A Systematic Review of High Intensity Progressive Resistance Strength Training of the Lower Limb Compared to Other Intensities of Strength Training in Older People.

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REVIEW ARTICLE (META-ANALYSIS)

Systematic Review of High-Intensity Progressive Resistance Strength Training of the Lower Limb Compared With Other Intensities of Strength Training in Older Adults

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Abstract

Objective: To examine the effect of high-intensity progressive resistance strength training (HIPRST) on strength, function, mood, quality of life, and adverse events compared with other intensities in older adults.

Data Sources: Online databases were searched from their inception to July 2012.

Study Selection: Randomized controlled trials of HIPRST of the lower limb compared with other intensities of progressive resistance strength training (PRST) in older adults (mean age ≥65y) were identified.

Data Extraction: Two reviewers independently completed quality assessment using the Physiotherapy Evidence Database (PEDro) scale and data extraction using a prepared checklist.

Data Synthesis: Twenty-one trials were included. Study quality was fair to moderate (PEDro scale range, 3–7). Studies had small sample sizes (18–84), and participants were generally healthy. Meta-analyses revealed HIPRST improved lower-limb strength greater than moderate- and low-intensity PRST (standardized mean difference [SMD]=.79; 95% confidence interval [CI], .40 to 1.17 and SMD=.83; 95% CI, −.02 to 1.68, respectively). Studies where groups performed equivalent training volumes resulted in similar improvements in leg strength, regardless of training intensity. Similar improvements were found across intensities for functional performance and disability. The effect of intensity of PRST on mood was inconsistent across studies. Adverse events were poorly reported, however, no correlation was found between training intensity and severity of adverse events.

Conclusions: HIPRST improves lower-limb strength more than lesser training intensities, although it may not be required to improve functional performance. Training volume is also an important variable. HIPRST appears to be a safe mode of exercise in older adults. Further research into its effects on older adults with chronic health conditions across the care continuum is required.

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Loss of muscle mass and strength is common among older adults, with a strong association between reduced lower-limb function and dependence in activities of daily living.[1-3] Evidence demonstrates that exercise in older adults can minimize the effect of functional decline,[2,4-8] with progressive resistance strength training (PRST) a commonly employed method. Progressive resistance strength training, where the resistance is progressed to maintain intensity,[9] improves strength[10] and functional ability[11,12] and can eliminate the need for gait aids in older adults.[13] Moderate-intensity progressive resistance strength training (MIPRST) and high-intensity progressive resistance strength training (HIPRST) have also been shown to have a positive impact on depression and quality of life (QOL).[3,14] A previous

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meta-analysis suggests that HIPRST is better than lesser intensities for strength outcomes, however, may not be required for functional outcomes.[15] Training volume may also be an important variable, because some trials have reported similar strength gains with low repetitions at high intensity and high repetitions at low intensity.[16,17] The risks associated with HIPRST may be greater than for lower intensities, although the safety of HIPRST in this population is not well understood. At present there is no consensus regarding the optimal training intensity for achieving improvements in functional status, mood, and QOL while maintaining safety in older adults.

Other reviews have examined PRST in older adults without examining the effect of intensity[18] or the effect of intensity on a wide variety of outcomes.[15] This review was performed to summarize the evidence comparing high intensity to other intensities of PRST in older adults on a broader range of outcomes and to provide recommendations for clinical practice and future research. The primary aims were to examine the effectiveness of HIPRST in older adults in improving strength, endurance, and functional performance and assess its safety compared with other intensities of PRST. Secondary aims were to examine the effect of HIPRST on cognition, psychological status, QOL, falls rate, power, flexibility, and cardiovascular fitness in those who have undertaken such training.

Methods

Selection criteria

Only published randomized controlled trials comparing HIPRST with other intensities of PRST were considered for inclusion.

Studies with participants' mean age of ≥65 years were included, but excluded if any participants were aged <60 years old. Participants were untrained in PRST. There were no exclusions on the basis of health, sex, residence, or setting of therapy.

There are no consistent criteria for maximal-, high-, moderate-, and low-intensity strength training in the literature.[2,8,19-23] Percentage of 1 repetition maximum (1RM) is often used to specify intensity. This is the maximum weight a person can lift once only "before fatigue using good form and technique"[24(p984)] "performed primarily by the specified muscle groups without the use of momentum or any changes in body position, other than those directly resulting from the movement of the weight, during the exercise motion."[25(p1913)] Although not specifically defined in a previous systematic review,[18] many studies with 70% to 90% 1RM were labeled as high intensity.[26-28] Other articles have described moderate intensity as 50% to 70%[2,3,21] and low intensity as <50%.[11,12,21,29-32] Therefore, for the purposes of this systematic review, HIPRST was defined as 70% to 89% of 1RM, maximal intensity was defined as ≥90% 1RM, MIPRST as 50% to 69% 1RM, and low-intensity progressive resistance training (LIPRST) as <50% 1RM.

Studies were considered if the HIPRST program was land based and performed against any type of resistance within the above percentage 1RM ranges. All studies were required to have at least 1 control group who undertook another intensity of strength training: higher, lower, and/or variable. Trials of HIPRST of the lower limb with or without additional upper limb, trunk, or abdominal strengthening were considered. Trials were excluded if the high-intensity range was outside of the defined percentage 1RM; where the specified intensity was not defined as a percentage of 1RM; where HIPRST was combined with other types of exercise other than a warm-up and cool-down (eg, aerobic exercise); where training was performed at different velocities, such as power training at high velocities; or where the comparison group did not include a second intensity of training (a no training control group).

Strength, endurance, gait speed, functional limitation, power, torque, flexibility, maximum oxygen consumption, cognition, psychological status, and QOL were analyzed as continuous variables. Falls and adverse events were reported as dichotomous outcomes. Relative training volumes were calculated (total repetitions × relative load as percentage 1RM[22]) where they were not reported in studies. For each trial, these were reported as a percentage of the training volume undertaken by HIPRST group participants.

List of abbreviations:

CI	**confidence interval**
GDS	**Geriatric Depression Scale**
HIPRST	**high-intensity progressive resistance strength training**
LIPRST	**low-intensity progressive resistance strength training**
MIPRST	**moderate-intensity progressive resistance strength training**
1RM	**1 repetition maximum**
PEDro	**Physiotherapy Evidence Database**
POMS	**Profile of Mood States**
PRST	**progressive resistance strength training**
QOL	**quality of life**
SMD	**standardized mean difference**
WMD	**weighted mean difference**

Search strategy

The following online databases were searched from the earliest date available until July 2012: the Cochrane Central Register of Controlled Trials, MEDLINE, Embase, Cumulative Index to Nursing and Allied Health Literature, AMED, AgeLine, and the Physiotherapy Evidence Database (PEDro). Reference lists from relevant studies and review studies were hand searched for additional articles. No language restrictions were applied.

