

(3)

Training monotony and strain of each group was calculated based on the formulas proposed by Foster et al. [39]:

Monotony = Weakly mean TL / SD,

(4)

Strain = Total weekly TL × Monotony,

(5)

where, *weekly mean TL* is the *average daily TL* during the week, and *SD* is the standard deviation of the daily TL calculated over a week.

2.5. Statistical Analysis

The sample size was determined using the freeware G*Power (version 3.1.9.4) as outlined in the study by Ferhi et al. [32]. For the power analysis, an ANOVA test was preselected, with the parameters set to control for a Type I error (alpha = 0.05) and a Type II error (beta = 0.60). Assuming a moderate estimated effect size (r = 0.35), the calculation indicated that a minimum of 40 participants would be required.

Statistical analysis was performed using Statistica Software 13.0 (StatSoft, Tulsa, OK, USA). The normality of the data sets and the homogeneity of variances were assessed using the Shapiro-Wilk and Levene’s tests, respectively. The effects of time (pre- and post-training) and group (EXG and STG) on neuromuscular and functional parameters, as well as their interaction, were tested using a two-factor ANOVA (group × time). Subsequently, a post-hoc analysis was conducted to determine significant inter- and intra-group effects. Finally, Pearson correlation analysis (r) was performed to examine the relationship between walking speed and the neuromuscular parameters of the PF before and after interventions. Results at baseline and after the intervention were presented as mean ± standard deviation. The significance level was set at *p*<0.05.

3. Results

3.1. Participants

A total of 57 volunteers were initially recruited for this study (**Figure 2**). However, only 46 participants met the established eligibility criteria and were randomly assigned to either the EXG (n = 23) or the STG (n = 23). Six participants did not complete the study due to non-adherence to the protocol—five from the EXG and one from the STG. Reasons for discontinuation included hospitalizations due to stroke, hip fracture, and ankle sprain in four participants, while two others withdrew for personal reasons. Consequently, adherence to the study protocol was 87%. Ultimately, a cohort of 40 participants successfully completed the study (**Table 3**), with the EXG consisting of 18 participants (age = 80.41 ± 10.12 years; BMI = 22.89 ± 2.77 kg/m²) and the STG consisting of 22 participants (age = 82.89 ± 5.32 years; BMI = 23.81 ± 3.45 kg/m²).

Table 3. Anthropometric characteristics of the two groups before and after the intervention.

Parameters	Groups	Mean ± SD	Mean ± SD	Time	p (F)	
		At baseline	After		Time × Group	Group
Age (years)	STG	82.89 ± 5.32	82.89 ± 5.32	0.92 (0.48)	0.91 (0.01)	0.76 (0.09)
	EXG	80.41 ± 10.12	80.41 ± 10.12			
Height (m)	STG	1.70 ± 0.13	1.70 ± 0.13	0.84 (0.69)	0.792 (0.07)	0.92 (0.16)
	EXG	1.64 ± 0.16	1.64 ± 0.16			
Weight (kg)	STG	68.81 ± 5.60	70.43 ± 7.60	0.76 (0.85)	0.746 (0.03)	0.81 (0.02)
	EXG	61.62 ± 9.45	64.19 ± 4.45			
BMI (kg/m²)	STG	23.81 ± 3.45	24.39 ± 3.34	0.71 (0.85)	0.746 (0.32)	0.87 (0.24)
	EXG	22.89 ± 2.77	23.78 ± 3.23			
Lean mass (kg)	STG	44.90 ± 4.74	48.34 ± 2.71	0.54 (0.48)	0.908 (0.01)	0.76 (0.09)
	EXG	41.65 ± 3.65	44.94 ± 5.64			
Fat mass (kg)	STG	23.91 ± 9.26	22.09 ± 7.28	0.95 (0.69)	0.792 (0.07)	0.90 (0.02)
	EXG	19.97 ± 4.60	19.25 ± 6.55			
Fat mass (%)	STG	34.76 ± 3.04	31.38 ± 5.10	0.79 (0.75)	0.75 (0.03)	0.87 (0.02)
	EXG	32.40 ± 6.15	29.99 ± 7.16			

BMI: body mass index; STG: strength resistance training group; EXG: explosive resistance training group; SD: standard deviation.

