ORIGINAL REPORT

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HIGH-INTENSITY ARM RESISTANCE TRAINING DOES NOT LEAD TO BETTER OUTCOMES THAN LOW-INTENSITY RESISTANCE TRAINING IN PATIENTS AFTER SUBACUTE STROKE: A RANDOMIZED CONTROLLED TRIAL

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Objective: To describe the effects of 2 levels of intensity of arm resistance training on grip strength, arm function, activities, participation, and adverse events in patients with subacute stroke.

Design: A randomized controlled and preregistered trial with concealed allocation, assessor blinding and intention-to-treat analysis.

Patients: Patients with subacute stroke and upper extremity hemiparesis.

Methods: After randomization the experimental group received a 3-week high-intensity arm resistance training (HIT). The control group completed a 3-week low-intensity arm resistance training (LIT). The primary outcome was grip strength. Secondary outcomes included the Motricity Index, Fugl-Meyer Assessment for the upper limb, Box and Block Test, Goal Attainment Scale, Modified Ashworth Scale, and adverse events. All outcomes were assessed at baseline and after 3 weeks of intervention.

Results: A total of 43 patients were investigated (HIT, *n* = 23; LIT, *n* = 20). All primary and secondary outcomes improved after the 3-week training, but no significant between-group differences were found. Adverse events occurred in 5% of training sessions (19/369).

Conclusion: The results of this study did not show differential effects on any outcome of 2 forms of arm resistance training in patients with subacute stroke.

Key words: upper limb; rehabilitation; resistance training; strength training; stroke.

LAY ABSTRACT

The aim of this study was to describe the effects of 2 levels of intensity of arm resistance training to improve grip strength, arm function, activities, participation, and adverse events in patients with subacute stroke. Patients were randomized after a stroke to either a 3-week high-intensity arm resistance training (HIT) or a 3-week low-intensity arm resistance training (LIT). The following measurements were performed: grip strength, Motricity Index, Fugl-Meyer Assessment for the upper limb, Box and Block Test, Goal Attainment Scale, Modified Ashworth Scale, and adverse events before and after 3 weeks of training. A total of 43 patients were included. No significant differences were found between groups. Neither the HIT nor the LIT led to an increase in spasticity. The results did not show differential effects of different arm resistance training intensities on any outcome in patients with subacute stroke.

after stroke, 3) to reduce or prevent the need for care due to the loss of arm function. Resistance training is a well-known intervention in rehabilitation to preserve or improve muscle strength and is recommended in current guidelines for patients after stroke, such as the recommendations of the American College of Sports Medicine (4). Resistance training is characterized by a large resistance, a small-to-moderate number of repetitions, and requires progression of training (4).

Weakness after stroke is caused by changes in neural and muscular structures (5, 6). Non-use of muscles leads to alterations in muscle structure, such as muscle atrophy (7). To prevent such adaptations after stroke resistance training can be used, e.g. to improve arm muscle strength (8, 9).

Resistance training increased strength (8) and arm function (10) in patients with chronic stroke (at least 6 months after stroke, (3)). In patients with subacute stroke, however, only a few studies investigated resistance training compared with other active interventions (11, 12). One study examined a resistance training that only increased the number of repetitions instead of increasing the weight. This resistance training was compared with a functional training, and the authors found that no intervention was superior (12). Another clinical phase II trial found functional improvements through resistance training, which would justify future studies (11).

Impaired arm and hand function occurs in 48% of patients within 72 h after stroke (1). Impaired function was associated with a longer stay in acute care and a lower chance of discharge directly home (1). Arm impairments often persist after discharge from the rehabilitation hospital, so that 41% of stroke survivors need help with daily activities and 20% require care from relatives or friends (2). Therefore, a specific and effective therapy is needed that can be used for patients with subacute stroke (1 week up to 6 months

A systematic review investigating progressive resistance training with high intensities (according to recommendations of the American College of Sports Medicine (4)) found only 2 trials targeting the upper extremity (8). Here, a large effect on strength could be found only in studies comparing resistance training with no intervention or placebo. The authors of this review summarized that there were not enough studies investigating arm resistance training. Therefore, it is uncertain whether it is effective to improve arm function or the level of activity (8). Another systematic review found no increase in side-effects after arm resistance training in patients after subacute stroke, but the authors state that side-effects were insufficiently reported in the included studies (13).

To date there has been little research published in the peer-reviewed literature about the effects and adverse events of upper extremity strength training in patients with subacute stroke. There seems to be no published research on a direct comparison of 2 arm resistance training programmes with different intensities.