Search terms (appendix 1) were used in the search strategy in MEDLINE and adapted for use in the other databases. These terms were limited to randomized controlled trials.

Quality assessment and data extraction

Data were extracted independently by 2 reviewers using a prepared checklist. Disagreements were resolved by consensus. Extraction from each trial included: (1) characteristics of trial participants (age, sex, and level of normative physical activity) and the trial's inclusion and exclusion criteria; (2) HIPRST and comparison PRST program details (intensity, repetitions and sets, duration, frequency, number of lower-limb exercises, equipment used); and (3) type of outcome measure(s) and adverse events. Methodologic quality assessment was conducted independently by 2 reviewers (M.J.R. and R.E.B.T.) using the PEDro scale.[33] Disagreements were resolved by consensus. Where unclear, authors of included studies were approached via email and asked to provide details of missing data or clarification regarding methods.

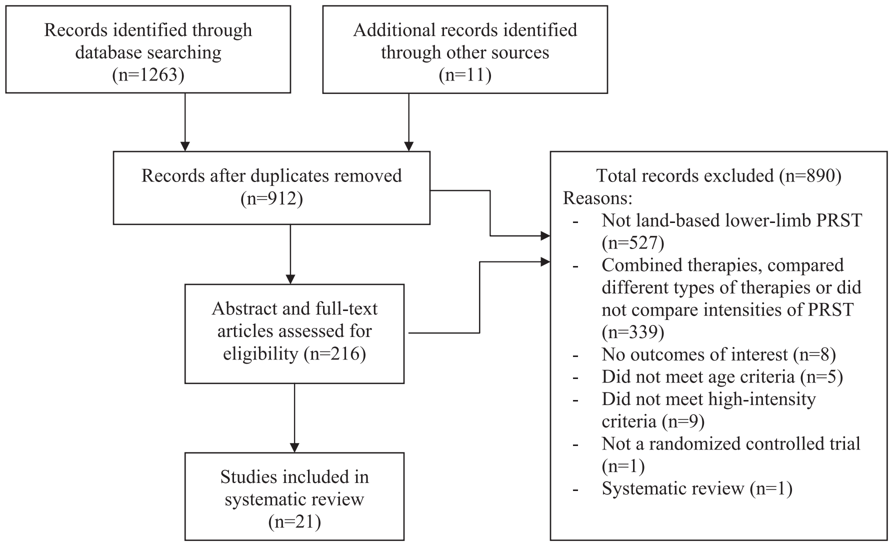

Fig 1 Flowchart showing the selection of studies for this systematic review.

Data analysis

Where studies were considered clinically homogeneous, data were pooled for meta-analyses using Review Manager 5.1 software[a] and weighted mean differences (WMDs) with 95% confidence intervals (CIs) were calculated. A fixed or random effects model was used depending on assessment of heterogeneity. To enable comparison between continuous variables with different units, standardized mean differences (SMDs) with 95% CIs were calculated. Based on Cohen conventional definition for SMD, values of 0.2 were considered small, 0.5 was considered medium, and 0.8 was considered large.[34] To assess the effects of our definitions of intensity on the review outcomes, a sensitivity analysis was performed where only extreme values were included (high vs low intensity). Where sufficient data were available, a second sensitivity analysis examined whether the effects differed in higher-quality trials (PEDro $\geq$6) compared with lower-quality trials (PEDro $\leq$5).

Results

The search strategy returned a total of 912 citations. Details on study selection can be found in figure 1. Where a single randomized controlled trial resulted in $\geq$2 publications, each article was included if they investigated a separate outcome measure of interest. Eight of the included articles fell into this category.[8,12,16,32,35-38] Multiple articles are referenced as the first published article only. Twenty-one articles of 17 trials were eligible for inclusion (see fig 1), with a total of 830 enrolled participants and 724 participants' data reported.

Table 1 summarizes details from included trials. Eight trials (10 articles) investigated high- and moderate-intensity training only,[2,3,16,20,22,35,39,40] 6 trials (7 articles) examined high- and low-intensity training only,[11,12,14,17,29,30] 1 trial examined maximal-, high-, and moderate-intensity training,[21] 1 trial (2 articles) examined high-, moderate-, and low-intensity training,[8,32] and 1 trial reported on high- versus a variable-intensity program.[41] Some trials included upper limb and trunk PRST as part of their programs.

Methodologic quality assessment

Most studies were of poor to moderate methodologic quality and ranged from 3 to 7 (out of 10) on the PEDro scale. No study involved blinded participants or therapists because of the nature of the interventions. Two studies used blinded assessors,[12,37] and 1 study employed concealed allocation.[14] One study reported that groups were not of similar age at baseline.[38] The majority of studies obtained at least 85% of data for a primary outcome,[2,3,12,14,20,21,29,32,35,39-41] and 6 studies used intention-to-treat analysis.[3,12,20,21,35,40] All studies reported between-group statistical comparisons and point measures and measures of variability for at least 1 primary outcome.

Participants

All participants were untrained in PRST. Group characteristics are summarized in table 1.

Programs

Where reported, programs were carried out in community-based training facilities[14,16] and local fitness centers.[41] The length of training sessions was reported in only 7 trials ranging from approximately 45[41] to 90 minutes.[40] Some programs included a warm-up[2,3,12,16,22,30,32,37,40,41] prior to PRST and a cool-down[2,14,16,30,35,40] after training. Where specified, these warm-up and cool-down programs consisted of low-intensity repetitions of the intended PRST exercise, low-intensity cardiovascular exercise, stretching, and/or calisthenics.

Programs ranged from 8 to 52 weeks (mean $\pm$ SD, 20.5$\pm$13.3), with participants attending 2 to 3 times per week.

Outcome measures

Lower-limb strength

Table 2 summarizes the SMDs of HIPRST versus other intensities on maximal lower-limb strength. Positive SMDs favor HIPRST and negative SMDs favor comparison intensity. In the trials that included leg or knee extension, the movements were not described