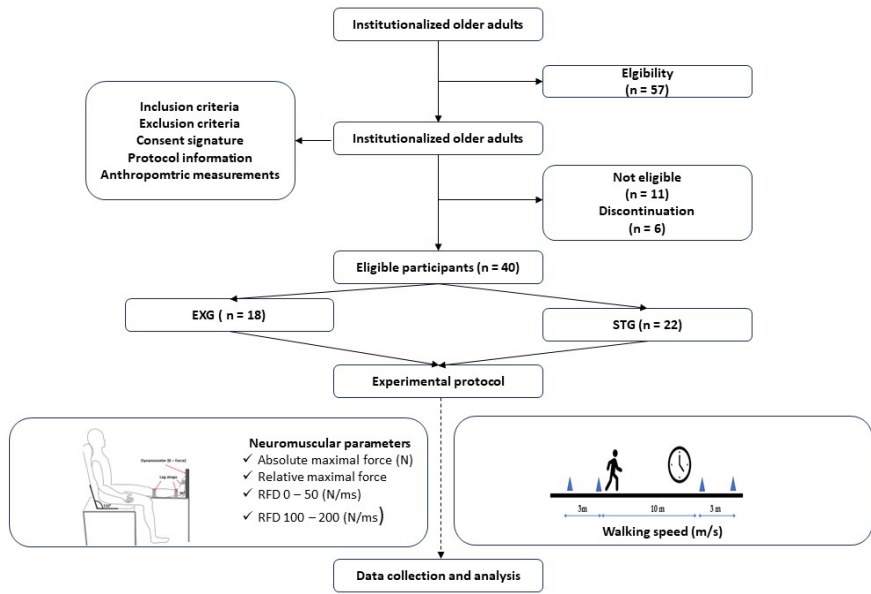
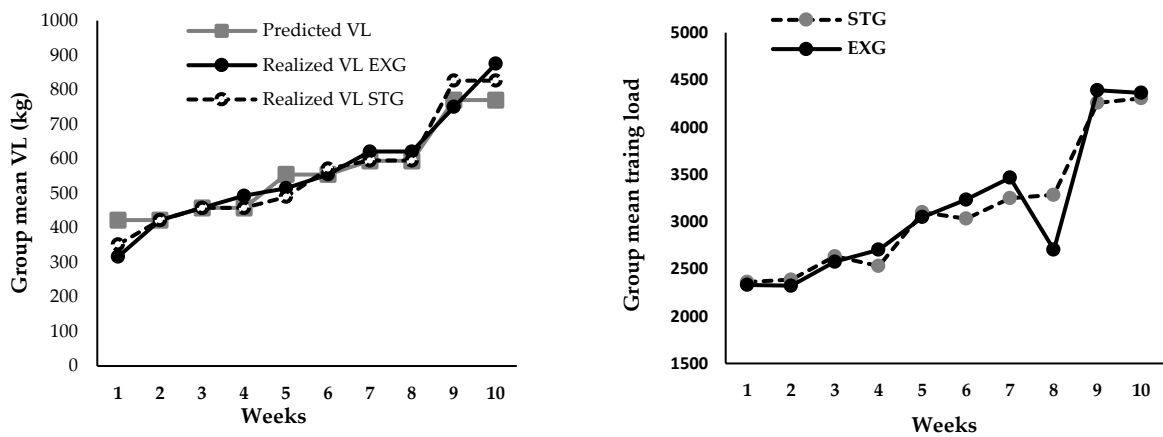


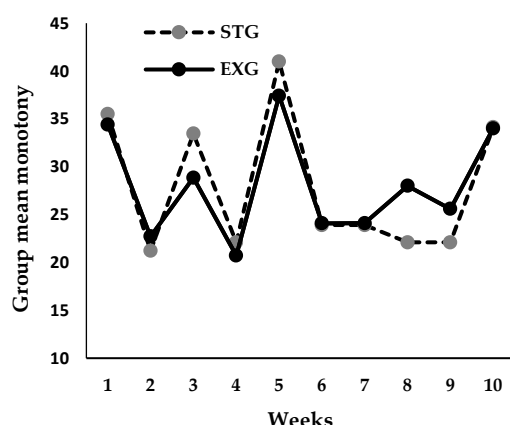
Figure 2. Study design.