Therefore, the aim of this study was to investigate the effects of HIT compared with a LIT. The hypothesis for this study was that HIT might improve grip strength, arm function, activities, and participation more than arm resistance training with lower intensity in patients with subacute stroke.

METHODS

Study design

An assessor-blinded, parallel-group, single-centre randomized controlled trial (RCT) with concealed allocation of patients with upper limb paresis after stroke was conducted.

This study was carried out according to the principles of the Declaration of Helsinki and with ethical approval from the local ethics commission (*Universitätsmedizin Göttingen* 405 Germany, 23/3/17). The study was registered before publication (German Register of Clinical Trials, DRKS00012484). The protocol of this study has been published (14). The Consolidated Standards of Reporting Trials guidelines (CONSORT (15)) were followed to conduct this study and to write the manuscript.

A random number generator was used to create a random sequence list. Allocation to groups was concealed with numbered, opaque, sealed envelopes with sequential numbering. An independent person randomly assigned each participant to one of two intervention groups, the LIT group or the HIT group. The persons who assessed eligibility, obtained informed consent, and enrolled patients in the trial (SH, CH) had no knowledge of group assignment. After recruitment and after the baseline assessment the envelopes were opened, and the randomization information was given to the treating therapists.

Patients and setting

All patients admitted to our neurological rehabilitation hospital were screened for admission to the study. Patients who met the following criteria, as previously described, were recruited (14):

Inclusion criteria:
- diagnosis of stroke confirmed by a neurologist;
- in subacute phase (within 3 months) after stroke;
- older than 18 years;
- Barthel Index (BI, 16) of at least 30 points;
- ability to sit freely for 30 s;
- ability to lift the affected hand from their lap to a desk in front of them;
- Medical Research Council Scores (17) from 2 to 4 points for shoulder abduction, elbow flexion, and finger flexion;
- passive range of motion (ROM) allowing touch of fingertips and thumb, submaximal finger extension, at least 90° of shoulder abduction and flexion, 90° of elbow flexion, 30° of wrist extension, and 30° between pronation and supination; and
- Apraxia Screen of TULIA Score (18) of 5 or more.

Exclusion criteria:
- 4 or 5 points on the Modified Ashworth Scale (16);
- more than 5 points on a pain rating scale at rest;
- manifest heart diseases, such as cardiac insufficiency (>New York Heart Association Stage 1), angina pectoris, myocardial infarction within 120 days before recruitment, cardiomyopathy, hypertonia (European Society of Hypertension, grade 2, 19), or severe cardiac arrhythmia;
- inflammation or infection with fever;
- myopathy (e.g. muscular dystrophy, myasthenia gravis, or myotonia).

Measures and outcomes

According to the study protocol (14) the primary efficacy end-point was grip strength. We measured grip strength in kg in a standardized testing position (seating position, shoulder adducted and neutrally rotated, elbow flexed at 90°, forearm in neutral position (20)) using a hand-held dynamometer. Measuring grip strength is simple, time-saving, associated with activities of daily living, and has a high predictive value for arm recovery. Therefore, grip strength of the affected hand was our primary outcome assessment. A change of 5 kg was considered clinically meaningful in the first 2 weeks after stroke (21).

Secondary outcomes were:
- muscle strength of the upper limb (shoulder, elbow, and wrist) using the Motricity Index with a score range of 0–100;
- Fugl-Meyer Assessment for the upper limb with a score range of 0–66, to measure sensorimotor impairments and recovery of arm function (16); 9 points on the 66-point subscale is the minimal clinically important difference score in patients with subacute stroke (22);
- dexterity of the affected arm using the Box and Block Test with 0–150 cubes per min (23);
- Goal Attainment Scale with a score range from –2 to +2 as a scale to measure participation allowing standardized evaluation of individual goals with the patient (24);
- muscle hypertonia using the Modified Ashworth Scale with score range of 0–5 (4).

All these measurements are frequently used in rehabilitation research and clinical practice dealing with patients who have had a stroke (16).

During the training, heart rate and rating of perceived exertion were monitored according to Borg's 20-point scale (25) using a standardized procedure. After each intervention, the treating physiotherapist recorded the presence of pain, muscle soreness, and any other adverse events (14) in a standardized interview. Pain was measured with the 11-point numeric rating

scale. During the intervention phase and at the final assessment, the following parameters were systematically recorded: cardiovascular or cerebrovascular events, referral to an acute hospital, and death (14).