Table 1 Summary of 21 included studies

Study	PEDro Score (/10)	Age Range (mean)	Participants	Sample Size* (final no.)	No. of LL Ex	Frequency and Duration†	High Intensity Resistance (%1RM), Sets × reps	Comparison Intensity: (%1RM) Sets × reps			Adverse Events	Outcomes‡
								Maximal	Moderate	Low/Other		
Beneka[21]	6	60+(65)	Healthy, sedentary	64 (64)	3	3×wk 16wk	70% 3×8–10	90% 3×4–6	50% 3×12–14	NA	Not reported	Strength
Cassilhas[3]	6	65–75	Male, sedentary	62 (62)	2	3×wk 24wk	80% 2×8	NA	50% 2×8	NA	Not reported	Strength, cognition, QOL, depression
Fatouros, Kambas et al[2]	5	(71.2)	Male, sedentary	59 (52)	3	3×wk 24wk	80%–85% 2–3×6–8	NA	50%–55% 2–3×14–16	NA	Reported, no details	Strength, power, functional performance, walking speed
Fatouros, Tournis[32]	5	65–78	Male, sedentary, overweight	57 (50)	3	3×wk 24wk	80%–85% 2–3×8	NA	60%–65% 2–3×10	45%–50% 2–3×14	Reported, no details	Strength, cardiovascular fitness
Fatouros[8]	5	As above										Strength, flexibility
Harris[22]	4	61–85 (71.2)	Healthy	76 (62)	3	2×wk 18wk	75% 3×9 84% 4×6	NA	67% 2×15	NA	Nil	Strength
Hortobagyi[29]	5	66–83 (72)	Healthy	30‖ (27)	1	3×wk 10wk	80% 5×4–6	NA	NA	40% 5×8–12	Yes	Strength
Hunter[41]	4	61–77 (>65)	Healthy	30 (28)	2	3×wk 25wk	80% 2×10	NA	NA	Variable: 50%, 65%, 80%	Not reported	Strength, perceived exertion, functional performance, cardiovascular fitness
Kalapotharakos[35]	6	60–74	Healthy, sedentary	33 (33)	2	3×wk 12wk	80% 3×8	NA	60% 3×15	NA	Not reported	Strength
Kalapotharakos[37]	6	As above		35 (33)							Not reported	Strength, functional performance, flexibility, walking speed
Pruitt[30]	4	65–79	Female, healthy	40 (26)	5	3×wk 52wk	80%§ 2×7 (warm up 40% 1×14)	NA	NA	40% 3×14	Yes	Strength
Seynnes[11]	4	73–95 (81.5)	Institutionalized	27 (22)	1	3×wk 10wk	80% 3×8	NA	NA	40% 3×8	Nil	Strength, endurance, 6MWT, disability
Singh[14]	6	60–85	Older adults with depression	60 (54)	3	3×wk 8wk	80% 3×8	NA	NA	20% 3×8	Yes	Strength, QOL, depression
Sullivan[38]	5	65–93 (79.4)	Recent functional decline	29 (24)	1	3×wk 12wk	80%§ 3×8	NA	NA	10%–20% 3×8	Yes	Strength, functional performance
Sullivan[12]	7	65–93 (78.2)	Recent functional decline	71 (61)	3	3×wk 12wk	80%§ 3×8	NA	NA	10%–20% 3×8	Yes	Strength, functional performance
Taaffe[17]	3	65–79	Female, healthy	36 (25)	3	3×wk 52wk	80% 2×7	NA	NA	40% 3×14	Not reported	Strength

(*continued on next page*)

Table 1 (*continued*)

Study	PEDro Score (/10)	Age Range (mean)	Participants	Sample Size* (final no.)	No. of LL Ex	Frequency and Duration†	High Intensity Resistance (%1RM), Sets × reps	Comparison Intensity: (%1RM) Sets × reps			Adverse Events	Outcomes‡
								Maximal	Moderate	Low/Other		
							(warm up 40% 1×14)					
Tsutsumi[39]	5	61–86 (68.6)	Healthy, sedentary	45 (42)	2	3×wk 12wk	75%–85% 2×8–10	NA	55%–65% 2×14–16	NA	Not reported	Strength, mood and anxiety, cognition, functional performance
Tsutsumi[20]	6	60–86 (68.5)	Female, healthy, sedentary	36 (36)	2	3×wk 12wk	75%–85% 2×8–10	NA	55%–65% 2×14–16	NA	Not reported	Strength, psychological measures
Vincent et al[16]	4	60–83 (68.4)	Healthy	84 (62)	6	3×wk 26wk	80% 1×8	NA	50% 1×13	NA	Yes	Strength, endurance
Vincent et al[36]	As above											Cardiovascular fitness
Willoughby[40]	6	(69)	Male, sedentary	18 (18)	3	3×wk 12wk	75%–80%§ 3×8–10	NA	60%–65% 3×15–20	NA	Not reported	Strength

Abbreviations: Ex, exercises; LL, lower limb; NA, not applicable; No., number; reps, repetitions; 6MWT, 6-minute walk test.

* Number of enrolled participants.

† Total duration – some studies included a 1- to 4-wk conditioning period, which gradually increased %RM to the target level.

‡ Outcomes of interest to this review.

§ Includes 1–2wk of pretraining/orientation at reduced number of sets, reps, and/or intensity – 1 set only.

‖ Participants 60 years or older.

Table 2 Effects of HIPRST versus other intensities of PRST on strength outcomes

Study	High Intensity Resistance % 1RM	Comparison Intensity 1 % 1RM	Comparison Training Volume as a % of High Intensity group (%)*	Outcome†	SMD	95% Confidence Interval or *P* value	Comparison Intensity 2 % 1RM	Comparison Training Volume as a % of High Intensity Group (%)*	SMD	95% Confidence Interval
Beneka[21]	70	50	140	Knee extension	ND		90	144	ND	
Cassilhas[3]‡	80	50	63	Leg press	0.87	(0.22 to 1.53)	NA			
				Leg curl	1.15	(0.47 to 1.82)				
Fatouros, Tournis[32]	80–85	60–65	95	Leg extension	1.14	(0.30 to 1.98)	45–50	101	2.05	(1.11 to 2.98)
Fatouros[8]	As above	As above	As above	Leg press	0.65	(−0.16 to 1.42)	45–50	As above	1.90	(0.96 to 2.73)
Fatouros, Kambas[2]	80–85	50–55	137	Leg press	1.66	(0.91 to 2.41)	NA			
Harris[22]	75	67	100	Lower body strength§	0.26	(−0.46 to 0.99)	84 vs 67	100	0.10	(−0.58 to 0.77)
Hortobagyi[29]	80	40	100	Leg press	0.40	(−0.54 to 1.34)	NA			
				Max eccentric strength	0.11	(−0.11 to 0.33)				
				Isometric	0.03	(−0.89 to 0.96)				
				Concentric	0.49	(−0.49 to 1.39)				
Hunter[41]	80	50, 65, 80	82	Knee extension	0.62	(−0.14 to 1.38)	NA			
Kalapotharakos[37]	80	60	141	Lower body strength‖	1.00	(0.12 to 1.88)				
Kalapotharakos[35]	As above	As above		Knee extension	1.04	(0.16 to 1.92)	NA			
				Knee flexion	0.80	(−0.06 to 1.65)				
Pruitt[30]	80	40	75	Hips¶	0.21	(−0.81 to 1.22)	NA			
				Legs#	0.21	(−0.94 to 1.36)				
Seynnes[11]	80	40	50	Knee extension	0.62	(−0.48 to 1.71)	NA			
Singh[14]	80	20	25	Average strength**	ND, RS	$P<.0001$	NA			
Sullivan[38]	80	10–20	25	Leg press	ND, RNS	$P>.05$	NA			
Sullivan[12]	As above	As above		Leg press	ND, RS	$P<.05$	NA			
Taaffe[17]	80	40	75	Leg press††	ND, RNS	$P>.05$	NA			
				Knee extension††	ND, RS‡‡	$P<.05$				
				Knee flexion††	ND, RNS	$P>.05$				
Tsutsumi[39]	75–85	55–65	105	Leg strength (10RM)	RNS	RNS	NA			
Tsutsumi[20]	75–85	55–65	125	Leg extension	0.23	(−0.57 to 1.03)	NA			
Vincent et al[16]	80	50	102	Leg press	0.00	(−0.58 to 0.58)	NA			
				Leg curl	0.32	(−0.27 to 0.90)				
				Leg ext	0.29	(−0.29 to 0.87)				
Willoughby[40]	75–80	60–65	162	Leg press	0.62	(−0.46 to 1.70)	NA			

