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Effects of Exercise Training on Handgrip Strength in Older Adults: A Meta-Analytical Review

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Aged · Exercise · Physical fitness · Hand strength · Muscle strength dynamometer

Abstract
Background: Handgrip strength measurements are feasible with older adults and a reliable indicator for vitality, physical function, and several risk factors in the ageing process. Interventions with exercise training induce a variety of strength, balance, and endurance improvements. The pooled transfer effects of exercise training on handgrip strength has not been investigated to date. Thus, the objective of this meta-analytical review is to examine the effects of different exercise training on handgrip strength in healthy community-dwelling older adults of 60 years or older. ***Methods:*** The literature search was conducted in three databases (PubMed, Web of Science, SPORTDiscus) using the following search terms with Boolean conjunctions: (hand grip* OR grip strength OR grip power) AND (sport* OR train* OR exercis* OR strength OR intervention OR endurance OR resistance OR balance OR aerob*) AND (old* OR elder* OR senior*). Non-randomized and randomized controlled trials with an exercise training and handgrip strength as the outcome parameter were screened. Study quality was independently assessed by two researchers using the PEDro scale. Comparison of handgrip strength between the intervention and control groups was conducted by using the hedges g (including adjustment for small sample sizes), calculating standardized mean differences (SMDs). A random effects inverse-variance model was applied for statistical analysis. ***Results:*** Twenty-four trials (mean PEDro score 5.8 ± 0.9) with a total of 3,018 participants (mean age 73.3 ± 6.0 years) were included. Small but significant effects ($p < 0.001$) on handgrip strength were observed (SMD 0.28, 95% CI 0.13–0.44). Study heterogeneity (I^2 56%) and the funnel shape for publication bias analyses were acceptable. ***Conclusions:*** Meaningful but small transfer effects of a multitude of different training approaches on handgrip strength occurred in healthy community-dwelling older adults. Handgrip strength cannot clearly be recommended to assess general functional performance for all kinds of exercise programs, whereas task-specific training and multimodal training modes seem to provide an appropriate stimulus to also improve handgrip strength.

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Introduction

Handgrip strength testing evaluates static force that is squeezed around the dynamometer, given in kilograms, pounds, or Newtons [1]. Handgrip strength assessment serves as a feasible, quick, and reliable tool to examine vitality and physical function in the elderly population. A standardized and calibrated equipment is required, especially when different assessors [2] or different brands of dynamometers are employed [3]. The test-retest reliability is considered high: The ICC (intraclass correlation coefficient) ranges between 0.91 and 0.95 for healthy older adults [4]. According to recommendations of the American Society of Hand Therapists [5], participants should be seated, with the shoulder adducted and neutrally rotated, the elbow flexed at 90°, and the forearm and the wrist in a neutral position. This society recommends three trials of grip strength and suggests using the best trial for further analysis [5].

Beside other declines of physical function (endurance, strength, balance capacity), aging people show a decrease in handgrip strength [6]. Women have weaker handgrip strength compared to men [6–8]. The handgrip strength reflects a variety of physical function indices and is therefore regarded as an important indicator of health-related quality of life of older adults [9]. Hence, handgrip strength predicts disability, morbidity, and mortality [10], accelerated dependency in activities of daily living and cognitive decline in the most elderly (over 85 years of age) [11]. A weak handgrip strength is also associated with hypertension, coronary heart disease, peripheral arterial disease, heart failure, stroke, or chronic obstructive pulmonary disease [8]. Furthermore, handgrip strength is negatively associated with physical frailty even when the effects of body mass index and arm muscle circumference are considered [12].

Strength, endurance, and balance training have been shown to attenuate numerous adverse effects of biological aging [13]. The occurrence and magnitude of potential transfer effects of these interventions with exercise training on handgrip strength as a well-established and feasible surrogate parameter in community-dwelling older adults have not yet been addressed systematically. Therefore, the objectives of the present systematic review and meta-analysis were: (1) to calculate the effects of numerous interventions with exercise training on handgrip strength in healthy community dwellers, (2) to describe training characteristics for older adults, and (3) to provide recommendations for future studies.

Materials and Methods

Search Strategy and Study Selection

The PRISMA guidelines were used for reporting this meta-analytical review [14]. A literature search was independently conducted by two researchers (B.K.L. and H.B.) in three health- and sport-related databases (PubMed, Web of Science, SPORTDiscus). The search was conducted from November 25, 2018 until December 1, 2018. The relevant search terms were divided into three search levels and were combined with Boolean conjunctions (AND/OR). On the first search level "hand grip* OR grip strength OR grip power," on the second level "AND (sport* OR train* OR exercis* OR strength OR intervention OR endurance OR resistance OR balance OR aerob*)" and on the third level "AND (old* OR elder* OR seniors*)" were used as search terms. The screening process consisted of title, abstract, and full-text screening. First, all resulting titles of the search were screened manually by the two researchers (B.K.L. and H.B.) and discussed for eligibility. All chosen articles were then transferred to a reference management software (Citavi 6.3, Swiss Academic Software GmbH, Waedenswil, Switzerland). Both researchers screened abstracts separately and their inclusion was discussed afterwards. Consent has been found upon the independent search procedure and through discussion. Irrelevant articles were excluded and the full texts were screened for the final inclusion/exclusion of the studies. The inclusion and exclusion criteria were defined based on the PICOS approach [population (P), intervention (I), comparators (C), main outcome (O) and study design (S)].

