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Effects of exercise training programs on walking competency after stroke: a systematic review

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Abstract

To determine the effectiveness of training programs that focus on lower limb strengthening, cardio-respiratory fitness or gait-oriented tasks in improving gait, gait-related activities and health-related quality of life (HRQoL) after stroke. Randomized controlled trials (RCTs) were searched for in the databases of Pubmed, Cochrane Central Register of Controlled Trials, Cochrane Database of Systematic Reviews, DARE, PEDro, EMBASE, DocOnLine and CINAHL. Databases were systematically searched by two independent researchers. The following inclusion criteria were applied: (1) participants were people with stroke, older than 18 years; (2) one of the outcomes focused on gait-related activities; (3) the studies evaluated the effectiveness of therapy programs focusing on lower limb strengthening, cardio-respiratory fitness or gait-oriented training; (4) the study was published in English, German or Dutch. Studies were collected up to November 2005, and their methodological quality was assessed using the PEDro scale. Studies were pooled, and summarized effect sizes were calculated. Best-evidence synthesis was applied if pooling was impossible. Twenty-one randomized contolled trails were included, of which 5 focused on lower limb strengthening, 2 on cardio-respiratory fitness training (e.g., cycling exercises) and 14 on gait-oriented training. Median PEDro score was 7. Meta-analysis showed a significant medium effect of gait-oriented training interventions on both gait speed and walking distance, whereas a small, non-significant effect size was found on balance. Cardio-respiratory fitness programs had a non-significant medium effect size on gait speed. No significant effects were found for programs targeting lower limb strengthening. In the best-evidence synthesis strong evidence was found to support cardio-respiratory training for stair-climbing performance. While functional mobility was positively affected, no evidence was found that activities of daily living, instrumental activities of daily living or HRQoL were significantly affected by gait-oriented training. This review shows that gait-oriented training is effective in improving walking competency after stroke.

Introduction

Stroke is a major cause of disability in the developed world, often resulting in difficulties in walking. According to the Copenhagen Stroke Study, 64% of survivors walk independently at the end of rehabilitation, 14% walk with assistance and 22% are unable to walk[1]. Since independent gait is closely related to independence in Activities of Daily Living (ADL), achieving and maintaining the ability to walk in the home and in the community is an important aim of stroke rehabilitation[2].

Saunders and colleagues evaluated the evidence for the effects of strength training, cardio-respiratory training and mixed training programs on gait. They suggested that programs concentrating on cardio-respiratory fitness resulted in improved scores for walking ability and maximum walking speed. They also noted that studies including strength and mixed training have been few, and inconclusive[3].

Recently, there has been increasing interest in combinations of strength and cardio-respiratory training, in which gait and gait-related tasks are practiced using a functional approach[4-6]. Salbach and colleagues suggested that high-intensity task-oriented practice may enhance 'walking competency' in patients with stroke better than other methods[5], even in those patients in which the intervention was initiated beyond 6 months post stroke[5,7]. Walking competency was defined as "the level of walking ability that allows individuals to navigate their community proficiently and safely"[5]. In addition, there is growing evidence that the link between physical training and improved cardio-respiratory fitness, as established in the general population, can be extrapolated to persons who are disabled by stroke[8].

To optimize the treatment of those with stroke, it is necessary to systematically evaluate the effects of the different training programs that aim to restore walking competency. We, therefore, conducted a systematic review of the literature on the effects of lower limb strength training, cardio-respiratory fitness training and gait-oriented training on gait, gait-related activities and health-related quality of life in those who had sustained a stroke.

Methods

Literature search

Potentially relevant studies were identified through computerized and manual searches. Electronic databases (Pubmed, Cochrane Central register of Controlled Trials, Cochrane Database of Systematic Reviews, DARE, Physiotherapy Evidence Database (PEDro), EMBASE, DocOnLine (Database of the Dutch Institute of Allied Health Care) and CINAHL (1980 through November 2005)) were systematically searched by two independent researchers (IvdP, WE). The following MeSH headings and keywords were used for the electronic databases: cerebrovascular accident, gait, walking, exercise therapy, rehabilitation, neurology and randomized controlled trial. Bibliographies of review articles, narrative reviews and abstracts published in proceedings of conferences were also examined. Studies were included if they met the following inclusion criteria: (1) participants were patients with stroke older than 18 years; (2) one of the study outcomes focused on gait-related activities; (3) the studies evaluated the effectiveness of therapy programs focusing on lower limb strengthening, cardio-respiratory fitness or gait-oriented training; (4) the study was published in English, German or Dutch; (5) the design was a randomized controlled trail (RCT). Studies were collected up to November 2005. Studies evaluating specific neurological treatment approaches (not specifically focusing on lower limb training), applying gait manipulations, for example by using specific devices such as body weight supported training, virtual reality or electrical stimulation, were excluded. Cross-over designs were treated as RCTs by taking only the outcomes after the first intervention phase. The full search strategy is available on request from the corresponding author.

Definitions

In the present review, stroke was defined according to the WHO definition as an acute neurological dysfunction of vascular origin with sudden (within seconds) or at least rapid (within hours) occurrence of symptoms and signs corresponding to the involvement of focal areas in the brain[9].

RCT was defined as a clinical trial involving at least one test treatment and one control treatment, in which concurrent enrolment and follow-up of the test- and control-treated groups is ensured and the treatments to be administered are selected by a random process, i.e. the use of a random-numbers table or concealed envelopes (Pubmed 1990).

Gait-related activities were defined in the present study as activities involving mobility-related tasks, such as stair walking, turning, making transfers, walking quickly and walking for specified distances. Lower limb strength training was defined as prescribed exercises for the lower limbs, with the aim of improving strength and muscular endurance, that are typically carried out by making repeated muscle contractions resisted by body weight, elastic devices, masses, free weights, specialized machine weights, or isokinetic devices[3]. Cardio-respiratory fitness training was defined as that aiming to improve the cardio-respiratory component of fitness, typically performed for extended periods of time on ergometers (e.g. cycling, rowing), without aiming to improve gait performance as such[3]. We defined gait-oriented training as that intended to improve gait performance and walking competency in terms of different parameters of gait (e.g., stride and stepping frequency, stride and step length), gait speed and/or walking endurance.