NOTE. A positive SMD indicates HIPRST having larger strength gains than the comparison group.
Abbreviations: NA, not applicable; ND, no data; RM, repetition maximum; RNS, reported not significant; RS, reported significant.
* Training volume each session as a percentage of high-intensity training volume. See Methods for further details.
† 1RM where not specified.
‡ Raw data (unpublished) obtained directly from authors.
§ Combined knee extension, leg press, leg curl.
‖ Combined knee extension and flexion.
¶ Hip abduction plus hip adduction.
\# Leg press plus knee extension plus knee flexion.
** Mean of percent change across 3 upper-limb and 3 lower-limb resistance exercises.
†† Outcome measure assessed at 3, 6, 9, and 12 months.
‡‡ Significant at 3 months only.

in adequate detail to determine the difference, if any, between these outcomes.

Lower-limb strength: high versus low

Seven trials reported on high- versus low-intensity training,[11,12,14,17,29,30,32] with SMDs in favor of HIPRST ranging from .21 to 2.05 (see table 2). One trial revealed large SMDs in favor of HIPRST for knee extension and leg press after 24 weeks in sedentary participants who were men.[8,32] During one 12-month program, there was no difference between training intensities for knee extension, knee flexion, or leg press strength at 3 monthly time points, except for knee extension strength at 3 months, which

Study or Subgroup	HIPRST Mean	HIPRST SD	HIPRST Total	LIPRST Mean	LIPRST SD	LIPRST Total	Weight	Std. Mean Difference IV, Random, 95% CI
Fatouros, Tournis 2005	102.2	14.6	14	75.5	10.4	14	26.0%	2.05 [1.11, 2.98]
Hortobagyi 2001	1,193	320	9	1,050	360	9	26.0%	0.40 [-0.54, 1.34]
Pruitt 1995	65.6	14.3	8	62.7	11.9	7	24.6%	0.21 [-0.81, 1.22]
Seynnes 2004	11.3	2.828	8	9.7	1.715	6	23.4%	0.62 [-0.48, 1.71]
Total (95% CI)			**39**			**36**	**100.0%**	**0.83 [-0.02, 1.68]**

Heterogeneity: Tau² = 0.50; Chi² = 8.82, df = 3 (P = 0.03); I² = 66%
Test for overall effect: Z = 1.91 (P = 0.06)

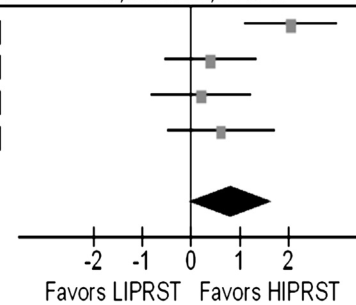

Fig 2 HIPRST versus LIPRST for maximal lower-limb strength. Abbreviations: IV, inverse variance; Std., standard.

was greater in HIPRST participants.[17] Another study[11] reported maximal knee extension strength improved significantly with both intensities, with a moderate but not statistically significant effect in favor of HIPRST (SMD = .62; 95% CI, −.48 to 1.71). Other trials found no difference between intensities in 1RM hip and leg strength at 15 and 52 weeks[30] nor for maximal eccentric or isometric quadriceps strength.[29] Pooled data from 4 out of 7 trials revealed a large SMD in favor of high-intensity training, but this just failed to reach statistical significance (SMD = .83; 95% CI, −.02 to 1.68). These trials were of moderate to low methodologic quality with PEDro scale scores rating ≤5 (fig 2).

Lower-limb strength: high versus moderate

Ten trials (13 articles) compared HIPRST versus MIPRST.[2,3,16,20-22,32,35,39,40] The SMDs tended to favor high-intensity training; however, there was marked variability with SMDs ranging from 0 to 1.66 (see table 2) and a pooled SMD of .79 (95% CI, .40−1.17) (fig 3). Studies were grouped by methodologic quality for further analysis and demonstrated consistency of results: lower-quality studies with PEDro scale scores of ≤5 resulted in an SMD of .67 (95% CI, .33−1.02), and those of higher quality (PEDro scale score of ≥6) resulted in an SMD of .80 (95% CI, .39−1.22). Four trials (5 articles) showed statistically significant differences between intensities for leg extension, leg press, leg curl, overall lower-body strength, and knee extension,[2,3,32,35,37] and 3 studies showed moderate to large SMDs favoring high-intensity training for various lower-limb strength outcomes without statistically significant differences between groups (knee flexion and leg press).[11,35,40] Three studies showed small SMDs without statistically significant differences between groups,[16,20,22] including no effect for leg press strength.[16] Two studies reported insufficient data to analyze differences between intensities.[21,39] Pooled data from 4 trials revealed a WMD of 14.17kg (95% CI, 9.86−18.48) (leg extension, leg press, and knee extension).

Lower-limb strength: high versus maximal

One trial reported on high compared with maximal training[21] and tested 1RM knee extensor strength at various speeds, from 60 to 180°/s. They reported a 7.3% to 11.2% increase in strength for men and 2.3% to 15.2% increase for women across all intensities (high, maximal, and moderate) with no between-group comparison.

Lower-limb strength: high versus variable

One study reported significant strength gains for knee extension with both variable-intensity and high-intensity training, with no significant difference between intensity types (SMD = .64; 95% CI, −0.14 to 1.38).[41]

Outcomes other than strength

Table 3 shows SMDs for other non-strength-related outcome measures.

