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REVIEW

ESSENTIAL TRAINING VARIABLES OF ARM-HAND TRAINING IN PEOPLE WITH CERVICAL SPINAL CORD INJURY: A SYSTEMATIC REVIEW

Nele BERTELS, MSC[1], Henk SEELEN, PHD[2,3], Justine DEMBELE, MSC[1] and Annemie SPOOREN, PHD[1]

From the [1]Rehabilitation Research Center REVAL, Hasselt University, Diepenbeek, Belgium, [2]Adelante Centre of Expertise in Rehabilitation and Audiology, Hoensbroek and [3]Department of Rehabilitation Medicine, Maastricht University, Research School CAPHRI, Maastricht, The Netherlands

Objective: **To identify and evaluate 3 training variables of motor training programmes involving people with a cervical spinal cord injury: i.e. motor training strategies, therapy dosage, and persons' motivation for arm-hand functioning in subacute and chronic phases.**
Methods: **PubMed, Cochrane, CINAHL, EMBASE, and DARE databases were searched for active arm-hand motor training programmes. Two independent reviewers assessed methodological quality. Pre-post effect sizes were calculated using Hedge's g, and mean effect sizes were calculated to compare outcomes on the International Classification of Functioning, Disability, and Health levels of function and activity.**
Results: **Twelve training programmes integrated mainly skill training alone or combined with strength and/or endurance training. Task-oriented training components included: multiple movement planes, functional movements, clear functional goals, and bimanual practice. Training duration of 8 weeks was common. Quantitative analyses of 8 training programmes showed an overall small effect (0.34) on function level and an overall moderate effect (0.55) on activity level. In depth-analysis of activity level showed moderate effects of skill training only (0.55) or combined with strength and endurance training (0.53). Moderate effects (0.53–0.60) were found for integrating functional movements, clear functional goals, real-life object manipulation, multiple movement planes, total skill practice, context-specific environment, exercise variety, and bimanual practice. Training of minimum 8 weeks showed a moderate effect (0.60–0.69).**
Conclusion: **Based on limited studies, arm-hand functioning aiming to improve activity level can be improved using skill training with at least 8 task-oriented training components, additional strength and endurance training, with a minimum training duration of 8 weeks.**

Key words: activities of daily living; central nervous system; exercise therapy; neurological rehabilitation; upper extremity; spinal cord injuries; dosage.

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Correspondence address: Nele Bertels, Rehabilitation Research Center REVAL, Hasselt University, Agoralaan building A, BE-3590 Diepenbeek, Belgium. E-mail: nele.bertels@uhasselt.be

LAY ABSTRACT

Cervical spinal cord injury causes arm-hand movement problems, leading to difficulties in activities of daily living, independence, and participation. Motor training is the commonly used intervention to improve arm-hand functioning. Motor training programmes aim to promote neuroplasticity. However, it is not fully understood which exercise components are needed for a successful motor training programme. This review gives an overview of the use of motor training strategies, therapy dose factors and persons' motivation in active arm-hand motor training programmes to improve arm-hand functioning. Based on a limited number of studies, these findings suggest including skill training combined with endurance and strength training in motor training programmes. The motor training programmes need to include at least 8 task-based training components, including: focusing on movements involving task execution, using goals set during everyday-life activities, manipulation of objects in normal daily-life activities, movements in different joint axes, practicing skills as a whole and tasks for which both arms are involved. The duration of the training programme should be at least 8 weeks.

Spinal cord injury (SCI) has a has a global incidence of between 250,000 and 500,000 cases per year (1). Of these, 30% have a cervical spinal cord injury causing arm-hand problems, impairments impacting activities of daily living, independence, participation, and socio-economic activities (1–3). People with cervical spinal cord injury (PwC-SCI) reported improving arm-hand function and arm-hand skilled performance as an essential part of their functional recovery (4).

Dunlop (5) describes that neuroplasticity and its shaping by physical activity are major contributors to functional recovery in people with SCI. After a SCI, neuroplasticity occurs in the brain and the spinal cord, and this is enhanced by rehabilitation (6). Different studies have shown cortical reorganization in patients with SCI compared with healthy controls during the execution of motor and sensory tasks. Increased motor and sensory cortical activation was found, similar to that identified in patients with a brain injury (7–9). Studies exploring neuroplasticity at the spinal level showed that motor training promotes the activity of uninjured spinal pathways and residual supraspinal inputs (10). Training principles used in motor learning and neurological rehabilitation to improve functional recovery, described by Dunlop (5) and Kleim & Jones (11) share 3 essential training variables, i.e. motor training strategies, therapy dosage, and persons' motivation.

Regarding the first component, motor training strategies, the literature suggests using task-specific training to improve arm-hand function (AHF) and/or arm-hand skilled performance (AHSP) (5, 11). In the current systematic review, the term AHF refers to "function level", and the term AHSP refers to "activity level" of the International Classification of Functioning Disability and Health (ICF) (12, 13). Dunlop (5) suggests that SCI rehabilitation should include different tasks during training to drive neuroplasticity across neural circuitries. Kleim & Jones (11) describe the principles of experience-dependent neural plasticity after brain damage, indicating that skills can be reacquired by training specific tasks, leading to neural circuitry changes (11). From the available literature, the current study draws upon training characteristics that aid motor learning and training through active motor movements.

The second component is therapy dosage. Training programmes need a certain amount of training to improve AHF and/or AHSP. The optimal training dosage is unknown. Repetitive motor activity is a critical component in functional recovery in SCI. It must provide sufficient excitation to the brain and spinal cord to activate injured and residual spinal pathways (10). Kleim & Jones (11) described that a reacquired behaviour needs repetition to induce lasting changes in the neural circuitry and to generalize the behaviour beyond therapy. Training intensity in terms of the number of movement repetitions can affect the induction of neuroplasticity (11). Therapy dosage is a multidimensional concept. Hayward et al. (14) introduced a framework with different therapy dose dimensions from the outermost dimension, i.e. duration in weeks of intervention, to the innermost dimension, i.e. the episodes within a therapy session. The framework assumes that an intervention comprises a set of sessions with episodes that can be active (time on task) or inactive (time off task). The current systematic review uses the framework of Hayward et al. (14) to define therapy dosage.

