ISCoS The International Spinal Cord Society
www.nature.com/sc

ARTICLE

Check for updates

Arm-hand training strategies and therapy dose dimensions during the subacute rehabilitation of people with cervical spinal cord injury: a longitudinal observational study

Nele Bertels [1]✉, Yvonne Janssen-Potten [2,3], Charlotte van Laake-Geelen [2,3], Kathleen Borgions [4], Kristine Oostra [5] and Annemie Spooren [1]

STUDY DESIGN: Longitudinal observational study.
OBJECTIVES: To explore motor training strategies, therapy dosage, and motivation in subacute arm-hand rehabilitation for individuals with cervical spinal cord injury and their change over a 6-month rehabilitation period.
SETTING: Three rehabilitation centers in Belgium and the Netherlands.
METHODS: Individuals with lesions between C1-Th1 and AIS A–D were included between 4–8 weeks post-injury and observed for three weeks with an eight-week interval. Regular arm-hand training sessions, with at least 25% arm-hand training, were analyzed. Motor training strategies, therapy dosage, and motivation were collected by two trained observers, video recordings and patient-reported outcome measures.
RESULTS: 240 Sessions from thirteen participants (mean age 54.4 ± 12.9; C1-C5; AIS B–D) were included. Analytical training showed the highest active arm-hand use (30.3%), followed by skill training (26.6%). Of the 15 task-oriented components, only multiple movement planes, functional movements, and feedback were used in ≥60% of sessions. Actual session time averaged 78.3% of the planned duration. During the arm-hand session, 52.1% of the time involved active time. Skill training showed the lowest number of repetitions (MED: 66.5). Participants reported low physical fatigue (4/10) and difficulty (4/10) but high motivation (7/10). Limited changes in training variables were observed over six months.
CONCLUSION: Our findings reveal a gap between clinical practice and evidence-based guidelines for arm-hand training. Despite its importance, skill training and key task-oriented components are underused. Low perceived difficulty and intensity, contrasted with high motivation, suggest the potential to increase therapy doses for better rehabilitation outcomes.

Spinal Cord (2025) 63:557–565; https://doi.org/10.1038/s41393-025-01120-x

INTRODUCTION

Spinal cord injury (SCI) had a global incidence of 909.000 in 2019, with 54% of these cases involving people with a cervical spinal cord injury (PwC-SCI) [1]. Cervical SCI causes arm-hand impairment, impacting the performance of activities of daily living, independence, participation, and socio-economic activities [2, 3]. PwC-SCI prioritizes enhancing arm-hand skilled performance, which corresponds to the 'activity' level in the International Classification of Functioning Disability and Health, as a crucial aspect of their functional recovery [4, 5].

Repetitive motor training is considered the gold standard for improving arm-hand function [6], with systematic reviews demonstrating its positive effects on muscle strength and performance in daily activities [2, 5, 7]. However, variation in training modalities and therapy dosage makes it challenging to define optimal rehabilitation programs [5]. Effective arm-hand training depends on multiple variables [8]. Based on the literature, motor training strategies, therapy dosage, and motivation have been identified as key variables of effective arm-hand training [9, 10].

Evidence from a systematic review supports the efficacy of skill training alone or combined with strength and endurance training for improving arm-hand skilled performance [11]. The included studies support integrating eight task-oriented training components based on motor learning principles [11–13]. Although therapists acknowledge these principles [14], observational studies in PwC-SCI show clinical practice often focuses on stretching, range of motion, and strengthening [15, 16], a pattern also observed in general SCI rehabilitation [17]. Although a minimum of eight weeks of training is recommended [11], evidence from a systematic review suggests that increased therapy duration or repetitions do not result in consistently improved muscle strength or functional independence [18]. Therapists recommend tailoring therapy doses to the individual's optimal load capacity to maximize rehabilitation outcomes, though this remains challenging due to the multi-dimensional nature of therapy dosing [11]. An observational study

[1]Hasselt University, Rehabilitation Research Center REVAL, Diepenbeek, Belgium. [2]Adelante Centre of Expertise in Rehabilitation and Audiology, Hoensbroek, Netherlands. [3]Maastricht University, Research School CAPHRI, dept. of Rehabilitation Medicine, Maastricht, Netherlands. [4]University Hospitals Leuven, Department of Physical and Rehabilitation Medicine, Pellenberg, Belgium. [5]Ghent University Hospital, Department of Physical Medicine and Rehabilitation, Ghent, Belgium. ✉email: nele.bertels@uhasselt.be

Received: 7 April 2025 Revised: 11 September 2025 Accepted: 18 September 2025
Published online: 25 September 2025

by Zbogar et al. [19] reported that only 60% of therapy time involved direct therapist-patient interaction, with no significant change between admission and discharge. Notably, upper limb repetitions in this study were low and declined significantly through inpatient rehabilitation. The impact of motivation on arm-hand skilled performance remains understudied in the literature, though its importance for engagement is recognized by clinical experts [11, 14]. Despite the evidence supporting task-oriented training tailored to the individual's optimal load capacity, detailed descriptions of motor training strategies, therapy dosage, and motivational engagement in clinical practice remain scarce. Whether current arm-hand training aligns with recommended practices or how these training variables evolve over time remains unclear.

This study primarily aimed to explore (a) motor training strategies, i.e., training modality and task-oriented components, (b) therapy dose dimensions, and (c) motivation in current subacute arm-hand rehabilitation. The secondary aim was to assess changes in these factors over a 6-month rehabilitation period. Changes in these training variables were expected over time.

METHOD

Study design and setting

The multicenter longitudinal observation study was conducted at the SCI rehabilitation wards of Adelante Zorggroep (The Netherlands), University Hospitals Leuven (Belgium), and University Hospital Ghent (Belgium). Data was collected from September 2022 until July 2023. The study was approved by the ethical committees of Adelante Zorggroep (NL81062.015.22), University Hospitals Leuven (S66546), University Hospital Ghent (ONZ-2022-0187), and Hasselt University (CME2022/007). The study was registered on ClinicalTrials.gov (NCT05452707).