Only full-text articles published in English and with a target group of healthy, community-dwelling older adults of 60 years and older (P) were included in the meta-analysis. Further inclusion criteria were that studies had to be intervention studies (I) with an exercise intervention in the form of a controlled trial (C). There had to be at least one control group per study. Handgrip strength (O) had to be the main outcome and pre- and post-testing had to be performed (S).

The exclusion criteria were additional diet changes or nutrition supplements as part of the intervention. Furthermore, the authors aimed at investigating community-dwelling, healthy older adults, so that older adults living in a nursing home or receiving long-term care as well as older adults with mental decline, chronic diseases of the heart or vascular system, orthopaedic conditions, diabetes, sarcopenia, frailty, or obesity were excluded from the analysis.

Methodological Quality

To evaluate the methodological quality of the included studies, a scale by the Physiotherapy Evidence Database (PEDro scale) with 11 dichotomous items was used [15]. The two researchers independently rated all included studies and came to a consensus on every item after completing the individual rating (online suppl. table 1; see www.karger.com/doi/10.1159/000501203 for all online suppl. material). Researchers were not blinded to authors, place of publication, or results of the studies.

Data Extraction

Handgrip strength outcomes (in kilograms, pounds, or Newtons) were extracted and transferred to a separate excel sheet that contained the equations for all relevant calculations that are described in the statistical analysis section. Furthermore, other relevant study information (author, year, number of participants, intervention groups, and details about the intervention) were extracted and compiled in Table 1.

Table 1. Characteristics of the included interventions

Reference	Study design	Sample population (sample size; mean age ± SD)	Groups	Intervention	Training	Intensity of IG training	Outcome measures	PEDro score
Alexander et al. [38] (2000)	Three-arm control trial	Female subjects 65 years or older	POOL (n = 24, 67 years)	(a) POOL (aqua group) aquatics exercises	12 weeks, 3 sessions/week, 60 min/session	Intensity not explicitely specified	Handgrip strength (left, right, and total; kg)	5
			IG walking (n = 25, 67 years)	(b) IG walking and flexibility program				
			CG (n = 17, 70 years)	(c) CG no particular physical activity				
Borges et al. [23] (2018)	Two-arm control trial	Community-dwelling adults (n = 71; 68±7.5 years)	IG (n = 35)	(a) supervised training; aerobic, flexibility, muscular strength, and balance exercises associated with cognitive tasks	12 weeks, 3 sessions/week, 50 min/session	Assessed with Borg scale and heart rate monitor	Handgrip strength (kgf)	7
			CG (n = 36)	(b) supervised training; aerobic, flexibility, muscular strength, and balance exercises				
Campa et al. [24] (2018)	Two-arm RCT	Older women (n = 30; 66.1±4.7 years)	IG (n = 15)	(a) IG supervised training: TRX suspension training (squat, rear deltoid row, biceps curl, chest press, low row, rotational ward)	12 weeks, 2 sessions/week, 60 min/session	Adjusting straps of TRX, encouraged to increase intensity	Absolute and dominant handgrip strength (kg)	7
			CG (n = 15)	(b) CG: no certain activity, normal physical activity				
Cancela Carral et al. [39] (2017)	Three-arm control trial	Very old people (80+ years; n = 36; 87.9±4.7 years)	IG (n = 13)	(a) IG: pedalling	3 month, 3 sessions/week, 45 min/session	Pedalling on level 1–3, and exhaustion of 5–6 on a 10-point Borg scale	Handgrip strength (left/right; kg)	7
			CG (n = 12)	(b) CG: resistance training Thera-Band				
			JM (n = 11)	(c) JM: joint mobilisation exercises				
Dondzila et al. [25] (2016)	Two-arm RCT	Elderly (n = 39; 74.6±6.4 years)	IG (n = 20)	(a) IG: supervised exercise while sitting (knee extension, knee flexion, hip lift, toe raise, chest press, seated row, arm curl and arm extension)	(a) 8 weeks, 2 sessions/week	Pedometer: increasing 10% above baseline steps each week Exercises: more repetitions and sets	Maximal handgrip strength (lbs)	7
			CG (n = 19)	(b) CG: one orientation session for pedometer	(b) once			
Englund et al. [26] (2005)	Two-arm RCT	Community-living women (n = 48)	IG (n = 24; 73±4 years)	(a) IG: supervised weight-bearing (2 × 8–12 reps for each muscle group)	12 months (5 weeks summer break), 2 sessions/week, 50 min/session	Increase of intensity through more weight (dumbbells), more complex and faster movements	Isometric grip muscle strength (N)	6
			CG (n = 24; 73±5 years)	(b) CG: normal physical activity				
Gudlaugsson et al. [27] (2012)	Two-arm RCT, cross-over	Older individuals from AGES Reykjavik Study (n = 117)	IG (n = 56, 81±5 years)	(a) IG: endurance and strength training + workshops, partly supervised	6 months, 7 sessions/week endurance and 2 sessions/week strength training + 3 lectures nutrition, 4 healthy ageing and training, 20–34 min/session (increasing)	50–70% of HRR and 50% of 1 RM and 1 RM	Maximal isometric muscle strength of the dominant hand (N)	6
			CG (n = 61, 78±4 years)	(b) CG: delayed intervention group				

Table 1 (continued)