Methodological quality

Two independent reviewers (IvdP and WE) assessed the methodological quality of each study using the PEDro scale[10,11] (Table 1). In the case of persistent disagreement, a third reviewer made the final decision after discussions with the primary reviewers. PEDro scores were used as a basis for best-evidence syntheses and to discuss the methodological strengths and weaknesses of the studies.

Quantitative analysis

Data contained in the abstract (numbers of patients in the experimental and control groups, mean difference in change score and standard deviation (SD) of the outcome scores in the experimental and control groups at baseline) were entered in Excel for Windows. If necessary, point estimates were derived from graphs presented in the article. Outcomes were pooled if the studies were comparable in terms of the type of intervention (i.e., lower limb strengthening, cardio-respiratory fitness or gait-oriented training), and if they assessed the same construct. Pooled SD_i was estimated using the baseline SDs of the control and experimental groups. The effect size g_i (Hedges' g) for individual studies was assessed by calculating the difference in mean changes between the experimental and control groups, divided by the pooled SD_i of the experimental and control groups at baseline[12]. If additional information was required, we contacted the authors or derived SDs from t- or F-statistics, p-values or post-intervention distributions.

Because g_i tends to overestimate the population effect size in studies with a small number of patients, a correction was applied to obtain an unbiased estimate: g_u (unbiased Hedges' g). The impact of sample size was addressed by estimating a weighting factor w_i for each study and applying greater weight to effect sizes from studies with larger samples, which resulted in smaller variances. Subsequently, g_u values of individual studies were averaged to obtain a weighted summarized effect size (SES), while the weights of each study were combined to estimate the variance of the SES[13]. SES was expressed as the number of standard deviation units (SDUs) and a confidence interval (CI). The fixed effects model was used to decide whether the SES was statistically significant. The homogeneity (or heterogeneity) test statistic (Q-statistic) of each set of effect sizes was examined to determine whether studies shared a common effect size from which the variance could be explained by sampling error alone[14,15]. Since the Q-statistic underestimates the heterogeneity in a meta-analysis, the percentage of total variation across the studies was calculated as I^2, which gives a better indication of the consistency between trials[16]. When significant heterogeneity was found (I^2 values > 50%)[16], a random effects model was applied[14]. For all outcome variables, the critical value for rejecting Ho was set at a level of 0.05 (two-tailed). Based on the classification by Cohen, effect sizes below 0.2 were classified as small, those from 0.2 to 0.8 as medium and those above 0.8 as large[15].

Best-evidence synthesis

A best-evidence synthesis was conducted if pooling was impossible due to differences in outcomes, intervention category and/or numbers of studies found. Using criteria based on the methodological quality score of the PEDro scale, we classified the studies as 'high-quality' (4 points or more) or 'low-quality' (3 points or less)[7]. Subsequently, studies were categorized into four levels of evidence, based on van Tulder et al.[17]

1) Strong evidence: provided by generally consistent findings in multiple, relevant, high-quality RCTs;
2) Moderate evidence: provided by generally consistent findings in one, relevant, high-quality RCT and one or more relevant low-quality RCTs;
3) Limited evidence: provided by generally consistent findings in one, relevant, high-quality RCT or in one or more relevant low-quality RCTs;
4) No or conflicting evidence: no RCTs are available or the results are conflicting.

If the number of studies that showed evidence was less than 50% of the total number of studies found within the same methodological quality category, this was regarded as no evidence[18].

Results

The initial search strategy identified 486 relevant citations. Based on title and abstract we excluded 440 studies, since, for example, studies were not randomized, used an intervention that not fitted within our definition, or the study was conducted in different patient population. Forty-six full-text articles were selected. Of these, three

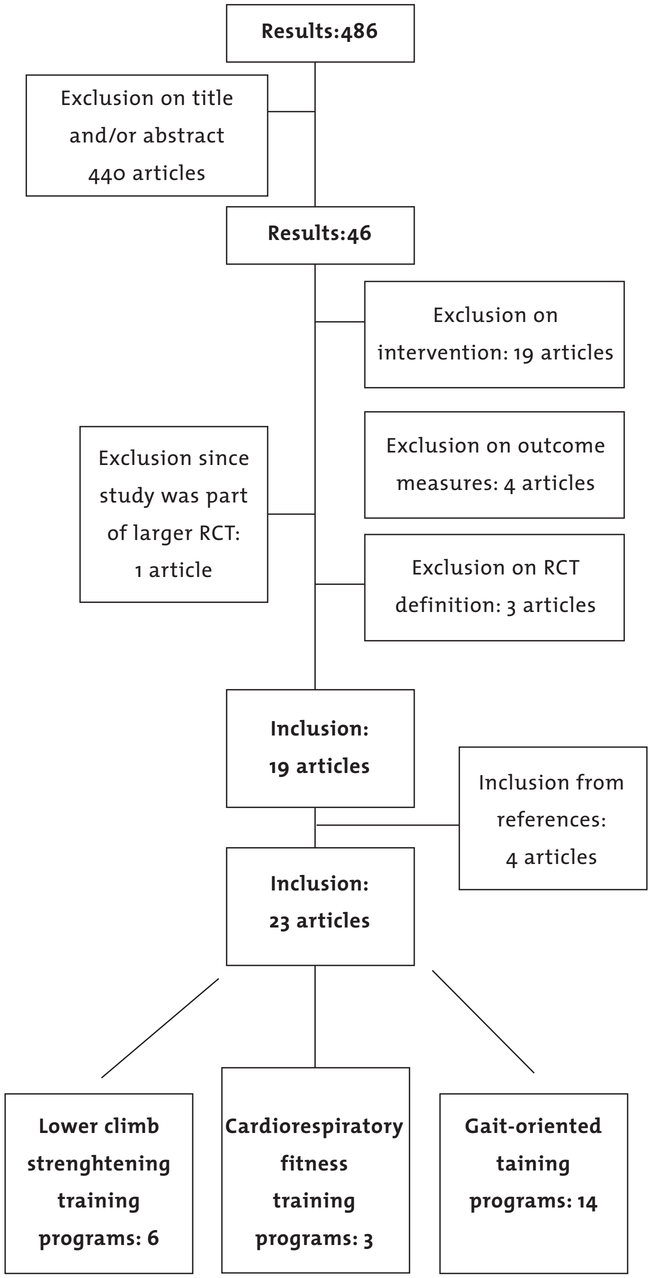
Table 1. The 11 items of the PEDro scale for methodological quality