The third component relates to persons' motivation, which is essential in promoting task engagement (11). For inducing plasticity, stimuli need to be behaviourally relevant (5). Research indicates that active involvement in goal-setting enhances motivation for participation in rehabilitation (15). This systematic review discusses the various components utilized in therapy to motivate pwC-SCI, such as employing client-centred training goals.

Earlier systematic reviews on AHF and AHSP in pwC-SCI have looked into different training modalities. Kloosterman et al. (2) reported positive effects of exercise therapy, electrical stimulation, and biofeedback, on muscle strength, muscle grade, and functional abilities in the chronic phase. Spooren et al. (16) found possible improvements in AHSP after motor training in the acute and chronic phases. They highlighted that, due to differences in training modalities, training levels, and outcome measures reported in the literature, no definitive conclusion could be drawn about the superiority of the different motor training programmes (16). Lu et al. (17) also found a wide range of training programmes and outcomes, drawing with a comparable conclusion, i.e. that exercise therapy and functional electrical stimulation improved AHF, arm-hand muscle strength, and activities of daily living. However, the above-mentioned systematic reviews reported poorly on therapy dose dimensions.

A recent systematic review by Mateo et al. (18) investigated therapy duration and number of movement repetitions of arm-hand training in pwC-SCI. They found no significant effect favouring intensive or less intensive training. However, therapy dosage represents more than just therapy time or the number of movement repetitions. To date, no systematic review has investigated motor training strategies, therapy dosage, and persons' motivation in training programmes to improve AHF and/or AHSP in pwC-SCI in the subacute and chronic phases.

The objectives of this systematic review are: (*i*) to identify information on the chosen 3 training variables, i.e. motor training strategies, therapy dose dimensions, and persons' motivation in arm-hand training programmes in current research, and (*ii*) their effect on AHF and AHSP in pwC-SCI in the subacute and chronic phases.

METHODS

Protocol and registration

The protocol was registered in PROSPERO on 31 May 2022 (https://www.crd.york.ac.uk/prospero/: ID CRD42022328754).

Literature search

The authors conducted a search for all peer-reviewed randomized controlled trials, controlled clinical trials, crossover studies, case series (with at least 5 participants), and single case design studies published in English, French, German, or Dutch from January 1970 until May 2022. Due to few high qualitative RCT studies, different study designs were included to obtain more comprehensive information. The following databases were searched: Medline (PubMed), Cochrane, CINAHL, EMBASE, and DARE. Screening or reference lists and selected full-texts were examined to identify relevant additional publications. The search strategy was developed for Medline and adapted to the other databases. Medical Subject Headings (MeSH) and text words were combined in the following search string: ("Spinal cord injuries" OR "Spinal injuries" OR "Quadriplegia" NOT "cerebral palsy" NOT "paraplegia" NOT "stroke") AND ("Exercise movement techniques" OR "Rehabilitation" OR "Occupational therapy" OR "Physical therapy modalities" OR "Exercise therapy" OR "Motor training" OR "Skill training" NOT "walking") AND ("Recovery of function" OR "Upper extremity" OR "Activities of daily living"). Two independent reviewers analysed the included studies. They independently screened the title and abstract using the online screening tool Ryyan (19). Subsequently, a consensus was obtained before starting full-text screening.

Eligibility of participants and studies

People aged 16 years or older with traumatic or non-traumatic C-SCI (C1-T1), with American Impairments Scale (AIS) scores between A and D in all phases of rehabilitation were included. Studies need to describe motor training programmes including a series of active movements and exercises with a description on motor training strategies, therapy dose dimensions or persons' motivation and aiming to improve AHF and/or AHSP. Studies were excluded if they reported on (functional) electrostimulation. Animal and observational studies were also excluded.

Methodological quality assessment

Two independent reviewers (NB and JD) assessed the methodological quality of the studies. RCTs and controlled clinical trials were assessed with Van Tulder's quality assessment system and case series with the JBI Critical Appraisal Checklist for case series (20, 21). Inter-rater reliability for both assessments was tested with Cohen's kappa. The final score was obtained with the consensus method

The Van Tulder scale assesses the internal validity (maximum 11 points) with the following subscales of selection [2 points], performance [5 points], attrition [2 points], and detection bias [2 points]. The items "blinding of care provider" and "blinding of patient" were considered not applicable and were removed from the subscale performance bias because care providers and patients were unblinded to the motor training that they were receiving. Therefore, the quality assessment was based on 9 items. Studies with a score lower than 5 were considered a high risk of bias and were excluded (21).

The JBI Critical Appraisal Checklist for Case Series assesses the internal validity and risk of bias in case series with 10 questions (20). Previous research has classified studies scoring below 6 as having a high risk of bias (22, 23) resulting in their exclusion from the analysis.

Data extraction and analysis

Characteristics of included participation were age, time since injury, AIS grade, and neurological level of injury. Information about the study characteristics concerning sample size and study design and different aspects of the intervention, i.e. motor training strategies, therapy dose dimensions, and persons' motivation, were also extracted.

Specifically, motor training strategies included training modalities, task-oriented training components, and trained regions. According to Timmermans et al. (24) 15 task-oriented training components were used to analyse the training programmes. The main researcher, with a team of experts, reached a consensus that when training activities of daily living was incorporated in the training programme, the components: clear functional goal, functional movements, real-life object manipulation, multiple movement planes, and bimanual training will be extracted. Training of ADL also implied training of the whole upper limb region. The outcomes of the included studies on ICF function level and ICF activity level were identified. When discrepancies arose among the reviewers, a consensus was reached to ensure consistency for all extracted information.