Reference	Study design	Sample population (sample size; mean age ± SD)	Groups	Intervention	Training	Intensity of IG training	Outcome measures	PEDro score
Kamegaya et al. [28] (2014)	Two-arm RCT	Community dwelling elderly (n = 52)	IG (n = 26, 73.6±5.6 years)	(a) IG: physical activity and exercise program (resistance and aerobic) + program in community centre	12 weeks, 1 session/week, 45 min/session	Not specified	Grip strength	5
			CG (n = 26, 76±6 years)	(b) CG: no intervention program				
Niemelä et al. [29] (2011)	Two-arm RCT	Women of war generation (n = 51)	IG (n = 26, 80±3 years)	(a) IG: rocking chair exercises, home based	6 weeks, 10 sessions/week, 15 min/sessions (2 sessions a day)	Not explicitly specified	Handgrip (kg)	7
			CG (n = 25, 81±4 years)	(b) CG: normal physical activity				
Ponce-Bravo et al. [30] (2015)	Two-arm control trial	Healthy elderly (n = 54, 71.8±6.0 years)	IG (n = 22)	(a) IG: multidimensional activity program (endurance, strength, balance, gross motor, and flexibility training), supervised	4 weeks, 5 sessions/week, 50 min/session	From 5 to 8 on a 10-point Borg scale	Handgrip strength (kg)	6
			CG (n = 32)	(b) CG: recreational training, supervised				
Ramírez-Campillo et al. [40] (2014)	Three-arm control trial	Older women (n = 45)	IG (n = 15, 66±4 years)	(a) IG: high-speed resistance training (bench press, standing upper row, biceps curl, leg press, prone leg curl, leg extension), 3 sets (at 45, 60, and 75% of 1 RM) of each exercise, 8 reps per set and 1 min of rest between sets)	12 weeks, 3 sessions/week, 70 min/session	75% of 1 RM and 45–75% of 1 RM	Maximum isometric strength, both hands (kg)	4
			SG (n = 15, 69±6 years)	(b) SG: (low-speed group) low-speed resistance training (same exercises as IG, 3 sets of each exercise 8 repetitions at 75% of their baseline 1 RM, 1 min rest)				
			CG (n = 15, 67±5 years)	(c) CG: no intervention				
Rhodes et al. [31] (2000)	Two-arm control trial	Health elderly women (n = 44, 69 years)	IG (n = 22)	(a) IG exercises: chest press, leg press, biceps curl, triceps extension, quadriceps curl, hamstrings curl, first 3 months supervised, then 9 months not supervised	3 months supervised, 3 sessions/week, 60 min/week + 9 months non-supervised, same training volume	75% of 1 RM	Grip strength (kg)	6
			CG (n = 22	(b) CG: no intervention program				
Santanasto et al. [22] (2017)	Two-arm RCT	Sedentary older adults (n = 1,635; 79±5 years)	IG (n = 818)	(a) IG: overground walking + strength and balance training	36 months, 2× week: 40 min walking, 10 min strength training, 10 min balance	Walking at a "somewhat hard" intensity and strength training at a "hard" intensity (12–16 on a 20-point Borg scale), resistance training used ankle weights that were adjustable up to 20 lbs in 0.5 lb	Handgrip strength (kg)	6
			CG (n = 817)	(b) CG: weekly and then monthly workshops	36 months, 1 workshop (weeks 1–26); From week 27–>2 workshops / month with 5–10 min of light, upper extremity stretching			

Table 1 (continued)

Reference	Study design	Sample population (sample size; mean age ± SD)	Groups	Intervention	Training	Intensity of IG training	Outcome measures	PEDro score
Santin-Medeiros et al. [32] (2015)	Two-arm control trial	Elderly women (n = 37, 82±6 years)	IG (n = 19)	(a) IG: 18 exercises on vibration platform	8 months, 2 sessions/week, 18 exercises 6–7 min/session	Not explicitly specified	Handgrip strength (kg)	5
			CG (n = 18)	(b) CG: no intervention program				
Shigematsu et al. [33] (2002)	Two-arm control trial	Elderly women (n = 38, 78.6±4.0 years)	IG (n = 20)	(a) IG: dance-based aerobic exercise	3 month, 3 sessions/week, 60 min/sessions	Was set at individual's heart rate (±15 beats/min) and rating of perceived exertion corresponding to the lactate threshold	Hand grip strength (kg)	5
			CG (n = 18)	(b) CG: no exercise classes				
Shiotsu et al. [41] (2018)	Three-arm control trial	Community-dwelling men over 60 years (n = 45, 70±4 years)	IG (n = 16)	(a) IG: first aerobic, then resistance training Resistance training: 5 exercises on weight machines, 3 sets of 8–12 repetitions, 70–80% of 1 RM Aerobic training: cycling at 60% of HRR	10 weeks, 2 sessions/week	60% of HRR and 12–14 on a 20-point Borg scale and 70–80% of 1 RM	Grip strength (left/right; kg)	6
			RA (n = 16)	(b) RA: first resistance training, then aerobic				
			CG (n = 13)	(c) CG: no physical activity				
Skelton et al. [34] (1995)	Two-arm control trial	Healthy community-dwelling women (n = 40, 80 years)	IG = 20	(a) progressive resistance exercises + home sessions	12 weeks, 1 session/week	Up to 70% of Hf max	Handgrip strength (N)	5
			CG = 20	(b) no active or placebo intervention				
Song et al. [42] (2013)	Three-arm control trial	Women over 65 years (n = 67, 68 years)	IG (n = 21, 67.8±2.5 years)	(a) IG Nordic walking	12 weeks, 3 sessions/week, 60 min/session	11–16 on a 20-point Borg scale	Grip strength (kg)	6
			Normal (n = 21, 68.2±2.6 years)	(b) walking without poles				
			CG (n = 25, 68.0±2.5 years)	(c) no physical activity				
Sun et al. [35] (2015)	Two-arm RCT	Community-dwelling elderly (n = 138)	IG (n = 72, 68.3±5.9 years)	(a) IG: 24-form Yang-style Tai Chi	6 months, 2 sessions/week, 60 min/session	Not explicitly specified	Handgrip strength (kgw)	6
			CG (n = 66, 70.1±5.7 years)	(b) CG: other activities as playing cards or singing				
Taunton et al. [36] (1996)	Two-arm control trial	Elderly women aged 65–75 years (n = 29, 70±3.2 years)	IG (n = 16)	(a) IG: water-based aerobic exercise, flexibility and balance, strength and endurance exercises	12 weeks, 3 sessions/week, 45 min/session	60–65% of Hf max	Grip strength (kg)	6
			CG (n = 13)	(b) CG: land-based aerobic exercise, flexibility and balance, strength and endurance exercises				