Participants

Participants were consecutively recruited after screening for eligibility by the rehabilitation physician. The inclusion criteria were: non-traumatic or traumatic cervical SCI between C1 and T1; AIS score A–D according to the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI); four to eight weeks post-injury; age over 16 years; and ability to follow standard arm–hand training. Exclusion criteria were co-morbidity concerning neurological, rheumatologic, and orthopedic diseases that might strongly interfere with arm-hand training. Therapists who participated in the study by performing the therapy sessions had at least two years of experience working with SCI. All participants signed an informed consent before entering the study. Observations were conducted in rehabilitation facilities after patients were medically stable and enrolled in standard rehabilitation. PwC-SCI participated in three observation weeks, spaced eight weeks apart: measuring moment (MM) 1 (weeks 4–8 post-injury), MM2 (weeks 12–16), and MM3 (weeks 20–24). Each week, data were collected on three randomly selected weekdays using a computer-generated sequence (Random.org) to ensure allocation concealment.

Observation protocol

A trained observer recorded all therapy sessions conducted by occupational therapists, physiotherapists, and sports therapists. These sessions were also video-recorded for further analysis. The analysis included only sessions where arm-hand therapy constituted at least 25% of the total session time.

The observation protocol used on-site observation, video recordings, and patient-reported outcome measures. Data on motor training strategies, therapy dose dimensions, and motivation were collected during the observations of a single participant during both individual and group sessions. Table 1 outlines the variables and the corresponding measurement methods. The motor training strategies were categorized into four training modalities and 15 task-oriented training components as defined by Timmermans et al. [13]. Therapy dose dimensions were based on the framework proposed by Hayward et al. [20], developed for stroke rehabilitation but adapted for the context of this study. Five objective and two subjective therapy dose dimensions were collected during the sessions.

Additionally, participants rated how motivating the session was via a patient-reported outcome measure. The first author trained master's students in occupational and rehabilitation science to assist in data collection. To prepare, students reviewed video recordings of arm-hand therapy sessions for PwC-SCI and completed predefined scoring sheets. To ensure reliability, each student had to achieve at least 90% agreement on test videos with the first author (occupational therapist with six years of clinical experience) before collecting data. For the initial 70 sessions, two independent observers analyzed the videos. The inter-rater reliability, calculated using the intra-class correlation coefficient, was 0.91, indicating excellent agreement. As a result, the remaining sessions were analyzed by a single rater.

Initially, all variables were analyzed by video recordings. As observers became more experienced with data processing, the variables 'session length arm-hand,' 'active time arm-hand,' and 'objective session intensity' were recorded in real-time during the sessions.

To minimize social desirability bias, participants were informed that the study's purpose was to document therapy practices rather than evaluate individual behavior. Therapists were instructed to conduct sessions as usual and to avoid interacting with the observer. A weekly process evaluation was conducted to further control for bias, asking therapists, "Do you think you adjusted the therapy content/dose this week compared to weeks without observation?" Responses were rated on a visual analog scale from 0 (not adjusted) to 10 (adjusted).

Study size

The sample size calculation for this study was guided by the study of Lang et al. [21], who observed 312 therapy sessions and a post hoc power calculation based on data from the first five participants. The power analysis was conducted using a one-way ANOVA for all therapy dose dimensions, with data log-transformed for normality. Calculations were performed in IBM SPSS version 29.0, using a predetermined power of 0.80 and a significance level of 0.05. Power calculation determined that a sample size of 118 sessions was required, with the calculation based on the variable "physical fatigue after the session," which had the largest sample size requirement. Consequently, the study aimed to include between 118 and 312 sessions to capture the natural variability in the observed training variables over time.

Statistical analysis

All statistical analyses were conducted using IBM SPSS version 29.0. Participant characteristics were summarized using means and standard deviations (SD). The normality of continuous variables was assessed using the Shapiro-Wilk test and graphical methods, including symmetry checks. Log transformations were applied to variables analyzed for differences between measuring time points to meet normality assumptions.

Descriptive statistics for motor training strategies, therapy dose dimensions, and motivation were reported as medians with interquartile ranges (IQR), frequencies, and percentages. Statistical differences between measurement moments were assessed using one-way ANOVA, except for task-oriented training components, which were analyzed using the chi-square test due to their nominal nature. The subanalysis was conducted using the Spearman correlation coefficient to explore the relationship between the therapy dose dimensions, 'active time' and 'session intensity objectively', and 'session difficulty' and 'session intensity subjectively'.

RESULTS

Participant and session characteristics

During the recruitment period of six months, thirteen individuals were found eligible, agreed to participate, and participated in the study across the three participating rehabilitation centers. Table 2 describes the participant and session characteristics. The analysis includes 240 sessions distributed over three measurement moments, with most sessions conducted by physiotherapists. Four participants (AIS D; C4–C5) did not complete the third measuring moment due to early discharge.

Motor training strategies

As shown in Table 3, among the various training modalities, the largest proportion of active therapy time dedicated to upper limb function was allocated to analytical training (30.3%). Of all modalities, only endurance training increased significantly ($p = 0.03$) across the three measurement time points. Within skill training, most therapy

Table 1. Overview variables.

