The British Journal of Occupational Therapy

The effect of sensory discrimination training on sensorimotor performance in individuals with central neurological conditions: a systematic review

Journal:	*British Journal of Occupational Therapy*
Manuscript ID	032-Feb-2021-CR.R1
Manuscript Type:	Review
Key Areas:	Clinical, Research Methods and Methodology
Keywords:	neurological, sensory discrimination, somatosensation, systematic review, tactile discrimination, proprioception
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Conclusions: SDT may have potential to be an efficacious treatment option for improving sensorimotor performance in individuals with neurological conditions. However, at present there is limited evidence on which to base any firm clinical recommendations.

Background

Altered or lost somatosensation (tactile and proprioception) is common in individuals who have a central nervous system condition including: Stroke (Kessner et al., 2019); Parkinson's disease (PD) (Gorst et al., 2019); Multiple Sclerosis (MS) (Jamali et al., 2017); and Focal Dystonia (Konczak and Abbruzzese, 2013). Since somatosensation guides movement and minimises the risk of injury. A loss of somatosensation has a significant impact on sensorimotor function including that of the upper limb, balance and mobility and subsequently participation and independence in activities of daily living (ADL) (Carey et al., 2018). This represents a significant economic challenge from a health and social care point of view, especially due to the progressive and long-term nature of these conditions (Rabert et al., 2012). Since the primary purpose of Occupational Therapy is to support people in meaningful and purposeful occupation, including participation in ADL, this topic is a specific area of concern for the profession (Wæhrens 2015).

Cutaneous receptors within the skin on the hands and feet transmit signals to the primary somatosensory cortex (S1), from which the brain processes if a stimulus is present and where it is located, a process paramount for effective upper and lower limb sensation and movement. S1 is organised as a map containing primary representations of specific locations on the skin. These representations are plastic and neurons can alter and take on a different representation of a bodily location in the presence of neurological damage or disease (Brooks and Medina 2017).

Sensory discrimination training (SDT), often referred to as somatosensory retraining, involves tasks of somatosensory recognition and discrimination that focus on the development and relearning of sensory motor performance through the promotion of S1 neuroplasticity. SDT has been shown to have

potentially positive outcomes in a number of neurological conditions including phantom limb pain (Flor et al., 2001), Stroke (Carey et al., 2011), PD (Elangovan et al., 2018), Focal Dystonia (Byl et al., 2003) and MS (Kalron et al., 2013).

Four systematic reviews have investigated the efficacy of SDT for people following Stroke (Chia et al., 2019; Schabrun and Hillier 2009; Serrada et al., 2019; Turville et al., 2019). They found some evidence towards its effectiveness for improving somatosensory function in the lower and upper limbs, but ultimately conclude that this is limited due to poor quality study designs, inadequately powered with inconsistencies in outcome measurement tools. All four studies highlight the need for further research with rigorous methods, specifically RCTs. No systematic reviews have investigated the efficacy of SDT in the wider population of individuals with a neurological condition. Such a systematic review would help to guide future research and clinical practice in this field. Therefore, the aim of this systematic review was to investigate the efficacy of SDT on sensorimotor performance in individuals with a neurological condition affecting the central nervous system.

Methods

Procedure

The Cochrane Handbook for systematic reviews (Higgins and Green 2011; Higgins et al., 2020) was used to guide this review and it is reported in keeping with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). The protocol has been registered on PROSPERO (CRD42017055237). The PICOS (Population, Intervention, Comparison, Outcome and Study) framework was used to structure the systematic literature search and develop inclusion/exclusion criteria (Thomas et al., 2020).

Participants: Studies that included adult males and females aged ≥ 18 years with a diagnosed central neurological condition defined as any long-term condition "with a pathological process directly affecting the central nervous system (post-traumatic, degenerative, ischaemic or neoplastic), such as multiple sclerosis, spinal cord injury, cerebrovascular diseases, Parkinson's disease" (Coggrave et al., 2014) and Dystonia. Acute conditions or those that only affect the peripheral nervous system were excluded.

Intervention: Due to the lack of a standardised definition for SDT, for the purpose of this review, SDT was operationally defined as having three components 1) the delivery of an external stimulus (e.g. mechanical or electrical) to an individual, which requires 2) a judgement by the individual about a characteristic of that stimulus (e.g. localisation or discrimination of texture), and 3) immediate feedback on whether or not the judgement is correct/incorrect. The feedback is usually provided by a trainer/therapist. The intervention requires the active participation of the individual with the stimulus, rather than simply the passive receipt of the stimulation. SDT that involved the delivery of visual, auditory or olfactory stimuli were excluded. Single session and multiple session interventions were included. Studies where SDT was delivered in combination with other interventions were included if SDT was the sole difference in treatment received between groups.

Control: No treatment (true control), usual care (e.g. standard physiotherapy or occupational therapy) or placebo (e.g. pure passive sensory stimulation with no active involvement from the participant) control groups were all acceptable.

Outcomes: The primary outcome of interest was sensorimotor performance such as measures of local motor or sensory impairments including but not limited to; two-point discrimination, postural sway, balance, graphesthesia, texture discrimination, joint position sense, tactile object recognition.

Secondary outcome measures did not form part of the eligibility criteria but included measures that evaluated any aspect of health and well-being.

Study design: Only RCTS were included in order to reduce bias and maximise the quality of the evidence (Bradley and Nolan, 2008; Higgins et al., 2011; O'Connor et al., 2008; McKenzie et al., 2020). This included randomised parallel-group controlled trials where the primary outcome was the difference between SDT and the non SDT control phase. Non-randomised controlled trials were excluded to reduce the risk of bias in this review. The age of the studies was not limited. Studies written in any language and published in any country were eligible for inclusion.