Table 1 (continued)

Reference	Study design	Sample population (sample size; mean age ± SD)	Groups	Intervention	Training	Intensity of IG training	Outcome measures	PEDro score
Timmons et al. [20] (2018)	Four-arm RCT	Community-dwelling elderly (n = 84, 69±4 years)	AER (n = 21)	(a) AER (aerobic): cross-trainer and stationary cycle ergometer	12 weeks, 3 sessions/week, 72 min/session	AER: 80% of Hf max RES: 60% of 1 RM (5% weight increase) IG: combination of AER and RES intensity	Handgrip strength (kg)	6
			RES (n = 21)	(b) RES (resistance): Milon cycle (leg press, seated row, chest press, lat pulldown, leg extension, and tricep dips)				
			IG (n = 21)	(c) IG: aerobic + resistance training (half of AER and half of the RES training volume)				
			CG (n = 21)	(d) no exercise				
Tsourlou et al. [21] (2006)	Two-arm control trial	Health elderly women (n = 22)	IG (n = 12, 69±2 years)	(a) IG: aquatic aerobic training	24 weeks, 3 sessions/week, 60 min/session	65–80% of Hf max	Handgrip strength (kg)	5
			CG (n = 10, 86±7)	(b) CG: no intervention program				
Wolf et al. [43] (1996)	Three-arm RCT	n = 200	IG (n = 72, 77±5 years)	(a) IG: Tai Chi exercises (synthesis of 108 forms into 10)	15 weeks, 2 sessions/day, 15 min/session	Modest intensity	Grip strength (kg)	7
			CB (n = 64, 76±5 years)	(b) CB (computer-based): computer game on force plate to increase sway				
			CG (n = 64, 75±4years)	(c) CG: no change in exercise levels, weekly meeting for several discussions				
Zisi et al. [37] (2001)	Two-arm control trial	Independently living older adults (n = 30, 69±6 years)	IG (n = 15)	(a) IG: calisthenics (stepping accompanied with music, after the second week use of dumbbells)	9 weeks, 3 sessions/week, 60 min/session	60–70% of Hf max	Grip strength (lbs)	4
			CG (n = 15)	(b) CG: no intervention				

CG, control group; IG, intervention group; HRR, heart rate reserve; 1 RM, 1 repetition maximum; Hf max, maximum heart frequency.