Power and torque

High-, maximal-, and moderate-intensity PRST improved isokinetic peak torque ($P<.05$), with no difference between high- and moderate-intensity training.[21] The SMDs favored maximal intensity over high intensity and ranged from −.12 to −1.25. Another study reported statistically significant improvements in isokinetic peak torque after HIPRST and MIPRST, with high-intensity training significantly better than moderate-intensity training on only 1 of the 8 outcomes.[35] A third study reported no statistically significant differences between HIPRST and LIPRST for explosive strength measures, including maximal rate of tension development.[29] When investigating peak power, 1 study reported that HIPRST resulted in significantly greater gains than MIPRST (SMD = .69; 95% CI, .02−1.33).[2]

Endurance

In residents of aged care facilities, both high- and moderate-intensity training increased knee extension endurance by 284% and 117%, respectively, with significantly greater improvements for HIPRST over MIPRST (SMD = 1.71; 95% CI, .42−3.01).[11] In a healthy older population, leg press endurance increased with both high- and moderate-intensity training; however, there was no significant difference between intensities (SMD = .14; 95% CI, −.44 to −.72).[16] In this same population, treadmill time to exhaustion increased with both high- and moderate-intensity training, with no significant difference between intensities (SMD = .25; 95% CI, −.34 to −.82).[36]

Cardiovascular fitness

There was no clear benefit of high-intensity training on peak oxygen consumption[16,32,39,41] or submaximal oxygen consumption[41] over other intensities of training. Two studies found improvement with both HIPRST and MIPRST with no significant difference between groups[32,36]; a third study reported no effect with either intensity of PRST.[39] Pooled data from 2 studies revealed a WMD of .93mL·kg^{-1}·min^{-1} (95% CI, −.69 to 2.55). When compared with variable intensity training, there was a moderate but nonsignificant effect on submaximal oxygen

Study or Subgroup	HIPRST Mean	HIPRST SD	HIPRST Total	MIPRST Mean	MIPRST SD	MIPRST Total	Weight	Std. Mean Difference IV, Random, 95% CI
Cassilhas 2007	131.5	18.72	20	110.53	17.07	19	14.2%	1.15 [0.46, 1.83]
Fatouros 2005	91.7	8.2	20	76.8	9.4	18	13.0%	1.66 [0.91, 2.41]
Fatouros, Tournis 2005	102.2	14.6	14	85.9	12.9	12	11.6%	1.14 [0.30, 1.98]
Harris 2004	244.04	71.67	13	222.72	83.47	17	13.4%	0.26 [-0.46, 0.99]
Kalapotharakos 2004	43.12	11.49	11	31.54	10.03	12	11.0%	1.04 [0.16, 1.92]
Tsutsumi 1998	30.68	8.27	12	28.73	8	12	12.1%	0.23 [-0.57, 1.03]
Vincent...Magyari 2002	347.1	167	22	305.6	114	24	16.2%	0.29 [-0.29, 0.87]
Willoughby 1998	1.88	0.32	7	1.63	0.43	7	8.5%	0.62 [-0.46, 1.70]
Total (95% CI)			**119**			**121**	**100.0%**	**0.79 [0.40, 1.17]**

Heterogeneity: Tau² = 0.15; Chi² = 14.00, df = 7 (P = 0.05); I² = 50%
Test for overall effect: Z = 3.99 (P < 0.0001)

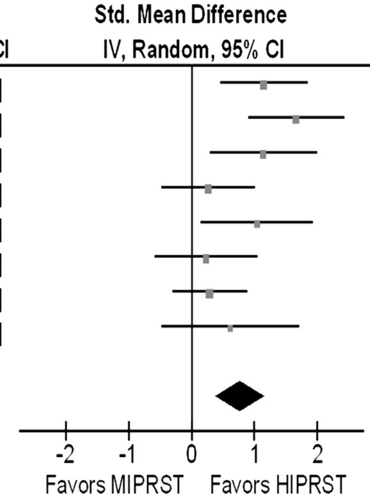

Fig 3 HIPRST versus MIPRST for lower-limb strength. Abbreviations: IV, inverse variance; Std., standard.

consumption in favor of variable intensity (SMD=.66; 95% CI, −.10 to 1.42).[41]

Flexibility

Two studies examined flexibility. One trial[37] reported both HIPRST and MIPRST significantly improved sit and reach with no difference between intensities. Mean improvements across training groups were approximately 3.5 to 5cm: a 13% and 15.5% increase from baseline for HIPRST and MIPRST, respectively.[37] A second trial[8] also reported significant improvements with both HIPRST and MIPRST in flexibility. Knee flexion and hip extension range improved with no difference between intensities. There were large and statistically significant SMDs with HIPRST over LIPRST for increasing knee flexion and hip extension range. Across all intensities tested, the increase in range was 5° to 14° of knee flexion and 0.3° to 4.7° for hip extension, with the largest gain of 4.7° of hip extension after HIPRST. There was no improvement in the hip flexion range for any intensity examined.[8]

Functional performance

Both variable PRST and HIPRST reduced perceived exertion while carrying an object with a larger reduction observed in those who received variable resistance training (SMD=−.77; 95% CI, −1.55 to 0.00). Relative muscle activation was calculated by dividing the integrated electromyography measured during the weighted walking task by maximal elbow flexion. This was reduced only in the variable intensity group, with a large SMD. Two studies reported reductions in stair climb time with HIPRST versus MIPRST (SMD=−.34; 95% CI, −1.16 to .49[37] and SMD=−.57; 95% CI, −1.16 to .02,[16] respectively). A small but nonsignificant improvement in stair climb power was reported for HIPRST over LIPRST.[11]

One trial (2 articles) examined an aggregate physical performance score, which included sit to stand time, habitual and maximal safe walking speeds, and stair climb time,[12,38] and reported similar improvements in performance with high- and low-intensity training with no difference between intensities (*P*>.05). The authors reported that those with the lowest scores at baseline had the greatest improvements,[38] independent of training intensity.

There were significant improvements with both HIPRST and LIPRST for chair-rise time with no difference between intensities (SMD=−.06; 95% CI, −1.12 to 1.00).[11]

HIPRST improved six-minute walk test distance more than moderate-intensity training, with a moderate but not significant effect (SMD=.65; 95% CI, −.44 to 1.75).[11]

Disability

Disability, as measured by the Health Assessment Questionnaire Disability Index, was reduced by both high and low intensities with no difference between intensities[11] (SMD=.09; 95% CI, −.97 to 1.15).

Falls

Falls rate was reported in 1 study in an older population with depression.[14] While there were less falls per person in the HIPRST group when compared with the LIPRST group (mean ± SD, .15±.37 and .28±.75, respectively), this was not statistically significant.