All assessments were administered by trained, experienced therapists. baseline measures were collected prior to randomization (t_0). After the 3-week intervention period, the training ceased and outcome measures were collected (t_1).

Intervention

Experimental group. Patients in the HIT group received arm resistance training on 3 afternoons per week for a duration of 3 weeks in addition to standard treatment.

Each training session lasted 60 min. The additional training programme contained 5 standardized exercises arranged in a circle. The training included unilateral, active, and functional exercises performed in a sitting position:

- lifting objects from the lap to a high desk;
- pulling a resistance band from the forehead to the lap;
- pulling a mineral-water crate on a desk from the unaffected to the affected side;
- lifting objects over a block of wood with the elbow resting on the table (as in arm wrestling); and
- pulling a laundry bag lying on an exercise mat with a rowing motion.

The objects used for training were water bottles and water canisters with different weights (0.25, 0.5, 1, 1.5, 2, 2.5, 3, 4, 5 kg). The laundry bag was also filled with water bottles. The workload in the HIT group was 80% of 1RM (Appendix I), examined at the beginning of the first training session. Participants performed 3 sets of 10 repetitions of each exercise. In the first training, the participants were asked to perform the exercises without weight to determine the maximum ROM. Patients were encouraged to achieve or increase the full ROM with each movement. For each exercise, a 1 repetition maximum (1RM) was determined for these maximum ROMs. The resistance was gradually increased after the participants were able to perform 15 repetitions (Appendix I). The resting period was 120 s after each exercise and set. During this time, the participants changed to the next exercise place, so 2 or 3 persons could train at the same time. Qualified and instructed therapists led the training. The therapists had to guide and motivate the participants without active intervention in the exercise (hands-off), except in the case of imminent danger. If it was not possible to grasp the objects, a wrist cuff could be used to support grasping. The therapists documented ROMs, repetitions, and intensities for each exercise in each session.

Control group. Patients in the LIT group performed the same exercises (A–E) in addition to standard treatment, but with a workload of 40% of 1RM (Appendix II). Training duration, frequency, and treatment time were the same as in the experimental group. Participants did 3 sets of each exercise with increasing repetition numbers at each training session (Appendix II). In the first training session, they performed 10 repetitions, followed by one more in each later training session, adding up to 18 repetitions in the final 9th session. The weight was not changed.

Standard treatment

The standard arm rehabilitation included 30 min of physiotherapy and occupational therapy 3 times a week with mobilization exercises, stretching, positioning, functional training, strengthening exercises, and activity training. The participants also received group therapy. The content and duration of these therapies were recorded in intervention protocols.

Statistical analyses

Descriptive and inference statistics were used dependent on type of test and data distribution. The global α level was set at 0.05.

The sample size calculation (14) was based on the study of da Silva et al. (26). We assumed a mean group difference of 10 kg in the intervention and a mean difference of 8 kg in the control group with a standard deviation of 3 kg. An α level of 5% and a statistical power of 80% (beta=20%) using a 2-sample t-test for mean differences were assumed. For the sample size calculation, the power and sample size programme "G*Power (3.1.9.2)" was used. According to this programme, 37 patients were needed per study arm. Due to the expected drop-out rate of 5%, 2 additional patients were supposed to be enrolled per study arm, giving a total of 78 patients.

Both intention-to-treat and per-protocol analyses were conducted, with the intention-to-treat analysis being always the primary analysis for the primary and secondary outcomes. Our descriptive statistics include means and standard deviation (SD) for continuous variables, and the numbers and proportions for categorical variables, as appropriate. The 2 intervention groups were compared at baseline regarding characteristics and demographics, using 2-tailed Student's t-tests or Fisher's exact tests, as appropriate. To avoid multiplicity, we used a Bonferroni alpha adjustment for multiple comparisons.

A minimum difference of 5 kg of the grip strength was considered clinically important (21).

RESULTS

A total of 846 patients were screened for eligibility in our inpatient rehabilitation centre from May 2017 to April 2018 (Fig. 1; CONSORT flow chart). Of these, 43 participants fulfilled the eligibility criteria for this pilot study. Twenty-three patients were randomly allocated to the HIT group and 20 to the LIT group. One patient dropped out of the HIT group after the intervention started due to pain during training.