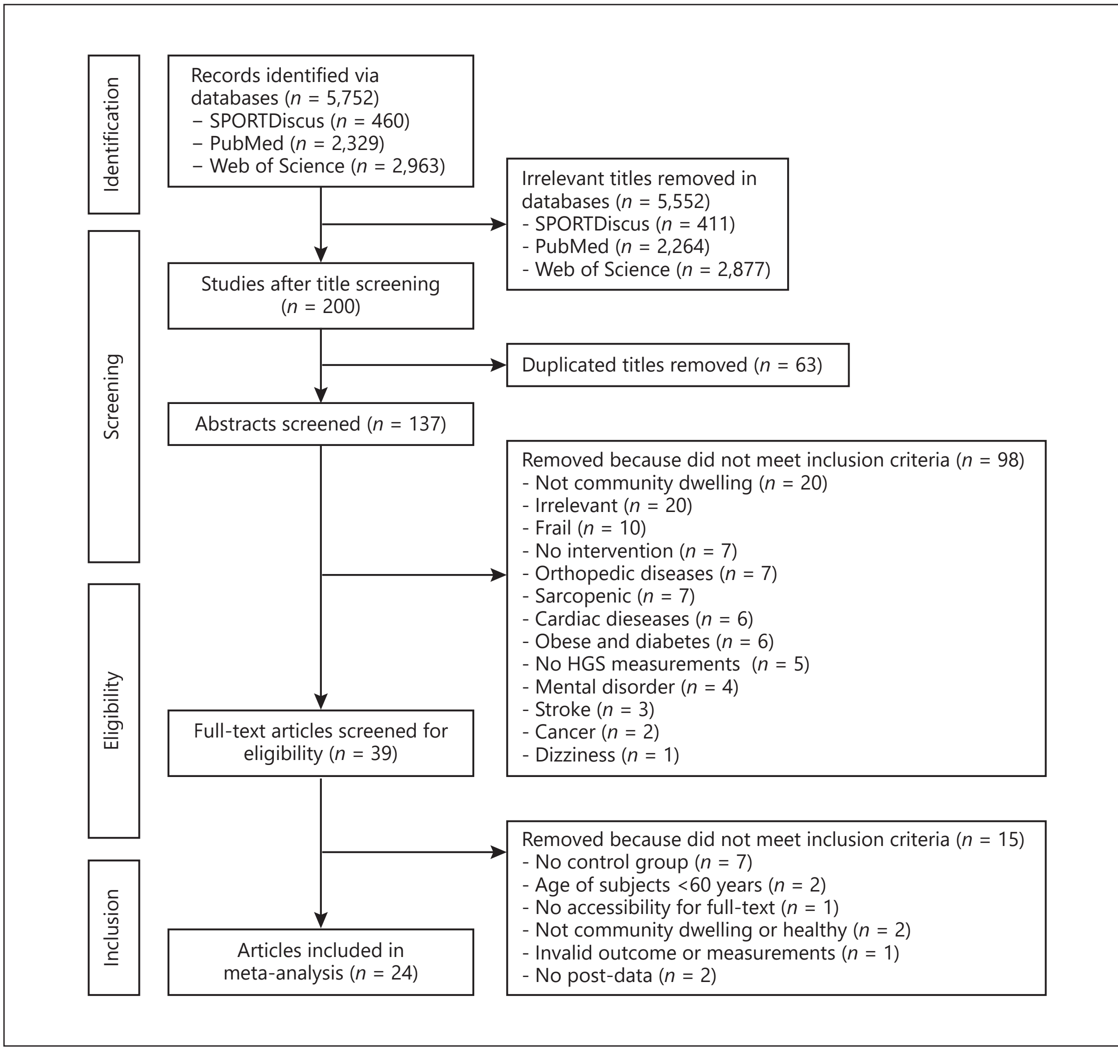

Fig. 1. Flow of study screening and selection.

Statistical Analysis

Standardized mean differences (SMD, with 95% confidence intervals [CIs]) were calculated for each study according to Hedges' (adjusted) g, which can be used for diverged and small sample sizes [16]. Negative values (–) reflect negative effects. The Cochrane Review Manager Software (RevMan 5.3.5, Cochrane Collaboration, Oxford, UK) was used to conduct the inverse-variance method [17]. Analyses were conducted using the random effects model [18]. The forest plot was generated for the respective outcome measure. The following scale was used to evaluate the standardized mean differences (SMDs) [19]: 0–0.19 = negligible effect, 0.20–0.49 = small effect, 0.50–0.79 = moderate effect, and 0.80 and higher = large effect. Study heterogeneity was assessed using I^2. A funnel plot was created to examine potential publication bias by comparing the effect sizes direction with the standardized mean differences. All statistical analyses were performed within the Cochrane Review Manager Software.

Results

Trial Flow

In the three databases, 5,752 relevant articles were initially detected (Fig. 1). After removing all irrelevant studies based on the title and removing duplicates, 137 articles remained for abstract screening. Ninety-eight studies did not meet the inclusion criteria. Thirty-nine articles were left for full-text screening. Three of them were excluded during data extraction because of lacking post-values for handgrip measurements. The authors were contacted in order to get the data for post-measurements which were not reported in the published version of the article. However, only one of the respective authors [20] reacted to the request and sent the missing post-values.

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Finally, 15 studies were excluded based on the defined exclusion criteria. For the final meta-analysis, 24 studies were included. All studies were published between 1995 and 2018.

Study Population

In the 24 trials, 3,018 healthy community-dwelling older adults with a mean age of 73.3 ± 6.0 years were enrolled. The mean sample size was 81 ± 263, with a range from 22 [21] to 1,635 [22] participants.

Study Quality

Seventeen studies used a two-armed design [21–37], six studies used a three-armed design [38–43], and one study [20] used a four-armed design. The mean study quality was 5.8 (±0.9), ranging from 4 [37, 40] to 7 [23–25, 29, 39, 43]. None of the included studies blinded participants or instructors.

Scope of the Studies

Training types of all 24 studies included aquatic exercise, walking, flexibility, TRX-training, home-trainer exercise, strength training in different forms, training on a vibration platform, dance, Tai Chi, exergames balance training, calisthenics, and multi-dimensional training regimes. Intervention durations ranged from 4 weeks [30] to 36 months (mean 22 ± 30 weeks) [22], whereas the majority of the interventions lasted for 8–15 weeks. Session duration varied between 15 [29, 43] and 72 [20] min per session (mean 51 ± 15 min per session) with most of the sessions lasting 60 min. Training frequency varied between one session per week [34] and two sessions per day [29, 43] (mean 3 ± 2 sessions per week) with mostly 2–3 sessions per week. The training intensity was measured differently with the Borg scale, 1 repetition maximum (1 RM), or maximum heart frequency (Hf max). Using the Borg rating of perceived exertion (RPE) scale the intensity ranged from 11 to 16 [22, 41, 42], and using the RPE ratio scale the intensity varied from 5 to 8 [30, 39]. Five studies [20, 27, 31, 40, 41] measured the training intensity with 1 RM ranging from 45 to 80%. The intensity measured with heart frequency varied from 60 to 80% of the maximum heart frequency [20, 21, 27, 34, 36, 37, 41]. Two studies did not report the intensity level [28, 35] and one study [23] used the Borg scale and heart rate monitor for assessing intensity but did not report values. One study reported not to have monitored training intensity [29]. Wolf et al. [43] reported modest training intensity in Tai Chi, and Campa et al. [24] encouraged the participants to increase intensity individually by changing position towards the anchor point of TRX. Englund et al. [26] increased the training intensity by using heavier dumbbells and by doing more complex and faster movements. Dondzila et al. [25] increased the walking intensity by 10% of baseline steps each week and the resistance training by increasing repetition and sets of exercises. Alexander et al. [38] used water exercise equipment for the aquatics exercise group to increase the intensity while the walking group exercised at a comfortable pace. Exercises increased progressively in the vibration platform training of Santin-Medeiros et al. [32]. The focus of the majority of the 24 included studies was on multimodal training, including aerobic and resistance exercises [20, 22, 23, 27, 28, 30, 36, 41].