Search Strategy

In accordance with the Cochrane Collaborations process (Higgins and Green, 2011), the search strategy was designed with support from a specialist Librarian. Large generic databases and subject-specific databases were used to ensure a comprehensive literature search (Bettany-Saltikov, 2010; Dickersin et al., 1994; Lefebvre et al., 2011). The following electronic databases were searched applying no language or date restrictions: the Cochrane Central Register of Controlled Trials (CENTRAL), CINAHL, Allied and Complementary Medicine Database (AMED), MEDLINE, EMBASE, Web of Science (science and social science citation index), Scopus, PEDro, PsycINFO, OT Seeker, ETHOS and OpenGrey. Additionally, the reference lists of key studies were hand searched (Dickersin et al., 1994).

Table 1. Review question based on the PICOS model and relevant search terms

PICOS	Population	Intervention	Outcome	Study Design	
Definition	Neurological disease or injury affecting the central nervous system.	Sensory discrimination training	Sensorimotor performance, health and well-being.	Randomised Controlled Trials	
Search Terms	Nervous System Diseases neurological disorders Neurodegenerative Diseases Motor Neuron Disease Parkinson* Dystonia neurological disease neurological conditions neurological impairment Multiple Sclerosis Stroke cerebrovascular accident CVA somatosensory disorder Spinal Cord Injuries	Nervous System Diseases discrimination task sensory retraining somatic sensation sensory training sensory re-education sensory re-education sensorimotor training			

A Population-Intervention (PI) based search strategy was used (adapted from the PICOS model (Bettany-Saltikov, 2010; Lefebvre et al., 2011)) and modified as appropriate for each database. Appropriate terms were identified, then, synonyms for the population and intervention components were identified (Table 1). Examples for the specific search strategies used can be seen in Appendix 1. A filter was applied to include only adult human participants. Search filters for RCTs were applied to the MEDLINE, CINAHL and PsychInfo searches. The database searches were carried out at three separate time points to ensure the review was kept up to date (February 2018, December 2018 and August 2020). After all searches, merging of search results and removal of duplicates was carried out by the first author (ST), using ProQuest RefWorks reference management software. At least two review authors (ST, CM and MAJ) independently screened each article by title and abstract. Where articles could not be excluded the full text was obtained to determine eligibility. The list of studies eligible for inclusion was agreed between the two reviewers (ST, CM and MAJ) through discussion. A third reviewer was available should the initial reviewers be unable to reach consensus: however, the third reviewer was not needed.

Methodological quality assessment

Quality assessment was undertaken independently by two reviewers (ST and CR) using the Cochrane collaboration's risk of bias tool which is a domain-based evaluation of potential biases in RCTs in which seven risk of bias questions are marked for a low, high or unclear risk of bias (Higgins et al., 2011). Where there was insufficient information for appraisal of bias, attempts were made to contact the

original authors for further information using the contact details provided within the articles, however this was unsuccessful on each occasion.

Data collection process

At least two review authors (ST, JK and MAJ) independently extracted data from the included studies using an adapted version (created by ST for topic specificity) of the Cochrane Collaboration's (Higgins et al., 2011) tool for data extraction and included data relating to: study eligibility, methodological characteristics of included studies, participant characteristics, intervention group characteristics, outcome characteristics, risk of bias assessment, data analysis, and key study conclusions. Results were compared between review authors and disagreement was resolved by discussion.

Data analysis and synthesis

Due to the degree of heterogeneity among the studies, a narrative synthesis was used, as traditional meta-analysis was not considered appropriate (Bettany-Saltikov, 2010; Deeks et al., 2011). However, where possible the effect size (ES) was calculated for each of the outcomes within each included study, to support the narrative synthesis and provide useful statistical information on results. This is advised by the Cochrane Handbook when studies assessing the same outcome, measure it in different ways (McKenzie and Brennan, 2020). In this review, the included studies used various different outcome measurement tools to assess the primary outcome of sensorimotor performance. This method of calculating the ES enabled standardisation of the outcome results of the studies to a uniform scale, to facilitate quantifying the estimate of the effect and help interpret the clinical relevance of the mean treatment effect of the specific intervention in each individual study. The ES expresses the magnitude of the intervention effect in each study relative to the between-participant variability in outcome measurement tools. The ES was calculated by dividing the difference in mean outcome post intervention between the two groups by the pooled baseline SD, with effect sizes of 0.2, 0.5 and 0.8 considered to be small, medium and large, respectively (Cohen, 2013). As advised in the Cochrane Handbook (Higgins and Thomas 2020) two authors (ST and CR) assessed the quality of evidence through the use of the GRADE approach (Schünemann et al., 2020; Ryan and Hill 2016) considering five domains: risk of bias, inconsistency, indirectness, imprecision and publication bias. An overall judgment was made across studies.

Results

The electronic search generated 1,846 initial hits. Hand searching identified no additional records. After the removal of duplicates there were 1,058 that were screened for eligibility of which 1,034 were excluded on initial screening, based on a review of the title and abstract. Twenty-four full texts were assessed for eligibility and of these 18 were excluded. Thus, six studies were included in the final review (Table 2 and Figure 1).

