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Effects of free weights and machine training on muscular strength in high-functioning older adults

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ABSTRACT

Background: Resistance training is assumed to be a key player in counteracting the age-related decline of functional capacity as well as the incidence of falls in older adults. Functional training using free weights is presumed to mimic daily activities, but there is a lack of studies comparing free weight training with barbells and machine training in older adults. The purpose of this study was to evaluate the development of muscle strength for high resistance training in high functioning older people for machines as well as free-weights as well as testing the feasibility of free weight training for this target group.

Methods: Thirty-two fitness trained women and men aged 60 to 86 years (mean: 66.9, SD: ± 5.5) participated in this study. Machine exercisers ($n = 16$; chest press, leg press, upper row, biceps cable curls, triceps cable extension) vs. free weight exercisers ($n = 16$; squat, bench press, bent-over rowing, biceps curls, lying triceps press) participated twice à week for a total of 26 weeks. They trained the same five muscle groups for three sets with 10 to 12 repetitions at the 10-Repetition-Maximum, followed by 20 min of endurance training over six months. Three measurements (dynamic, isometric strength and endurance) were taken at the beginning, after 10 weeks and again after 26 weeks.

Results: Repeated measures MANCOVA analysis revealed significant increases in the free weights training group (FWT) as well as in the machine training group (MT) over the period of 6 months. However, only for leg strength (113 vs. 44%) and triceps (89.0 vs. 28.3%) the free-weights group exhibited significant differences for the percentage increase over a period of 26 weeks compared to the machine group. A detraining period revealed the decline of the dynamic strength without training. The analysis of the follow-up questionnaire resulted in higher demands for safety, but also higher values for fun, motivation, future, and benefit for daily life for the FWT group compared to the MT group indicating an overall better evaluation of their training specific regime.

Conclusion: Our results demonstrate that especially free-weight training has benefits in improving leg and triceps strength as well as in the subjective perception in older adults. Nevertheless, our results do not overall indicate that free-weight training is superior to machine training for increasing strength.

1. Introduction

The decrease of muscle mass (sarcopenia), strength and muscular power (dynapenia) are physiological processes of aging, in particular with the onset of the sixth decade (Borde et al., 2015; McKinnon et al., 2017; Steffl et al., 2017). Fortunately, there is ample evidence that resistance training (RT) is beneficial in counteracting the age-related muscle and nerve degenerating processes (Marques et al., 2013; Borde et al., 2015; Law et al., 2016; McKinnon et al., 2017).

RT consists of muscle-strengthening exercises typically performed with machines or free weights (e.g. dumbbells, barbells). These exercises have been confirmed to have positive effects in numerous factors in older adults including markedly increased muscle mass, strength, and power (Grgic et al., 2018; Guizelini et al., 2018; McCrum et al., 2018), improved body composition (Cavalcante et al., 2018), bone mineral density (Huovinen et al., 2016), mobility and balance (Aartolahti et al., 2019), decreased risk of falls (Burton et al., 2017; Cadore et al., 2013; Sherrington et al., 2019), increased cognitive functions (Li et al., 2018; Northey et al., 2018), and an overall improved quality of life (Hart and Buck, 2019; Ramirez-Campillo et al., 2018).

Although much is known about positive effects of RT, designing the "optimal" RT program for a special target group (here older adults with or without motor and/or cognitive impairments) remains difficult due to the large number of organizational variables and mechano-biological factors involved (Borde et al., 2015; Paoli and Bianco, 2012). This understanding emphasizes the proposition that RT should be

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investigated more thoroughly and rigorously by taking into account different variables such as exercise mode, intensity, volume, and progression (Paoli and Bianco, 2012; Gentil et al., 2017; Suchomel et al., 2018).

One intensively discussed topic designing RT programs is the training modality by means of training predominantly with machines or free weights (Carpinelli, 2017; Haff, 2000). As is often the case, both modalities are characterized by clear advantages and disadvantages depending on the target group and training goal (Suchomel et al., 2018; Wirth et al., 2016). There is a widespread assumption that free weight training (FWT) is superior to machine training (MT), because it requires greater motor control and muscle recruitment demands that may produce greater strength-power adaptations which transfer to functional tasks important to older adults (Carpinelli, 2017; Haff, 2000; Myers et al., 2017; Shurley et al., 2017; Suchomel et al., 2018). However, taking a closer look at studies comparing FWT with MT, the current state of research does not confirm the aforementioned assumption (e.g. Carpinelli, 2017; Haff, 2000).

Recent studies with older adults between 50 and 94 years (Balachandran et al., 2016; Brill et al., 1998; Maddalozzo and Snow, 2000) identified no significant group differences in strength improvements comparing different training modalities within an intervention period of 8 to 24 weeks. Nevertheless, they reported superior results for the FWT group improving function (Balachandran et al., 2016), and bone mineral density (Maddalozzo and Snow, 2000). Both studies incorporated a high number of exercises (10–13) with 3 sets of 12 repetitions, which might have led to a progressive increase in participant's fatigue affecting their overall training success. In addition, strength is typically assessed at machines, which might mask the training effects of the free weight training by giving the machine training group an advantage of testing familiarity. These findings do not allow clear statements regarding the "better" exercise modality, which is also a result of the heterogeneity of the study designs (subjects, intervention period, exercises, intensity).

Therefore, the aims of our study were (a) comparing the effects of a high-intensity FWT with a MT during 26 weeks in high-functioning older adults and (b) testing the feasibility of high-intensity FWT with barbells for this target group. Although the basic movements during FWT vs. MT are similar (e.g. squat), these training modalities have unique characteristics that can cause different adaptation performances (Luebbers and Fry, 2016). For example, the individual does not have to balance the weight himself during MT and can therefore use higher weights. In contrast, FWT is attributed to muscle activation close to natural movement, a higher range of motion, and better physiological responses (Cotterman et al., 2005; Gutierrez and Bahamonde, 2009; Shaner et al., 2014). Women also seem to achieve better adaptation performance in MT compared to FWT (Cotterman et al., 2005). Therefore, in order to test training-specific adaptation processes, the testing was specifically adapted to the training method of the respective group, i.e. changes in the force parameters in the FWT group were tested with free weights, while the MT group was tested on machines accordingly. We hypothesized that both programs would lead to increases in maximal strength production in older men and women. It was also hypothesized that FWT would result in a greater increase in muscular strength compared to training on machines (Luebbers and Fry, 2016; Shaner et al., 2014).

2. Methods

2.1. Experimental design

A 6-month randomized, controlled, two-group study with a pre-post design study following the CONSORT statement (Schulz et al., 2010) was performed to test the feasibility and effectiveness of resistance training programs using either free weights (FW) or machines (M) in healthy older adults.