3.2. Training Programs

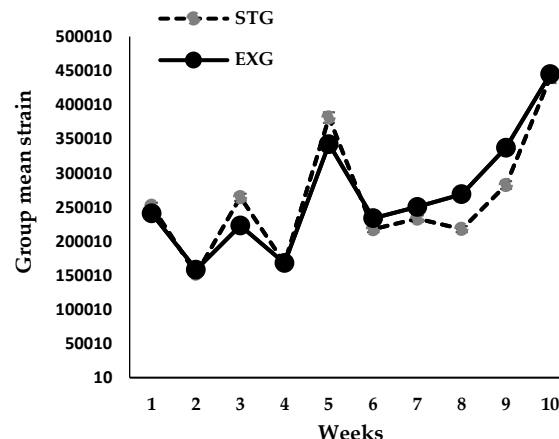
Attendance was calculated as the average percentage of training sessions attended over the 12-week period. Overall, attendance was $91.9 \pm 3.5\%$ for both the EXG and STG, with no statistically significant differences between the groups in session attendance. The 1 – RM values ranged from 22 kg to 25 kg in the EXG and from 22 kg to 27 kg in the STG. Overall, no statistically significant differences were observed between the predicted VL and the realized VL in both groups. A notable deviation occurred during the first week, where the predicted load was overestimated by 20% for the EXG and by 15% for the STG. Conversely, in the 10th week, the load was underestimated by 13% for EXG and 7% for STG (Figure 3a). Except for the 8th week, no significant differences in group mean TL (Figure 3b), monotony (Figure 3c) and strain (Figure 3d) were observed between the two groups. Monotony values for both groups ranged from 22 to 42 (Figure 3c), indicating that the variability in training load was effectively managed, thereby preventing excessive uniformity that could potentially lead to overtraining. The similar strain values further indicate that the overall training stimulus was appropriately balanced, promoting analogous adaptation processes in both groups.



(a) Predicted and realized volume load (VL) in explosive (EXG) and strength (STG) Groups.



(b) Weekly progression of training load in explosive (EXG) and strength (STG) Groups.



(c) Weekly training monotony in explosive (EXG) and strength (STG) Groups.

(d) Weekly training strain in explosive (EXG) and strength (STG) Groups.

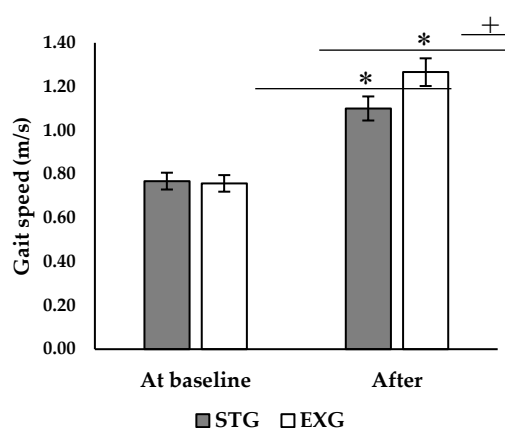
Figure 3. Comparative analysis of training metrics over the specialized training phase (10 weeks).

3.3. Anthropometric Parameters

No significant inter- or intra-group differences were observed between the STG and EXG groups, both before and after training, across all anthropometric parameters presented in **Table 3**.