		OB	VR	PROM
Motor training strategies				
Training modality	**A specific training form with active motor movements** [11]			
	1. Endurance training: Training to reduce neuromuscular fatigue and/or increase cardiovascular fitness[24]	x	x	
	2. Strength training: Training to increase voluntary strength [24]	x	x	
	3. Analytical training: Movements without a specific goal, usually occurring in one single movement plane and one single joint [13]	x	x	
	4. Skill training (basic and complex): Defined according to the International Classification of Functioning, Disability and Health ***Basic:*** sitting balance, fine hand use, and hand and arm use ***Complex***: washing oneself, dressing, preparing meals, caring for body parts, eating, doing housework, toileting and drinking	x	x	
Task-oriented training components	**Training characteristics supporting motor learning** [13]			
	1. Functional movements	x		
	2. Clear functional goal	x		
	3. Client-centered goal	x		
	4. Overload	x		
	5. Real-life object manipulation	x		
	6. Context-specific environment	x		
	7. Exercise progression	x		
	8. Exercise variety	x		
	9. Feedback	x		
	10. Multiple movement planes	x		
	11. Total skill practice	x		
	12. Patient-customized training load	x		
	13. Random practice	x		
	14. Distributed practice	x		
	15. Bimanual practice	x		
Therapy dose dimensions				
Objective therapy dose dimensions	**1. Planned therapy time:** The planned session time on the person's schedule	x		
	2. Session length: The time the patient and therapist interact in the therapy context	x		
	3. Session length arm-hand: The time of the session length that is spent on arm-hand training	x	x	
	4. Active time arm-hand: Active time was measured by the time the person actively moved the upper limb during the session length. When the person was not actively moving the upper limb for more than 5 s, this was accounted as rest and indicated as non-active time.	x	x	
	5. Session objective intensity: Every repetition of the upper limb during endurance, strength, and analytical training was defined as any movement from the initial position and back, from the initial position to the desired position, and from one surface to another using the upper limb [19]. The repetitions during skill training were defined as any movement that accomplishes or attempts to accomplish a functional task [21]. Every repetition with the upper limb was counted using a hand counter	x	x	
Subjective therapy dose dimensions	**1. Session subjective intensity:** How intense the person perceives the task, is indicated by the level of physical fatigue. The person indicated before and after the session how physically fatigued he was on a visual analog scale from 0 (not physically fatigued at all) to 10 (extremely physically fatigued)			x
	2. Session difficulty: How hard the person intrinsically perceives the task. The person indicated after each session how difficult the session was for him on a visual analog scale from 0 (not difficult at all) to 10 (extremely difficult)			x
Motivation				
Motivation	**The person indicated after each session how motivated the session was for him on a visual analog scale from 0 (not motivating at all) to 10 (extremely motivating)**			x

OB observer, *VR* video-recording, *PROM* patient-reported outcome measures.

time (95.5%) was focused on basic skills, including sitting balance, fine hand use, and hand-arm use, rather than on more complex skills, such as activities of daily living. Among the fifteen task-oriented training components, the most frequently implemented were multiple movement planes (76.3%), functional movements (64.6%), feedback (64.2%), exercise variety (55%), patient-customized training load (55%), and client-centered goals (53.3%). Notably, real-life object manipulation increased significantly ($p = 0.01$) while exercise progression ($p = 0.02$) and distributed practice ($p = 0.01$) significantly decreased across the three measurement time points.

Therapy dose dimensions

The median planned weekly therapy hours was 16h (IQR: 14h19 – 17h34), including physiotherapy, occupational therapy, and sports therapy, corresponding to a daily median between 3h and 3h30.

In-depth analysis at the session level revealed the following median values for objective therapy dose dimensions: a planned therapy duration of 60 min (IQR: 30–60 min), actual session length of 47 min (IQR: 25–56 min), the session length specifically focused on arm-hand activities of 37 min and 29 s (IQR: 17–52 min), and an

Table 2. Participant and session characteristics.

Patients (n = 13)			
	MM1 (n = 13)	**MM2 (n = 13)**	**MM3 (n = 9)**
AIS score	B–D • B: 1 • C: 5 • D: 7	B–D • B: 1 • C: 5 • D: 7	B–D • B: 1 • C:5 • D:3
Lesion levels	C1–C5 • C1: 1 • C3: 1 • C4: 7 • C5: 4	C1–C5 • C1: 1 • C3: 1 • C4: 7 • C5: 4	C1–C5 • C1: 1 • C3: 1 • C4: 6 • C5: 1
Age mean (SD)	54.4 (12.9)	54.4 (12.9)	57.7 (13.6)
Gender	Male (13)	Male (13)	Male (9)
Post-injury in weeks mean (SD)	6.7 (1.8)	14.5 (1.8)	23.1 (1.8)
Traumatic/ non-traumatic	Traumatic (13)	Traumatic (13)	Traumatic (9)
Inpatient/ outpatient	Inpatient (13)	Inpatient (11) Outpatient (2)	Inpatient (7) Outpatient (2)
Therapists (*n* = 38)			
Disciplines	Physiotherapist: 48.6%		
	Occupational therapists: 32.4%		
	Sports therapists: 16.2%		
	Physiotherapy assistants: 2.7%		
Experience in years mean (SD)	13 (8.4)		
Sessions (*n* = 240)			
Measuring moment	MM1: 92 sessions		
	MM2: 91 sessions		
	MM3: 57 sessions		
Disciplines	Physiotherapy: 55%		
	Occupational therapy: 38%		
	Sports therapy: 5%		
	Physiotherapy assistant: 1%		
	Physiotherapy and sports therapy: 1%		

AIS American Spinal Injuries Association Impairment Scale, *MM* measuring moment.

active arm-hand engagement time of 19 min and 44 s (IQR: 11 min 30 s–31 min 18 s). The actual session length accounted for only 78.3% of the planned therapy time; active arm-hand engagement represented 52.1% of the arm-hand session length.

Figure 1 illustrates the changes in objective therapy dose dimensions across measuring time points. No statistically significant differences were observed over time for planned therapy time ($p = 0.63$), session length ($p = 0.59$), arm-hand session length ($p = 0.94$), or active time arm-hand ($p = 0.87$).