For semantic clarity, several definitions used in this paper are introduced in Table I.

Quantitative assessment

All studies with Van Tulder score ≥ 5 and JBI score ≥ 6 were included in the quantitative analysis. When the publication did not provide means and standard deviations (SDs), the authors were contacted by email to request the data. When the standard error of measurement (SEM) was given, the SD was calculated using the formula: SEM baseline * Square root (number of samples). The effect size of the pre-post test effect was calculated based on the pre-post results of all included training programmes with the Hedge's g. The differences between the means of the pre-and post-intervention were divided by the pooled SD. Hedge's g and 95% confidence intervals (95% CI) were calculated separately for each training programme and each outcome of interest with ReviewManager version 5.4 (25). When multiple outcome measures were given, the outcome

Table I. Definitions

Motor training strategies	
Training modality	A specific training form with active motor movements, which can be subdivided into analytical, strength, endurance, and skill training
Task-oriented training components	Training characteristics supporting motor learning can be subdivided into 15 task-oriented training components, according to Timmermans et al. (24). A clear description of each task-oriented training component is shown in Appendix S1.
Trained body region	The specific joints and segments of the upper limbs used during the training
Therapy dose dimensions by Hayward et al. (14)	
Duration in weeks	Total length of time over which the intervention is provided, reported in weeks
Intervention days per week	Total number of days per week the intervention is provided
Sessions per day	Total number of sessions per day
Session length	Total time spent in the intervention environment/location
Session density	Total amount of time on a task as a proportion of the total session length
Episode length	Total time a task is performed during the intervention
Episode difficulty objectively	Task difficulty is how intrinsically hard the task is
Episode difficulty subjectively	Task difficulty as subjectively experienced by the patient
Episode intensity objectively	Task performed expressed as movement repetitions
Episode intensity subjectively	Task performance expressed as perceived exertion or muscle fatigue
Persons' motivation	
Persons' motivation	Persons' motivation includes a personal sense of self-determination, self-efficacy, and attention, which are essential factors in learning motor skills (44)

measure with the largest effect size was used to link the elements of interest to their maximal possible treatment effect. Heterogeneity of the results was tested with I².

An in-depth analysis was performed on the training programmes with an overall moderate effect size (Hedge's g>0.5) on ICF function or activity level and with at least 5 training programmes providing information on the training variable studied. The in-depth analysis involved a mean effect size (MES) for each training variable based on the pre-post effect size (Hedge's g) of the training programme incorporating the training variable. MES values between 0.2 and 0.5 were considered to represent a small effect, between 0.5 and 0.8 a moderate effect, and higher than 0.8 an important effect.

RESULTS

Study selection

Fig. 1 shows a flow chart of the inclusion of the studies. Overall, 304 studies were retrieved. Twenty-two duplicates were discarded. After screening on title, 211 studies were excluded and after screening on abstract, another 44 studies were excluded. Full texts of the 27 remaining studies were screened, with 14 more studies being excluded, 2 studies were then added after screening the reference lists of the full-texts. Of the 15 studies meeting the inclusion criteria, 3 (26–28) were excluded based on the high risk of bias as indicated by the Van Tulder scale score. The qualitative narrative analysis encompassed 12 studies that collectively contributed 15 training programmes for inclusion in the analysis. In the studies of Dimbwadyo-Terrer et al. (29), Kim et al. (30), and Spooren et al. (31), the experimental group (EG) and control group (CG) were included in the analysis. In 5 (32–36) studies, only 1 group involved an active motor training programme. Table II indicates which study group was included in the analysis.

For the quantitative analysis, 4 studies (30, 32, 36, 37) were excluded from the quantitative analysis because of unavailable data based on means and SDs. The quantitative analysis incorporated 7 studies, resulting in the inclusion of 10 training programmes. All the training programmes were considered as case series in the quantitative analysis.

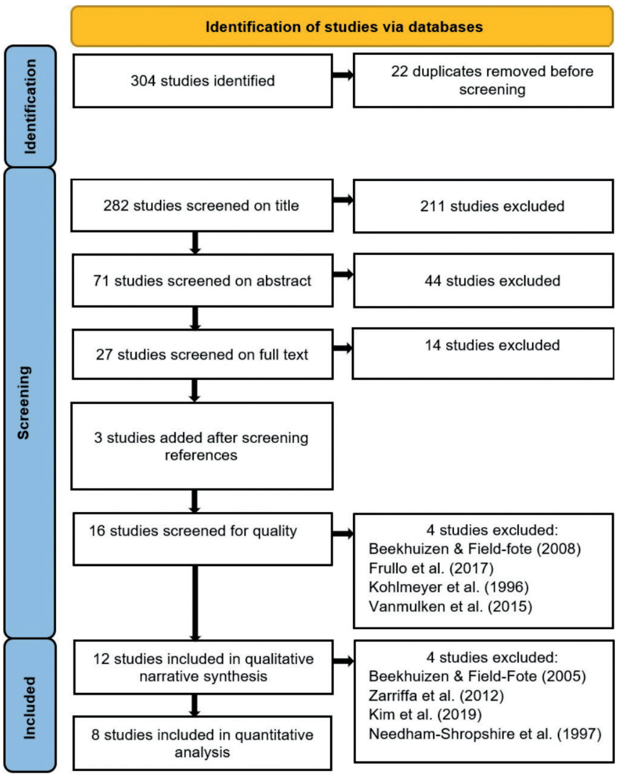

Fig. 1. Flow chart of study inclusion.