Figure 1: PRISMA Flowchart

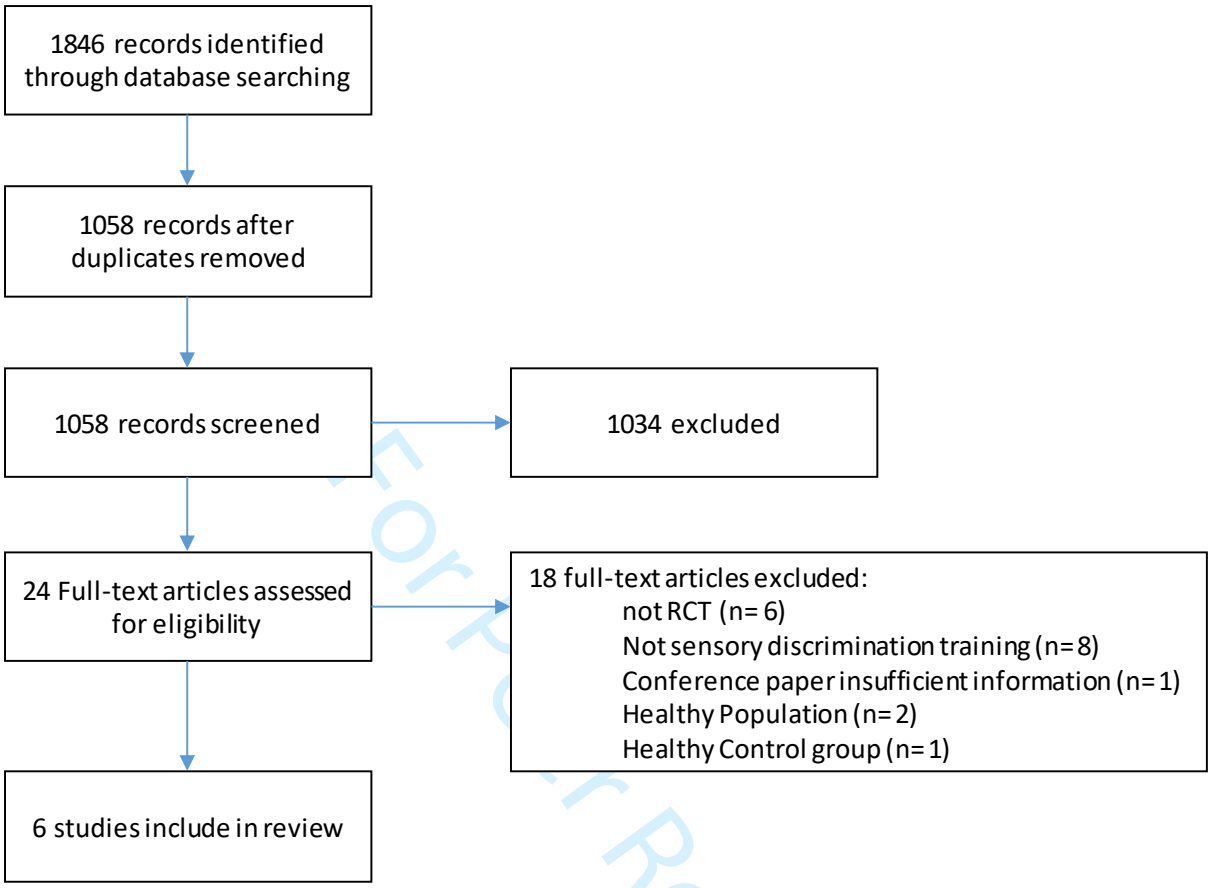


Table 2: Summary of Included Studies

Authors (year)	Study (Setting)	Participants	Intervention and dosage	Control and dosage	Somatosensory Outcomes	Motor Outcomes
Carey et al., 2011	Setting: 6 participating hospitals in metropolitan Melbourne. This included rehabilitation and long-term community-based facilities associated with the hospitals. Informed consent: Yes Ethics approval: Yes	Stroke patients with impaired texture discrimination, limb Position sense, and/or tactile object recognition. n = overall = 50 Intervention group: n = 25 17 males, 8 females Mean age (years): 61 Median time since stroke (weeks): 32.6 Control group: n = 25; 20 males 5 females Mean age (years): 61 Median time since stroke (weeks): 51.9	3 sensory discrimination tasks: texture discrimination, limb position sense, and tactile object recognition, feedback provided and education regarding neuroplasticity and treatment principles. Two phases - a phase consisted of 60-minutes/session, 10 sessions, 3 times a week (15-20min per task), 10 weeks.	Non-specific repeated exposure to stimuli varying in texture, shape, size, weight, hardness, and temperature, via grasping of common objects, and passive movements of the upper limb. 60-minutes/session, 10 sessions, 3 times a week (15-20min per task), 10 weeks. In phase two the control group also received the SDT intervention in a cross-over arm. However this was not the primary outcome.	Primary Outcome: SSD (end of A1) –a composite index of functional somatosensory discrimination capacity, derived from standardized indexes of: Texture discrimination: FMT Proprioception: WPST Tactile object recognition: fTORT A0, baseline; A1, end of phase 1; A2, end of phase 2; A3, 6-week follow-up; A4, 6-month follow-up.	SODA MAL Results from the SODA and MAL were not reported in published study.
Ghanjal et al., 2016	Setting: Bagaite University, Iran Informed consent: Yes Ethics approval: Yes	Ischemic stroke n overall = 30; 21 males, 9 females. Intervention group: n = 15 Mean age (years): 54.3 Duration of illness (months): 6.3 Control group: n = 15 Mean age (years): 55 Duration of illness (months): 6.2	Sensory retraining: sensory discrimination of weights, harnesses, textures, shapes, vibrations, graphesthesia. feedback provided. 24 sessions, 60min (40 min standard physiotherapy and 20 min sensory retraining), 3 interval days (Monday, Wednesday, Friday)	Standard physiotherapy 24 sessions, 40min, 3 interval days (Monday, Wednesday, Friday)		Upper extremity motor performance: Fugl-Meyer. BBT. Motoricity index. Pre and Post intervention

Authors (year)	Study (Setting)	Participants	Intervention and dosage	Control and dosage	Somatosensory Outcomes	Motor Outcomes

Lynch et al., 2007	Australia / inpatient rehab
	
	Informed consent: Yes
	
	Ethics approval: Yes
		Stroke patients with sensory dysfunction of the lower limb
		
		n overall = 21
		
		Intervention group:
		n = 10;
		7 males 3 females
		Mean age (years): 61
		Mean time since stroke (days): 48.7
		
		Control group:
		n = 11;
		9 males, 2 females
		Mean age (years): 62
		Mean time since stroke (days): 47.8
			Sensory Retraining – education, detection, localisation, discrimination (of hardness, texture, temperature) of the sole of the feet; and proprioception training of the big toe and/or ankle. Quantitative feedback on outcome and performance and summary feedback.
			