A descriptive overview of objective therapy dose dimensions was conducted based on planned therapy time and session format (individual versus group). The highest proportion of active arm-hand time was observed in sessions planned for ≤30 min (75.4%). Group and individual sessions were comparable in session length (82.5 versus 76.7%, respectively) and in the proportion of active time (51.6 vs. 54.4%).

Figure 2 presents the total number of repetitions performed during active arm-hand time, categorized by training modality. Across all sessions, endurance training exhibited the highest median number of repetitions (MED: 371) and skill training the lowest (MED: 66.5). No statistically significant differences in the number of repetitions were observed across measurement time points for endurance training ($p = 0.21$), strength training ($p = 0.77$), analytical training ($p = 0.56$), or skill training ($p = 0.22$). A subanalysis reveals strong significant correlations between active time and number of repetitions across all training modalities: endurance training ($r = 0.75$; $p < 0.001$), strength training ($r = 0.87$; $p < 0.001$), analytical training ($r = 0.85$; $p < 0.001$) and skill training ($r = 0.60$; $p < 0.001$).

The subjective therapy dose dimensions analysis of the total sessions showed that physical fatigue before the session, was scored a median of 3 (IQR: 2–4), and after the session, a median of 4 (IQR: 3–5). The median score for session difficulty was 4 (IQR: 3–6).

Figure 3 illustrates the variations in these subjective therapy dose dimensions between the measuring moments; no significant changes were found for physical fatigue after the session ($p = 0.21$) or session difficulty ($p = 0.25$). A subanalysis reveals a significant high correlation between session difficulty and physical fatigue after the session ($r = 0.70$; $p < 0.001$).

Motivation

The motivation scores showed a median of 7 (IQR: 6–8) for the total session. With an equal score of 7 over the three measuring moments (IQR: 6–8; 6–8; 5.25–8 respectively).

Bias

Therapists completed 83 weekly process evaluations using a 0-10 visual analog scale to rate: “Do you think you adjusted the therapy content/dose this week compared to weeks without observation?” The results were identical for content and dose adjustments; the median score was 1 (IQR: 0–2).

DISCUSSION

Our results reveal critical insights into applying motor training strategies and therapy dose dimensions in clinical practice. Analytical training resulted in the highest proportion of active arm-hand use, whereas complex skill training demonstrated surprisingly low active time. Endurance training was the only modality that increased significantly over six months. Although task-specific training is considered essential for skill acquisition, only six of the 15 observed task-oriented training components were implemented in more than half of the sessions, with minimal changes over time. Only half of the arm-hand session time was devoted to active training, with particularly low repetition rates during skill training. Despite this, PwC-SCI reported low physical fatigue and difficulty levels, accompanied by high motivation.

Motor training strategies

The data suggest that most active arm-hand training focuses on analytical training, identified by therapists as essential for creating optimal conditions for task-specific training [14]. However, contrary to our expectations, analytical training decreased only between the first and second measurements, without a corresponding shift toward skill training. Skill training, particularly for complex skills, was allocated minimal time and was rarely practiced. This is further reflected in the underuse of task-oriented training components essential for effective skill acquisition [12], such as clear functional goals, real-life object manipulation, context-specific environments, and total skill practice.

Evidence confirms the use of skill training combined with strength and endurance training to improve arm-hand skilled performance [11]. Experienced therapists support this approach,

Table 3. Motor training strategies.

Training modality									
	%				Median (Q1–Q3) (min:sec)				Significance (p > 0.05)
	Total	MM1	MM2	MM3	Total	MM1	MM2	MM3	
Endurance training	**22.2**	7.4	23	22.7	**9:36 (04:02–17:31)**	2:46 (00:51–10:47)	9:57 (04:22–18:18)	10:49 (08:27–17:53)	0.03*
Strength training	**21**	26.6	19.2	22.4	**9:05 (02:58–15:35)**	10:00 (03:21–18:12)	8:19 (02:57–13:01)	10:42 (02:56–16:38)	0.66
Analytical training	**30.3**	40.9	26.2	28	**13:06 (06:57–20:38)**	15:22 (06:02–19:39)	11:21 (07:25–20:09)	13:22 (06:46 –25:42)	0.6
Skill training	**26.6**	25.2	31.5	26.9	**11:30 (03:33–21:29)**	9:28 (04:39–18:39)	13:39 (01:57–26:37)	12:51 (06:09–21:29)	0.41
Basic	***91.5***	*88.9*	*92.3*	*92.9*	***11:10 (03:54–21:05)***	*10:04 (06:33–20:43)*	*13:38 (02:36–23:53)*	*12:44 (04:27–20:29)*	*0.98*
Complex	**8.5**	11.1	7.7	7.1	**1:02 (00:37–04:08)**	1:15 (00:36–04:10)	1:08 (00:33–17:05)	0:58 (00:46–03:00)	0.66

Task-oriented training components									
	%				Frequencies				Significance (p > 0.05)
	Total	MM1	MM2	MM3	Total	MM1	MM2	MM3	
Functional movements	**64.6**	59.8	68.1	66.7	**155**	55	38	38	0.46
Clear functional goal	**41.7**	42.4	38.5	45.6	**100**	39	35	26	0.68
Client-centered goal	**53.3**	46.7	53.8	63.2	**128**	43	49	36	0.15
Overload	**13.3**	10.9	15.4	14	**32**	10	14	8	0.66
Real-life object manipulation	**25**	25	16.5	38.6	**60**	23	15	22	0.01*
Context-specific environment	**9.6**	13	5.5	10.5	**23**	12	5	6	0.21
Exercise progression	**32.9**	41.3	33	19.3	**79**	38	30	11	0.02*
Exercise variety	**55**	58.7	58.2	43.9	**132**	54	53	25	0.15
Feedback	**64.2**	71.7	60.4	57.9	**154**	66	55	33	0.15
Multiple movement planes	**76.3**	69.6	83.5	75.4	**183**	64	76	43	0.08
Total skill practice	**20.4**	16.3	23.1	22.8	**49**	15	21	13	0.46
Patient-customized training load	**55**	56.5	60.4	43.9	**132**	52	55	25	0.13
Random practice	**37.9**	39.1	41.8	29.8	**91**	36	38	17	0.33
Distributed practice	**10.4**	14.1	13.2	0	**25**	13	12	0	0.01*
Bimanual practice	**47.1**	46.7	47.3	47.4	**113**	43	43	27	0.99