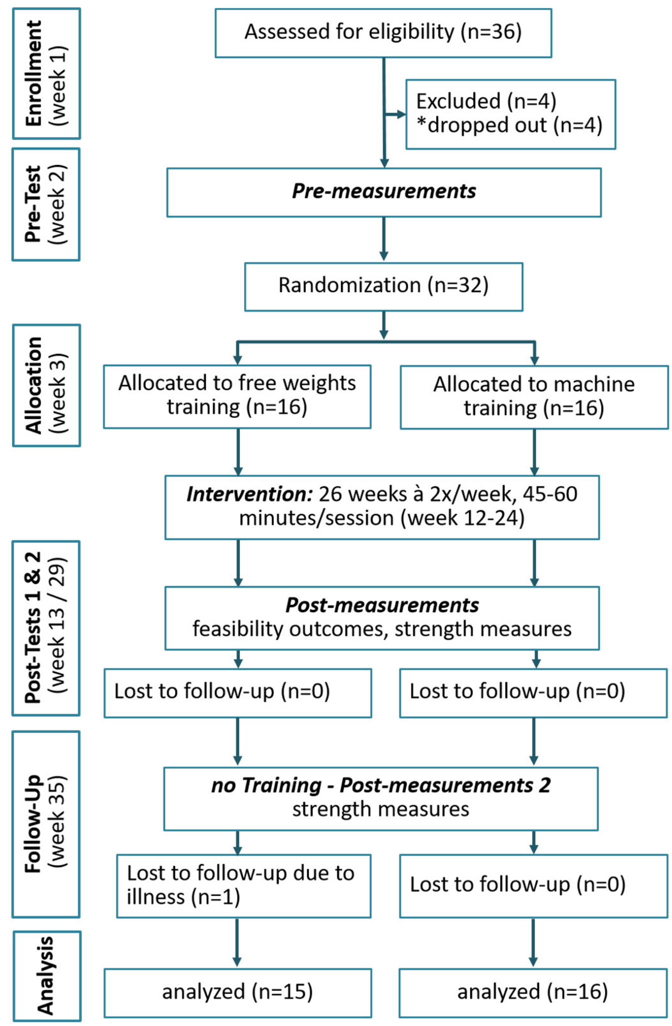

Fig. 1. Design and time flow of participants through the study.

Participants were matched for baseline strength on a leg press machine and then randomly assigned to one of the two training groups: MT (n = 16, 5 males) or FWT (n = 16, 5 males). They were asked to put their current fitness training on hold and replace it with that of the current study. In addition, they were advised not to alter their customary nutritional regimen during the study. All subjects were tested before (week 2), during (week 13, 29), and after (week 35) the intervention. The measurements included dynamic and isometric strength tests. A consort flow diagram of the study is presented in Fig. 1.

The procedures, purpose and risks associated with the study were explained to all the subjects before they gave their written informed consent to participate in this investigation. All procedures were in accordance to the Declaration of Helsinki with ethical standards, legal requirements and international norms, and were approved by the local Institutional Review Board.

2.2. Participants

Pretrial statistical power from a recent meta-analysis of resistance training (Straight et al., 2016) was conducted using G*Power 3.1 (http://www.gpower.hhu.de/en.html; Faul et al., 2007). Based on a medium effect size (f = 0.25; 2 groups, 5 assessment times, 20% attrition rate) a sample size of 26 was necessary to reach 80% probability that treatment differences could be observed with a 5% level of significance.

Recruitment was made from university courses (University of the

3rd Age). The database included participants living around a metropolitan area in Germany, represented both sexes, a range of socioeconomic status, and varying physical activity levels. Inclusion criteria were age between 60 and 90 years, living independently, and not having lifted weights in the past 6 months, but participated in fitness classes in the past 6 months. These classes were visited by the participants 1 to 2× a week. They included functional fitness training, active cognitive training and motor skill training (including athletic techniques). Individuals with medical risk factors like heart failure, stroke, hypertension, or arteriosclerosis were excluded (American College of Sports Medicine, 2014).

2.3. Training program

All training sessions were performed at a gym at the university, and were supervised by certified fitness coaches to ensure proper performance of the respective routines. During the intervention period, training was conducted twice per week (at least 48 h between sessions) for 6 months (26 weeks). Each training session lasted for ~75 to 90 min, and consisted of a 5 to 10 minute warm-up, 5 exercises for different muscle groups (2 warm-up sets of 15–20 repetitions; 3 sets of 10–12 repetitions maximum [10-RM]) using either machines or free weights, and 20 min endurance training using cycle ergometer, cross-trainer, or rowing ergometer. Two trainers supervised all subjects so that all program characteristics were strictly enforced. They were responsible for seeing that exercise prescription were followed and achieved through each training session (e.g., safety considerations, accuracy and velocity of movement). To ensure consistent performances, all exercises were performed with a partner (e.g., rest period, social facilitation, motivation; Sheridan et al., 2017). The MT group performed exercises involving the M. quadriceps femoris (leg press), the M. pectoralis major (chest press), the M. latissimus dorsi (seated rowing), the M. triceps brachii (triceps cable extension), and the M. biceps brachii (biceps cable curls), while the FWT group trained the same muscle groups with barbells using squats, bench press, bent-over rowing, lying triceps press, and biceps curls. Participants were instructed to alternate the concentric phase with the eccentric phase by e.g., lowering the weight during the bench press exercise over the course of 2 s, and then returning it to the starting position over the course of another 2 s. The order of exercises was not fixed and dependent upon preference and availability of equipment in the gym where training was conducted. Rest between exercises lasted for ~2 min. Attempts were made to progressively increase the loads lifted each week within the confines of maintaining the target repletion range (10-RM). Initial loads for each exercise were based on 70 to 80% of subjects 10-RM (depending on the task), as determined during initial testing, consistent with recognized guidelines established by the National Strength and Conditioning Association (Sands et al., 2012).

2.4. Testing procedures and measurements

2.4.1. Demographics and BMI

At study entry, we obtained general health history, social support, quality of life, subjective motor fitness, and demographic information by questionnaire. In addition, we ascertained height and body weight using a calibrated stadiometer and a balance-beam scale, respectively. Height and weight were used to determine body mass index (BMI; kg/m^2).

2.4.2. Adherence

Adherence to the exercise intervention was measured by the number of sessions attended out of 52. A 70% attendance rate for the training sessions was set as the definition for being adherent to the training program (van Tulder et al., 2003).