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Table II. Patient group descriptions and study characteristics

Author, year (Ref.)	Age, years Mean (SD) or median (range)	TSI, months Mean (SD) or median (range)	AIS grade	Level of injury	Sample size	Study design	Included group
Beekhuizen & Field-Fote 2005 (32)	39 (22–63)	44 (12–154)	C–D	C5–C7	5	RCT	CG
Cortes et al. (2013) (41)	44.8 (16.3)	56.4 (30)	A–D	C4–C6	10	Case-series	
Dimbwadyo-Terrer et al. 2016 EG (29)	34.53 (13.71)	4.31 (2.06)	A–B	C5–C8	16	RCT	EG
Dimbwadyo-Terrer et al. 2016 CG (29)	40.27 (13.61)	5.60 (2.50)	A–B	C5–C8	15	RCT	CG
Francisco et al. 2017 (39)	40 (17.66)	49.36 (61.98)	B–D	C2–C7	10	Case-series	
Glinsky et al. 2008 (33)	37 (16)	12 (44.4)	A–D	C4–C7	16	RCT	EG
Glinsky et al. 2009 (34)	38 (16)	5 (4–16)	A–D	C4–C7	32	RCT	CG
Harvey et al. 2016 (35)	29 (22–49)	2.27 (1.5 – 3.6)	A–D	C1–C7	33	RCT	CG
Kim et al. 2019 EG (30)	56.65 (13.62)	3.1 (1.72–5.75)	A–D	C2–C8	17	RCT	EG
Kim et al. 2019 CG (30)	47.12 (14.90)	5.2 (2.9–8.75)	A–D	C2–C8	17	RCT	CG
Needham-Shropshire et al. 1997 (36)	24 (NR)	48 (NR)	NR	NR	11	RCT	CG
Osuagwu et al. 2020 (40)	50.3 (33–60)	28 (14–192)	C–D	C2–C5	15	Case-series	
Spooren et al. 2011 EG (31)	50 (20)	5.5 (2)	A–D	C0–C5	11	CCT	EG
Spooren et al. 2011 CG (31)	38 (11)	6.5 (2)	A–D	C5–C6	11	CCT	CG
Zariffa et al. 2012 (37)	41.5 (17.48)	2.53 (1.57)	A–D	C4–C6	15	Case-series	

TSI: time since injury; AIS: American Impairments Scale score; NR: not reported; RCT: randomized controlled trial; CCT: controlled clinical trial; EG: experimental group; CG: control group.

Risk of bias

Risk of bias score of the 15 studies is shown in Table III; the fully completed Van Tulder assessment and JBI Critical Appraisal Checklist for Case Series is shown in Appendix S1. The Van Tulder assessment showed an inter-rater disagreement on 23 of the 187 items. Resulting in a Cohen's kappa of 0.77 (38). The JBI Critical Appraisal Checklist for Case Series showed an inter-rater disagreement on 4 of the 50 items, resulting in a Cohen's kappa of 0.82.

Research characteristics

Participant characteristics. In total, 234 participants were included. The mean age of the included participants was 40.7 years, with a range between 29 and 56.7 years and with a mean time since injury of 18 months, ranging between 2.27 and 56.4 months. AIS scores between A and D were reported, and the level of injury was between C0 and C8 (Table II).

Study characteristics. The study designs consisted of 7 RCTs (29, 30, 32–36), 1 controlled clinical trial (31), and 4 case series (37, 39–41). Only 2 studies had a sample size of more than 30 (34, 35).

Results of the qualitative narrative analyses

Motor training strategies. An overview of the training modalities and the body regions involved in the selected training programmes is shown in Table IV.

The use of skill training was reported in 8 training programmes, i.e. skill training alone (29, 32, 40) combined with strength training (29, 30) or combined with strength and endurance training (31, 35). Two training programmes reported strength training (33, 34), 1 training programme endurance training (36), and 4 training programmes described analytical training (30, 37, 39, 41).

Eight training programmes reported whole upper limb training (29–32, 35, 40), whereas 3 training programmes focused on the upper limb without the fingers (30, 37, 39). The latter were robot-assisted training programmes.

All reported task-oriented training components of the selected studies are shown in Table V.

Functional movements, clear functional goal, real-life object manipulation, multiple movement planes, and bimanual practice were used in every skill training programme in the selected training programmes (29–32, 35, 40), except for the experimental group in the study of Dimbwadyo-Terrer et al. (29) in which

Table III. Risk of bias

RCT and CCT with Van Tulder's quality assessment	Selection bias (2)	Performance bias (3)	Attrition bias (2)	Detection bias (2)	Total (9)	Case series with JBI Critical Appraisal Checklist for Case Series	Total (10)
Dimbwadyo-Terrer et al. 2016 (29)	2	3	2	2	9	Francisco et al. 2017 (39)	8
Glinsky et al. 2009 (34)	2	3	2	2	9	Osuagwu et al. 2020 (40)	7
Harvey et al. 2016 (35)	2	3	2	2	9	Cortes et al. 2013 (41)	7
Kim et al. 2019 (30)	2	3	2	2	9	Zariffa et al. 2012 (37)	6
Glinsky et al. 2008 (33)	2	2	2	2	8		
Needham-Shropshire et al. 1997 (36)	1	2	1	2	6		
Spooren et al. 2011 (31)	0	3	2	1	6		
Beekhuizen & Field-Fote 2005 (32)	2	1	1	1	5		
Frullo et al. 2017 (27)	0	1	1	1	3		
Kohlmeyer et al. 1996 (28)	1	1	0	1	3		
Beekhuizen & Field-Fote 2008 (32)	1	0	0	1	2		

RCT: randomized controlled trial; CCT: controlled clinical trial.