MM1: 4–8 weeks post-injury; MM2: 12–16 weeks post-injury; MM3: 20–24 post-injury.
MM measuring moment.
*Statistical significance with One-way ANOVA (training modality) and Chi-square Test (Task-oriented training components).

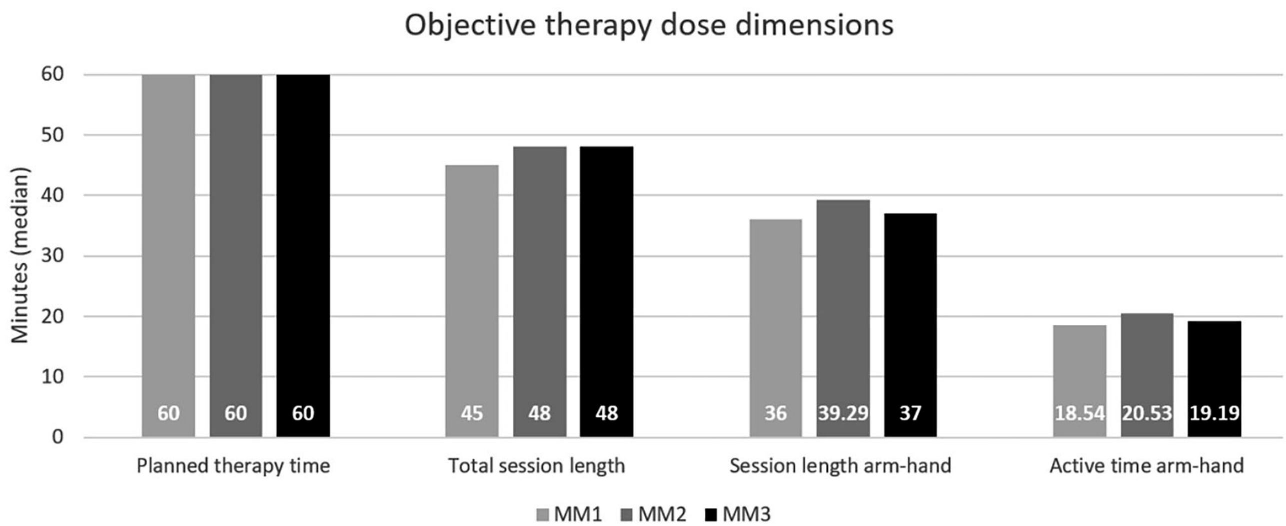

Fig. 1 Objective therapy dose dimensions across measuring time points. This figure shows the objective therapy dose dimensions: plannend therapy time, total session length, session length arm-hand and active time arm-hand from measuring moment (MM) 1 to measuring moment (MM) 3.