3.4. Walking Speed

ANOVA analysis revealed a significant interaction between the effect of time and group on walking speed ($p < 0.001$; $F = 11.6$). Post-hoc analysis showed that there was no significant difference between the two groups before the intervention (**Figure 4**). After the intervention, both the EXG and STG showed a significant increase in walking speed ($+63.2\%$, $p < 0.001$; $+45.6\%$, $p < 0.001$, respectively). However, walking speed was higher in the EXG compared to the STG ($p < 0.05$, **Figure 4**).

**Figure 4.** Comparison of walking speed between the two groups before and after the intervention. *: significant difference between before and after the intervention ($p < 0.05$), +: significant difference between groups ($p < 0.05$).

3.3. Neuromuscular Parameters

ANOVA analysis revealed a significant interaction between the effects of time and group (**Table 4**) on both absolute ($p < 0.001$; $F = 1.77$) and relative Fmax ($p < 0.001$; $F = 14.6$). Post-hoc analysis revealed a significant increase in both absolute and relative Fmax in the EXG ($+20.5\%$, $+21.1\%$, $p <$

0.001, respectively) and in the STG (+16.2%, +17.1%; $p < 0.001$, respectively). The improvement in both absolute and relative Fmax was greater in EXG ($p < 0.05$). Additionally, post-hoc analysis showed a significant increase in RFD 0 – 50 of 10% in the STG ($p < 0.05$) and 20.1% ($p < 0.05$) in the EXG. The improvement in RFD 0 – 50 was greater in the EXG ($p < 0.05$). Moreover, RFD 100 – 200 improved only in the EXG (+20.4%, $p < 0.05$).

Table 4. Neuromuscular parameters of the two groups before and after interventions.

Parameters	Groups	Mean ± SD		p (F)		
		At baseline	After	Time	Time × Group	Group
Absolute F max (N)	STG	220.00 ± 13.69	265.00 ± 13.69 *	<0.001 (113.00)	<0.001 (81.77)	0.130 (2.53)
	EXG	216.50 ± 9.44	251.50 ± 9.44*+			
Relative F max (N/kg)	STG	3.45 ± 0.53	4.177 ± 0.61 *	<0.001 (973.71)	0.001 (14.62)	0.376 (0.83)
	EXG	3.31 ± 0.45	3.875 ± 0.53*+			
RFD 0 – 50 (N/s)	STG	630.00 ± 41.07	693.22 ± 45.23*	<0.001 (625.51)	0.07 (8.71)	0.106 (2.92)
	EXG	627.50 ± 27.00	753.40 ± 32.87*+			
RFD 100 – 200 (N/s)	STG	320.00 ± 27.38	352.00 ± 30.12	<0.001 (908.95)	<0.001 (107.70)	0.202 (1.76)
	EXG	318.00 ± 18.88	383.60 ± 19.99*+			

STG: strength resistance training group; EXG: explosive resistance training group; SD: standard deviation. *: Significant difference between before and after the intervention ($p < 0.05$), +: Significant difference between the two groups ($p < 0.05$).

3.5. Relationship between Neuromuscular Parameters of the PF and Walking Speed

3.5.1. At Baseline

Figure 5 presents correlations between walking speed and neuromuscular parameters at baseline in STG and EXG. Walking speed was positively correlated with relative Fmax (**Figure 5a**) of STG ($r = 0.51$; $p < 0.05$) and EXG ($r = 0.54$; $p < 0.05$).