Risk of Bias

The funnel plot (see online suppl. Fig. 1) shows a triangular funnel-shape with few outliers. The number of studies on the left and right side of the dashed SMD line seems equally distributed. Normally, studies with small sample sizes build the basis of the triangle. There is only one study [21] with a small sample size at the right bottom of the funnel plot. This two-armed controlled trial included 22 participants, 12 in the intervention group, and analysed the effects of a 24-week aquatic aerobic training. There are more studies with a bigger sample size of 30–70 participants, located in the middle of the funnel shape. The study with the biggest sample size [22] is clearly identified to the top left, outside of the funnel shape. This two-armed controlled trial included 1,635 participants, with 818 in the intervention group, and analysed the effects of a combined walking training the intervention group performed twice a week over 36 months.

Data Analysis

Small effects were observed for handgrip strength outcome ($p < 0.001$, SMD 0.28, 95% CI 0.13–0.44, $I^2 = 56\%$; Fig. 2) in favour of exercise training groups compared to control groups.

Discussion

To the best of the authors' knowledge, no previous systematic review with meta-analysis has addressed potential transfer effects of interventions with exercise training on handgrip strength serving as a well-established surrogate parameter of vitality and physical function in healthy community-dwelling older adults. Measuring handgrip strength is an inexpensive, quick, and objective means to evaluate physical frailty [44] or change in performance

Study or subgroup	SMD	SE	Weight	SMD IV, Random, 95% CI
Alexander et al. [38], 2000	0.28	0.32	3.8%	0.28 [–0.35, 0.91]
Borges et al. [23], 2018	0.43	0.24	5.1%	0.43 [–0.04, 0.90]
Campa et al. [24], 2018	0.52	0.37	3.1%	0.52 [–0.21, 1.25]
Cancela Carral et al. [39], 2017	–0.08	0.4	2.8%	–0.08 [–0.86, 0.70]
Dondzila et al. [25], 2016	–0.08	0.33	3.6%	–0.08 [–0.73, 0.57]
Englund et al. [26], 2005	0.65	0.33	3.6%	0.65 [0.00, 1.30]
Gudlaugsson et al. [27], 2012	0.84	0.2	6.0%	0.84 [0.45, 1.23]
Kamegaya et al. [28], 2014	–0.19	0.28	4.4%	–0.19 [–0.74, 0.36]
Niemelä et al. [29], 2011	0.04	0.28	4.4%	0.04 [–0.51, 0.59]
Ponce-Bravo et al. [30], 2015	0.5	0.28	4.4%	0.50 [–0.05, 1.05]
Ramírez-Campillo et al. [40], 2014	0.47	0.37	3.1%	0.47 [–0.26, 1.20]
Rhodes et al. [31], 2000	0.49	0.31	3.9%	0.49 [–0.12, 1.10]
Santanasto et al. [22], 2017	–0.05	0.05	9.2%	–0.05 [–0.15, 0.05]
Santin-Medeiros et al. [32], 2015	0.05	0.33	3.6%	0.05 [–0.60, 0.70]
Shigematsu et al. [33], 2002	–0.29	0.33	3.6%	–0.29 [–0.94, 0.36]
Shiotsu et al. [41], 2018	0.3	0.41	2.7%	0.30 [–0.50, 1.10]
Skelton et al. [34], 1995	0.27	0.32	3.8%	0.27 [–0.36, 0.90]
Song et al. [42], 2013	0.91	0.31	3.9%	0.91 [0.30, 1.52]
Sun et al. [35], 2015	0.19	0.17	6.6%	0.19 [–0.14, 0.52]
Taunton et al. [36], 1996	0.14	0.37	3.1%	0.14 [–0.59, 0.87]
Timmons et al. [20], 2018	0.28	0.31	3.9%	0.28 [–0.33, 0.89]
Tsourlou et al. [21], 2006	1.37	0.48	2.1%	1.37 [0.43, 2.31]
Wolf et al. [43], 1996	0.15	0.19	6.2%	0.15 [–0.22, 0.52]
Zisi et al. [37], 2001	0.27	0.37	3.1%	0.27 [–0.46, 1.00]
Total [95% CI]			**100.0%**	**0.28 [0.13, 0.44]**

Heterogeneity: $\tau^2 = 0.07$; $\chi^2 = 51.88$, df = 23 ($p = 0.0005$) $I^2 = 56\%$
Test for overall effect: $Z = 3.53$ ($p = 0.0004$)