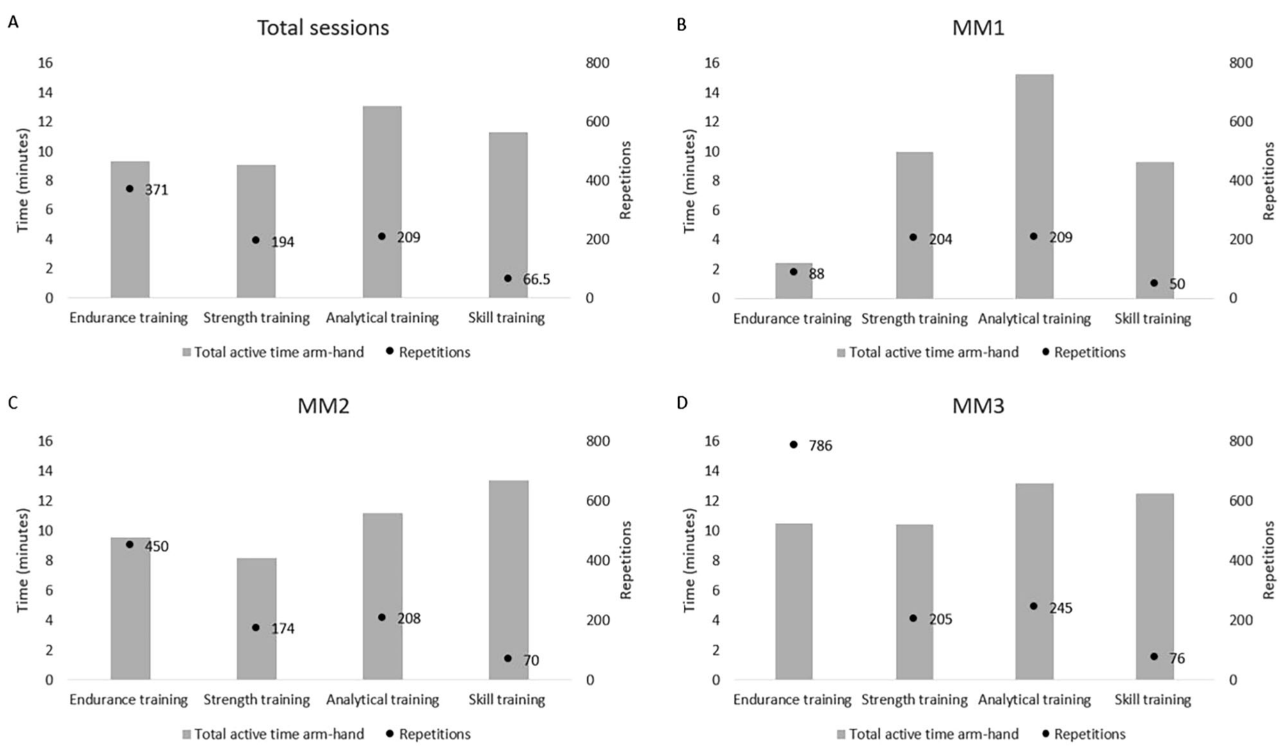

Fig. 2 Total Repetitions during active arm-hand time. A Repetitions during active arm-hand time of the total sessions; **B** Repetitions during active arm-hand time of measuring moment (MM) 1; **C** Repetitions during active arm-hand time of measuring moment (MM) 2; **D** Repetitions during active arm-hand time of measuring moment (MM) 3.

prioritizing skill training while integrating analytical, strength, and endurance training to optimize conditions for task-specific training, a form of skill training. However, the optimal balance among these modalities remains unclear, requiring therapists to rely on intuition [14]. In contrast, our study did not observe a prioritization of skill training over other training modalities, and key task-oriented training components remain underutilized, potentially limiting individuals' abilities to perform meaningful activities. This raises the question of whether therapists are unaware of the limited time spent on skill training or whether other factors influence its application.

The distribution of training modalities observed in this study aligns with previous research, including the SCIRehab project [15, 16] and Van Langeveld et al. [17], who already highlighted the limited emphasis on complex skill training over a decade ago.

The decline in exercise variety and progression over time may suggest that training content stabilizes in the later stages of rehabilitation. While this could be beneficial if PwC-SCI engage in repeated, task-specific practice, the limited focus on complex skill training likely indicates a plateau in the progression and variety of the training, potentially hindering further improvements in arm-hand skilled performance. PwC-SCI were also asked whether

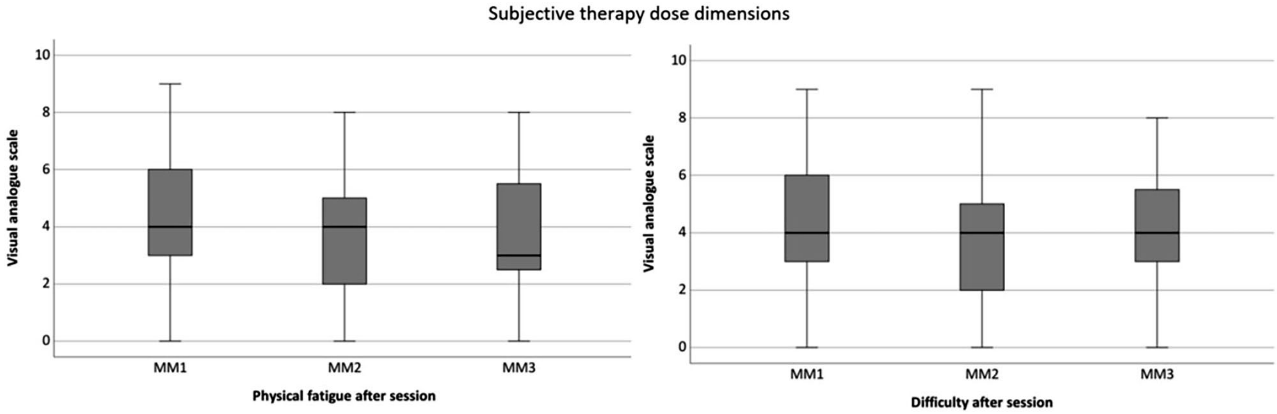

Fig. 3 Subjective therapy dose dimensions.

sessions aligned with their personal goals; only 53.3% reported that activities reflected these goals. This unexpectedly low percentage surprised therapists, who believed they addressed client-centered goals more often. Questions arose about the individuals' awareness of their therapeutic goals or how training activities relates to them. Despite this, evidence supports the benefits of client-centered goals in programs like ToCUEST for PwC-SCI [22]. Given its importance for rehabilitation outcomes, better implementation of person-centered care is needed [23].

Therapy dose dimensions

The current findings demonstrate that during arm-hand training, PwC-SCI actively move their arm-hands for 52.1% of each session, with repetition counts varying by training modality. Interestingly, endurance, strength, and analytical training demonstrated very strong correlations between active time and repetitions, suggesting that active time measurement could offer a practical alternative for manual repetition counting. However, skill training shows a weaker correlation, as each repetition took longer than in other modalities. Active time in our study was lower than the 60% therapeutic time reported by Zbogar et al. [19], though their definition included education and assessments, whereas we defined active time strictly as upper limb movement excluding inactivity over five seconds.

PwC-SCI reported relatively low levels of difficulty and subjective intensity. This aligns with the limited use of task-oriented training components, exercise progression, and patient-customized training load, with a notable decrease in exercise progression over time. Additionally, the principle of overload—a critical factor for effective training [2],—was rarely applied; which may help explain the low subjective intensity levels observed. These findings suggest that the training load could be increased to enhance rehabilitation outcomes. The absence of reliable tools to objectively assess difficulty and intensity in SCI rehabilitation remains a significant limitation [24]. Currently, therapists must rely on subjective judgment to tailor the training to the individual's optimal load capacity. This approach may result in suboptimal training adjustments that may not fully challenge PwC-SCI or maximize functional gains [14].

Motivation

Motivation remained high throughout training, with no significant changes over time. Motivation was assessed using the question, "How motivating was this session for you?"—allowing individuals to interpret the concept of motivation subjectively. However, the visual analog scale (VAS) may not fully capture motivation's complex and multidimensional nature, which arises from the interaction of various factors [25]. Motivation's impact on arm-hand training in PwC-SCI is underexplored; evidence from neurological rehabilitation highlights its role in driving behavioral change and functional improvement [10, 25]. Therapists reported motivation as critical, as it significantly influences individuals engagement [14].