			30-minutes/session
			10 sessions
			2 weeks
				Relaxation Techniques + standing with eyes closed
				
				30-minutes/session 10 sessions
				2 weeks
					Light touch at the sole of the Foot: SWM; Proprioception: Distal Proprioception Test.
					
					Baseline, on completion of treatment, and then at a 2-week follow-up.
						Balance: BBS. Gait: Timed 10m gait and ILAS). Use of a Walking aid.
						
						Baseline, on completion of treatment, and then at a 2-week follow-up.

Morioka and Yagi 2003	Japan/Hospital rehabilitation
	
	Informed consent: Yes
	
	Ethics approval: Not Stated
		Stroke patients with hemiplegia Lower limb
		
		n overall = 26
		
		Intervention group:
		n = 12;
		9 males 3 females
		Mean age (years): 62.6
		Mean time since stroke (days): 65.4
		
		Control group:
		n = 14;
		8 males 6 females
		Mean age (years): 61.3
		Mean time since stroke (days): 61.9
			Hardness discrimination perceptual learning exercise (three different levels of rubber sponge hardness placed under the sole of the foot, subjects required to estimate hardness.).
			
			Three trials with immediate verbal feedback given on the correct hardness of the sponge. Followed by 10 random trials no feedback given.
			
			10 trials/session 10 sessions, 2 weeks
				Physiotherapy and occupational therapy (including ordinary Postural control exercises).
				
				Dosage not reported.
					Number of correct answers and incorrect answers regarding hardness discrimination	Centre of Gravity Sway (LNG [cm], ENV-AREA [cm^2], REC-AREA [cm^2])
						
						Pre and Post treatment

Authors (year)	Study (Setting)	Participants	Intervention and dosage	Control and dosage	Somatosensory Outcomes	Motor Outcomes
Taghizadeh et al., 2017	Setting: hospitals and rehabilitation centers in Tehran Informed consent: Yes Ethics approval: Yes	Idiopathic PD (levels 1-3 on the Hoehn and Yahr scale of PD progression) n overall = 40; 35 males 5 females Intervention Group: n = 20 Mean age (years): 61 Duration of PD (years): 7.8 Control group: n = 20 Mean age (years): 59 Duration of illness (years): 8.7	Sensorimotor training – sensory discrimination of temperatures, weights, textures, shapes, and objects, random verbal feedback provided by trainer. 5 days (average 2 hours/day), 2 weeks.	Common rehabilitation therapies Dosage not reported	Tactile acuity: MTPD. Proprioception: WPST. Touch Threshold: WEST. Weight and texture discrimination: HAST. Haptic performance: HORT. Pre and Post intervention	Motor Performance: Fine: PPT. Upper extremity: BBT. Motor performance: Progression of PD: The Hoehn and Yahr Scale (only baseline results reported). Pre and Post intervention
Weinberg et al., 1979	Setting: Institute of Rehabilitation Medicine, New York University Medical Center Informed consent: Not reported Ethics approval: not reported	CVA (RBD) (at least 4 weeks previously) n overall = 53 Mean age (years): 65.35 Time since stroke onset (days): 41.87 Experimental group: n = 30 Control group: n = 23	Scanning (15 hours): practice in tracking a target, searching for lights on a board, reading. Perceptual retraining (5 hours): training in sensory awareness (localization of touch on a corresponding manikin). Training in spatial organization (size estimation of 5 plexiglass rods). Verbal feedback given after each test by examiner. 20 hours (1 hour each day for 4 weeks)	Standard rehabilitation (physio and OT) 20 hours (1 hour each day for 4 weeks)	Battery of 17 psychologic tests yielding 26 scores. Proprioception: BML and BMR Pre and post	N/A

SSD = Standardized somatosensory deficit, FMT = Fabric Matching Test, WPST = Wrist Position Sense Test, Ftort = functional Tactile Object, Recognition Test, SODA = Sequential Occupational Dexterity Assessment; MAL = Motor Activity Log, BBT = Box and block test, SWM = Semmes-Weinstein monofilaments, BBS = Berg Balance Scale, ILAS = Iowa Level of Assistance Scale, LNG = Total locus length, ENV-AREA = Enveloped area, REC-AREA = Rectangular area, MTPD = Moving 2-point discrimination test, WEST = Weinstein enhanced sensory test, HAST = Hand active sensation test, HORT = Haptic object recognition test, PPT = Purdue pegboard test, BML = Body Midline Left, BMR = Body Midline Right. N/A = Not applicable

Characteristics of included studies

A total of 220 adults with a neurological condition and subsequent sensorimotor deficit (40 with PD and 180 who had experienced a Stroke) participated in the six included studies. In five of the studies the gender ratio was reported, and these studies had a higher male to female ratio. The mean age of the participants ranged from 55 to 65 years. Five studies investigated SDT for people following a Stroke (Carey et al 2011., Ghanjal et al., 2016., Weinberg et al., 1979., Lynch et al., 2007 and Morioka and Yagi, 2003) and one for people with PD (Taghizadeh et al., 2017). Time since Stroke ranged from 6.8 weeks (Lynch et al., 2007) to 51.9 weeks (Carey et al., 2011). Five studies were conducted in hospital settings and one in a university setting (Ghanjal et al., 2016). Studies were conducted in the USA, Australia, Iran and Japan. All six studies used manual tactile discrimination including hardness, temperature, weights, textures, shapes, objects, vibrations, graphesthesia and localisation as the stimulus for the experimental intervention. The duration of individual SDT sessions ranged from 30 to 120 minutes, with a range of 10 to 20 sessions, with treatment periods from 2 to 10 weeks in duration.