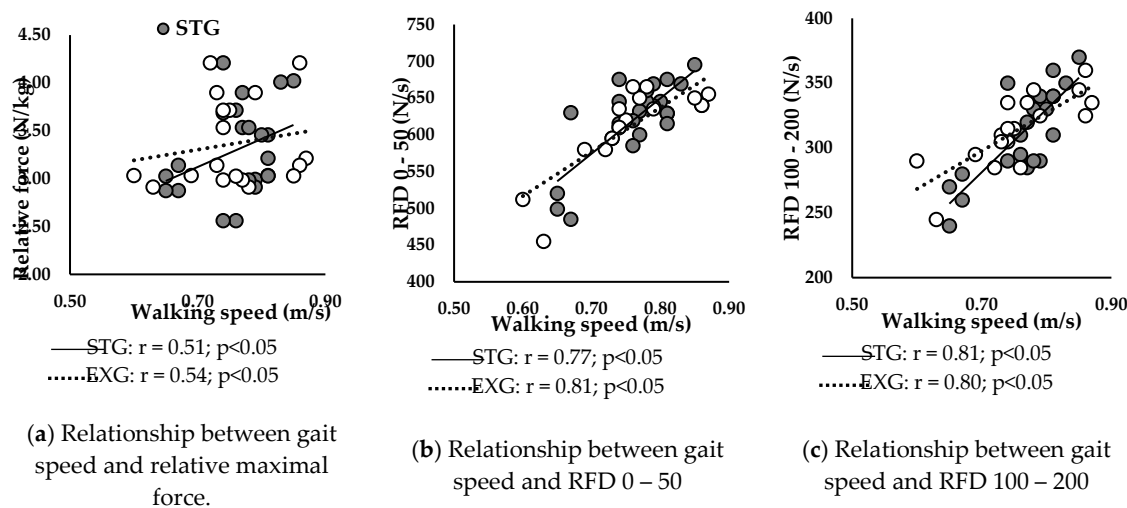


Figure 5. Relationships between walking speed and neuromuscular parameters of plantar flexors at baseline.

Additionally, RFD 0 – 50 (**Figure 5b**) and RFD 100 – 200 (**Figure 5c**) were positively correlated with walking speed in STG ($r = 0.77$; $r = 0.81$; $p < 0.05$, respectively) and in EXG ($r = 0.81$; $r = 0.80$; $p < 0.05$, respectively).

3.5.2. After Training Programs

Figure 6 presents correlations between ameliorations in walking speed and improvements in neuromuscular parameters in STG and EXG. Δ walking speed was positively correlated with Δ relative Fmax (**Figure 6a**) of STG ($r = 0.52$; $p < 0.05$) and EXG ($r = 0.48$; $p < 0.05$). Additionally, Δ RFD 0 – 50 (**Figure 6b**) and Δ RFD 100 – 200 (**Figure 6c**) were positively correlated with Δ walking speed in STG ($r = 0.76$; $r = 0.82$; $p < 0.05$, respectively) and in EXG ($r = 0.79$; $r = 0.83$; $p < 0.05$, respectively).