At study onset, groups did not differ in baseline variables (Table I). The median time since stroke was 24 days in both groups. Most participants had moderate impairments (BI 35–80 points, 78% of the HIT group and 70% of the LIT group) and one had severe impairments (BI 0–30 points). Twenty-six percent of the HIT group and 20% of the LIT group had had a previous stroke. All demographic and clinical characteristics at study onset in our post-acute rehabilitation (t_0) are shown in Table I.

Adherence to the study protocol

The interventions were conducted as allocated, with 9 training sessions during the rehabilitation period being completed by 83% of the experimental group (19/23) and 90% of the control group (18/20). Five participants were discharged before they had received all training

units and one of the HIT group dropped out. All prospectively registered primary and secondary outcomes were reported and all assessors were successfully blinded during the study. Due to the unexpectedly low recruitment rate, it was not possible to recruit sufficient patients ($n=43$ instead of $n=78$) within the fixed study period of 12 months, which deviated from our a priori sample size calculation. Thus, the trial did not achieve the originally planned number of participants. The data for 43 participants, however, was analysed as intended to treat.

Primary outcome: grip strength

After 3 weeks of arm training both the experimental and control group showed improved grip strength (Table II). The improvement of grip strength in the HIT group was greater in comparison with the LIT group, even though grip strength did not differ between the experimental and control groups (HIT group mean difference 4.8 kg (SD 6.2 kg) vs. LIT group mean difference 3.5 kg (SD 4.8 kg); $p=0.48$). Thirty-nine percent of the HIT group (9/23) and 30% of the LIT group (6/20) achieved an increased grip strength of at least 5 kg, which corresponds to the minimal clinically important difference. Again, there was no significant group difference ($\chi^2(1)=0.393$; $p=0.53$).

Table I. Baseline characteristics

	HIT (n = 23)	LIT (n = 20)	p-value
Age, years, mean (SD)	63 (14)	70 (11)	0.08[a]
Sex, % (n)			0.10[c]
Male	70 (16)	45 (9)	
Female	30 (7)	55 (11)	
Type of stroke, % (n)			0.42[d]
Ischaemic	87 (20)	75 (15)	
Haemorrhagic	13 (3)	15 (3)	
Subarachnoid haemorrhage	–	10 (2)	
Cerebral sinus venous thrombosis	–	–	
Hemiparesis, %			0.82[c]
Left	57 (13)	60 (12)	
Right	44 (10)	40 (8)	
Duration of illness in days, median (IQR)	24 (22)	24 (30)	0.45[b]
BI, mean (SD)	59 (22)	65 (19)	0.30[a]
Severity, % (n)			0.47[d]
Mildly impaired (BI 85–100 points)	17 (4)	30 (6)	
Moderately impaired (BI 35–80 points)	78 (18)	70 (14)	
Severely impaired (BI 0–30 points)	4 (1)	–	
Previous stroke, %			0.73[d]
Yes	26 (6)	20 (4)	
No	74 (17)	80 (16)	
Apraxia Screen of TULIA, mean (SD)	10.1 (1.8)	9.9 (1.9)	0.64[c]
Neglect, % (n)			0.05[c]
Yes	22 (5)	50 (10)	
No	78 (18)	50 (10)	
Pain in shoulder or arm, % (n)			0.14[d]
Yes	30.4 (7)	10 (2)	
No	69.6 (16)	90 (18)	