1.	Eligibility criteria specified	Yes / No
2.	Random allocation	Yes / No
3.	Concealed allocation	Yes / No
4.	Baseline prognostic similarity	Yes / No
5.	Participant blinding	Yes / No
6.	Therapist blinding	Yes / No
7.	Outcome assessor blinding	Yes / No
8.	More than 85% follow-up for at least one primary outcome	Yes / No
9.	Intention-to-treat analysis	Yes / No
10.	Between- or within-group statistical analysis for at least one primary outcome	Yes / No
11.	Point estimates of variability given for at least one primary outcome	Yes / No

more were excluded since the studies were not RCTs[19-21] and four were excluded because the outcome measures did not reflect gait-related activities[22-24]. Another 19 studies were excluded because the intervention did not meet the criteria[25-44] and one study was excluded since it focused on a subgroup of a larger RCT[45]. Screening of references of the articles led to another four studies[46-49] being included. In total, 23 studies were included in the present systematic review (Figure 1).The selection included six RCTs that focused on strength training of the lower limb[46-48,50-52], three that concentrated on cardio-respiratory fitness[53-55] and 14 that targeted gait-oriented training[4,5,49,56-66]. Two RCTs concentrating on the effects of cardio-respiratory fitness employed the same population[53,54]. One of these[53] was used in our meta-analysis, while the second study was used to obtain additional information. Despite being a RCT, the study by Lindsley et al. was excluded because of lack of information[48]. Table 2 shows the main characteristics of the 21 studies included in the present meta-analysis.

The studies centered on lower limb strength training included 240 participants, of whom 121 were assigned to the intervention group. Sample sizes ranged from 20[46,47] to a maximum of 133 participants[51]. Time between stroke onset and the start of the intervention ranged from three months[46] to a mean of four years[47]. Studies focusing on cardio-respiratory fitness training included 104 participants, of whom 53 were assigned to the intervention group. Individual study sample sizes were 12[55] and 92 participants[53], respectively. Time between stroke onset and the start of the intervention ranged from a mean of 16 days[53] to more than one year[55]. The studies focusing on gait-related

Figure 1. Flow-chart included studies



training included 574 participants, of whom 332 were assigned to the intervention group. Individual sample sizes ranged from 9[58] to a maximum of 100 participants[4]. Time between stroke onset and the start of the intervention varied between eight days[65] to a mean of eight years[66].

Methodological quality

PEDro scores ranged from 4 to 8 points, with a median score of 7 (Table 3). All studies, except for one[46] specified the eligibility criteria. In no study was the therapist blind to group status. This was as expected, since the therapists had to conduct the therapy, therefore they cannot be blinded. All studies applied statistical analysis to group differences and reported point estimates and measures of variability. All studies, except the work by Glasser[46], Teixeira-Salmela[66], Dean[58] and Macko[63] and their colleagues, scored a minimum of 6 points. RCTs centered on lower limb strengthening scored a median of 7 points (range 4–8). The two RCTs focusing on cardio-respiratory fitness both scored 6 points[53]. A median of 7 points (range 4–8) was scored by RCTs targeting gait-oriented training.

Quantitative analysis

Pooling was possible for balance (4 RCTs, N=274)[4,5,49,59], gait speed (17 RCTs, N=692)[4,5,46,47,50,52,53,55,56,58,59,61-66] and walking distance (13 RCTs, N=743)[4,5,49-53,56-60,63]. Balance was determined by the Berg Balance Scale (BBS)[67] in all studies. Gait speed was measured over distances ranging from 5 to 30 meters[65]. Walking distance was assessed by the 2-minute[51] or 6-minute[4,5,49,52,56-60,68] walk test. Only Katz and colleagues[53] asked the patients to walk as far as they could.

One study on cardio-respiratory training[53] failed to report baseline SDs, so we used the SD of the post-intervention measurement to calculate g_i (Figures 2 and 3). Another study[59] on gait-oriented training did not provide baseline SDs either, so SDs were derived from p-values. The study by Richards and colleagues included two control groups. We decided to include the early control group (ECON) in our review, since the number of patients who completed this trial was larger than that in the other control group (CON)[65].

Lower limb strengthening

Four studies[46,47,50,52] targeting lower limb strengthening (N=107) measured gait speed. A heterogeneous non-significant SES was found compared to the control groups (SES [random] -0.13 SDU; CI -0.73 to 0.47; Z=-0.43, p=0.667, I^2=57.1%). Three studies (N=200)[50-52] determined walking distance and found a homogenous non-significant SES compared to control groups (SES [fixed] 0.00 SDU; CI -0.28 to 0.28; Z=0.02, p=0.98, I^2=21%).