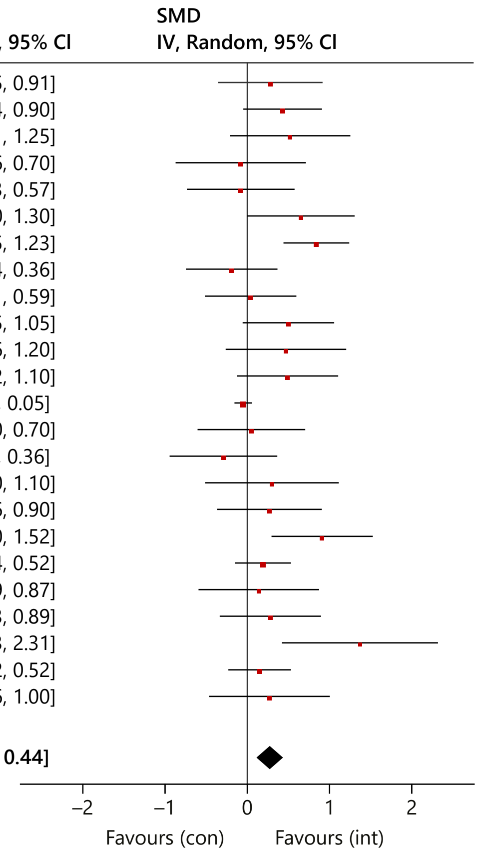

Fig. 2. Forest plot of the analysis on handgrip strength between the intervention groups (int) and the control groups (con). SE, standard error; IV, independent variable; CI, confidence interval; SMD, standardized mean difference.

[45] in small and large samples. Furthermore, handgrip strength measurements can be used to identify older adults who are sarcopenic, frail, and malnourished [46]. This meta-analytical review provides a solid estimate of exercise-induced transfer effects of various interventions with exercise training on handgrip strength. The results of this review displayed small effects of a variety of interventions on handgrip strength measures.

In order to evaluate the effects of interventions with a measurement tool, i.e. handgrip strength dynamometer, besides reliability and validity, the standard error of measurement (SEM) and minimal detectable change (MDC) have to be known. In a recent systematic review, Bohannon [46] included 17 studies about the reliability and MDC of handgrip strength measurements in different older target groups. Four of the included studies included older community-dwelling adults without any disease. The review demonstrated a relative reliability with ICC > 0.91 in these four studies with 211 participants with a mean age of 75.2 years [46]. Regarding absolute reliability, these four studies used the variables SEM, technical error of measurement (TEM) and least significant change (LSC). The SEM was 3.9 and 1.9 kg, TEM was 1.6 (left hand) and 2.2 (right hand), and LSC was 6.0 kg. These four relevant studies were evaluated by Bohannon [46] regarding their study quality with scores between 9 and 13 on a 14-point scale. If one takes the best results for absolute reliability for older community-dwelling older adults from Bohannon's review [46], a change (for example via an intervention) above 1.6 kg can be interpreted as a real change.

Measuring handgrip strength with a dynamometer can be a useful assessment tool for determining the efficacy of different treatments and for an overall fitness assessment [45]. The studies included in this meta-analysis measured handgrip strength as a general parameter of the

state of physical function but they did not include handgrip-specific exercises. In fact, the variety in exercise mode, duration, and intensity was large. For most of the studies, the “task-specificity principle” of neuromuscular adaptation, which was manifested for balance training, seems to apply: if the positions that are tested in pre- and post-testing are not trained during the intervention, no improvement compared to the control group is revealed [47, 48]. The outcome of this meta-analytical review supports the transfer of this idea of task specificity on handgrip strength training and measurements. Effects are more likely to appear when the tested tasks are closely related to the training contents [47–49]. Only small effects in favour of the exercise training groups, which were training with different training modes not specifically addressing handgrip strength, were found. In one of the included studies with the largest effect sizes in favour of the intervention group, participants trained with dumbbells, which included gripping of the weights [26]. Corroboratively, in another study with large effects, participants did Nordic walking [42], which included a repetitive movement similar to a gripping task by holding the pole and executing the correct Nordic walking technique. In contrast to handgrip strength assessment, Nordic walking improves the muscular endurance component and capacity instead of maximum strength, necessary for handgrip measurements. In most of the other studies, showing positive effect without task-specific training, transfer effects might account for positive changes. Additionally, it has to be taken into account that measurements of handgrip strength are usually performed isometrically, whereas exercises were mostly performed dynamically. To summarise, handgrip strength would benefit from training that mainly targets upper extremity exercises in which handgrip movements are performed.

As was mentioned, exercise mode, duration, and intensity varied among the studies included in this meta-analysis, and so did the changes in handgrip strength. As for training mode, improvements in handgrip strength indices were not only seen in interventions with pure strength/resistance training, but also in multimodal interventions as well as in a Nordic walking intervention. Interestingly, the majority of the studies that featured large effects in favour of the intervention group followed a multimodal approach to exercise training. It is assumed that handgrip strength capacity benefits more from incorporating different training focuses (strength, balance, flexibility, endurance). This finding should be taken into consideration when evaluating the efficacy of interventions with exercise training [48].