[a]Unpaired *t*-test. [b]Mann–Whitney *U* test. [c]χ² test. [d]Fisher's exact test Apraxia Screen of TULIA (TULIA: test of Upper Limb Apraxia, 0–12 points).
BI: Barthel Index (0–100 points); HIT: high-intensity training; IQR: interquartile range; LIT: low-intensity training; SD: standard deviation.
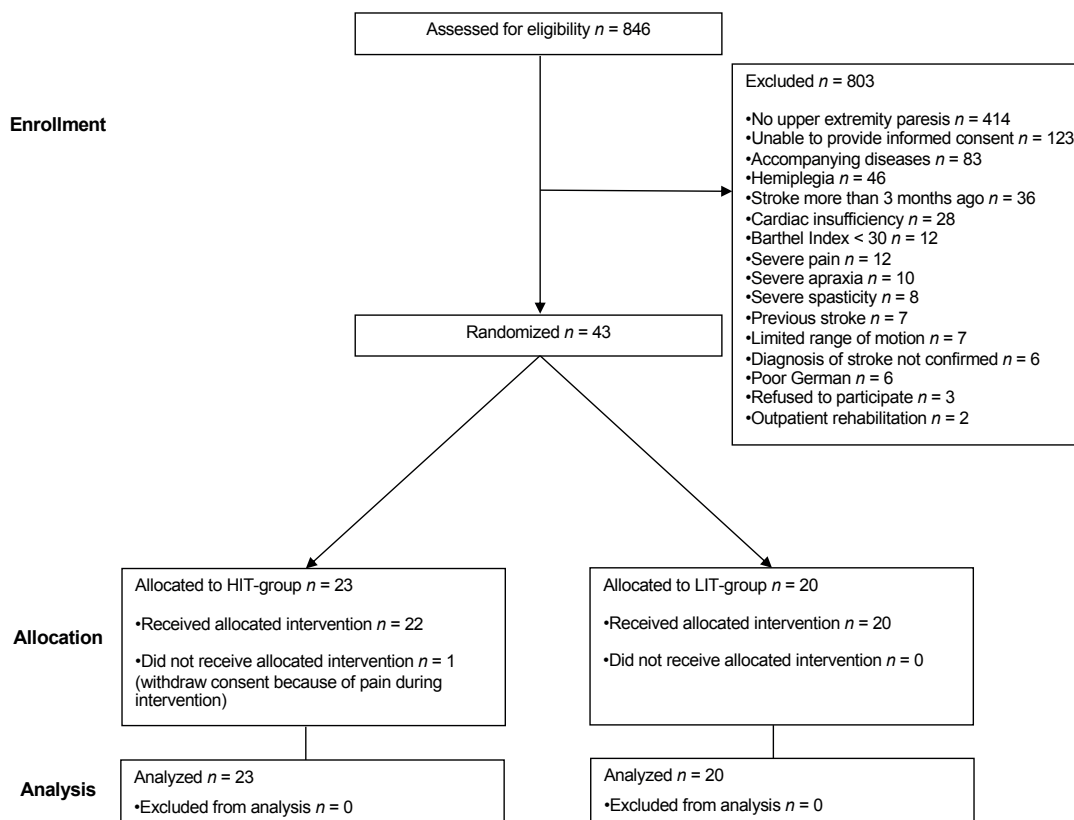
Enrollment

Assessed for eligibility *n* = 846

Excluded *n* = 803

- No upper extremity paresis *n* = 414
- Unable to provide informed consent *n* = 123
- Accompanying diseases *n* = 83
- Hemiplegia *n* = 46
- Stroke more than 3 months ago *n* = 36
- Cardiac insufficiency *n* = 28
- Barthel Index < 30 *n* = 12
- Severe pain *n* = 12
- Severe apraxia *n* = 10
- Severe spasticity *n* = 8
- Previous stroke *n* = 7
- Limited range of motion *n* = 7
- Diagnosis of stroke not confirmed *n* = 6
- Poor German *n* = 6
- Refused to participate *n* = 3
- Outpatient rehabilitation *n* = 2

Randomized *n* = 43

Allocation

Allocated to HIT-group *n* = 23
- Received allocated intervention *n* = 22
- Did not receive allocated intervention *n* = 1 (withdraw consent because of pain during intervention)

Allocated to LIT-group *n* = 20
- Received allocated intervention *n* = 20
- Did not receive allocated intervention *n* = 0

Analysis

Analyzed *n* = 23
- Excluded from analysis *n* = 0

Analyzed *n* = 20
- Excluded from analysis *n* = 0

Fig. 1. Flow diagram of study design according to Consolidated Standards of Reporting Trials guidelines (CONSORT).

Table II. Results of the primary and secondary outcomes by group

	HIT (*n* = 23)		Difference within groups		LIT (*n* = 20)		Difference within groups		Difference between groups
	t_0	t_1			t_0	t_1			
Outcome	Mean (SD)	Mean (SD)	MD (IQR)	*p*-value	Mean (SD)	Mean (SD)	MD (IQR)	*p*-value	*p*-value
Primary outcome									
Grip strength, kg	9.9 (13)	14 (12)	4.8 (6.2)	0.00[a]	10 (7.2)	14 (8.9)	3.5 (4.7)	0.00[a]	0.48[b]
Secondary outcomes									
Motricity Index (points)	66 (22)	84 (20)	17 (15)	0.001	65 (9.5)	76 (11)	11 (8.7)	0.00[c]	0.23[b]
Fugl-Meyer Assessment upper limb (points)	37 (13)	48 (11)	11 (8.5)	0.003	45 (16)	50 (6.0)	6.5 (7.9)	0.00[a]	0.06[b]
Box & Block Test (blocks)	21 (17)	32 (18)	11 (9.80)	0.003	27 (15)	37 (15)	10 (6.8)	0.003	0.58[b]

[a]*p*-value calculated with the Wilcoxon signed-rank test. [b]*p*-value calculated with the Mann–Whitney *U* test. [c]*p*-value calculated with the paired *t*-test.
HIT: high-intensity training; IQR: interquartile range; LIT: low-intensity training; MD: mean difference (mean$_{end}$ – mean$_{beginning}$); t_0: baseline, t_1: post-treatment.