2.4.3. Strength

Testing was conducted at baseline, after 10 and 26 weeks, and after a 6-weeks detraining phase. Participants were invited to attend two familiarization sessions, during which exercise techniques were demonstrated and practiced. Lower and upper body muscular strengths (kg) were only assessed with the group specific machines or free weights. Then baseline testing with the 10-RM was undertaken. The 10-RM is generally used for older adults due to the reduced absolute load of the exercise, as well as for increased safety (American College of Sports Medicine, 2014). Initial loads for the 10-RM test were estimated based on researcher experience. If the participant reached 12 repetitions, and reported being able to do more, then the participant was given a 5-min rest period followed by a subsequent 10-RM test wherein we increased the resistance by approximately 20%. This process was repeated until the participant could perform no more than ten consecutive repetitions (no more than three sets; Häkkinen et al., 2001). These estimations were used to calculate the RT intensity for the remainder of the program, with the target of training being 70–80% of 1-RM.

Handgrip strength, using the squeezing muscles of the dominant hand, was measured as an index of static grip strength needed for such activities as rising from a chair or bathtub; this measurement also determined the initial dumbbell weight for each resident. Handgrip was measured by a Smedeley II handgrip dynamometer. Three trials were given. Scores were recorded to the nearest kilogram, and the best score was used for analyses.

2.4.4. Follow-up questionnaire

After the intervention, every subject was asked to answer eight questions about the individual perception of the RT using a 7-point Likert scale with 1 (=do not agree at all) to 7 (=I entirely agree). The following questions were asked:

1. During strength training, I feel safer with a training partner.
2. Strength training is fun.
3. My training motivation has increased significantly through strength training.
4. I find strength training very strenuous.
5. I will continue with strength training in the future.
6. Strength training makes everyday life easier for me.
7. A proper care and a good coach are very important for me in strength training.
8. Strength training gives me increased self-confidence in my physical performance.

The exploratory factor analysis resulted in a single factor that explained 46.6% of the variance of the eight questionnaire items with factor loadings between 0.384 and 0.885. Cronbach's alpha coefficient for this scale was 808.

2.5. Data analysis

All analyses were performed with the software package SPSS 25.0, and an alpha level of 0.05 was used for all statistical tests. All descriptive values are presented as means ± standard deviation (SD), unless otherwise stated.

The total volume load (VL) was calculated from training logs for each participant using the following formula: total VL = weight (kg) lifted (i.e., [repetitions (no.) × external load (kg) × sets (no.)]. Total VL was determined for the 2nd, the 13th, and the 24th week and summed to compile an overall VL aggregate for all five exercises for the entire 26 weeks of RT. Only repetitions performed through a full range of motion were included for analysis.

Differences between MT and FWT for baseline demographic, anthropometric measures, subjective motor fitness, quality of life, social support, and the evaluation of the training were evaluated through independent t-tests. Pearson product–moment correlations were used to examine selected bivariate correlations between various baseline subject characteristics (i.e., age, body mass, body mass index, baseline strength capacity), total VL and the dependent variables.

For variables with three and four time points (baseline, week 10, week 26, follow-up) a Group (MT, FWT) × Time (week 0, week 10, week 26, follow-up) repeated-measures analysis of covariance (MANCOVA) adjusted for sex and adherence was used to examine change among groups and paired t-tests were used to investigate within-group changes. Where appropriate, the Bonferroni post hoc procedure was used to locate the source of differences. Percent change was calculated on individual data (e.g., (week 26 − baseline) / baseline × 100)), with the mean of the group change reported. In addition, to determine whether within-group changes were significant, paired t-tests were used on absolute values with delta% values reported.

Furthermore, effect sizes (ES) using Cohen's d (Cohen, 1992) were calculated for each outcome to determine the magnitude of differences found within and between each training condition. The ES were calculated from the difference between mean post-test scores and divided by pooled SD. An ES of 0.20 or less was considered a trivial effect, 0.21 to 0.59 a small effect, 0.60 to 1.19 a moderate effect, 1.20 to 1.99 a large effect, 2.0 to 3.9 a very large effect, and > 4.0 a nearly perfect effect (Cohen, 1992). The eight questions of the follow-up questionnaire were analyzed using a MANOVA.

3. Results

3.1. Baseline characteristics and dropout

Thirty-six potential participants were invited to an information session; 32 provided informed consent, four persons dropped out due to personal reasons. At the end of the 26-week intervention, 16 participants in the FWT group and 16 in the MT group completed the pre-test, the 2nd assessment 10 weeks into the intervention, and the post-test after 26 weeks. One subject in the FWT group was lost due to illness during the follow-up period (see also Fig. 1).

The baseline data for the characteristics of the participants randomized to the FWT and MT groups are summarized in Table 1. There were no significant differences in the demographic profiles of the participants who remained in the study. The mean age of the 32 remaining participants was 66.9 ± 5.56 years (range: 60–86). The majority of participants were female (68.8%). Furthermore, both intervention groups reported high subjective motor fitness, good social support, and a high quality of life. Specifically, there was a higher overall score on the Physical Fitness Questionnaire (FFB-Mot; Bös et al., 2002) compared to the age group of the 51 to 60 years olds of the validation study (45.2 ± 8.18 vs. 36.6 ± 9.5), supporting the high functional status of this sample.

Table 1
Baseline characteristics of participants.

	Machine training (MT) n = 16	Free weights training (FWT) n = 16	p[a]
Sex: female (%)	68.8	68.8	.999
Age (years)	67.7 ± 6.56	66.1 ± 4.43	.436
Height (cm)	172 ± 7.50	169 ± 7.25	.222
Weight (kg)	75.8 ± 10.9	70.9 ± 13.6	.272
BMI (kg/m^2)	25.4 ± 2.43	24.7 ± 4.13	.548
Education (years)	10.4 ± 2.16	10.8 ± 2.72	.721
Marital status (%)			
Married/cohabitation	43.8	43.8	.999
Single/divorced/widowed	56.3	56.3	
Exercise (min/week)	213 ± 173	271 ± 129	.291
FFB-Mot (12 to 60 points)	43.4 ± 8.21	47.1 ± 8.00	.215
Social support			
General (1 to 5 points)	3.93 ± 0.59	3.93 ± 0.52	.984
Through sports (1 to 5 points)	2.75 ± 0.81	3.18 ± 0.75	.131
Quality of life (15 to 60 points)	47.3 ± 6.50	50.2 ± 4.65	.152

Notes. Mean and standard deviations or frequencies presented.
[a] Differences between groups tested by t-tests for independent for variables and Chi-square test for categorical variables.

3.2. Intervention adherence

There were 52 sessions in each of the strength training regimes. Overall adherence to the program was good, the participants ($n = 32$) attended 76.2% (39.6 ± 9.56) and 71.2% (37.0 ± 8.67) in the FWT and MT group, respectively. No adverse effects in any of the training sessions were observed.

3.3. BMI

Descriptive data for BMI and all time points and 95% CIs and ESs for changes are reported in Table 2. Repeated measures ANCOVA controlled for sex and adherence revealed no significant results for main effects or the interaction time × group.