All six studies assessed sensorimotor performance using a variety of outcome measures, with the box and block test (BBT), wrist proprioception sensation test (WPST) and Semmes-Weinstein monofilaments being the most commonly used (two studies each). None of the six studies used secondary outcome measures as defined in this review. All studies recorded a measure at baseline and immediately post treatment. The follow-up outcome measurement period ranged from two weeks (Lynch et al., 2007) to six months (Carey et al., 2011) post-treatment.

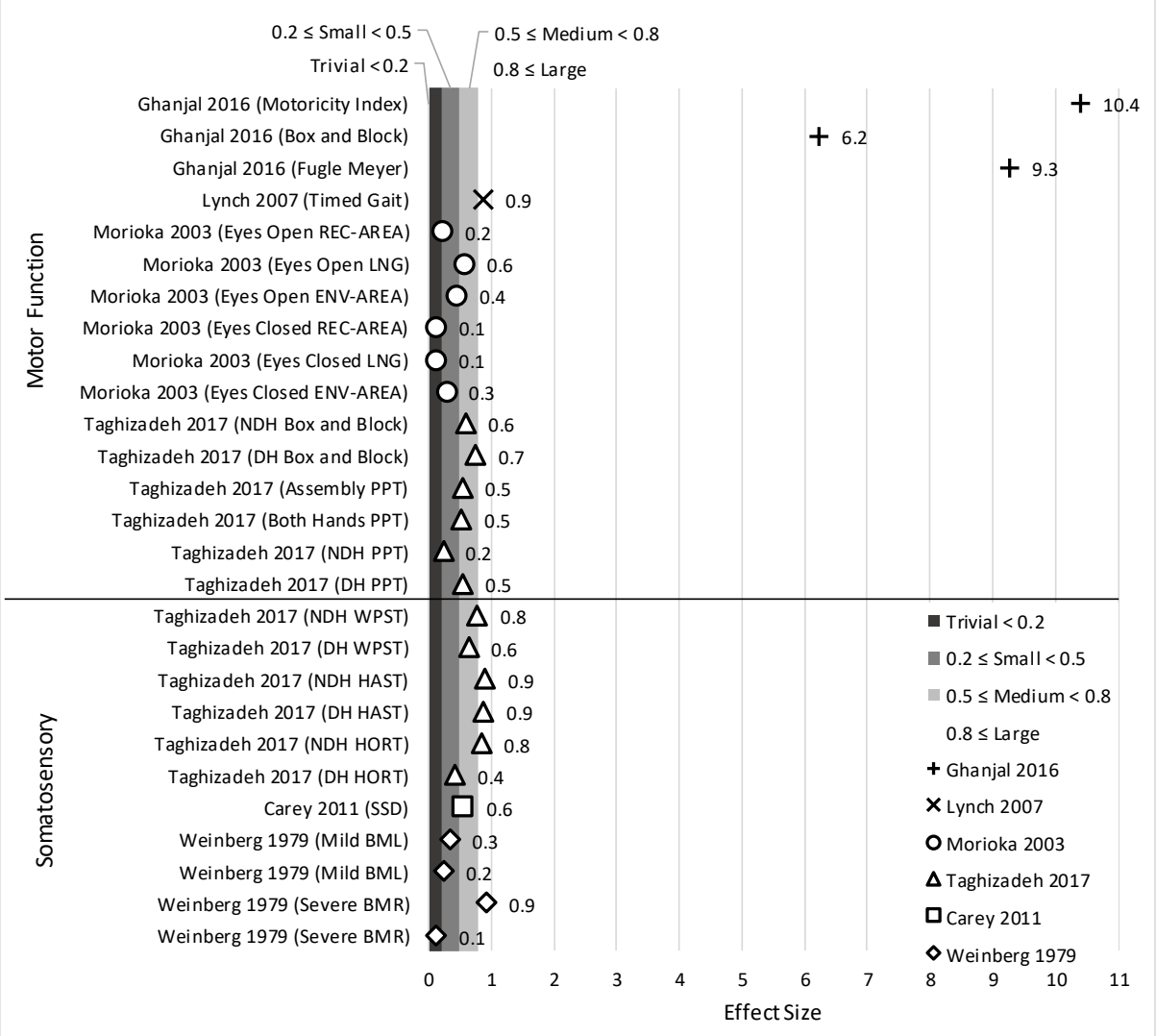
Adverse effects reporting

Only one study (Carey et al., 2011) reported that there were no adverse events associated with the intervention, the other five studies made no statements regarding adverse events. Three studies (Ghanjal et al., 2016, Taghizadeh et al., 2017 and Weinberg et al., 1979) did not report retention (withdrawals and exclusions). Morioka and Yagi (2003) reported that two participants in the experimental group were lost from the study due to discharge prior to completion, compared to zero lost in the control group. Lynch et al. (2007) reported one participant was lost to follow up in the experimental group due to discharge to their own country prior to final assessment and one discontinued sensory retraining and standard care as acutely unwell, compared to zero lost to the control group. Carey et al. (2011) reported one participant was lost to follow-up in the intervention group due to being unwell and two were lost in the control group due to being unwell but zero participants discontinued the intervention.

Analysis and effect measures

Meta-analysis was not carried out as the delivery of the interventions, the specific outcome measures used, and the targeted body parts and specific populations were too diverse. Standardised effect sizes were calculated as a means of quantifying effectiveness. Effect sizes are displayed in Figure 2 and are discussed below.

Figure 2: Effect sizes for each outcome measure



NDH = non dominant hand, DH = dominant hand, PPT = Purdue pegboard test, WPST = Wrist proprioception test, HAST = Hand active sensation test, HORT = Haptic object recognition test, SSD = Standardized somatosensory deficit, BML = Body Midline Left, BMR = Body Midline Right.