Table IV. Training modality and trained body region

	Training modality				Trained body region					A short description training programme
	Skill	Strength	Endurance	Analytical	Shoulder	Elbow	Forearm	Wrist	Fingers	
Harvey et al. 2016 (35)	×	×	×		×	×	×	×	×	UL intervention with practicing functional activities combined with regular therapy
Spooren et al. 2011 EG (31)	×	×	×		×	×	×	×	×	Task-oriented Client-centred Upper Extremity Skilled Performance Training (ToCUEST)
Spooren et al. 2011 CG (31)	×	×	×		×	×	×	×	×	Basic functional training of skills, maintaining joint mobility, and increasing muscle strength
Dimbwadyo-Terrer et al. 2016 CG (29)	×	×			×	×	×	×	×	Strengthening exercise of UL, training of ADL, passive and active ROM
Kim et al. 2019 CG (30)	×	×			×	×	×	×	×	Strengthening functional activities and training for ADL
Beekhuizen & Field-Fote 2005 (32)	×				×	×	×	×	×	Massed practice training with repetitive upper limb tasks
Dimbwadyo-Terrer et al. 2016 EG(29)	×				×	×	×	×	×	VR intervention using VR system Toyra
Osuagwu et al. 2020 (40)	×				×	×	×	×	×	Intervention with the SEMGlove at home
Glinsky et al. 2008 (33)		×						×		Progressive resistance exercise programme with a special device
Glinsky et al. 2009 (34)		×						×		Resistance training of the wrist with a special device
Needham-Shropshire et al. 1997 (36)			×		×	×				Voluntarily arm ergometry exercise
Cortes et al. 2013 (41)				×			×	×		Robotic training with the InMotion 30 wrist robot
Francisco et al. 2017 (39)				×	×	×	×	×		Robotic training with the MAHI Exo-II
Kim et al. 2019 EG (30)				×	×	×	×	×		Robotic intervention with Armeo Power
Zariffa et al. 2012 (37)				×	×	×	×	×		Intervention with Armeo-spring

EG: experimental group; CG: control group; UL: upper limb; ADL: activities of daily living; ROM: range of motion; VR: virtual reality

real-life object manipulation and bimanual practice were not used in their virtual reality (VR) training programme. In strength, endurance, and analytical training, the components overload, exercise progression, and patient-customized training load were frequently used (30, 34, 36, 37, 39, 41), but these were not reported in programmes involving skill training.

Therapy dose dimensions. All reported therapy dose dimensions in the selected studies are shown in Table VI.

Five training programmes reported durations of 8 weeks (31, 33–36), and 1 reported more than 12 weeks (40). Eighth training programmes reported 3 intervention days per week (31–37, 39, 41). Eight training programmes reported 1 therapy session a day (29, 31–34, 37, 39, 41). Five training programmes reported a session length of 30 min (29–31, 36, 39), and 3 a session length of more than 60 min (32, 39, 40). Only 1 training programme described the session density, of active 20 min and inactive 9 min of training (36). Only 3 training programmes described episode lengths, i.e. 25 min (32), 4.8 min (30), and 5 min (36). Four training programmes described the increased episode objective difficulty based on objectively measured parameters (33, 34, 36, 39). With regard to episode intensity, 5 training programmes described movement repetitions between 30 and 1,000 (30, 33, 34, 40, 41). None of the training programmes described the subjective episode difficulty or the subjective episode intensity.

Eight of the included training programmes featured additional usual care, but the papers did not describe therapy dose dimensions of the usual care (29–31, 33–35, 37).

Persons' motivation. Only the experimental group of the training programme of Spooren et al. (31) reported using client-centred training goals. None of the other training programmes described personal motivation components.

Results of the quantitative analysis

In the quantitative analysis, 10 training programmes were included (29, 31, 33–35, 39–41), with a total of 169 participants. For AHF outcome, measures of upper limb strength were used, whereas, for AHSP, outcome measures on basic and complex activities on ICF activity level were used (Table VII).

An overall small effect of 0.34 ($p=0.01$) was found on AHF for the 6 included training programmes, illustrated in Fig. 2. The I^2 shows no substantial heterogeneity in the analysis. All the individual training programmes had a small effect (33–35, 39–41). An overall moderate effect of 0.55 ($p<0.001$) was found on AHSP for the 7 included training programmes, illustrated in

Table V. Task-oriented training components.

	Functional movements	Clear functional goal	Client-centered patient goal	Overload	Real-life object manipulation	Context-specific environment	Exercise progression	Exercise variety	Feedback	Multiple movement planes	Total skill practice	Patient-customized training load	Random practice	Distributed practice	Bimanual practice	Total components
Harvey et al. 2016 (35)	1	1	0	0	1	0	0	0	0	1	1	0	0	0	1	6
Spooren et al. 2011 EG (31)	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	13
Spooren et al. 2011 CG (31)	1	1	0	0	1	0	0	0	0	1	0	0	0	0	1	5
Dimbwadyo-Terrer et al. 2016 CG (29)	1	1	0	0	1	0	0	0	0	1	0	0	0	0	1	5
Kim et al. 2019 CG (30)	1	1	0	0	1	0	0	0	0	1	0	0	0	0	1	5
Beekhuizen & Field-Fote 2005 (32)	1	1	0	0	1	0	0	1	1	1	1	1	1	0	1	10
Dimbwadyo-Terrer et al. 2016 EG (29)	1	1	0	0	0	0	1	0	1	1	1	0	0	0	0	6
Osuagwu et al. 2020 (40)	1	1	0	0	1	1	0	1	0	1	1	0	0	0	1	8
Glinsky et al. 2008 (33)	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	3
Glinsky et al. 2009 (34)	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	3
Needham-Shropshire et al.1997 (36)	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	5
Cortes et al. 2013 (41)	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	2
Francisco et al. 2017 (39)	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	3
Kim et al. 2019 EG (30)	0	0	0	1	0	0	1	0	1	1	0	1	0	0	0	5
Zariffa et al. 2012 (37)	0	0	0	1	0	0	1	0	0	1	0	1	0	0	0	4
Frequency	9	8	1	6	7	2	7	3	5	11	5	7	2	2	8	

EG: experimental group; CG: control group.