3.4. Handgrip strength (isometric)

Descriptive data for handgrip strength and all time points and 95% CIs and ESs for changes are reported in Table 2. Repeated measures ANCOVA controlled for sex and adherence revealed no significant results for main effects or the interaction time × group.

3.5. Dynamic strength

Descriptive data for all strength outcomes and all time points and 95% CIs and ESs for changes are reported in Table 2. Fig. 2a–e shows individual responses at each time point for strength measures.

3 (time) × 5 (exercises) repeated measures MANCOVA analysis controlled for sex and adherence revealed for the FWT group a significant multivariate time (Pillai's Trace = 0.68, $F = 8.48$, $df = 2,8$, $p = .011$, $\eta_p^2 = 0.679$) and exercise effect (Pillai's Trace = 0.83, $F = 7.37$, $df = 4,8$, $p = .017$, $\eta_p^2 = 0.831$). The univariate F tests showed there were significant improvements for squats ($F(2, 18) = 14.9$, $p < .001$, $\eta_p^2 = 0.623$), bench press ($F(1.36, 17.7) = 9.05$, $p = .004$, $\eta_p^2 = 0.410$), bent-over rowing ($F(2, 24) = 2.63$, $p = .093$, $\eta_p^2 = 0.179$), biceps curls ($F(2, 26) = 5.88$, $p = .008$, $\eta_p^2 = 0.311$), and lying triceps press ($F(2, 26) = 7.77$, $p = .002$, $\eta_p^2 = 0.374$). We also found significant interaction effects for time × sex (Pillai's Trace = 0.77, $F = 13.6$, $df = 2,8$, $p = .003$, $\eta_p^2 = 0.773$) and exercise × sex (Pillai's Trace = 0.87, $F = 9.90$, $df = 4,8$, $p = .008$, $\eta_p^2 = 0.86$). Subsequent analysis showed that men had higher overall gains compared to women. In addition, men produced significantly larger weights for squat, chest press, and bent-over rowing.

3 (time) × 5 (exercises) repeated measures MANCOVA analysis controlled for sex and adherence revealed for the MT group a significant multivariate time (Pillai's Trace = 0.64, $F = 9.02$, $df = 2,10$, $p = .006$, $\eta_p^2 = 0.643$) and exercise effect (Pillai's Trace = 0.94, $F = 33.4$, $df = 4,8$, $p < .001$, $\eta_p^2 = 0.943$). The univariate F-tests showed there were significant improvements for leg press ($F(1.20, 13.2) = 9.14$, $p = .007$, $\eta_p^2 = 0.454$), chest press ($F(2, 24) = 7.80$, $p = .002$, $\eta_p^2 = 0.394$), seated rowing ($F(2, 24) = 6.28$, $p = .006$, $\eta_p^2 = 0.343$), biceps cable curls ($F(1.31, 15.7) = 4.99$, $p = .032$, $\eta_p^2 = 0.294$), and triceps cable extension ($F(2, 24) = 11.5$, $p < .001$, $\eta_p^2 = 0.489$). These findings were consistent when expressed relative to body mass. We also found significant interaction effects for exercise × sex (Pillai's Trace = 0.88, $F = 14.6$, $df = 4,8$, $p = .001$, $\eta_p^2 = 0.88$), but not time × sex. Subsequent analysis showed that men had higher overall gains compared to women. In addition, men

Table 2
Means and standard deviations (SD) of strength measures and BMI at baseline, after 10 and 26 weeks, and after follow-up period; Δ %; effect sizes (ES) for mean changes between time points.

	Time point				Δ % (ES)			
	Baseline	10 weeks	26 weeks	Follow-Up	t1 to t2	t2 to t3	t1 to t3	t3 to t4
Leg press/squat (10 RM, kg)								
MT absolute	69.6 ± 17.7	86.8[a] ± 17.4	98.3[a,b] ± 18.1	95.4[a,c] ± 13.1	27.8 (3.34)	14.2 (2.05)	47.1 (2.47)	−1.40 (−0.28)
MT relative	0.94 ± 0.22	1.17[a] ± 0.22	1.33[a,b] ± 0.24	1.29[a] ± 0.17	27.2 (3.52)	14.0 (1.81)	46.1 (2.65)	−1.40 (−0.28)
FWT absolute	22.8 ± 9.74	37.7[a] ± 13.7	46.9[a,b] ± 17.9	42.1[a,c,d] ± 16.6	71.1 (4.28)	24.0 (3.23)	113 (4.60)	−10.2 (−1.72)
FWT relative	0.33 ± 0.10	0.55[a] ± 0.11	0.68[a,b] ± 0.15	0.61[a,c,d] ± 0.14	70.0 (5.02)	23.7 (2.59)	111 (4.64)	−10.2 (−1.51)
Chest press/bench press (10 RM, kg)								
MT absolute	27.6 ± 9.96	42.5[a] ± 13.5	47.0[a,b] ± 12.8	41.7[a,d] ± 13.9	58.3 (3.56)	13.0 (1.38)	76.9 (6.22)	−12.4 (−0.41)
MT relative	0.37 ± 0.13	0.57[a] ± 0.16	0.63[a,b] ± 0.15	0.55[a,d] ± 0.16	57.4 (4.21)	12.5 (1.44)	75.8 (6.90)	−12.4 (−0.49)
FWT absolute	20.9 ± 8.91	29.9[a] ± 11.1	33.2[a,b] ± 13.1	29.8[a,d] ± 13.9	47.2 (2.86)	10.2 (1.75)	61.9 (3.22)	−10.4 (−1.56)
FWT relative	0.29 ± 0.09	0.41[a] ± 0.10	0.46[a,b] ± 0.12	0.41[a,d] ± 0.11	46.9 (2.84)	9.69 (1.73)	60.7 (3.30)	−10.4 (−1.87)
Seated row/bent-over rowing (10 RM, kg)								
MT absolute	30.4 ± 7.34	40.6[a] ± 8.51	44.8[a,b] ± 11.5	39.2[a,d] ± 10.1	35.6 (1.90)	10.3 (1.03)	49.3 (1.76)	−12.2 (−1.62)
MT relative	0.41 ± 0.10	0.54[a] ± 0.09	0.60[a] ± 0.12	0.52[a,d] ± 0.11	35.0 (2.34)	9.95 (0.89)	48.2 (2.04)	−12.2 (−1.65)
FWT absolute	24.6 ± 10.1	37.4[a] ± 13.6	40.4[a,b] ± 13.9	35.6[a,d] ± 13.6	56.6 (2.82)	8.75 (0.70)	70.3 (2.62)	−12.5 (−1.13)
FWT relative	0.35 ± 0.10	0.53[a] ± 0.11	0.57[a] ± 0.13	0.50[a,d] ± 0.12	56.2 (2.88)	8.37 (0.73)	69.1 (2.71)	−12.5 (−1.75)
Biceps cable curls/biceps curls (10 RM, kg)								
MT absolute	56.9 ± 9.50	74.3[a] ± 12.6	80.8[a] ± 17.3	76.8[a] ± 16.8	30.9 (3.34)	8.93 (0.61)	41.7 (2.67)	−4.76 (−0.82)
MT relative	0.77 ± 0.15	1.00[a] ± 0.17	1.08[a] ± 0.21	1.03[a] ± 0.20	30.3 (3.46)	8.58 (0.54)	40.7 (2.50)	−4.76 (−0.76)
FWT absolute	12.5 ± 3.21	17.0[a] ± 4.97	18.4[a,b,c] ± 5.78	16.3[a,d] ± 5.04	35.4 (2.51)	8.08 (1.08)	45.8 (3.14)	−10.8 (−1.34)
FWT relative	0.18 ± 0.03	0.24[a] ± 0.04	0.26[a,b,c] ± 0.05	0.23[a,d] ± 0.04	35.0 (2.29)	7.52 (1.16)	44.6 (2.93)	−10.8 (−1.37)
Triceps cable extension/lying triceps press (10 RM, kg)								
MT absolute	16.5 ± 2.80	19.8[a] ± 3.47	21.2[a,c] ± 4.32	16.8[c,d] ± 2.92	21.1 (1.29)	6.75 (0.59)	29.6 (1.23)	−15.4 (−1.68)
MT relative	0.22 ± 0.04	0.27[a] ± 0.04	0.28[a,c] ± 0.05	0.24[c,d] ± 0.04	20.7 (1.41)	6.47 (0.33)	28.7 (1.17)	−15.4 (−1.16)
FWT absolute	10.2 ± 3.04	16.0[a,b] ± 6.10	19.3[a,b,c] ± 7.50	16.8[a,d] ± 6.69	54.7 (2.46)	21.8 (2.54)	88.0 (2.91)	−13.7 (−1.72)
FWT relative	0.14 ± 0.03	0.22[a] ± 0.06	0.27[a,b,c] ± 0.07	0.23[a,d] ± 0.07	54.2 (2.43)	21.2 (2.82)	86.6 (3.21)	−13.7 (−1.97)
Hand strength (kg)								
MT	22.3 ± 4.81	22.1 ± 5.38	23.1 ± 5.85	–	−1.58 (−0.31)	4.03 (0.41)	2.58 (0.65)	–
FWT	22.9 ± 6.25	23.3 ± 5.67	23.8 ± 6.43	–	2.79 (0.47)	2.05 (0.30)	5.11 (0.22)	–
BMI								
MT	25.4 ± 2.43	25.4 ± 2.51	25.4 ± 2.67	–	−0.03 (0.00)	0.07 (0.00)	0.04 (0.00)	–
FWT	24.7 ± 4.13	24.7 ± 3.97	24.9 ± 3.97	–	0.24 (0.00)	0.73 (0.50)	0.50 (0.42)	–