Hospitalization

Number of days spent in hospital was also reported in an older population with depression over an 8-week period. These were 0.5±0.2 days per person in the HIPRST group compared with none in the LIPRST, reported to be not statistically significant.[14]

Quality of life

QOL was reported in 2 studies using the Medical Outcomes Study 36-Item Short-Form Health Survey.[3,14] There was no improvement in QOL with moderate- or high-intensity training in any of the domains in Medical Outcomes Study 36-Item Short-Form Health Survey reported (*P*>.05).[3] However, another study showed moderate improvements in the vitality domain for high- over low-intensity training in an older population with depression (SMD=.59; 95% CI, −.10 to 1.25).[14] In this study, both HIPRST and LIPRST were reported to improve QOL across 6 of the 8 health-related QOL domains: physical function, role physical, vitality, social function, role emotional, and mental health (*P* range, <.001−.04).

Table 3 SMD table for high intensity versus other intensity PRST — various outcomes

Study	High Intensity Resistance % 1RM	Comparison Intensity 1 % 1RM	Comparison Training Volume as a % of High Intensity Group (%)	Outcome	SMD (95% Confidence Interval) or *P* value	Comparison Intensity 2 %1RM	Comparison Training Volume as a % of High Intensity Group (%)	SMD (95% Confidence Interval)
Beneka[21]	70	50	140	Isokinetic peak torque		90%	144	
				Males: knee ext 90° deg/sec	0.51 (−0.49 to 1.51)			−0.30 (−1.29 to 0.69)
				Females: knee ext 90° deg/sec	0.71 (−0.31 to 1.73)			−0.71 (−1.71 to 0.31)
				Males: knee ext 60° deg/sec	0.63 (−0.38 to 1.64)			−0.34 (−1.33 to 0.64)
				Females: knee ext 60° deg/sec	−0.10 (−1.08 to 0.88)			−1.18 (−2.27 to −0.09)
Cassilhas[3]	80	50	63	Quality of life	ND, RNS	NA		
				Depression — self rated (GDS)	ND, RNS			
				Mood	ND, RNS			
				Cognition	ND, RNS			
Fatouros, Tournis[32]	80–85	60–65	95	$\dot{V}O_2$ Max	0.56 (−0.23 to 1.34)	45–50	101	0.50 (−0.28 to 1.29)
Fatouros[8]	80–85	60–65	As above	Flexibility — knee flexion	0.10 (−0.67 to 0.87)	45–50	As above	0.88 (0.10 to 1.66)
				Flexibility — hip flexion	0.04 (−0.73 to 0.82)			0.06 (−0.68 to 0.80)
				Flexibility — hip extension	0.29 (−0.48 to 1.07)			2.93 (1.82 to 4.04)
Fatouros, Kambas[2]	80–85	50–55	137	Peak power	0.69 (0.02 to 1.33)	NA		
				Mean power	0.38 (−0.27 to 1.01)			
				Timed Up & Go Test	−0.07 (−0.70 to 0.57)			
				Walking speed	−0.05 (−0.68 to 0.59)			
				Stepping up	−0.18 (−0.82 to 0.46)			
				Stepping down	−0.21 (−0.85 to 0.42)			
Hortobagyi[29]	80	40	100	Explosive strength:		NA		
				Max rate of tension development	0.27 (−0.66 to 1.20)			
Hunter[41]	80	50, 65, 80	82	Performing functional tasks:		NA		
				Perceived exertion	0.77 (0.00 to 1.55)			
				Submaximal $\dot{V}O_2$	0.66 (−0.10 to 1.42)			
				Relative muscle activation*	1.23 (0.41 to 2.04)			
Kalapotharakos[35]	80	60	141	Isokinetic peak torque		NA		
				Left knee ext 60° deg/sec	−0.06 (−0.93 to 0.82)			
				Right knee ext 60° deg/sec	0.26 (−0.62 to 1.14)			
				Left knee flex 60° deg/sec	−0.12 (−1.00 to 0.76)			
				Right knee flex 60° deg/sec	0.18 (−0.70 to 1.05)			
				Left knee ext 180° deg/sec	0.30 (−0.58 to 1.17)			
				Right knee ext 180° deg/sec	0.05 (−0.83 to 0.92)			
				Left knee flex 180° deg/sec	0.15 (−0.73 to 1.03)			
				Right knee flex 180° deg/sec	0.14 (−0.74 to 1.02)			
Kalapotharakos[37]	80	60	As above	Flexibility — sit and reach	−0.24 (−1.06 to 0.58)	NA		
				Walking speed	0.12 (−0.70 to 0.94)			
				Chair rise	0.12 (−0.69 to 0.95)			

(*continued on next page*)

Table 3 (*continued*)

Study	High Intensity Resistance % 1RM	Comparison Intensity 1 % 1RM	Comparison Training Volume as a % of High Intensity Group (%)	Outcome	SMD (95% Confidence Interval) or *P* value	Comparison Intensity 2 %1RM	Comparison Training Volume as a % of High Intensity Group (%)	SMD (95% Confidence Interval)
				Stair climb	−0.34 (−1.16 to 0.49)			
Seynnes[11]	80	40	50	Endurance	1.71 (0.42 to 3.01)	NA		
				Chair rise time	−0.06 (−1.12 to 0.99)			
				Stair climb power	0.29 (−0.78 to 1.35)			
				6-minute walk distance	0.65 (−0.44 to 1.75)			
				Disability (HAQ − DI)	0.09 (−0.97 to 1.15)			
Singh[14]	80	20	25	Quality of life − vitality	0.59 (−0.10 to 1.25)	NA		
				Depression				
				Therapist rated (HRSD)	−0.15 (−0.82 to 0.51)			
				Self-rated (GDS)	−0.16 (−0.83 to 0.50)			
Sullivan[12]	80	20	25	Aggregate physical score(sit to stand, stair climb, safe and maximal gait speed)	ND, RNS	NA		
Sullivan[38]	80	20	As above	Aggregate physical score (as above)	ND	NA		
Tsutsumi[39]	75−85	55−65	105	Physical activity efficacy:				
				Walking	−0.25 (−0.99 to 0.50)	NA		
				Stair climb	0.40 (−0.35 to 1.15)			
				Physical Self-efficacy Scale:				
				PPA	0.37 (−0.38 to 1.12)			
				PSPC	−0.54 (−1.29 to 0.22)			
				Cognition				
				Mental arithmetic	0.48 (−0.28 to 1.23)			
				Mirror drawing				
				Time	0.26 (−0.48 to 1.01)			
				Dots	−0.14 (−0.88 to 0.60)			
				Errors	−0.97 (−1.77 to −0.16)			
				$\dot{V}O_2$ Max	ND to RNS			
Tsutsumi[20]	75−85	55−65	125	POMS tension	0.59 (−0.23 to 1.41)	NA		
				POMS vigor	−0.27 (−1.07 to 0.54)			
				State anxiety (STAI)	0.27 (−0.53 to 1.08)			
				Trait anxiety (STAI)	0.86 (0.02 to 1.71)			
				$\dot{V}O_2$ Max	ND to RNS			
Vincent et al[36]	80	50	102	Muscular endurance (leg)	0.14 (−0.44 to 0.72)	NA		
				Stair climb time	−0.57 (−1.16 to 0.02)			