Evidence versus clinical practice

Discrepancies were observed between evidence-based recommendations, therapists' perspectives, and clinical practice regarding motor training strategies and therapy dosage. The challenge of translating research into clinical practice is well-documented in rehabilitation science, mainly due to vague definitions and limited information regarding individual characteristics, intervention components, and contextual factors of scientific evidence [26, 27]. Therapists identify these barriers and emphasize the need for clearer, more structured guidelines to facilitate evidence-based, person-centered rehabilitation [14]. Conceptual frameworks that translate research into structured, actionable plans may offer a practical solution [28].

Methodological considerations

Data from 240 sessions across 13 male participants were analyzed. Variability in functional levels and the early discharge of four participants who missed the third measurement moment (AIS D, C4–C5) may have influenced the findings. Fixed eight-week intervals enabled standardized comparisons but led to variability in time from injury to measurement and length of stay, potentially limiting full coverage of the rehabilitation period. The study focused on clinical practice patterns, not individual recovery trajectories. Sessions were observed in rehabilitation wards associated with the Dutch-Flemish Spinal Cord Society, which follows joint rehabilitation guidelines and processes for PwC-SCI. Regional policies regarding therapy doses may limit generalizability. Only sessions with ≥25% arm-hand training were included to focus on relevant motor training and dose parameters. To assess the 'client-centered goals' component, participants reported post-session whether training aligned with personal goals. Weekly process evaluations indicated therapists maintained typical practice during observations. The use of VAS to assess domains beyond pain lacks extensive validation but was chosen for its practicality in a clinical setting. This limitation should be considered when interpreting the findings. Motivation measured via VAS, may be prone to social desirability bias. Participants may have reported higher motivation levels to meet the rehabilitation team's or researchers' perceived expectations.

Future research

First, the distribution of training modalities and use of task-oriented components did not align with literature recommendations [11] and therapists' suggestions explored in a qualitative study [14]. Future studies should explore more specifically why these recommendations are not fully implemented in clinical practice and identify the ideal distribution of motor training strategies to optimize arm-hand performance. Additionally, gaining insight into therapists' rationale for selecting specific motor training strategies would be valuable.

Second, the active arm-hand time, difficulty, and session intensity appeared relatively low, suggesting that the therapy dose could be increased. Research should examine whether increasing the therapy dose impacts arm-hand performance and neurophysiological outcomes.

Third, while motivation may influence functional outcomes, our study measured this variable unidimensionally. Future research could benefit from more extensive questionnaires or qualitative approaches, such as semi-structured interviews or focus groups with PwC-SCI, to gain a more comprehensive understanding. These methods could provide richer insights into how and why motivation levels are maintained and how specific training elements influence motivation.

Lastly, improving arm-hand skilled performance involves a complex interaction of training variables. Developing a comprehensive framework could help guide clinical practice.

CONCLUSION

Our findings reveal a critical gap between clinical practice and evidence-based recommendations for arm-hand training to improve arm-hand skilled performance. Despite the importance of skill training—particularly complex skill training—its application remains limited. The high correlation between active time and the number of repetitions highlights an opportunity to quantify these dose dimensions through active time measurement in clinical practice. Moreover, the low training difficulty and intensity, contrasted with high motivation scores, indicate an untapped potential to push training intensity further to optimize rehabilitation outcomes.

DATA AVAILABILITY

Additional data are available from the corresponding author on reasonable request.