Note: a indicates significant difference ($p \leq .05$) with post hoc pairwise comparison of baseline (t1) compared with 10 weeks (t2), 26 weeks (t3), and follow-up (t4); b indicates significant difference ($p \leq .05$) with post hoc pairwise comparison of t2 compared with t3; c indicates significant difference ($p \leq .05$) with post hoc pairwise comparison of t2 compared with t4; d indicates significant difference ($p \leq .05$) with post hoc pairwise comparison of t3 compared with t4.

produced significantly larger weights for chest press, biceps cable curls, and seated rowing.

Although the FWT group lost a significant amount of strength after the detraining (DET) period ($p < .001$ for all measures) (Table 2), this value was still significantly higher than their baseline values ($p < .001$ for all measures) (Table 2). After DET, the MT group's strength also decreased significantly ($p < .001$ for all measures, but leg press), but this value was still significantly higher compared to their baseline values ($p < .001$ for all measures, but triceps cable extension) (Table 2).

Fig. 3 shows the absolute mean changes of the absolute weights for all five muscle groups by intervention group from baseline to week 26. There were larger effects for the squat exercise ($t(24) = 4.91$, $p < .001$, $d = -1.92$), the lying triceps press ($t(24) = 4.91$, $p < .001$, $d = -1.94$), and the bent-over rowing ($t(24) = 4.91$, $p = .087$, $d = -0.65$) in the FWT compared to the MT group.

As presented in Table 2, the MT as well as the FWT group showed very large ESs for all 5 assessments at week 10 and 26 when compared to baseline, whereas there were small to moderate ESs found at week 26 when compared to baseline. For squat/leg press, lying triceps press/triceps cable extension, and the bent-over rowing/seated rowing, there were large to very large ES favoring the FWT compared to the MT group, while for bench press/chest press the MT group achieved higher ES compared to the FWT group.

3.6. Overall volume load

Repeated measures ANOVA controlled for age and sex revealed a significant time × group effect in average weekly volume load, $F(2.36, 38.9) = 9.67$, $p = .001$, $\eta_p^2 = 0.257$. Fig. 4 shows the total loads for the 2nd, the 13th, and the 24th week and the mean changes for each group indicating that changes occurred in both groups. While there is a large difference in overall volume load between the FWT group and the MT group, after 13 weeks and upon completion of the 6-month training program, the intervention groups did not differ in relative increases of volume load (MT: 26.4 ± 11.9%; 11.6 ± 10.6%; FWT: 28.3 ± 13.3; 12.5 ± 11.0%), resulting in overall increases of volume load of 41.5% and 43.7%, respectively.

3.7. Relationship between strength and volume-load

Correlational analysis revealed only significant relationships between change in lower extremity strength and change in VL for both groups (MT: $r = 0.539$; FWT: $r = 0.694$; see Table 3). Furthermore, for the MT group, baseline strength, age and baseline strength, and adherence were determined as predictors for changes in chest press, leg press, and triceps cable extension, respectively. For the FWT group, age and adherence were identified as positive predictors for bent-over rowing, biceps curls, and lying triceps press.