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Table VI. Therapy dose dimensions

Author (Year)	Duration in weeks	Intervention days per week	Sessions per day	Session length (min)	Session density (min)	Episode length (min)	Episode difficulty (objectively)	Episode difficulty (subjectively)	Episode intensity (objectively)	Episode intensity (subjectively)
Beekhuizen & Field-Fote 2005 (32)	3	5	1	120	/	25	/	/	/	/
Dimbwadyo-Terrer et al. 2016 EG (29)	5	3	1	30	/	/	/	/	/	/
Dimbwadyo-Terrer et al. 2016 CG (29)	5	5	/	/	/	/	/	/	/	/
Cortes et al. 2013 (41)	6	3	1	60	/	/	/	/	1000	/
Francisco et al. 2017 (39)	4	3	1	180	/	/	Gradually progress – by increasing the number of repetitions, – by changing from passive to triggered to active-constrained mode, – by increasing the threshold force in subject-triggered mode – by increasing the amount of resistance to be overcome in the active-constrained mode	/	/	/
Glinsky et al. 2008 (33)	8	3	1	/	/	/	Resistance adjusted to ensure that participants could only lift the weight 10 times through a full range of motion	/	30	/
Glinsky et al. 2009 (34)	8	3	1	/	/	/	Increasing according to the principles of progressive resistance training.	/	60	/
Harvey et al. 2016 (35)	8	3	/	/	/	/	/	/	/	/
Kim et al. 2019 EG (30)	4	/	/	30	/	4.8	/	/	100–300	/
Kim et al. 2019 CG (30)	4	/	/	30	/	/	/	/	/	/
Needham-Shropshire et al. 1997 (36)	8	3	/	29	20 active, 9 inactive	5	Resistance-adjusted cycling could be tolerated at 60 RPM for 5 min without physical discomfort	/	/	/
Osuagwu et al. 2020 (40)	12	7	/	> 240	/	/	/	/	> 60	/
Spooren et al. 2011 EG (31)	8	3	1	30 /	/	/	/	/	/	/
Zariffa et al. 2012 (37)	6	3–5	1	60	/	/	/	/	/	/

EG: experimental group; CG: control group; min: minutes. / indicates that the information was not provided in the studies

Table VII. Therapy dose dimensions

	AHSP	AHF
Harvey et al. 2016 (35)	SCIM	GRASSP: summed upper limb strength
Spooren et al. 2011 (31)	QIF	
Dimbwadyo-Terrer et al. 2016 (29)	SCIM self-care subscore	
Osuagwu et al. 2020 (40)	TRI-HFT	Pinch strength
Glinsky et al. 2008 (33)		Strength Maximal voluntary isometric torque (Nm)
Glinsky et al. 2009 (34)		Voluntary strength (Nm)
Francisco et al. 2017 (39)	JTHFT	Pinch strength
Cortes et al. 2013 (41)		Upper extremity motor score

AHSP: arm-hand skilled performance; AHF: arm-hand function; JTHT: Jebsen-taylor Hand Function Test; SCIM: Spinal cord independence measure; ARAT: Action Research Arm Test; GRASSP: Graded Redefined Assessment of Strength Sensibility and Prehension; TRI-HFT: Toronto Rehabilitation Institute hand function test; VLT: Van Lieshout test; QIF: quadriplegia index of function.

Fig. 3. The I^2 shows no substantial heterogeneity in the analysis. A small effect was found for the training programmes of Francisco et al. (39), Dimbwadyo-Terrer (29), and Spooren et al. (31). A moderate effect was found for the training programmes of Osuagwu et al. (40) and Harvey et al. (35).

Furthermore, a more in-depth analysis on the effect of training variables on AHSP is provided in the next section of the quantitative analysis, based on 8 training programmes.

The results regarding the training modality are shown in Fig. 4. A moderate effect was found in skill training alone or combined with strength and endurance training of 0.55 and 0.53, respectively. Analytical training and skill training combined with strength training showed small MES values between 0.35 and 0.41.

The effect of the task-oriented training components is shown in Fig. 5. Functional movements, clear functional goals, real-life object manipulation, context-specific environment, exercise variety, multiple movement planes, total skill practice, and bimanual practice had moderate MES values between 0.53 and 0.60. The task-oriented training components, client-centred patient goal, overload, exercise progression, feedback, random practice, and distributed practice show small MES values between 0.41 and 0.45.

Fig. 6 shows the duration in weeks. Training for 8 weeks or more showed moderate MES values between 0.60 and 0.69. Training 3–4 weeks and 5–6 weeks shows small MES values of 0.41 and 0.44, respectively.

DISCUSSION

The objectives of this systematic review are: (*i*) to identify information on the chosen 3 training variables, i.e. motor training strategies, therapy dose dimensions, and persons' motivation in arm-hand training programmes in current research, and (*ii*) their effect on AHF and AHSP in pwC-SCI in the subacute and chronic phases.

Of the included training programmes, 53% used skill training alone or combined with strength and/or endurance training. More than 50% of the training programmes incorporated the task-oriented training components multiple movement planes, functional movements, clear functional goals, and bimanual practice. The in-depth analysis of 8 training programmes showed that training programmes using only skill training or combined with strength and endurance training exhibited a moderate effect on AHSP. Training programmes that integrate the task-oriented training components: functional movements, clear functional goals, real-life object manipulation, multiple movement planes, total skill practice, context-specific environment, exercise variety, and bimanual practice demonstrated a moderate effect on AHSP.