(*continued on next page*)

Table 3 (*continued*)

Study	High Intensity Resistance % 1RM	Comparison Intensity 1 % 1RM	Comparison Training Volume as a % of High Intensity Group (%)	Outcome	SMD (95% Confidence Interval) or *P* value	Comparison Intensity 2 %1RM	Comparison Training Volume as a % of High Intensity Group (%)	SMD (95% Confidence Interval)
Vincent to Braith to Feldman to Kalls et al 2002	80	50	As above	$\dot{V}o_2$ Peak	−0.06 (−0.63 to 0.52)	NA		
				Endurance — treadmill time	0.25 (−0.34 to 0.82)			

NOTE. Improvements in depression to stair climbing time to stepping up/down to disability to anxiety to mirror drawing errors (cognition) to and perceived exertion are indicated by a negative SMD. Improvements in all other outcomes are indicated by a positive SMD.

Abbreviations: Ext to extensors; Flex to flexors; GDS to Geriatric Depression Scale; HAQ DI to Health Assessment Questionnaire Disability Index subscale (French version); HRSD to Hamilton Rating Scale of Depression; Max to maximal; ND to no data; POMS to Profile of Mood States; PPA to Perceived Physical Ability; PSPC to Physical Self-Presentation Confidence; RNS to reported not significant; STAI to State-Trait Anxiety Inventory; $\dot{V}o_2$, oxygen consumption per unit time.

* As calculated by dividing integrated electromyography of the weight load while walking by maximal elbow flexion.

Psychological status

One study reported no improvement in self-rated depression (Geriatric Depression Scale [GDS]) with HIPRST or MIPRST in a sedentary, older population of men (*P*>.05).[3] In an older population with a diagnosis of depression, HIPRST participants experienced more than twice the relative response of LIPRST participants in both the GDS (58%±7% vs 23%±7%) and the Hamilton Rating Scale for Depression (52%±7% vs 25%±8%).[14] Sixty-one percent of HIPRST participants had a clinically important response (a 50% improvement in therapist-rated scores) compared with 29% of LIPRST participants (*P*=.05). The authors described a significant inverse relation between strength and self-reported depression levels with high-intensity exercise only.[14]

Mood was reported in 2 studies investigating MIPRST and HIPRST. One study reported that both intensities improved overall mood scores (Profile of Mood States [POMS]), with no statistically significant difference between intensities (*P*>.05).[3] The second study reported that MIPRST tended to improve the POMS-tension domain more than HIPRST (SMD=.59; 95% CI, −.23 to 1.41).[20] In the same study, trait anxiety, as measured by the State and Trait Anxiety Inventory, was significantly lessened with MIPRST compared with HIPRST (SMD=.86; 95% CI, .02−1.71).

Two studies investigated the effects of HIPRST and MIPRST on cognition. One reported improvements in cognitive functioning for both high and moderate intensities in some areas of cognitive testing (Digit Span Forward, Corsi Block-Tapping Task Backward, similarities, Rey-Osterreith Complex Figure Immediate Recall), with no difference between intensities (*P*>.05).[3] This population had at least 8 years of schooling and a Mini-Mental State Examination score of ≥24 (out of 30). The other study found no treatment effects for neurocognitive function in healthy but sedentary older adults with at least a high school education.[20]

Program duration

There was no strong link between duration of the HIPRST program and 1RM strength outcomes (fig 4). Some shorter programs (range, 8−12wk) were sufficient to produce significantly greater strength gains for HIPRST compared with lesser intensities.[12,14,37]

Training volumes

Seven out of 8 trials where the groups undertook similar training volumes (comparison of 75% to 125% of the HIPRST volume) displayed similar lower-limb strength gains, regardless of training intensity[2,16,17,20,22,29,30,41] (see table 2). There was no clear link between the magnitude of strength increase and training volume across studies; larger training volumes did not necessarily result in larger strength gains. Conversely, smaller training volumes did not result in lesser strength gains.

Adherence

Where reported, drop outs ranged from 0%[3,21] to 44%[17] of participants, and adherence to training ranged from 66%[30] to 100%[3,21] of sessions. Reasons for lack of adherence and drop outs ranged from lack of interest,[14,17,22] personal reasons,[11,14,17,29,37]

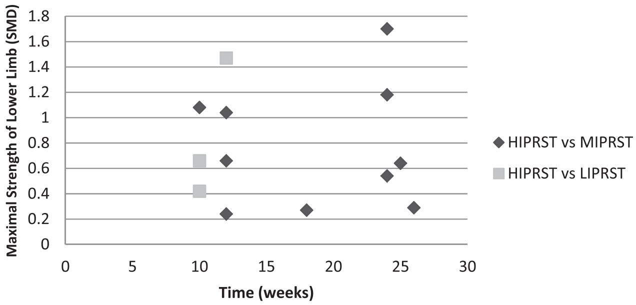

Fig 4 Effect of program duration on lower-limb 1RM strength outcomes. An SMD >0 favors HIPRST.

medical reasons unrelated to the study,[11,12,16,22] conflicts arising from project/job,[22,39] commuting issues,[16,39] and pain or injury.[12,14,16] On analysis of all reported data, adherence and drop outs did not differ according to training intensity.

Adverse events

Eight studies did not specifically state the absence or presence of adverse events.[3,17,20,21,37,39-41] Nine studies reported on the presence of adverse events[2,11,12,14,16,22,29,30,32]; however, these were generally not reported in detail. Two of these studies reported no training-induced adverse events,[11,22] and 2 reported injuries without detail.[2,32] The remainder of studies[12,14,16,29,30] reported adverse events that ranged from musculoskeletal discomfort to the exacerbation of underlying medical conditions[30] to a more serious event in 1 trial. This was an exacerbation of chronic obstructive pulmonary disease and myocardial infarction 3 days post-HIPRST.[12] Although independent monitors suggested that the exercise program could have contributed, the authors stated that HIPRST remains safe for older adults to undertake.

Where injuries were reported, rates of injury appeared comparable among high-, moderate-, and low-intensity training. One trial reported no difference in adverse events between those participating in various intensities of PRST and those not.[14]

Sensitivity analysis for definitions of intensity

Sensitivity analyses were limited by the small number of trials comparing extreme values of intensity (ie, high vs low). However, where data were available, the pattern of findings was similar to when all 3 intensities were considered. Sensitivity analysis for the outcomes of maximal strength showed moderate to large effects for HIPRST over LIPRST in 3 out of 7 trials, with statistically significant differences in 3 other trials where raw data were unable to be obtained. There were only 2 trials which had similar training volumes across high and low intensities. These trials showed disparate effects, with 1 trial showing no significant benefit of HIPRST over LIPRST (SMD=0.4)[29] and the other favoring HIPRST with a large effect (SMD=2.05).[32] While only examined in single trials, depression,[14] QOL,[14] and flexibility[8] demonstrated significantly larger effects when HIPRST was compared with LIPRST than when HIPRST was compared with MIPRST, although raw data were not available for analyses on depression and QOL. Adverse events and drop outs were similar across high- and low-intensity training. Although not able to be performed on all outcomes in this meta-analysis, sensitivity analyses support the between-group differences, favoring high-intensity training that was found in the primary analyses.