3.8. Evaluation of the training

The analysis of the follow-up questionnaire resulted in a higher demand on safety in terms of a training partner, but also in higher values for fun, motivation, future, and benefit for daily life for the FWT

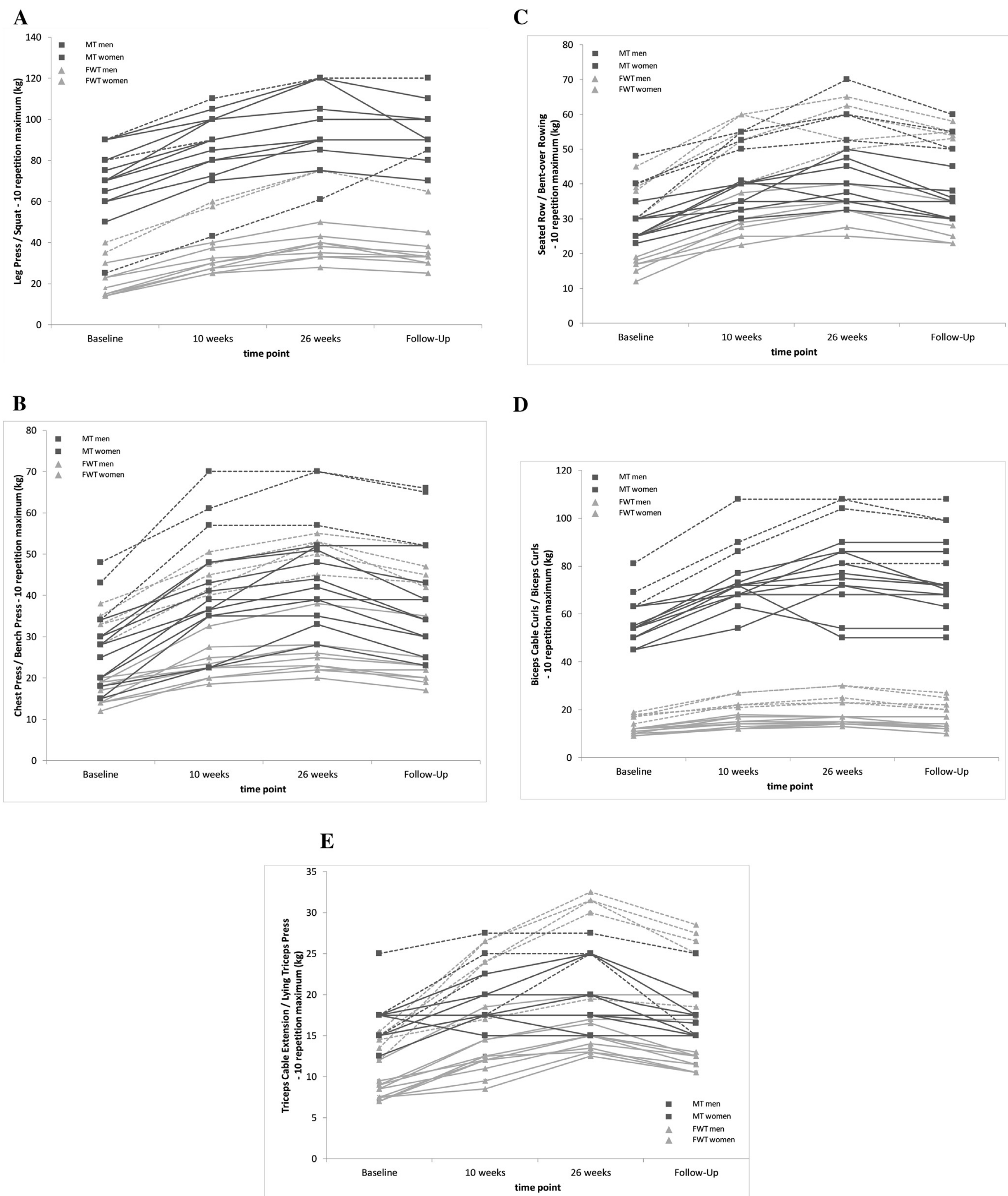

Fig. 2. a) to e). Individual values for the 10 repetition maximum at baseline, 10 weeks, 26 weeks, and follow-up period: (a) leg press/squat, (b) chest press/bench press, (c) seated row/bent-over rowing, d) biceps cable curls/biceps curls, and e) triceps cable extension/lying triceps press.

group compared to the MT group indicating an overall better evaluation of their training specific regime (see Fig. 5). The group differences were significant for safety ($F(1, 30) = 13.02$, $p = .001$, $\eta_p^2 = 0.303$) and motivation ($F(1, 30) = 6.42$, $p = .017$, $\eta_p^2 = 0.176$). The results for fun ($p = .092$), future ($p = .098$) and benefit for daily life ($p = .056$) approached significance.

4. Discussion

The aim of this study was to examine the effects of a high-intensity free weights training versus a machine resistance training during 26 weeks in high-functioning older adults. The results of the study demonstrated a significant increase in the overall dynamic strength in

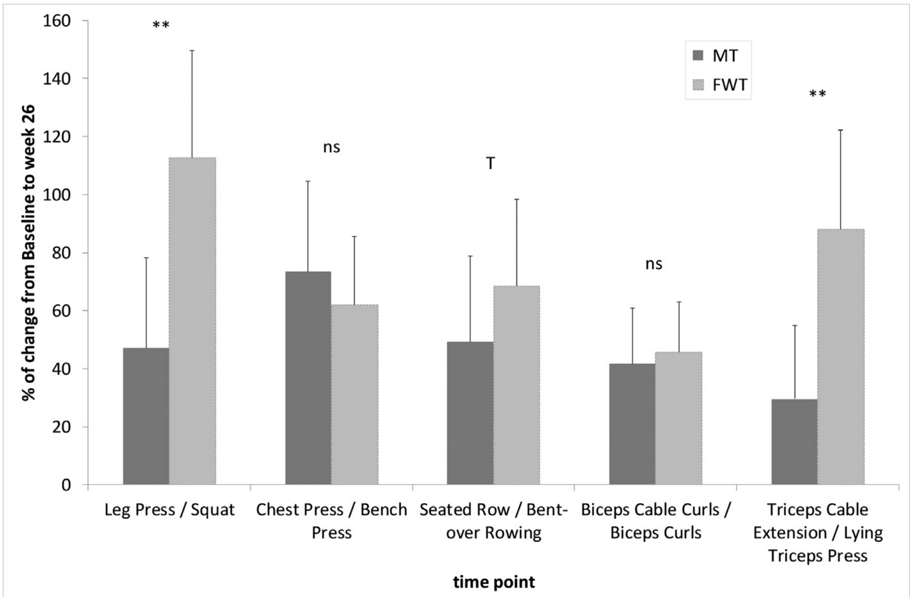

Fig. 3. Mean percentage change (± SD) of the absolute weights from baseline to week 26 by training group (ns: $p > .1$, T: $p \le .1$, $^{**}p \le .01$).