Duration in weeks emerged as the most commonly reported therapy dose dimension, with 35% of the programmes documenting an 8-week training duration. Half of the training programmes described 3 intervention days per week. The in-depth analysis of 8 training

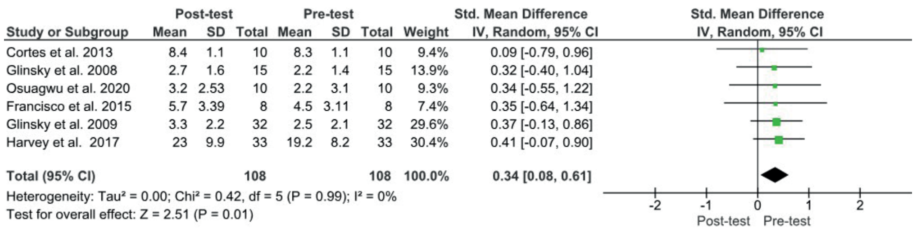

Fig. 2. Effect of motor training on arm-hand function (AHF). SD: standard deviation; 95% CI: 95% confidence interval.

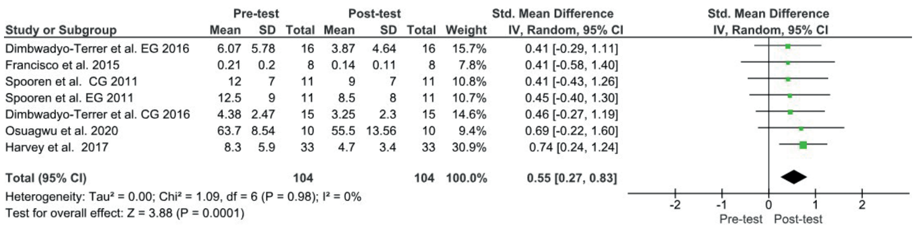

Fig. 3. Effect of motor training on arm-hand skilled performance (AHSP). EG: experimental group; CG: control group. SD: standard deviation; 95% CI: 95% confidence interval

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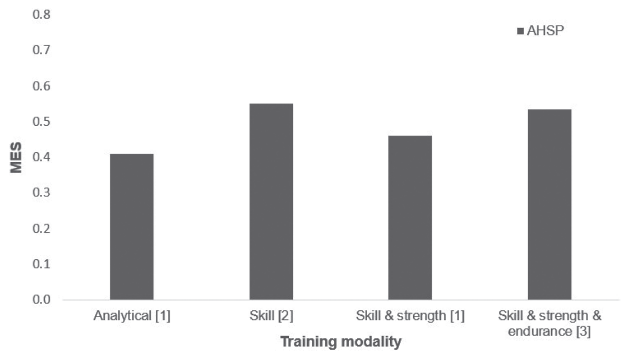

Fig. 4. Training modality. MES: mean effect in size; AHSP: arm-hand skilled performance [number of motor training programmes].

programmes revealed that engaging in training for a minimum of 8 weeks yielded a moderate effect on AHSP. Only 1 training programme reported on a persons' motivation element, using client-centred goals.

Motor training strategies

The findings regarding training modalities demonstrated enhanced AHSP through either skill training alone or combined with strength and endurance training. These findings align with the theories proposed by Dunlop (5) and Kleim & Jones (11), suggesting skill reacquisition through task-specific training and the training of diverse tasks to drive neural plasticity across different neural circuitries (5, 11). Furthermore, these results are consistent with studies conducted on animal models in SCI, where it is established that task-specific training improves arm-hand function (6, 42). To guide clinical practice, it is necessary to have a clear description of task-specific training. Hubbard et al. (43) define task-specific training as "practicing context-specific motor tasks with some form of feedback and focusing on improving performance in functional tasks by using goal-oriented practice and repetition".

This definition supports the findings of the current review on the importance of functional movements, clear functional goals, real-life object manipulation, multiple movement planes, bimanual practice, context-specific environments, exercise variety, and total skill practice.

However, Hubbard et al. (43) highlight the importance of feedback, which was poorly reported in the included motor training programmes, and the in-depth analysis showed a small effect on AHSP. Literature suggests feedback is critical in promoting skill acquisition and overall motivation (44). This aligns with research on task-oriented training components in stroke rehabilitation, which provided evidence supporting the incorporation of feedback within training programmes (24). In stroke rehabilitation, the importance of random and distributed practice was highlighted, which was not included in SCI (24). However, both reviews indicate the importance of including clear-functional goals in the training programmes. The only similarity with research on task-oriented training components in MS was the importance of using functional movements (45).

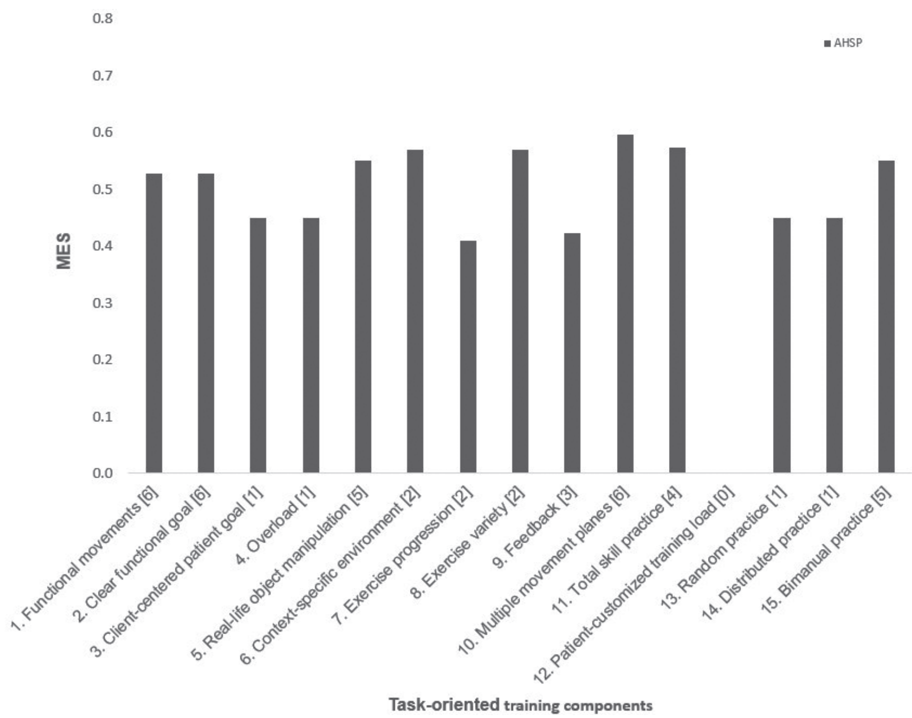

Fig. 5. Task-oriented training components. MES: mean effect in size; AHSP: arm-hand skilled performance [number of motor training programmes].