Table 2. Characteristics of the studies included in the review

Study	N (E/C)	Time since stroke (mean days at inclusion)	Intervention
Lower Limb strengthening training			
Glasser 1986	20 (10/10)	3-6 months (137)	I: Therapeutic exercise programme based on neurophysiological and development theories and gait training + isokinetic training. C: Therapeutic exercise program based on neurophysiological and development theories and gait training.
Kim et al. 2001	20 (10/10)	> 6 months (1460)	I: Maximal concentric isokinetic strength training. C: Passive range of motion.
Bourbonnais et al. 2002	25 (12/13)	Chronic (1096)	I: Motor re-education program for the paretic lower limb, based on the use of a static dynamometer. C: Motor re-education program for the paretic upper limb, based on the use of a static dynamometer.
Moreland et al. 2003	106 (54/52)	< 6 months after stroke (38)	I: Conventional therapy + progressive resistance exercises performed with weights at the waist or on the lower extremities. C: Conventional therapy.
Ouellette et al. 2004	42 (21/21)	6 months to 6 years after stroke (874)	I: High-intensity resistance training program consisting of bilateral leg press, unilateral paretic and nonparetic knee extension, ankle dorsiflexion, and plantarflexion. C: bilateral range of motion and upper body flexibility exercises.
Cardio-respiratory training			
Katz et al. 2003	90 (46/44)	Subacute (16)	I: Regular therapy and leg cycle ergometer training. C: Conventional therapy.
Chu et al. 2004	12 (7/5)	> 1 year post stroke (1315)	I: Intervention group participating in a water-based exercise program that focused on leg exercise to improve inclusive cardiovascular fitness and gait speed. C: Arm and hand exercise while sitting.

Intensity	Outcome	Author's Conclusion
5 wks; 5 days a week; 2 hours a day	Functional Ambulation Profile (FAP), ambulation time	Differences in ambulation times and FAP scores were non-significant.
6 wks; 3 times a week; 45 min	Lower limb strength, gait speed, stair climbing speed, quality of life (SF36)	Intervention aimed at increasing strength did not result in differences in walking between groups.
6 wks; 3 times a week	Motor function (FM), finger-to-nose movements, gait speed, timed up-and-go, walking distance	Treatment of the lower limb produces an improvement in gait velocity and walking speed.
During rehabilitation (mean 8 wks); 3 times a week; 30 min	Disability (CMSA Disability Inventory), gait speed	Progressive resistance training was not effective compared to the same exercises without resistance.
12 wks; 3 times a week	Lower extremity muscle strength, peak muscle power, walking distance, stair climbing, chair rising, gait speed, functional limitation and disability (LLFDI), depression (GDS), quality of life (SIP)	Progressive resistance training safely improves lower limb strength in the paretic and non paretic limb and results in reductions in functional limitations and disabilities.
8 wks; first 2 wks: 5 times a week; 30 min; last 6 wks: 3 times a week; 30 min	Walking distance, gait speed, workload, exercise time	Stroke patients in the subacute stage improved some of their aerobic and functional abilities, including walking distance, after submaximal aerobic training.
8 wks; 3 times a week; 60 min	Gait speed, balance (BBS)	The experimental group attained significant improvement compared to the control group in cardiovascular fitness and gait speed.

Study	N (E/C)	Time since stroke (mean days at inclusion)	Intervention
Gait-oriented training			
Richards et al. 1993	27 (10/8/9)	Acute (about 10 days)	I: Intensive and focused approach incorporating the use of tilt table and limb-load monitor, resisted exercise with a Kinetron isokinetic device, and a treadmill. C1: started early and was as intensive as for the experimental group but included more traditional approaches to care (ECON) C2: therapy composed of similar techniques as provided to the other control group. This one started later, and was not as intensive (CON).
Duncan et al. 1998	20 (10/10)	Subacute (61)	I: Therapist-supervised home-based exercise program to improve strength, balance and endurance. C: Usual care.
Teixera-Salmela et al. 1999	13 (6/7)	>9 months (2799)	I: Program consisting of warm-up, aerobic exercises (graded walking plus stepping or cycling), lower extremity muscle strengthening, cooling down. C: No intervention.
Dean et al. 2000	12 (6/6)	> 3 months (658)	I: Circuit program including workstations designed to strengthen the muscles in the affected leg in a functional way and practicing locomotion-related tasks. C: Similar organization and delivery as the experimental group, except that it was designed to improve the function of the affected uppers limb.
Liston et al. 2000	18(10/8)		I: Treadmill retraining with the instruction to walk for as long as patients felt comfortable. C: Conventional physiotherapy.

Intensity	Outcome	Author's Conclusion
Exp: 5 wks; 10 times a week; 50 min ECON: 5 wks; 10 times a week; 50 min CON: 5 wks; 5 times a week; 40 min	Balance (FM-B), motor function (FM), ambulation (BI), balance (BBS), gait speed	Group results demonstrated that gait velocity was similar in the three groups.
12 wks; 3 times a week; 90 min	Motor function (FM), balance (BBS), gait speed, walking distance, ADL, instrumental ADL, quality of life	The experimental group showed greater improvement of neurological impairment and lower extremity function. Lower extremity scores and gait velocity were significantly different.
10 wks, 3 times a week; 60-90 min	Muscle strength and tone, level of physical activity (HAP), quality of life (NHP), gait speed	The combined program of muscle strengthening and physical conditioning resulted in gains in all measures of impairment and disability.
4 wk; 3 times a week; 60 min	Gait speed, walking distance, timed up-and-go, sit-to-stand, step test	This task-related circuit training improved locomotor function in chronic stroke. Walking distance, gait speed and the step test showed significant improvements between groups.
4 wks; 3 times a week; 60 min	Sit-to-stand, gait speed, balance, ADL, Nine Hole Peg test	Improvements were seen, but there were no statistically significant differences in gait between the conventional and treadmill re-training groups.

Study	N (E/C)	Time since stroke (mean days at inclusion)	Intervention
Laufer et al. 2001	25 (13/12)	< 90 days (34.2)	I: Physiotherapy treatment + ambulation on a motor-driven treadmill at comfortable walking speed. C: physiotherapy treatment + ambulation on floor surface at a comfortable speed using walking aids, assistance and resting periods as needed.
Pohl et al. 2002	60 (20/20/20)	> 4 weeks (114.6)	I1: Conventional physiotherapy + Limited Progressive Treadmill Training (LTT). I2: Conventional physiotherapy + Structured Speed-Dependent Treadmill Training (STT). C: Physiotherapeutic gait therapy based on the latest principles of proprioceptive neuromuscular facilitation and Bobath concepts.
Ada et al. 2003	27 (13/14)	6 months-5 years (822)	I: Both treadmill and overground walking, with the proportion of treadmill walking decreasing by 10% each week. C: Low-intensity, home exercise program consisting of exercises to lengthen and strengthen lower-limb muscles, and train balance and coordination.
Duncan et al. 2003	92 (44/48)	30-150 days (76)	I: Exercise program designed to improve strength and balance and to encourage more use of the affected extremity. C: Usual care.
Blennerhassett et al. 2004	30 (15/15)	Subacute (43)	I: Mobility-related group activities including endurance tasks and functional tasks. C: Upper limb group activities including functional tasks.