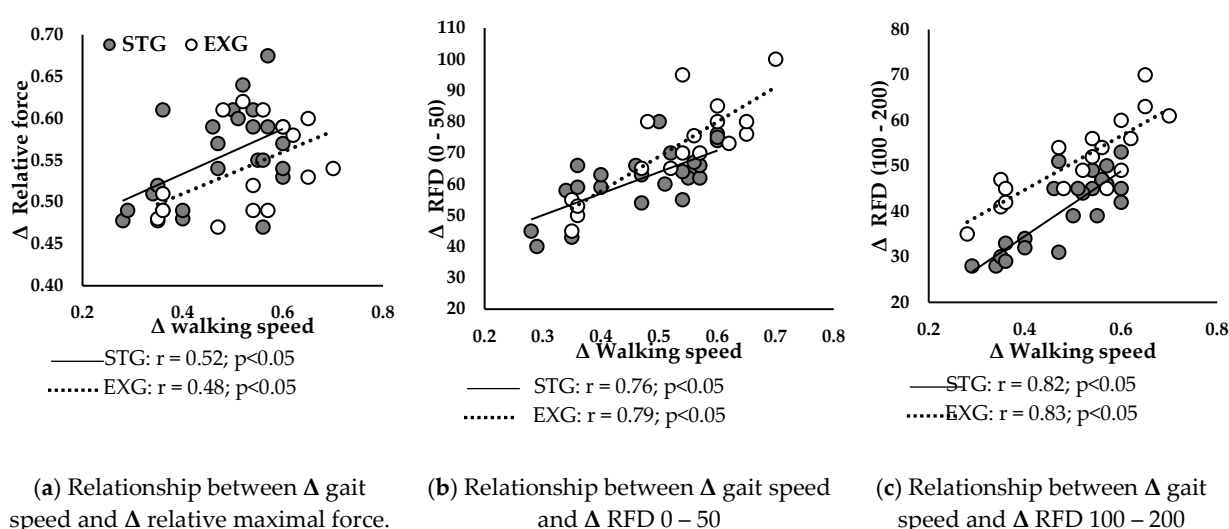


Figure 6. Relationships between ameliorations in gait speed and improvements in neuromuscular parameters of plantar flexors.

4. Discussion

This study aimed to evaluate the effects of explosive *versus* strength RT on the neuromuscular parameters of the PF, as well as to examine the relationships between improvements in these parameters and walking speed in institutionalized older adults. Our results revealed that both types of RT improved the neuromuscular capacities of the PF, but with different and specific adaptations. Strength RT led to a more significant improvement in Fmax, while explosive training favored improvements in RFD. Furthermore, regardless of the type of training, improvement in walking speed were more strongly correlated with RFD in both intervention groups.

The results of this study revealed that RT programs, regardless of the stimuli and cadence (explosive or strength), improved Fmax of PF. These findings are consistent with several studies highlighting possible neuromuscular adaptations related to resistance exercises, allowing for significant improvements after 12 weeks of muscle RT [23,40,41]. Specifically, our results showed a 21% improvement in relative Fmax in STG and 16% in the EXG. These results align with the systematic review of Lopez et al. [42] showing significant improvements in maximum knee extensor force ranged from 6.6% to 37.0%, after 12 weeks of RT in older adults. Several hypotheses can be proposed to explain the mechanisms of these neuromuscular adaptations to RT in older adults. Firstly, protein synthesis metabolism through the efficient transport of amino acids and growth factors (e.g., insulin-like growth factor-1 [IGF-1], hepatocyte growth factor [HGF], interleukin-6 [IL-6], and myostatin) to muscle fibers [43]. These elements play a crucial role in regulating satellite cells,

thereby supporting the repair and/or remodeling of neuromuscular adaptations, which is particularly essential after the age of 65 [44]. Additionally, an increase in the cross-sectional area of the muscle, and consequently muscle mass, may also promote increased muscle force. Kryger et al. [41] demonstrated a significant 22% increase in the number of type IIa muscle fibers of the knee extensor muscles in older adults, thus promoting muscle hypertrophy associated with improved Fmax. However, the results of this study did not reveal an increase in lean mass in the two groups after the intervention. It is possible that these subjects did not significantly improve muscle mass, but rather muscle quality through morphological adaptations, such as a decrease in fat infiltration [23]. It is also possible that improvement in Fmax is related to specific neural adaptations, such as increased recruitment of fast-fiber motor units and improved nerve transmission [45_47]. All these findings suggest that neuromuscular capacities in older adults can be effectively reversed through targeted adaptations induced by muscle RT.

The originality of this study lies in its investigation of the specific adaptations associated with both the cadence and stimuli of resistance exercises in older adults. Our results show that strength RT led to a more significant improvement in Fmax (+8% in STG), while explosive training favored improvements in early RFD (+9% in EXG) and late (+8% in EXG). Indeed, explosive exercise imposes high demands on the nervous system, resulting in significant improvements in neuromuscular function in older adults [48_50]. In this context, several studies have emphasized that explosive training could partially reduce muscle activation deficit in older adults [51] with a superior effect on muscle power compared to strength training [52]. Furthermore, early RFD is primarily influenced by neural factors, such as the maximum discharge frequency of motor neurons [15_16]. The late RFD is predominantly influenced by the structural properties of the muscle-tendon complex and the effectiveness of force transmission through both parallel (e.g., cellular matrix) and series elastic elements (e.g., tendons) [45]. Consequently, we propose that the observed improvement in early RFD can be attributed to increased motor unit discharge rate and recruitment, reduced cortical inhibition, and enhanced nerve conduction velocity [23,53,54]. The improvement in late RFD could be linked to enhanced capacity of the muscle-tendon complex to transmit force through elastic elements and potential structural adaptations in the muscle's pennation angle and fiber number [53,55].