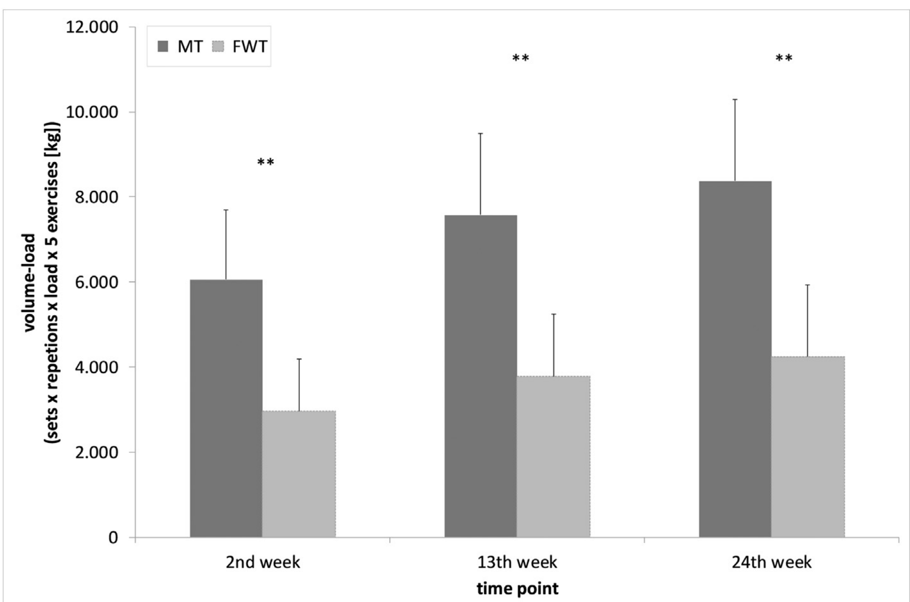

Fig. 4. Average volume-load (mean ± SD) for the 2nd week, the 13th week, and the 24th week by group ($^{**}p \le .01$).

both groups. The increase of strength in our group of high-functioning older adults varies between 28 to 75% (MT) and 44 to 111% (FWT) over 26 weeks (c.f. Table 2 and Fig. 3). In comparison to other studies, the rate of increase in our study is much higher, although the participants in our study already started at a high-functional level. For example, Guizelini et al. (2018) and Barrett and Smerdely (2002) showed in a 10-week-training intervention with elderly people (63.9–72.5 years; $n = 40$) a strength improvement of 6.3 to 18.1% (quadriceps) respectively 0.5 to 15.7% (biceps). Additionally Balachandran et al. (2016) showed after a 12 weeks training period with elderly (≥65 years; $n = 22$) an improvement of 23 to 24% (leg press) and 10 to 24% (chest press). A possible explanation for these differences could be the length of the intervention, although it is assumed, that the greatest rates of growth reveal at the beginning of an intervention (c.f. Table 2, relative changes from t1 to t2). High-functional also implies, that our sample were experienced in functional fitness training, motor skills training, and an active cognition training, which supports the feasibility for this target group.

The applied exercise types could explain the effect for bent-over rowing vs. seated-rowing when comparing the two groups (MT vs. FWT), the significant greater increase for the FWT group in squat vs. leg press (cf. Fig. 3). Squats and bent-over rowing of the FWT group are the only two closed kinetic chain (CKC) exercises used in this study. Compared to open kinetic chain (OKC) exercises, CKC exercises are characterized by co-contractions of muscles and categorized as more functional (Jang et al., 2016; Kwon et al., 2013). Studies with adults comparing OKC- and CKC-exercises showed that CKC-exercises seem to be more effective in improving dynamic balance ability (Kwon et al., 2013; Kim and Yoo, 2017). These findings, together with the observed increased strength in our study are in accordance with the hypothesis about the greater functionality of FWT compared to MT (Carpinelli, 2017; Haff, 2000; Myers et al., 2017; Shurley et al., 2017), and

Table 3
Multiple regression models for mean change of strength adaptive responses to resistance training for MT and FWT.

	Model: predictors	β	t	*p*	F	Adjusted R^2	VIF
Leg press/squat							
MT	Age	0.48	2.97	.014	21.8	0.834	1.94
	Baseline strength	−0.38	−2.33	.042			2.03
	VL	0.32	2.63	.025			1.10
FWT	VL	0.69	3.05	.012	9.28	0.431	1.00
Chest press/bench press							
MT	Baseline strength	−0.71	−3.65	.003	13.4	0.473	2.36
FWT	–	–	–	–	–	–	–
Seated row/bent-over rowing							
MT	–	–	–	–	–	–	–
FWT	Age	0.53	2.25	.043	5.06	0.225	1.00
Biceps cable curls/biceps curls							
MT	–	–	–	–	–	–	–
FWT	Adherence	0.58	2.66	.019	7.06	0.288	1.00
Triceps cable extension/lying triceps press							
MT	Adherence	−0.67	−3.21	.007	10.3	0.399	1.00
FWT	Adherence	0.77	4.51	< .001	20.4	0.563	1.00

Note. VL: volume-load.

therefore beneficial for Activities of Daily Living (ADL) (Carpinelli, 2017; Haff, 2000) as well as preventing the risk of falls (McKinnon et al., 2017). Many ADL demand greater leg strength, e.g. standing up, climbing steps. For this reasons leg strength could be seen as key factor to stay independent and thus keep or improve the quality of life. Looking on the physiological perspective, Shaner et al. (2014) showed, that the squat exercise (free weight) leads to a higher acute hormonal response of growth hormone, testosterone and cortisol accompanied by a greater heart rate and lactate response compared to the leg press (machine) in $n = 10$ young men. The authors explain these findings with a greater muscle mass involvement and more work performed (when considering body mass) in the squat. However, it is uncertain to what extend these results can be transferred to elderly people because the hormonal response seems to change with increasing age (Häkkinen et al., 2000; Smilios et al., 2007).

Furthermore, our results show, that the triceps-strength improves significantly in the FWT compared to the MT. This improvement seems also be helpful for ADL like getting up from a chair or stepping out of the bathtub. A closer look at the execution of the Lying Triceps Press exercise provides an interesting possible explanation for this effect. The triceps is a powerful extender of the forearm (Landlin et al., 2018), but recent studies (Kholinne et al., 2018; Landlin et al., 2018) report, that the activity and force of each head of the triceps brachii depends on the shoulder elevation. The long head of the triceps seems to be involved in every extension of the elbow (Landlin et al., 2018), but the medial head starts to be more involved from a shoulder angle beyond 90° (Kholinne et al., 2018), which is the case in lying triceps press exercise. Therefore, the rather unusual training position and muscle activation with regard to other activities could be seen as a new and effective training stimulus with a greater potential of improvement. Anyhow, for a greater all over triceps strength all parts of the triceps should be trained and targeted specifically (Ali et al., 2015). As for preventing serious fall injuries, the arm positions with a shoulder angle of 90° and flexed elbows are helpful to absorb forces during falls (Kawalilak et al., 2014; Moon and Sosnoff, 2017), which could be affected positively by a good triceps strength and activation.