Discussion

This meta-analysis has shown that HIPRST demonstrates advantages over lower intensities of PRST. However, trials with similar training volumes had similar gains in lower-limb strength, regardless of training intensity. Other outcomes, such as functional performance, improved similarly across all intensities of PRST. Flexibility increased more with HIPRST and MIPRST than LIPRST. The effects of HIPRST compared with other intensities of PRST on psychological status remains unclear.

Although there were greater improvements in strength with high-intensity training compared with moderate- and low-intensity training (see figs 2 and 3), this was not consistent across all trials. Training volume also appears to have an important effect on strength, with similar gains seen in training groups who performed a similar volume of PRST, regardless of absolute intensity. These results suggest that clinicians should consider whether there is a need for older participants to undertake HIPRST if the primary goal is to improve strength.

Reduced flexibility may contribute to limited function[42,43] and falls[44] in older adults. Studies in younger adults have shown strength training does not impair flexibility; in some cases it may improve it[45] to levels comparable with static stretching.[46] In this review, both HIPRST and MIPRST have been shown to increase flexibility to similar extents and were more beneficial than LIPRST. It has been suggested that strengthening muscle groups may also improve range of movement across the joints that these muscles span.[47]

Functional improvements have been demonstrated with HIPRST in older adults in other studies, with improvements in ability to stand from a chair,[6,10] reduced need for walking aids,[10] and self-paced gait speed.[6] Results from this review are consistent with this literature, however, walking speed, functional performance, and disability were found to improve similarly with MIPRST and LIPRST, also supported by other meta-analyses.[15] Therefore, high intensity may not be required to improve functional performance, and lesser intensities may suffice.

While there was no significant benefit in overall QOL from HIPRST compared with other intensities, a trend for improvement was shown for components of QOL measures.[14] Mixed results for other psychological outcomes were reported. Other research has reported HIPRST programs having reduced depressive symptoms in those with both minor and major depression, with the majority of exercisers no longer meeting the diagnostic criteria for depression after 10 weeks of exercise. Increased training intensity was also reported to predict the reduction in depressive symptoms.[31] Previous systematic reviews on exercise for depression suggest exercise may reduce depression in this population in the short-term; however, more robust, larger, and longer-term randomized controlled trials are required to define the parameters around the type of exercise, intensity, duration of programs, and target populations for optimal outcomes.[48,49]

There was no obvious relation between program duration and outcome, suggesting that longer programs are not required to achieve additional benefits. Shorter HIPRST programs of 12 weeks demonstrated significantly greater gains in outcomes, such as strength and endurance, than lower intensities of training. Because positive results may be seen within 2 to 3 months of HIPRST, this finding may encourage potential participants to undertake such a program, particularly where time commitments may be a barrier. This is also positive for clinicians in community-based settings, where longer programs may be cost-prohibitive and unfeasible because of long waiting lists.

Less than one third of the included studies reported on adverse events related to training; however, events were not reported in adequate detail for further analysis. Nearly half of the trials did not report the presence or absence of adverse events, and therefore it is plausible that underreporting occurred. The majority of events reported were minor musculoskeletal injuries, and there were no deaths because of high-intensity training. There was no difference in rates of adverse events between intensities of training. The single serious adverse event occurred 2 to 3 days after training, and it was unclear if this event occurred in the placebo or drug group.[12] Because of this period of delay, it would seem unlikely that strength training caused these events. HIPRST has been reported to be safe in older adults up to the age of 96 years.[10,13] Prior to implementation, medical screening of potential participants and supervised programs should be considered.

Study limitations

This review had some limitations. While some of the SMDs calculated were moderate to large, many were not statistically significant. This may have been because of the lack of power in studies because of small sample sizes. Caution must also be used when interpreting studies with low methodologic quality, because many studies did not use intention-to-treat analysis, concealed allocation, or blinded assessors, which reduced internal validity and may have overestimated the effect of the interventions. Prior training status has been reported to be an important factor in determining the most effective training intensity for optimal strength outcomes across the age spectrum, where moderate intensity may result in better outcomes in the untrained and high intensity may be more effective in those who are trained.[50] This effect was not considered in the review. Meta-analyses were limited for outcomes other than strength, and raw data were unable to be obtained in many instances. Because most participants were sedentary and previously untrained in PRST, the findings from this review may have limited application to physically active or trained older adults.

The literature in this area also had some limitations. The trials included in this systematic review contained programs of PRST primarily run in the community with resistance machines. Only 1 trial used elastic bands, which may be a low-cost equipment option in hospitals and community settings. Although resistance bands have been shown to achieve comparable strength gains compared with weight machines in a few studies,[51-53] to our knowledge, there are no similar comparison studies in older adults undertaking HIPRST. Outcomes other than strength were reported in few studies. There were no trials on the effect of HIPRST in hospitalized older adults, where HIPRST may play an important part in falls rate, length of stay, and health service use. There is a need for further research into outcomes other than strength, in particular with a focus on older adults with various health conditions in different settings through the care continuum.

Conclusions

HIPRST may improve strength more than lower intensities of strength training, although training volume also has an important effect on the strength gains achieved. Training intensity did not appear to impact greatly on outcomes other than strength. Long programs of HIPRST are not required to see initial benefits or to achieve additional improvements. Adverse events related to strength training in older adults are minor; however, screening prior to implementing new programs is recommended to minimize participant discomfort.

Future research needs to establish whether HIPRST results in clinically meaningful improvements in important outcomes, such as falls, hospitalization, and use of health care services. Larger trials are required, with particular emphasis on subgroups of older adults with chronic diseases, those who are hospitalized, and those in residential aged care.

Supplier

a. Review Manager (RevMan) [Computer program]. Version 5.1. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration. http://ims.cochrane.org/revman/about-revman-5.

Keywords

Aged; Rehabilitation; Resistance training; Review [publication type]

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Appendix 1 Terms Used in the Search Strategy

Population	Intervention	Outcome
Exp aged/	• Resistance training/ • Strength training.ti.ab. • Progressive resistance.ti.ab. • High intensity • Resistance exercise.ti.ab. • Exercise therapy/ • Exercise • Weight lifting	• Repetition maximum.mp • 1RM.mp

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