Intensity	Outcome	Author's Conclusion
3 wks, 5 times a week; 8-20 min	Standing balance, functional mobility (FAC), gait speed, gait cycle	Treadmill training may be more effective than conventional gait training in improving gait parameters such as functional ambulation, stride length, percentage of paretic single stance period and gastrocnemius muscular activity.
4 wks, 12 sessions; 30 min	Gait speed, cadence, stride length, functional mobility (FAC)	Structured STT in post-stroke patients resulted in better walking abilities than LTT or conventional physiotherapy.
4 wks; 3 times at week; 30 min	Gait speed, step length and width, cadence, quality of life (SA-SIP30)	The intervention program significantly increased walking speed and walking capacity compared with the control group.
12 wks; 3 times a week; 90 min	Lower extremity muscle and grip strength, motor function (FM), upper extremity function, balance (BBS), endurance, gait speed, walking distance	This structured, progressive exercise program produced gains in endurance, balance and mobility beyond those attributable to spontaneous recovery and usual care.
4 wks; 5 times a week; 60 min	Upper limb function (MAS, JTHFT), step test, timed up-and-go, walking distance	Findings support the use of additional task-related practice during inpatient stroke rehabilitation. The mobility group showed significantly better locomotor ability than the upper limb group.

Study	N (E/C)	Time since stroke (mean days at inclusion)	Intervention
Eich et al. 2004	50 (25/25)	<6 weeks (44)	I: Individual physiotherapy Bobath-oriented + treadmill training. C: Individual physiotherapy, Bobath-oriented.
Salbach et al. 2004	91 (44/47)	Chronic (228)	I: Ten functional tasks designed to strengthen the lower extremities and enhance walking balance, speed and distance. C: Upper extremity activities.
Macko et al. 2005	61 (32/29)	> 6 months after stroke (1125)	I: Progressive task-oriented modality to optimize locomotor relearning, providing cardiovascular conditioning. C: Conventional therapy.
Pang et al. 2005	63 (32/31)	> 1 year (1881)	I: Progressive fitness and mobility exercise program designed to improve cardio-respiratory fitness, balance, leg muscle strength and mobility. C: Seated upper extremity program.

E/C=experimental vs. control group; I=intervention group; C=control group; ECON=early control group; wks=weeks; min=minutes; FAP=Functional Ambulation Profile, SF36= Social Functioning 36, FM=Fugl Meyer; BBS=Berg Balance Scale, FM-B=Fugl Meyer balance, CMSA=Chedoke-McMaster Stroke Assessment, LLFDI= Late Life Function and Disability Instrument, GDS= Geriatric Depression Scale, SIP= Sickness Impact Profile, BI=Barthel Index,

Cardio-respiratory fitness training

Two studies involving cardio-respiratory training[53,55] (N=104) assessed gait speed. A homogeneous non-significant SES was found compared to control groups (SES [fixed] 0.36 SDU; CI -0.03 to 0.75; Z=1.83, p=0.07, I^2=0%).
Since only one study analyzed the effect of cardio-respiratory training on balance[55] and one on walking distance[53] these results are described in the best evidence syntheses.

Gait-oriented training

Four studies assessed balance after gait-oriented training[4,5,49,59] and found a homogenous non-significant SES (SES [fixed] 0.19 SDU; CI –0.05 to 0.43; Z=1.59, p=0.11, I2=0%). Twelve studies centered on gait-oriented training (N=501)[4,5,56,58,59-66] evaluated gait speed and found

Intensity	Outcome	Author's Conclusion
6 wks; 5 times a week; 60 min	Gait speed, walking distance, gross motor function (RGMF), walking quality	Addition of aerobic treadmill training to Bobath-oriented physiotherapy resulted in significant improvement in gait speed and walking distance.
6 wks; 3 times a week	Timed up-and-go, balance (BBS), gait speed, walking distance	The task-oriented intervention significantly improved gait speed and walking distance.
6 months; 3 times a week; 40 min	Gait speed, walking distance, endurance, functional mobility (RMI), Walking Impairment Questionnaire (WIQ)	Both functional mobility and cardio-vascular fitness improved more after the intervention than after conventional care.
19 wks; 3 times a week; 60 min	Muscle strength, balance (BBS), endurance, walking distance, physical activity (PAS)	The intervention group had significantly greater gains in cardio-respiratory fitness, mobility and paretic leg strength.

HAP= Human Activity Profile, NHP=Notthingham Health Profile, SA-SIP30= Stroke Adapted-Sickness Impact Profile 30; MAS=Modified Ashworth Scale; JTHFT=Jebsen Taylor Hand Function Test, RGMF=Rivermead Gross Motor Function, RMI=Rivermead Mobility Index, WIQ=Walking Impairment Questionnaire, PAS=Physical Activity Scale

a homogenous significant SES (SES [fixed] 0.45 SDU; CI 0.27 to 0.63; Z=4.84, $p<0.01$, I^2=31.3%). In addition, nine studies (N=451)[4,5,49,56-60,63] assessed the effect of gait-oriented training on walking distance. A heterogeneous significant SES was found compared to the control groups (SES [random] 0.62 SDU; CI 0.30 to 0.95; Z=3.73, $p<0.01$, I^2=61.2%).