REFERENCES

1. Ding W, Hu S, Wang P, Kang H, Peng R, Dong Y, et al. Spinal cord injury: the global incidence, prevalence, and disability from the global burden of disease study 2019. Spine. 2022;47:1532–40.
2. Kloosterman M, Snoek G, Jannink M. Systematic review of the effects of exercise therapy on the upper extremity of patients with spinal-cord injury. Spinal cord. 2009;47:196–203.
3. Rudhe C, van Hedel HJ. Upper extremity function in persons with tetraplegia: relationships between strength, capacity, and the spinal cord independence measure. Neurorehabil Neural Repair. 2009;23:413–21.
4. Snoek GJ, IJzerman MJ, Hermens HJ, Maxwell D, Biering-Sorensen F. Survey of the needs of patients with spinal cord injury: impact and priority for improvement in hand function in tetraplegics. Spinal Cord. 2004;42:526–32.
5. Spooren A, Janssen-Potten Y, Kerckhofs E, Seelen H. Outcome of motor training programmes on arm and hand functioning in patients with cervical spinal cord injury according to different levels of the ICF: a systematic review. Database Abstr. Rev. Eff. : Quality-assessed Rev. 2009;1:497–505.
6. Bilchak JN, Caron G, Côté MP. Exercise-induced plasticity in signaling pathways involved in motor recovery after spinal cord injury. Int. J. Mol. Sci. 2021;22:4858.
7. Lu X, Battistuzzo CR, Zoghi M, Galea MP. Effects of training on upper limb function after cervical spinal cord injury: a systematic review. Clin. Rehabil. 2015;29:3–13.
8. Hayward KS, Barker RN, Carson RG, Brauer SG. The effect of altering a single component of a rehabilitation programme on the functional recovery of stroke patients: a systematic review and meta-analysis. Clin. Rehabil. 2014;28:107–17.
9. Kleim JA, Jones TA. Principles of experience-dependent neural plasticity: implications for rehabilitation after brain damage. J. Speech Lang. Hear. Res. 2008;51:S225–39.
10. Dunlop SA. Activity-dependent plasticity: implications for recovery after spinal cord injury. Trends Neurosci. 2008;31:410–8.
11. Bertels N, Seelen H, Dembele J, Spooren A. Essential training variables of arm-hand training in people with cervical spinal cord injury: a systematic review. J. Rehabil. Med. 2023;55:jrm7147.
12. Hubbard IJ, Parsons MW, Neilson C, Carey LM. Task-specific training: evidence for and translation to clinical practice. Occup. Ther. Int. 2009;16:175–89.
13. Timmermans AA, Spooren AI, Kingma H, Seelen HA. Influence of task-oriented training content on skilled arm-hand performance in stroke: a systematic review. Neurorehabil Neural Repair. 2010;24:858–70.
14. Bertels N, Piškur B, Janssen-Potten Y, van Laake-Geelen C, Borgions K, Oostra K, et al. Therapists' perspectives on an interdisciplinary approach of arm-hand rehabilitation in cervical spinal cord injury: a qualitative study. Disabil Rehabil. 2025;6:1–8.
15. Foy T, Perritt G, Thimmaiah D, Heisler L, Offutt JL, Cantoni K, et al. The SCIRehab project: treatment time spent in SCI rehabilitation. Occupational therapy treatment time during inpatient spinal cord injury rehabilitation. J. Spinal Cord. Med. 2011;34:162–75.
16. Taylor-Schroeder S, LaBarbera J, McDowell S, Zanca JM, Natale A, Mumma S, et al. The SCIRehab project: treatment time spent in SCI rehabilitation. Physical therapy treatment time during inpatient spinal cord injury rehabilitation. J. Spinal Cord. Med. 2011;34:149–61.
17. van Langeveld SA, Post MW, van Asbeck FW, Gregory M, Halvorsen A, Rijken H, et al. Comparing content of therapy for people with a spinal cord injury in postacute inpatient rehabilitation in Australia, Norway, and The Netherlands. Phys. Ther. 2011;91:210–24.
18. Mateo S, Di Marco J, Cucherat M, Gueyffier F, Rode G. Inconclusive efficacy of intervention on upper-limb function after tetraplegia: A systematic review and meta-analysis. Ann. Phys. Rehabil. Med. 2020;63:230–40.
19. Zbogar D, Eng JJ, Miller WC, Krassioukov AV, Verrier MC. Movement repetitions in physical and occupational therapy during spinal cord injury rehabilitation. Spinal Cord. 2017;55:172–9.
20. Hayward KS, Churilov L, Dalton EJ, Brodtmann A, Campbell BCV, Copland D, et al. Advancing stroke recovery through improved articulation of nonpharmacological intervention dose. Stroke. 2021;52:761–9.
21. Lang CE, Macdonald JR, Reisman DS, Boyd L, Jacobson Kimberley T, Schindler-Ivens SM, et al. Observation of amounts of movement practice provided during stroke rehabilitation. Arch. Phys. Med. Rehabil. 2009;90:1692–8.
22. Spooren A, Janssen-Potten Y, Kerckhofs E, Bongers H, Seelen H. Evaluation of a task-oriented client-centered upper extremity skilled performance training module in persons with tetraplegia. Spinal cord. 2011;49:1049–54.
23. Rosewilliam S, Roskell CA, Pandyan A. A systematic review and synthesis of the quantitative and qualitative evidence behind patient-centred goal setting in stroke rehabilitation. Clin. rehabil. 2011;25:501–14.
24. Anderson KD, Field-Fote EC, Biering-Sørensen F, Bryden A, Harvey LA, Jones L, et al. International spinal cord injury physical therapy-occupational therapy basic data set (version 1.2). Spinal Cord. Ser. Cases. 2020;6:74.
25. Verrienti G, Raccagni C, Lombardozzi G, De Bartolo D, Iosa M. Motivation as a measurable outcome in stroke rehabilitation: a systematic review of the literature. Int. J. Environ. Res. Public. Health. 2023;20:4187.
26. Improved Clinical Effectiveness through Behavioural Research group (ICEBeRG). Designing theoretically-informed implementation interventions. Implement. Sci. 2006;1:4.
27. Dijkers MP, Murphy SL, Krellman J. Evidence-based practice for rehabilitation professionals: concepts and controversies. Arch. Phys. Med. rehabil. 2012;93:S164–S76.
28. Kafri M, Atun-Einy O. From motor learning theory to practice: a scoping review of conceptual frameworks for applying knowledge in motor learning to physical therapist practice. Phys. Ther. 2019;99:1628–43.

ACKNOWLEDGEMENTS

We want to thank the patients and SCI therapy teams of Adelante Zorggroep, University Hospitals Leuven, and University Hospital Ghent for participating in the study. We want to thank the rehabilitation and occupational science students for helping with the data collection and analysis. During the preparation of this work the author(s) used ChatGPT 3.5 and DeepSeek-V3 in order to improve the readability and language of the manuscript. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

AUTHOR CONTRIBUTIONS

NB, YJ, and AS conceived and designed the study. NB, KB, CV, and KO acquired the data. NB, YJ, and AS analyzed and interpreted the data. NB drafted the original manuscript. YJ, AS, KB, CV, and KO reviewed and edited the manuscript. NB administered the project, and YJ and AS provided supervision. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

FUNDING

Bijzonder Onderzoeksfonds (BOF) UHasselt 21OWB23.

COMPETING INTERESTS

The authors declare no competing interests.

ETHICAL APPROVAL

All methods were performed in accordance with the relevant guidelines and regulations. The study was approved by the ethical committees of Adelante Zorggroep (NL81062.015.22), University Hospitals Leuven (S66546), University Hospital Ghent (ONZ-2022-0187), and Hasselt University (CME2022/007).

INFORMED CONSENT

All participants provided written informed consent prior to study enrollment.

ADDITIONAL INFORMATION

Correspondence and requests for materials should be addressed to Nele Bertels.