Almost all studies in this review met the recommendations of more than 12 weeks of intervention, except two studies that lasted less than 12 weeks [29, 30]. No clear relationship is apparent between the duration of the intervention and the changes in handgrip strength. One study with only 6 weeks of daily rocking chair exercise found a slightly significant change in handgrip strength in favour of the intervention group [29]. Greater changes in handgrip strength were measured after a 9-week calisthenics intervention [37]. On the other hand, the study with the longest intervention duration (36 month) did not show any effects in favour of the intervention group [22]. This finding can be attributed to the control conditions that were requested to complete home exercises. Additionally, the training frequency differed a lot between the studies, so that a statement on the effect of the study duration is hardly possible. A further factor potentially influencing effects on handgrip strength might be training intensity. When the intensity of the intervention was reported as between 60 and 80% of 1 RM, handgrip strength increased. Of those measuring intensity with 1 RM as reference, the intervention of Gudlaugsson et al. [27], where the participants trained with 6 RM, had the greatest changes in favour of the intervention group. In the studies using the Borg scale as the reference, handgrip strength increased when the perceived exertion was reported as “somewhat hard” or “hard” (12–16) [41, 42] with the exception of the study by Santanasto et al. [22]. Regarding Hf max, interventions with a variation of 15–20% between minimum and maximum heart frequency in training seem to be the most effective [21, 27]. Continuous training with 80% Hf max [20] is not more effective than training with 60% Hf max [41].

Due to the high variability of the training designs of all studies, it is not possible to tell the influence of specific training modalities (training mode, duration, or intensity) on changes in handgrip strength. The confidence intervals of four studies that did not touch the zero-effect line indicate a large effect in favour of the intervention groups [21, 26, 27, 42]. These studies included weight-bearing training over 12 months [26], endurance training combined with strength training over 6 months [27], aquatic aerobic training over 3 months [21], and Nordic walking over 3 months [42], and therefore obviously differed in terms of exercise mode, duration, and intensity despite comparable effects. Only five of the included studies trended towards a favourable effect for the control group [22, 25, 28, 33, 39]. These studies consisted of seated strength training [25], resistance and aerobic exercises [28] and dance-based aerobic exercises [33]. Additional-

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ly, the participants of one study did either low-loaded pedalling or unspecific exercises using elastic bands [39], and the remaining comprised workshops, strength, or balance training [22]. Again, no prototype for mode, duration, or intensity of the training can be found. The reasons for unchanged handgrip strength might be attributed to the age of the participants [39], a short intervention period [25], the lack of weekly training sessions [28], or short duration of single training sessions [22, 33].

Older adults who do not train beside the normal activities of daily living lose their body strength and arm strength [50]. Therefore, based on the present meta-analytical review, the authors recommend exercise training for community-dwelling older adults in order to improve or maintain functions of activities of daily living and to remain independent. The overall effect of the studies analysed in this meta-analysis and the overlapping intervals indicate that there is neither a clear effect in favour of the control nor the intervention group after an unspecific training intervention. Thus, if the aim is to increase handgrip strength, the authors recommend at least 9 weeks of task-specific training with variable heart frequency, 75% 1 RM, and perceived "somewhat hard" or "hard" exertion. Whether the same is true for frail older adults or for older adults living in care facilities remains unclear and needs to be addressed in future analyses. Illness and frailty could have a strong impact on the results so that these target groups need to be investigated separately. This meta-analysis therefore focused on the effects of training on handgrip strength of a healthy population only. According to the results, handgrip strength cannot clearly be recommended as an alternative outcome to assess general functional performance for all kinds of exercise programs. It can be assumed though that handgrip strength changes after multimodal interventions and thus can be used as an outcome measure for this training modality. However, it is questionable whether pure lower extremity exercise or endurance exercise programs, for example, substantially alter handgrip performance, even if they cause other performance changes.

Strengths and Limitations

This meta-analytical review was performed in accordance with the PRISMA statement [14]. Despite notable but acceptable heterogeneity of the included studies (intervention programmes, number of study arms, sample sizes), our findings provide a structured view on the transfer effects of interventions with exercise training on handgrip strength, independent of the underlying exercise regimen. It needs to be kept in mind that although handgrip strength is a feasible and easily applicable tool of vitality and functioning assessment in older adults, few interventions with exercise training include this outcome even if muscle strength has been targeted. In most of the included studies the training procedure and performed exercises were clearly described. The different interventions might bias the effects as none primarily promoted handgrip strength explicitly. The relative reliability of handgrip strength measurements is very good; however, the measurement tool showed weakness in absolute reliability. Furthermore, the achieved intervention effects have to be interpreted allowing for SEM and MDC.

Conclusion

The present meta-analysis focused on healthy, non-institutionalized older adults and revealed evidence that several interventions provide an appropriate training for improving handgrip strength, especially those with multimodal training. Small transfer effects can be explained due to the lack of task-specific exercises, the lack of weekly training sessions, or short duration of single training sessions. For meaningful conclusions, substantial changes in handgrip strength may be required to confidently conclude that real changes have occurred over time. Still, the effectiveness of exercise training is not to be underestimated. Beyond that, handgrip strength cannot clearly be recommended as an alternative outcome to assess general functional performance for all kinds of exercise programs, possibly apart from multimodal training modes. Furthermore, the effects of interventions with exercise training on handgrip strength in specific target groups, such as institutionalized or frail older adults, must be investigated in the future.

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Statement of Ethics

The authors have no ethical conflicts to disclose.

Disclosure Statement

The authors have no conflicts of interest to declare.

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