Best evidence syntheses

Lower limb strengthening

Two high-quality studies on lower limb strengthening[47,52] selected stair climbing as a secondary outcome measure. Although they used different measures to determine stair climbing performance, both studies concluded that changes in stair climbing did not

Table 3. **PEDro scores for each RCT**

Study	1	2	3	4	5	6	7	8	9	10	11	Total score
Lower limb strengthening training												
Glasser 1986	No	1	0	0	0	0	0	1	0	1	1	4
Kim et al. 2001	Yes	1	0	1	1	0	1	1	1	1	1	8
Bourbonnais et al. 2002	Yes	1	1	1	0	0	0	1	0	1	1	6
Moreland et al. 2003	Yes	1	1	1	0	0	1	1	1	1	1	8
Ouellette et al. 2004	Yes	1	0	1	0	0	1	1	1	1	1	7
Cardio-respiratory fitness training												
Katz et al. 2003	Yes	1	0	1	0	0	1	1	0	1	1	6
Chu et al. 2004	Yes	1	0	1	0	0	1	1	0	1	1	6
Gait-oriented training												
Richards et al. 1993	Yes	1	0	1	0	0	1	1	0	1	1	6
Duncan et al. 1998	Yes	1	1	1	0	0	0	1	1	1	1	7
Teixera et al. 1999	Yes	1	0	0	0	0	0	1	0	1	1	4
Dean et al. 2000	Yes	1	1	0	0	0	0	0	0	1	1	4
Liston et al. 2000	Yes	1	0	1	0	0	1	1	1	1	1	7
Laufer et al. 2001	Yes	1	0	1	0	0	1	1	0	1	1	6
Pohl et al. 2002	Yes	1	0	1	0	0	1	1	0	1	1	6
Ada et al. 2003	Yes	1	1	1	0	0	1	1	1	1	1	8
Duncan et al. 2003	Yes	1	1	1	0	0	1	1	1	1	1	8
Blennerhassett et al. 2004	Yes	1	1	1	0	0	1	1	1	1	1	8
Eich et al. 2004	Yes	1	1	1	0	0	1	1	1	1	1	8
Salbach et al. 2004	Yes	1	1	1	0	0	1	1	1	1	1	8
Macko et al. 2005	Yes	1	1	1	0	0	0	0	0	1	1	5
Pang et al. 2005	Yes	1	1	1	0	0	1	1	1	1	1	8

significantly differ between the experimental and control groups. One study also evaluated health-related quality of life (HRQoL) by means of the Short Form-36 (SF-36), and concluded that there was no significant difference between the groups[47]. These findings provide strong evidence that programs focusing on lower limb strengthening do not produce greater improvement in stair climbing ability than conventional care. Moreover, there was limited evidence that programs of lower limb strengthening are not superior to conventional care in improving HRQoL.

Cardio-respiratory fitness training

There is limited evidence that cardio-respiratory training negatively affects balance[55] and limited evidence for a positive impact of cardio-respiratory training on walking distance[53]. One high-quality study[53] on cardio-respiratory fitness training also assessed stair climbing by asking the patients to climb as many stairs as possible at comfortable speed. The experimental group performed significantly better than the control group, suggesting limited evidence in favor of cardio-respiratory training for improving stair climbing.

Gait-oriented training

Standing balance showed no statistically significant differences between control and experimental groups in two high-quality studies focusing on gait-oriented training [61,62]. Two high-quality studies, however, presented statistically significant differences between groups on the Functional Ambulation Category[61,64], whereas another high-quality study failed to find significant results in favor of gait-oriented training on the Rivermead Mobility Index[63]. The high-quality studies also found no significant effects of gait-oriented training on outcomes such as ADL[59,62,65], instrumental ADL[4,62] or HRQoL of life[56,59], although one low-quality study did find significant differences in quality of life between groups[66]. Finally, one high-quality study concluded that there were no significant differences on walking quality between the control and experimental groups[60].

The above findings provide strong evidence that standing balance, ADL, IADL or quality of life are not significantly more improved by gait-oriented training than by conventional care. Strong evidence was found for improved functional mobility after gait-oriented training, whereas limited evidence was found that there is no effect of gait-oriented training on walking quality.

Figure 2. **Summarized effect size of gait speed**

Lower limb strengthening training			
Glasser 1986	N=20	-0.11	[-0.50-0.28]
Kim 2001	N=20	-0.19	[-0.58-0.20]
Bourbonnais 2002	N=25	0.64	[0.31-0.96]
Quelette 2004	N=42	-0.74	[-0.93--0.54]
S.E.S. (random effects model)	**N=107**	**-0.13**	**[-0.73-0.47]**
Cardio-respiratory training			
Katz 2003b	N=92	0.35	[0.26-0.44]
Chu 2004	N=12	0.47	[-0.21-1.15]
S.E.S. (fixed effects model)	**N=104**	**0.36**	**[-0.03-0.75]**
Gait oriented training			
Richards 1993	N=27	0.00	[-0.33-0.33]
Duncan 1998	N=20	0.78	[0.37-1.19]
Teixera-Salmela 1999	N=13	0.70	[0.07-1.33]
Dean 2000	N=9	0.14	[-0.75-1.02]
Liston 2000	N=18	-0.14	[-0.58-0.31]
Laufer 2001	N=25	0.83	[0.49-1.15]
Pohl I 2002	N=30	0.61	[0.31-0.91]
Pohl II 2002	N=30	1.94	[1.59-2.30]
Ada 2003	N=27	0.50	[0.20-0.79]
Duncan 2003	N=100	0.23	[0.15-0.31]
Eich 2004	N=50	0.75	[0.59-0.91]
Salbach 2004	N=91	0.31	[0.22-0.40]
Macko 2005	N=61	0.30	[0.17-0.43]
S.E.S. (fixed effects model)	**N=501**	**0.45**	**[0.27-0.63]**