Secondary outcome

The results for all secondary outcomes are shown in Tables II–V.

Arm function and activities

No significant differences were revealed between the groups with respect to Motricity Index, Fugl-Meyer Assessment for the upper limb, and Box & Block Test, even though there were major improvements (Motricity Index, Fugl-Meyer Assessment) in the HIT group (Table II). The mean estimate of the HIT group is 11 (SD 9) on the 66-point Fugl-Meyer Assessment scale, and thus, in contrast to the mean estimate of the LIT group, above the smallest worthwhile effect of 9.

Participation

Sixty percent (14/23) of the participants of the HIT group and 55% (11/20) of the LIT group indicated that they achieved their individual therapy goals as good as or better than expected (Goal Attainment Scale; Table III). The between-group difference for the achievement of individual participation goals did not differ between the experimental and control groups.

Adverse events

During 369 training sessions adverse events occurred 19 times (5%, 19/369). 13 participants in the HIT group (57%, 13/23) and 6 in the LIT group (30%, 6/20) were affected, each of them only once. There was no severe harm in either group. Neither HIT nor LIT resulted

in an increase in spasticity (Table IV). Thirty percent of the HIT group and 10% of the LIT group reported having shoulder or arm pain before starting training. Six of these patients in the HIT group also had pain during the intervention (moderate harm, Table V). This pain occurred only once and briefly, hence injury as a cause of pain could be ruled out and the training could be continued after a short break. Pain intensity was estimated to be less than 6 of 10 points on the numeric rating scale. One patient in the HIT group decided to leave the study because of pain during training. In both groups high perceived exertion and muscle soreness occurred in equal measures (Table V). The mean heart rate during training was 79 (10) beats per min (bpm) in the LIT group and 83 (14) bpm in the HIT group. No participant reached the maximum heart rate during training (Table V). During the intervention phase there were no cardiovascular or cerebrovascular events, referrals to an acute hospital, or deaths.

Post-hoc *analysis*

In a *post-hoc* analysis it was found that the participants in the HIT group stayed longer in the study (mean 18.9 days, SD 4.93) to achieve the postulated 9 training sessions than the LIT group (mean 16.8 days, SD 2.40). The aim was to conduct 9 training units within 3 weeks. If a

Table III. Secondary outcome, Goal Attainment Scale

Goal Attainment Scale[a]	HIT (*n* = 23) % (*n*)	LIT (*n* = 20) % (*n*)	*p*-value[b]
As expected (0 points)	30 (7)	25 (5)	0.70
Better than expected (1–6 points)	30 (7)	30 (6)	0.98
Worse than expected (–6 to –1 p.)	39 (9)	45 (9)	0.70

[a]Three goals were set for each patient. Each goal was evaluated with the Goal Attainment Scale (score range–2 to +2). Then the sum of the 3 scores was calculated. [b]*p*-value calculated with the Mann–Whitney *U* test.
HIT: high-intensity training; LIT: low-intensity training.

Table IV. Modified Ashworth Scale

	HIT *n* = 23 % (*n*)	LIT (*n* = 20) % (*n*)	*p*-value[a]
Modified Ashworth Scale hand flexors			
No changes[b]	65 (15/23)	60 (12/20)	0.52
Lower score[b]	30 (7/23)	35 (7/20)	0.53
Higher score[b]	4 (1/23)	5 (1/20)	0.92
Modified Ashworth Scale elbow flexors			
No changes[b]	65 (15/23)	65 (13/20)	0.99
Lower score[b]	30 (7/23)	20 (4/20)	0.44
Higher score[b]	4 (1/23)	15 (3/20)	0.24

[a]*p*-value calculated with the Mann–Whitney *U* test. [b]No changes: after intervention participants achieved same score as before intervention; lower score: after intervention participants achieved lower score as before intervention; higher score: after intervention participants achieved higher score as before intervention
HIT: high-intensity training; LIT: low-intensity training.