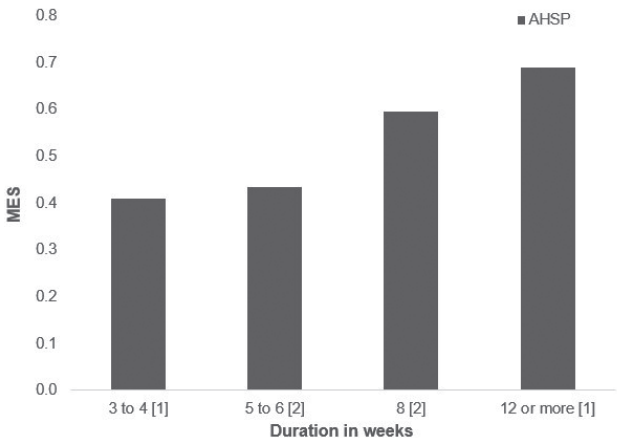

Fig. 6. Duration in weeks. MES: mean effect in size; AHSP: arm-hand skilled performance [number of motor training programmes].

Therapy dose dimensions

While suggestions in literature are made about the importance of therapy dose on SCI recovery (46, 47), little is known about the actual effect of therapy dose on functional outcomes. Clinicians need more evidence-based information on therapy doses to create an optimal training programme to improve AHSP.

Currently, studies are not reporting every therapy dose dimension. Based on our review, only duration in weeks and intervention days are frequently reported. At this point, too little is known about the dimensions at session level. Especially in skill training, session length, episode length, episode difficulty, and episode intensity are difficult to capture due to the complexity of upper limb movements in functional tasks (16). Overload, exercise progression, and customized training load possibly interlink with episode difficulty and intensity, which are scarcely reported in the included papers. These 3 components are embedded in strength, endurance, and analytical training programmes, but only a little attention is paid to it in skill training.

Person's motivation

Only one study reported using client-centred training goals as a component to increase motivation; client-centred training goals are still not widely used in motor training programmes. Literature suggests that personally meaningful goals may improve the overall rehabilitation process and outcomes (15). This is in accordance with Dunlop (5), and suggests that stimuli must be behaviourally relevant to induce neural plasticity.

Methodological considerations

This is the first study identifying different training variables in motor training programmes and their effect on AHF and AHSP in pwC-SCI. The number of high qualitative studies investigating motor training programmes in pwC-SCI is limited. Due to the lack of qualitative RCTs on motor training, different study designs were included in the review. The analysis was based on the effect size of the pre-post results. This may result in methodological heterogeneity; however, the analyses on the effect of motor training programmes on AHF and AHSP show no substantial heterogeneity based on the I^2 scores. Moreover, the studies included a wide range of patient characteristics, such as lesion levels and AIS scores, leading to clinical heterogeneity between participants. The included studies were also conducted in different populations, which may influence the effect (48). Separate analysis for complete and incomplete lesions and subacute and chronic stage was performed, and the results were in line with analyses of total groups, but were not reported here due to the insufficient number of studies on which the data was based. The findings of the meta-analysis must be interpreted with caution because it is impossible to untangle the proportion of the effect caused by the intervention compared with natural recovery.

Furthermore, a variety of outcome measures at the ICF activity level are classified under AHSP. Due to the limited number of studies included in the analysis, it was not feasible to further subdivide AHSP into basic and complex activities. This specific lack of detail may somewhat hamper the applicability of such information in AHSP treatment.

Eight studies did not reported on the therapy dosage of the additional standard care that participants received in the experimental groups. Therefore, the actual therapy dosage might be higher than the reported experimental intervention.

Future research

To guide clinical practice, it is necessary to comprehensively report on all therapy dose dimensions in future studies' interventions. Each element of therapy dose dimensions is important in the clinical decision-making of motor training programmes. It is also important to explore how the current therapy dose dimensions in arm-hand motor training programmes can be objectively measured. With these insights, future studies on optimizing therapy dosage can be measured accurately.

Little is known about the impact of motivation in training programmes on the recovery of arm-hand functioning. Literature on neurological recovery indicates the importance of motivation to induce neuroplastic changes (49). However, the complex interaction between motivation, neuroplasticity, and functional recovery is unclear. Further research is necessary to gain more insight into the effect of this training variable.

Improving AHF and AHSP is a complex interaction between training variables. In stroke rehabilitation, Kleynen et al. (50) and Hayward et al. (14) described that clinicians rarely use isolated interventions to improve functional recovery. Further research is necessary to investigate the influence of training variables, such as motor training strategies and therapy dose dimensions, and their combination and interaction on functional recovery in SCI. More insight into this topic will guide therapists in constructing optimal training programmes for their patients.

Furthermore, the underlying mechanisms of functional recovery at cortical and spinal levels are not fully understood. Insights into the impact of different training variables on the underlying mechanisms would greatly contribute to the evidence-based rehabilitation of arm-hand training in pwC-SCI.

In conclusion, the analysis based on the limited number of motor training programmes included in this review highlights the importance of incorporating specific training variables to enhance AHSP. Adopting a training modality with only skill training or combined with strength and endurance training is important. Furthermore, the integration of task-oriented training components, including functional movements, clear functional goals, real-life object manipulation, multiple movement planes, total skill practice, context-specific environment, exercise variety, and bimanual practice is suggested. Lastly, a minimum training duration of 8 weeks is recommended to optimize the outcomes of AHSP improvement.

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