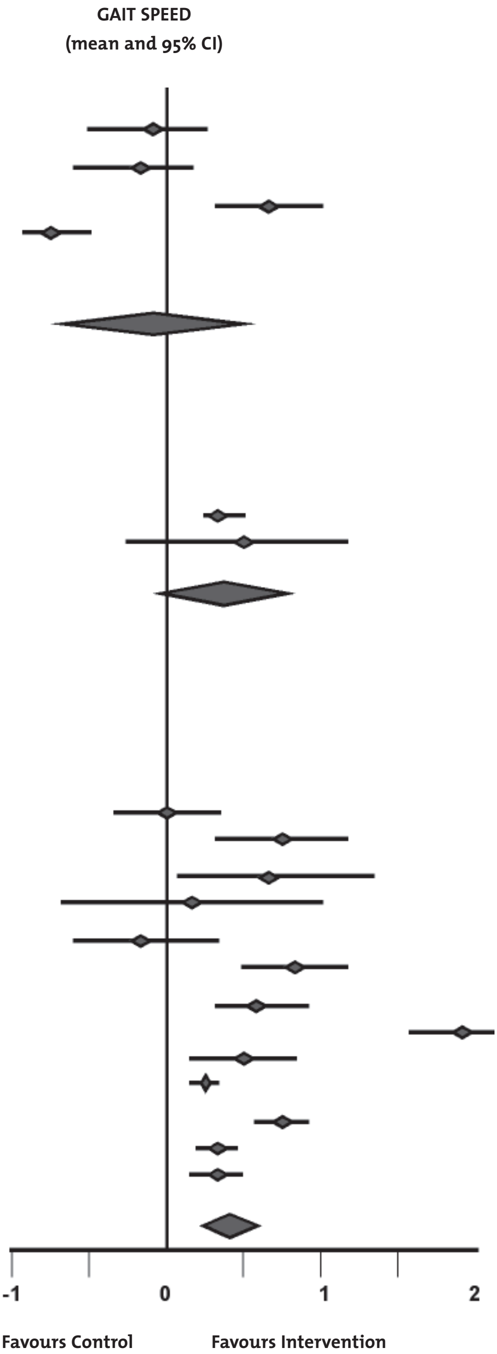
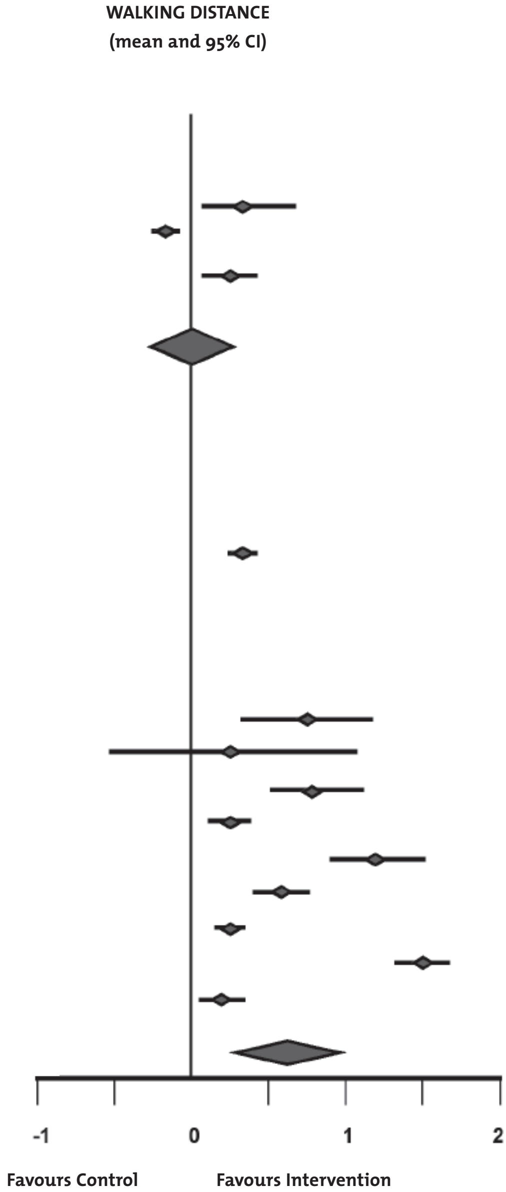


Figure 3. Summarized effect size of walking distance

Lower limb strengthening training			
Bourbonnais 2002	N=25	0.36	[0.04-0.68]
Moreland 2003	N=133	-0.14	[-0.20--0.08]
Quelette 2004	N=42	0.25	[0.06-0.44]
S.E.S. (fixed effects model)	**N=200**	**0.00**	**[-0.28-0.28]**
Cardio-respiratory training			
Katz 2003b	N=92	0.32	[0.23-0.41]
Gait oriented training			
Duncan 1998	N=20	0.73	[0.32-1.14]
Dean 2000	N=9	0.24	[-0.65-1.12]
Ada 2003	N=27	0.79	[0.49-1.10]
Duncan 2003	N=100	0.28	[0.20-0.36]
Blennerhassett 2004	N=30	1.30	[1.02-1.59]
Eich 2004	N=50	0.62	[0.46-0.78]
Salbach 2004	N=91	0.27	[0.18-0.36]
Macko 2005	N=61	1.51	[1.37-1.66]
Pang 2005	N=63	0.19	[0.07-0.32]
S.E.S. (random effects model)	**N=451**	**0.62**	**[0.30-0.95]**



Discussion

This systematic review included 21 high-quality RCTs. The results showed positive, significant effects of gait-oriented training on gait speed and walking distance, whereas no significant effects were found on balance control as measured by the BBS. Although there is evidence that the BBS is a responsive tool[69] there is some discussion about the clinical implication of the changes assessed by the BBS[70]. The significant SES for gait-oriented training programs corresponds to a mean improvement of 0.14m/s for gait speed and 41.2 m on the 6-minute walk test. The small number of studies that evaluated cardio-respiratory fitness training using non-functional approaches, by means of leg cycle ergometers and water-based exercises, also found positive effects on gait speed. In contrast, programs focusing on lower limb strengthening alone failed to show significant effects on gait speed and walking distance.