Table V. Adverse events

	HIT (n = 23) % (n)	LIT, (n = 20) % (n)	Relative risk
Shoulder pain/arm pain	26 (6)	0	N/A
BORG > 16 points	22 (5)	20 (4)	1.09
Muscle soreness	9 (2)	10 (2)	0.87
HR > HR$_{max}$	0	0	1.00
Total number of adverse events	13	6	

BORG: Borg Scale of Perceived Exertion (6–20 points); HR: heart rate; HR$_{max}$: maximum heart rate: 220 – age, HIT: high-intensity training; LIT: low-intensity training; N/A: not applicable.

training session was cancelled (e.g. due to examinations or illness) it should be made up as soon as possible. In the HIT group, appointments were cancelled more often, which extended the intervention period. Therefore, the HIT group obtained significantly more standard treatment than the LIT group (HIT group mean 1,735 min (SD 706)) vs. LIT group mean 1,290 min (SD 401)).

Because of pain occurring only in the HIT group the between-group differences in were analysed participants with and without shoulder pain or arm pain *post-hoc*. Of those having no pain 47% belonged to the HIT group (16/34) and 53% to the LIT group (18/34). After the 3-week intervention sensorimotor impairments decreased in both (a higher score in the Fugl-Meyer Assessment). The HIT group improved by 12 points (32%) and the LIT group by 6 points (13%). This means a significant group difference after training in people without shoulder or arm pain with a medium effect size in favour of the HIT group (r=0.36). The differences in the primary efficacy endpoint and the other secondary outcome measures were not significant. In addition, no significant differences were found between groups of participants who had shoulder or arm pain.

DISCUSSION

This study compared the effects and safety of 2 resistance training programmes with different intensities for patients with subacute stroke. No effects were found on any outcome in patients with subacute stroke. There was only a trend for improvements in grip strength, Fugl-Meyer Assessment, and Motricity Index in the HIT group compared with the LIT group; however, without statistical significance.

The results of this study are consistent with those of other studies that investigated arm strength training. Hunter et al. compared strength training with an active movement therapy and found similar improvements in function and activities of the upper extremity (27). Winstein et al. found, despite a longer intervention duration (5 weeks) compared with our study (3 weeks), that strengthening interventions increased strength and improved activity in patients who have had acute stroke, but without group differences (28). In comparison with the current study Hunter et al. and Winstein et al. increased the number of repetitions, while the current study kept the number of repetitions the same and increased the weights.

Many repetitions or long therapy durations seem to be advantageous for functional recovery after stroke (9, 29). A higher number of repetitions led to more improvement in the motor function (30) and might improve activities of daily life after stroke. In the current study participants of the LIT group moved their arm for between 150 and 285 repetitions in one therapy session. In contrast, the HIT group had only approximately 150 repetitions each session. Although the HIT group performed fewer repetitions, they had similar improvements in most outcomes. This could be explained by a larger amount of standard treatment, due to the extended stay of the HIT group, or by higher training weights for the affected arm.

Studies investigating lower limb resistance training in chronic stroke found significant group differences in leg muscle strength increases (31, 32). Resistance training for the upper limb does not seem to lead to comparable effects. Differences in the rehabilitation of upper and lower extremities can be caused by different functional motor performances and thus different response to therapy. In addition, the interventions in our study might be too similar to obtain different treatment outcomes. On the one hand, this study achieved differences in intensities due to different weights. On the other hand, both groups increased training intensity by progression either of the weights (HIT group) or of the number of repetitions (LIT group). It is possible that increasing the number of repetitions is more important than increasing the resistance.

The patients in the current study had no adverse events in 93% of the training sessions. This result is in accordance with Ada et al. (33), who reported no increase in spasticity due to resistance training. Adverse events, including high perceived exertion or muscle soreness, occurred in both training groups. Six patients in the HIT group had a single and brief period of slight pain in the affected arm during the training session. Pain during HIT is perhaps related to the biomechanics of the shoulder. This can occur by using high training weights, as the glenohumeral joint is extremely mobile at the expense of stability. However, the pain did not persist, and the patients were able to continue training without restrictions. In another study, patients with upper limb pain performed functional or strength training during the acute rehabilitation phase after stroke (28). After the intervention, there was no aggravation of symptoms. On average, the patients had less pain during passive motion in the affected upper extremity. Further studies reported no pain due to resistance training (34, 35). Pain is there-

fore not a reason to exclude participation in resistance training after stroke, but exercises should be performed and increased with caution. It seems that, for patients with subacute stroke with pain in the affected arm, a low-intensity resistance training should be preferred to increase muscle strength.