Methodological quality summary

All six included studies were deemed to possess a high risk of bias (Figures 3 and 4). In five of the six studies there was a considerable lack of information. Carey et al. (2011), was the only trial not scoring an 'unclear' in any of the components of the tool demonstrating more comprehensive reporting. Selective reporting bias was high risk in all six studies due to the fact that only one study published a protocol and the single study that did publish a protocol (Carey et al., 2011) did not report in the full paper data from three secondary outcome measures specified in the protocol.

Other sources of bias present within the studies not covered in the risk of bias tool were identified. The small samples (n=50 or less) presented a high risk of bias across all six studies since a large effect would be required to prevent a type II error. One study (Ghanjal et al., 2016) was translated from Persian and this may have resulted in some methodological issues being judged incorrectly. There were many unclear aspects to this paper in particular, which may have been, in part, due to the

language barrier. Weinberg et al., (1979) was also deemed to possess a considerable lack of clarity, which may have been due to the age of the paper, less rigorous reporting standards existed then as compared to now. Taghizadeh et al., (2017) lacked enough detail about the SDT intervention to make it easily replicable. The outcome of the overall quality of evidence assessment (undertaken in accordance with the Cochrane Grading of Recommendations Assessment, Development and Evaluation [GRADE] approach) is presented in table 3.

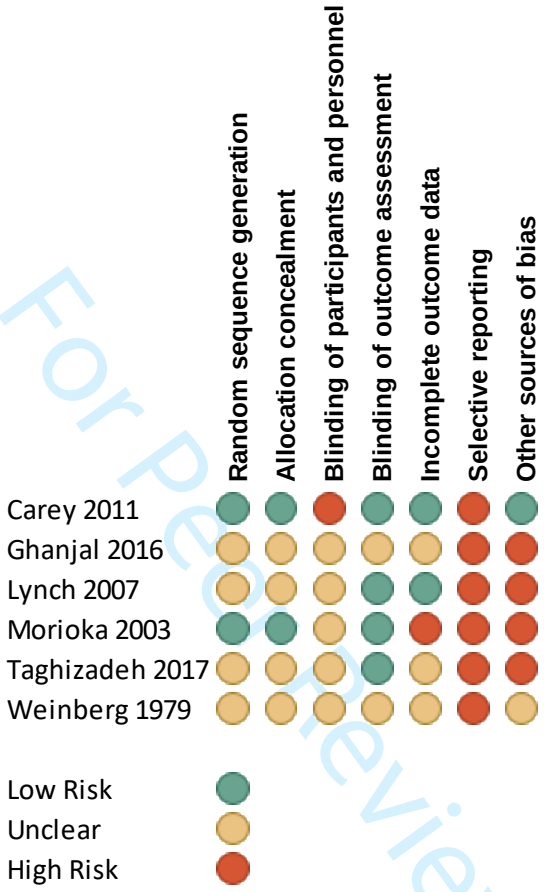


Figure 3: Risk of bias summary for each study based on GRADE

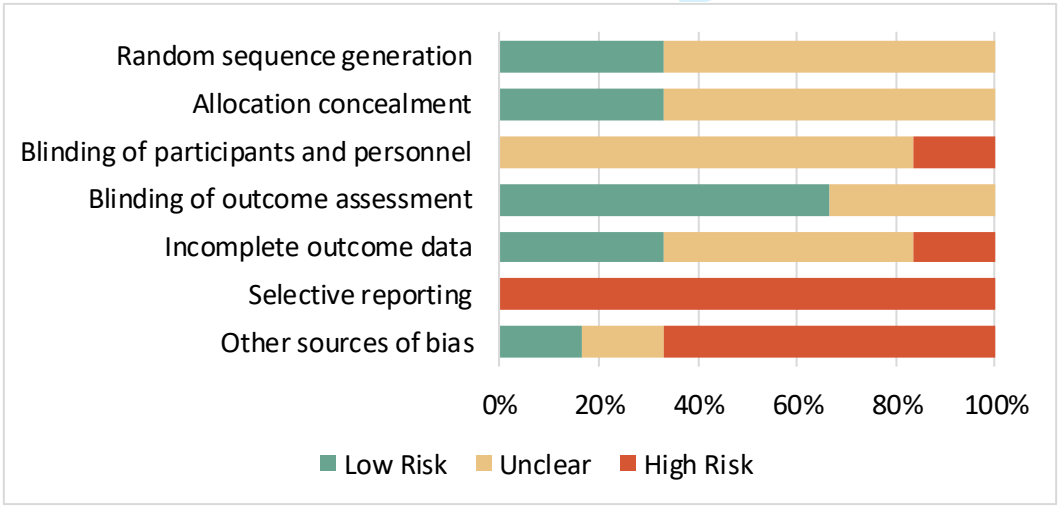


Figure 4: Risk of bias graph for each study based on GRADE: each risk of bias component is presented as percentages across all included studies

Table 3a. Summary of Findings for Included Stroke RCTs (GRADE)

Overview	Method	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty of evidence (GRADE)
Somatosensory Outcomes	RCT	Very serious limitation	Very serious limitation	Serious limitation	Very serious limitation	Strongly suspected	⨁⨀⨀⨀ Very Low
Motor Function Outcomes	RCT	Very serious limitation	Very serious limitation	Serious limitation	Very serious limitation	Strongly suspected	⨁⨀⨀⨀ Very Low

Table 3b. Summary of Findings for Included PD RCTs (GRADE)

Overview	Method	Risk of Bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Certainty of evidence (GRADE)
Somatosensory Outcomes	RCT	Very serious limitation	Very serious limitation	Serious limitation	Serious limitation	Strongly suspected	⨁⨀⨀⨀ Very Low
Motor Function Outcomes	RCT	Very serious limitation	Very serious limitation	Serious limitation	Serious limitation	Strongly suspected	⨁⨀⨀⨀ Very Low