In summary, our findings suggest that FWT has benefits especially in improving leg and triceps strength and could make a contribution to protecting against injuries and maintaining independent (Grgic et al., 2018; Guizelini et al., 2018; Li et al., 2018; McCrum et al., 2018; Ramirez-Campillo et al., 2018; Bauman et al., 2016; Myers et al., 2017; Northey et al., 2018).

Although the used follow-up questionnaire is not a validated instrument, a closer look at the results provides interesting insights. The significant group-difference for the item *During strength training, I feel safer with a training partner* ($p = .001$) is initially not surprising. In both groups, the participants trained with a partner, but the higher degrees of freedom in FWT may lead to increased risk for injury. Therefore, a spotter for safety is generally required (Carpinelli, 2017; Haff, 2000). On the one hand, this dependency on a training partner could be seen as a barrier to join training, for example if the training partner is not available. On the other hand, a permanent training partner with regular training times in the form of a habit means an obligation and familiar social contact, which are important motivational factors for participating in physical activities (Baert et al., 2015; Newitt et al., 2016). Furthermore, the study of Sheridan et al. (2017) showed for $n = 12$ adults, that the presence of a spotter improves the performance during resistance training. The authors explain this effect with a reduced Rate of Perceived Exertion (RPE) and increased self-efficacy. The aforementioned aspect of motivation as a basis of being physical active (Baert et al., 2015; Newitt et al., 2016) is in line with the other significant effect ($p = .017$; *My training motivation has increased significantly through the strength training*) and the tending effect ($p = .081$; *I will continue with strength training in the future*). Even though this is not

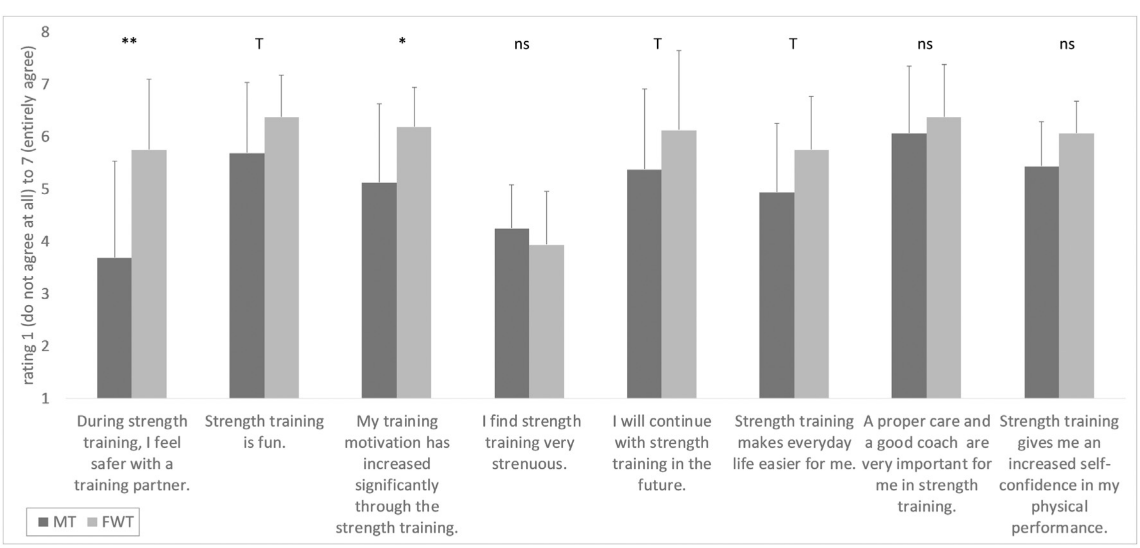

Fig. 5. Evaluation of the training by group (ns: $p > .1$, T: $p \leq .1$, *$p \leq .05$, **$p \leq .01$).

unique for resistance training, physical activity in general could be classified as "Building body capital for independence" (Bergland et al., 2018) and therefore as an important factor for better aging (Gutiérrez et al., 2018). With respect to everyday life, this understanding is supported by the other tending effect ($p = .056$; *Strength training makes everyday life easier for me*). In summary, the results of the questionnaire indicate, that free-weight training has a greater positive impact on motivators of physical activity (Baert et al., 2015; Newitt et al., 2016) compared to machine training.

4.1. Strength and limitations

Strengths of this study are the a priori power calculation and their realization, the low dropout rate, and the duration of the intervention period compared to similar studies (Balachandran et al., 2016; Rossi et al., 2018; Wirth et al., 2016), as well as the follow-up tests for obtaining information about the detraining process. The fact, that the strength testing was conducted for each group with the exercises they trained with, limits the comparability between the groups and could be seen as a limitation of the study. On the other hand, the testing of training effectiveness has to be specific for getting valid information considering the training goal (Wirth et al., 2016) as well as avoiding experienced-based advantages for one group. Another limitation is comparing the improvements using the percentage change, which is in the opinion of Dankel et al. (2017) an inappropriate way, because of different baseline performances. Regarding the possible different performance at baseline in both groups, our significant results must not be overestimated, but could be in turn an explanation for the other non-significant results. Although, the execution of the movements in FWT mimics more everyday activities in terms of functionality, unfortunately no testing of functionality was conducted. Therefore, regarding this topic the statements which are made are only justified assumptions, which have to be proven in future studies. Finally, it has to be mentioned, that the follow-up questionnaire in this study is not a standardized validated instrument. Therefore, these results have to be interpreted with caution.

5. Conclusion

The results suggest that: (1) dynamic strength gains from 6 months of resistance training in older individuals are sustainable (not entirely lost even after 6 weeks of detraining); (2) these effects are specifically related to the exercises performed in the training program (free weights vs. machine); (3) adoption of maintenance-level moderate-intensity training significantly attenuates the decline in dynamic strength of previously trained muscles; and (4) high-intensity free weights training is feasible for high-functional older adults.

Although there is still a lack of studies, when putting previous research (e.g. Balachandran et al., 2016; Carpinelli, 2017; Rossi et al., 2018; Wirth et al., 2016) and our results together the impression arises, that free weight training may lead to greater improvements in functionality and/or strength in leg and triceps strength compared to machine training. These findings are of particular interest, because these muscle groups seem to play an important role in preventing falls and accompanied injuries (Kawalilak et al., 2014; Moon and Sosnoff, 2017; Muehlbauer et al., 2015) and therefore in remaining mobile and maintaining independence. In conclusion, the opinion of Shurley et al. (2017) that free weight training is superior to machine training can only be assumed for the lower extremities and the M. triceps brachii, but for the desired aim to improve the life quality of elderly people, free weight training seems to be promising.

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Compliance with ethical standards

All reported data with human subjects performed by the authors complied with all applicable ethical standards (including the Helsinki declaration and its amendments, institutional/national research committee standards, and international/national/institutional guidelines).

Conflict of interest

The authors declare that they have no conflicts of interest.

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