This is one of the first studies investigating high-intensity resistance training in arm rehabilitation in the first weeks after stroke. Reporting of adverse events is another strength of this investigation, because there was limited evidence in earlier studies. Studies often examined resistance training using different comparators, e.g. conventional therapy (11) or repetitive training (36). Until now, however, it lacks studies with different types of resistance training, e.g. comparing higher and lower loads for the affected arm after stroke. In this study the current study found evidence for comparable training effects at low and high training weights.

Even in studies investigating active therapies for the affected arm at an early stage after stroke with a large sample size and sufficient power, no benefits were found for the investigated interventions (37, 38). Besides therapy-induced mechanisms, there are also spontaneous mechanisms of functional recovery after stroke (39). In the first 6–10 weeks, 16–42% of function and activity improvements are due to spontaneous recovery, i.e. even without the influence of exercise therapy (40). In addition, there are structural and functional changes following movement therapy (39), but it is difficult to say whether these changes were caused by training or by spontaneous recovery.

One could argue that the absence of a true control group, e.g. of standard or no other physiotherapy, might be a limitation of the study. There is a need for an effective therapy to maximize and accelerate the recovery of patients with stroke. Therefore, we decided to compare 2 potentially capable and reasonable active physical rehabilitation interventions. Whereas patients and assessors were blinded, the therapists instructing the patients and assessing side-effects were not blinded to group allocation. However, it is still unclear in which direction this might have biased the results of the study. Another limitation concerns the comparability of the interventions, which is impaired by the increased length of stay of the HIT group resulting in a larger amount of standard treatment. Furthermore, we did not reach the target sample size of 78 patients since the recruitment rate was unexpectedly low and the recruitment time was limited. Therefore, the sample size is not large enough to detect a statistically significant result and this study can be seen only as a pilot trial.

This study shows that high-intensity resistance training with a progression of weights is applicable for patients with subacute stroke. In the current study

2 forms of training with the same exercise content and training setting, but different intensities and forms of progression, lead to similar results. Future research is needed to clarify whether the results of this study were determined by insufficient test strength. Future RCTs should try to recruit a larger number of patients in multicentre studies in order to obtain an appropriate sample. We also recommend extending the intervention period beyond 3 weeks, with a follow-up after 6 months.

In conclusion, in subacute stroke, HIT seems to lead to similar improvements in strength and motor function as LIT, and neither intervention is superior. HIT does not increase spasticity, but may cause pain in some patients. Nevertheless, the current study supplies evidence of the feasibility of HIT for subacute stroke without risk of severe harm.

Clinical message

- Both HIT and LIT increase strength in patients with subacute stroke.
- Neither HIT nor LIT increases spasticity in these patients.

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Appendix I. Overview of the schedule for increasing intensity in the high-intensity arm training group

Session	Exercises	Weight	Repetitions	Increase in weight (if participant establish 15 repetitions)	Sets	Rest between sets (s)
1	5	80% of 1RM	10–15	By 1 unit of weight	3	120
2	5	As in previous session + increase	10–15	By 1 unit of weight	3	120
3	5	As in previous session + increase	10–15	By 1 unit of weight	3	120
4	5	As in previous session + increase	10–15	By 1 unit of weight	3	120
5	5	As in previous session + increase	10–15	By 1 unit of weight	3	120
6	5	As in previous session + increase	10–15	By 1 unit of weight	3	120
7	5	As in previous session + increase	10–15	By 1 unit of weight	3	120
8	5	As in previous session + increase	10–15	By 1 unit of weight	3	120
9	5	As in previous session + increase	10–15	By 1 unit of weight	3	120

1RM: 1 repetition maximum.

Appendix II. Overview of the schedule for increasing intensity in the low-intensity arm training group

Session	Exercises	Weight, % of 1 RM	Repetitions	Increase of repetitions	Sets	Rest between sets (s)
1	5	40	10	n. a.	3	120
2	5	40	11	By 1	3	120
3	5	40	12	By 1	3	120
4	5	40	13	By 1	3	120
5	5	40	14	By 1	3	120
6	5	40	15	By 1	3	120
7	5	40	16	By 1	3	120
8	5	40	17	By 1	3	120
9	5	40	18	By 1	3	120

1RM: 1 repetition maximum; n.a.: not applicable.