Narrative synthesis of included studies

Five studies (Carey et al., 2011; Ghanjal et al., 2016; Weinberg et al., 1979; Lynch et al., 2007 and Morioka and Yagi, 2003) assessed the efficacy of SDT in people who had experienced a Stroke affecting the upper and lower limb, and one study (Taghizadeh et al., 2017) looked at individuals with PD. All interventions focussed solely on retraining somatosensation accept one study (Weinberg et al., 1979) that also used additional therapeutic modalities to focus on scanning and spatial organisation to target visual neglect and thus administered associated outcome measures. Although these additions are reported in Table 2 only the training in sensory awareness and relevant perceptual outcomes (Body Midline Left [BML] and Body Midline Right [BMR]) were investigated in this review to keep the review focussed on its primary objective to evaluate sensorimotor performance.

All six studies used SDT activities in the intervention that differed from the assessment outcome measures. In all studies apart from one (Morioka and Yagi 2003) the intervention targeted retraining of more than one somatosensory modality. Morioka and Yagi (2003) only targeted retraining hardness discrimination. In all six studies the SDT intervention focussed on one or more of the following somatosensory modalities: tactile detection, localisation, discrimination, object recognition, and proprioception.

On average SDT occurred for a total of 17.3 sessions (SD=8.6), across 2 to 10 weeks, 3 – 5 times per week. The average treatment session lasted 57 minutes (SD=40.2), with an average of 16.8 (SD=11.3) total treatment hours. The intervention was delivered one-to-one by a trained therapist, in all six studies but there was insufficient/limited information regarding characteristics of the therapists (e.g. their training, experience and specialist skills).

Outcome results

Included Stroke Studies:

Somatosensory skills

A variety of somatosensory outcome measures were used in four of the studies (Table 2) but the intervention effect could be quantified for only two of these (Carey et al., 2011 and Weinberg et al., 1979). All somatosensory outcomes improved with training relative to control groups and effect sizes are displayed in Figure 2 (Carey et al., 2011; and Weinberg et al., 1979). The total sample for this outcome category (two studies) was small (n=103).

In one study (Lynch et al., 2007) narrative analysis suggested improvements over time in light touch threshold at three points of the foot (heel, lateral border and big toe), but no significant difference was observed between the intervention and control group (Lynch et al., 2007). However, a between-group difference was detected in light touch sensation at the first metatarsal at follow-up, with the intervention group showing significant Improvements over the control group. No significant difference in proprioception was observed over time or between groups. Again, the sample for this study was very small (n=21). Morioka and Yagi (2003) observed that the mean number of incorrect answers given by the intervention group during the hardness discrimination exercise, decreased significantly through the training period ($p < 0.01$) suggesting an improvement in hardness discrimination.

Overall, there was very low-quality evidence from the five studies supporting the efficacy of SDT for somatosensory discrimination skills in the Stroke population compared to a control treatment in the immediate to medium term. The quality of the evidence was downgraded due to very serious limitations in terms of risk of bias, inconsistency and imprecision (Table 3).

Motor function

Several measures of motor function were used (Table 2) to assess postural sway, balance, gait, upper extremity function and general motor performance within three studies (Morioka and Yagi 2003; Ghanjal et al., 2016; Lynch et al., 2007). All areas improved with training and effect sizes are displayed in Figure 2. Motor function effect sizes ranged from 0.12 – 10.39, spanning a trivial to large intervention effect in favour of the intervention group. The total sample was small (n=75).

It was not possible to calculate effect sizes for all the motor function measures used in one study (Lynch et al., 2007). However, narrative analysis suggested an improvement in balance detected through the Berg Balance Scale (BBS) which improved from baseline to the end of treatment in both the control and intervention groups ($p < 0.005$). However, there was no significant difference in scores between groups at any time period. Lynch et al., (2007) also found that the scores for use of a walking aid over the 10 m timed walk test decreased over time, indicating that the walking aids required became progressively less supportive over time suggesting an improvement in balance. However, they also found no significant change over time or between groups in the amount of assistance participants required from the therapist to walk 10 m.

Overall, there was very low-quality evidence from three studies supporting the efficacy of SDT for motor function in the Stroke population compared to a control treatment in the immediate to medium term. The quality of the evidence was downgraded due to very serious limitations in terms of risk of bias, inconsistency, and imprecision (Table 3).

Included PD Studies:

Somatosensory skills

Five somatosensory outcomes measures were used in the single PD study (Taghizadeh et al., 2017) as shown in Table 2. Effect size was quantified for three of these ranging from 0.42 – 0.90 spanning a small to large effect in favour of the intervention group.

It was not possible to calculate effect sizes for two outcomes (tactile acuity: Moving 2-point discrimination test (MTPD) and touch threshold: Weinstein enhanced sensory test (WEST) however, the authors of the study report that the main effect of the group and time, as well as the interaction of group time in the MTPD in both dominant hand (DH) hand non dominant (NDH), were not significant, and the WEST showed only interaction of group and time in NDH was significant ($p = 0.02$ and effect size = 0.14).

Two motor outcomes were used in the PD study (Table 2). Effect size was quantified ranging from small (0.22) to medium (0.75) in favour of the intervention group.

Overall, there was very low-quality evidence from one study supporting the efficacy of SDT for somatosensory and motor function in people with PD compared to a control treatment in the immediate term. The quality of the evidence was downgraded due to very serious limitations in terms of risk of bias, inconsistency, and imprecision (Table 3).