Our results revealed a significant improvement in walking speed for both EXG (+63.2%) and STG (+45.6%), consistent with several studies showing similar effects of muscle RT on habitual and maximum walking speed [42,56]. These improvements, ranging from 5.5% to 20.4% and observed after short-term interventions (10-12 weeks), have been attributed to enhanced neuromuscular capacities of lower limb muscles [23,57]. However, in our study, the EXG showed a significantly superior improvement of 12% in walking speed compared to the STG. Moreover, the improvement in walking speed was more strongly correlated with the RFD than with the improvement in Fmax (Figure 6). Indeed, during walking, the time to develop force is limited, typically less than 300 ms. Superior gains in RFD, both in the early (0 – 50 ms) and late (100 – 200 ms) phases, allow for a rapid and efficient response, essential for maintaining balance and stability during walking [45,58]. Additionally, improved RFD enhances propulsion and braking during walking, crucial for speed and movement efficiency [59]. These results suggest that improvements in RFD play a more decisive role in enhancing walking propulsion capacity than increases in Fmax. This underscores the importance of targeting these parameters in rehabilitation and training programs to optimize activities of daily living in older adults [60,61]. Moreover, an increased ability to rapidly develop force allows for better responses to situations of imbalance, such as during stumbling, and helps maintain equilibrium and stability while walking [17,57]. Therefore, rehabilitation programs should include explosive resistance exercises to maximize neuromuscular and functional benefits in older adults.

Limitations and Future Perspectives

This study acknowledges several limitations that warrant consideration. Firstly, our study primarily focused on the PF. It would be important to investigate other muscle groups, especially those around the knee, which are also crucial for walking. An analysis of neuromuscular activities through electromyography would also be necessary to understand the underlying mechanisms of

neural adaptations resulting from the two types of interventions. Finally, while bioelectrical impedance analysis is a practical and widely used method for estimating body composition due to its non-invasive nature, portability, and ease of use, it relies on population-specific algorithms that may not be universally applicable to our study population. In future studies, it would be beneficial to incorporate gold standard techniques such as Magnetic Resonance Imaging or Dual-Energy X-ray Absorptiometry for assessing body composition.

5. Conclusions

The cadence and stimuli of muscle resistance exercises elicit distinct neuromuscular adaptations in older adults. Explosive RT appears particularly effective in improving the ability to rapidly generate force, which is essential for many daily activities requiring explosive movements and quick responses. These results underscore the importance of including explosive resistance exercises, supported by regular assessments and adjustments based on individual progress, to maximize neuromuscular and functional benefits in older adults.

Author Contributions: Conceptualization, E.M. and W.M.; methodology, E.M. and Y.C.; software, J.J.; validation, N.P., A.R. and Y.C.; formal analysis, O.G.C.; investigation, E.M.; resources, J.J.; data curation, O.G.C.; writing—original draft preparation, E.M.; writing—review and editing, W.M.; visualization, N.P.; supervision, W.M.; project administration, A.R.; funding acquisition, A.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and was approved by the local Ethics Committee of the Intercommunal Health Center of Sarthe et Loir (protocol code 012, January 5, 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Written informed consent has been obtained from the patient(s) to publish this paper if applicable.

Data Availability Statement: The research was registered in the Pan African Clinical Trials Registry under the registration number PACTR202306912191110.

Acknowledgments: We gratefully acknowledge the medical staff and administration of the intercommunal Health Center of Sarthe et Loir for their invaluable support and assistance during this study. We also extend our heartfelt thanks to the patients who generously participated in this research.

Conflicts of Interest: The authors declare no conflicts of interest.

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