In agreement with the above findings, a best-evidence synthesis showed that lower limb strength training did not affect outcomes such as stair climbing or HRQoL, whereas strong evidence was found for a favorable effect of cardio-respiratory training on stair climbing performance. In addition, there is some evidence that cardio-respiratory training negatively affects balance[55] and has a positive impact on walking distance[53]. Finally, strong evidence was found that balance, ADL, IADL or HRQoL were not significantly affected by gait-oriented training, although functional mobility was positively impacted. However, these conclusions need to be interpreted with some caution, since the authors used ordinal scales to assess balance and ADL which they treated as continuous scales, reporting means and CI's.

The main finding of the present review is that programs focusing on cardio-respiratory and gait-oriented training are more beneficial in improving walking competency than programs centered on strengthening. This finding supports the general view of motor learning that exercise regimens mainly induce specific treatment effects, suggesting that gait and gait-related activities should be directly targeted. In other words, the training programs need to focus primarily on the relearning of functional gait-related skills that are relevant to the individual patient's needs[7,71]. Since gait speed over a short distance overestimates walking distance in a 6 minute walk test[72], one should realize that improving gait speed does not automatically result in improvements in walking distance. This underlines the fact that training should be task-specific. The lack of evidence to support the relationship between strength gains and improvements in walking ability[47,64] also suggests that, despite the significant improvement in strength, therapy-induced improvements do not automatically generalize to significant gains in gait performance[47,52,73].

The mechanisms underlying therapy-induced improvements in gait performance are not yet well understood. Recent electroneurophysiological studies in which the EMG activity of the paretic muscles was serially recorded[45] and studies recording improvements in standing balance[74,75] have shown that task-related improvements were poorly related to physiological gains on the paretic side. Closer associations have been found with compensatory adaptive changes on the non-paretic side, such as increased anticipatory activation of muscles of the non-paretic leg[75], strategies using increased weight-bearing above the non-paretic leg while standing[74] or stride lengthening of the non-paretic leg[32] while walking. In other words, there is growing evidence that functional improvements are closely related to the use of compensatory movement strategies in which patients learn to adapt to existing impairments[45]. Since it is still unclear which compensatory characteristics are most closely related to gains in walking competency, longitudinal kinematic and neurophysiologic studies are needed for a better understanding of the underlying mechanisms of functional improvement.

Although only two studies focusing on the effect of cardio-respiratory fitness interventions (without walking) on gait speed could be included, a positive effect on walking speed was found, however this effect was not statistically significant. This is in accordance with the Cochrane review of Saunders and colleagues[3]. The only study that assessed the effect of cardio-respiratory training on walking distance, showed that cardio-respiratory training was beneficial in improving distance walked[53]. These results are in agreement with the findings in the recently conducted review of Pang[76]. Obviously, improving aerobic capacity as a reflection of physical condition is an important factor in restoring walking competency, since it has been suggested that the energy costs of walking are substantially higher in people with stroke than in normal individuals[77]. These high energy demands are frequently associated with less efficient motor control in hemiplegic compared to healthy subjects, resulting from the use of compensatory or adaptive movement strategies to perform functional tasks such as walking[77,78]. Energy expenditure required to perform routine ambulation is increased approximately 1.5- to 2.0-fold in hemiparetic stroke patients compared to normal control subjects[79]. The lower walking speeds observed in patients with hemiparesis (30 m/min) consume approximately the same amount of oxygen (10 ml/kg/min)[80] as healthy people require when walking approximately twice as fast (i.e., 60 m/min)[81]. However, the number of studies investigating energy expenditure after stroke is limited.

The present review also suggests that enhancing walking endurance by improving physical condition seems to be less specific, since progressive bicycling programs resulted in significant gains in walking endurance[45]. Progression in training programs seems to be an important aspect of improving walking endurance[5]. The fact that balance is also improved by cardio-respiratory training might also suggest that it would be beneficial in improving gait speed and walking distance, since balance is highly related to independent gait[53,82]. However, more RCTs are needed to allow conclusions on the effects of non-specific cardio-respiratory training on walking competence.

Further improvement of stroke rehabilitation could be achieved by identifying which patients benefit most from supervised[83] physical fitness training programs. Salbach et al. indicated that most effects were gained in the group of patients with a moderate walking deficit[5]. Another study suggested that persons with severe depressive symptoms may be particularly responsive to therapeutic intervention[22]. Recently, Lai and co-workers concluded that depressive symptoms do not restrict gains in functional outcome as a result of physical exercise. They also suggested that exercise may help reduce post-stroke depressive symptoms[84]. Recently, we found that the presence of depressive symptoms, fatigue, reduced cognitive status and an inactive lifestyle are important factors related to a gradual decline in mobility over time[85]. In other words, these variables can be used to identify those patients who are at risk for mobility decline, since function-oriented training is effective in improving walking competency. The moment at which these gait-oriented treatments are introduced seems not to be restricted to a particular phase after stroke or a particular type of stroke.
Although this systematic review aimed at identifying all relevant trials, the study was subject to certain limitations. Firstly, the review did not include papers written in languages other than English, German or Dutch, or studies focusing on body weight support treadmill training programs. In addition, the definitions of strengthening, cardio-respiratory fitness and gait-oriented training we used were arbitrary.

Conclusion

This review shows that gait-oriented training, targeting improved strength and cardio-respiratory fitness is the most successful method to improve gait speed and endurance. This is an important finding for clinical practice, since about 20% of all chronic stroke patients show a significant decline in mobility status in the long run. Future studies should elucidate whether a functional training program can improve walking competency in patients who are susceptible to a decline in mobility such as the very old, those severely compromised and those who are depressed. In addition, current debate is concentrating on whether the critical variable for therapeutic efficacy is task-specificity or the intensity of the effort involved in therapeutic activities (increased volume, increased level of participation, increased intensity)[86], aspects which need further investigation. Future studies should establish whether the improvements in gait speed and walking distance that have been described are of clinical relevance for independent community ambulation. In addition, the long-term effects of these training interventions need to be investigated.

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