Discussion

The aim of this systematic review was to investigate the efficacy of SDT on sensorimotor performance in individuals with a neurological condition affecting the central nervous system. Six RCT's were included in the final review including 220 participants incorporating two distinct conditions: Stroke (five studies) and PD (one study). The general findings from this review suggest that SDT has the potential to be an efficacious treatment option for improving sensorimotor performance in individuals with neurological conditions specifically, the ability to discriminate bodily sensation in the upper and lower limbs in people who have had a Stroke or who have a diagnosis of PD based on the majority of effect sizes falling in the medium range (0.5 – 0.8) (Cohen, 2013). However, for several reasons, these improvements must be interpreted with caution. These reasons include the broad range of effect sizes in both populations as well as the small sample sizes and high risk of bias of the individual studies. Thus, at present there is limited evidence on which to base any firm clinical recommendations.

Four previous systematic reviews have investigated the efficacy of somatosensory discrimination training interventions for people following Stroke (Schabrun and Hillier 2009; Serrada et al., 2019; Turville et al., 2019; Chia et al., 2019). Although there was some evidence in favour of the experimental interventions as an efficacious treatment option, like the findings in this review, the evidence was limited by small sample size, inconsistency in clinical outcome measures and poor quality studies. Furthermore, all four reviews stressed the need for high quality RCTs, sufficiently powered with meaningful clinical outcome measures to accurately assess intervention effects. Specifically, Schabrun and Hillier (2009) and Serrada et al. (2019) both assessed intervention effects of 6 RCTs targeting the lower and upper limbs which included two studies (Lynch et al. 2007 and Morioka and Yagi 2003) also included in this review (two of the additional included studies were not in keeping with the definition of SDT used in this review because direct feedback on task performance was not given, one was not sufficiently randomised and the other study did not have a control). Turville

et al. (2011) assessed the efficacy of Somatosensory training interventions in the upper limb including both randomised and non-randomised controlled trials – only two RCTs were reviewed, one also included in this review (Carey et al., 2011) and a second in which the sensory intervention was not in keeping with the definition used in this study because direct feedback on task performance was not given. Chia et al. 2019 reviewed the efficacy of somatosensory retraining of the lower limb including all quantitative types of studies, two RCT's (Lynch et al. 2007 and Morioka and Yagi 2003) of which were also included in this review. This systematic review serves to fill a gap in the literature because it includes a more diverse population expanding from Stroke to neurological conditions; it's included studies are in keeping with the recommended gold standard (RCTs) and it has followed the Cochrane Collaboration methodology adopting use of the GRADE approach in an attempt to capture high quality studies (Higgins et al., 2020). In addition the findings are consistent with the four systematic review previously mentioned: SDT may have potential to be an efficacious treatment option for improving sensorimotor performance in individuals with neurological conditions. However, at present there is limited evidence on which to base any firm clinical recommendations due to the poor quality of the studies (despite being RCTs) and the heterogeneity seen within clinical outcome measures thus although this review has seen an advancement still further research studies are needed to obtain a more precise estimate of intervention effects.

Limitations

The studies included in this review were limited to individuals who have experienced stroke or have a diagnosis of PD and thus are under representative of the entire population group of neurological conditions or injury affecting the central nervous system; so the findings should be applied with caution to the population as a whole. Only a small number of studies were included in the review and they were all adjudged to be of high risk of bias. Furthermore, the total number of participants included in this review (n=220) was relatively small, well below the recommended 400 (Ryan and Hill, 2016) making it difficult to apply the findings with precision.

An additional limitation is that the intervention itself (SDT) is ill defined. Although SDT is clearly defined in this review, the lack of clarity in the literature in general could mean that some studies did not fit the definition required in this review but did in fact address somatosensory discrimination training.

In general, the outcome measures were heterogeneous across studies and measured different aspects of sensorimotor performance despite having similar interventions. For example, some focussed on measuring balance and limb function whilst others focussed on somatosensory skills, such as discrimination or proprioception hence making it difficult to draw comparisons. Furthermore, due to this heterogeneity a traditional meta-analysis was not possible, and although effect sizes were calculated, there is uncertainty that could only be addressed with an inferential meta-analysis. In addition, there is a high degree of inconsistency in the results seen in the large variations in the intervention effect sizes across studies deeming findings inconclusive. Specifically in the Stroke studies, there is a wide variation in time since Stroke among participants which could have impacted on recovery potential in the intervention groups and thus contributed to the inconsistency in intervention effect sizes.

Clinical implications and Future research

There is a need for RCT's of sufficient quality and power to detect a precise SDT intervention effect in participants with neurological conditions or injury affecting the central nervous system. It is particularly worth noting that no SDT RCT's meeting the inclusion criteria for this review were

identified for conditions such as Multiple sclerosis and Focal Dystonia, conditions where SDT has been identified as potentially beneficial (Jamali et al., 2017; Konczak and Abbruzzese, 2013). Thus, RCTs in these specific neurological clinical groups are particularly warranted. Furthermore, suitable quantitative outcome measures that capture sensorimotor performance in terms of somatosensory discrimination and motor function in this population group need to be further developed with a pre-defined minimal clinically important change so that size of effect can be accurately quantified and contextualised. Until then, SDT in people with neurological conditions or injury affecting the central nervous system for the specific improvement of somatosensory and motor function should be treated with caution in an individual clinical setting.

Conclusion

Although within the previous literature there was some evidence in favour of SDT as an efficacious treatment option, the evidence was limited by small sample size, inconsistency in outcome measures and poor quality studies, specifically a lack of RCTs. This systematic review has found similar findings, that SDT may have potential to be effective for improving sensorimotor performance in individuals with neurological conditions or injury affecting the central nervous system. However, currently there is insufficient evidence to make any firm clinical recommendations. Future, adequately powered, high quality RCTs are needed in this population group to provide more robust evidence regarding this intervention.

Key findings

- Sensory discrimination training may potentially be an efficacious treatment for improving sensorimotor performance in individuals with central neurological conditions.
- Currently there is insufficient evidence to make any firm clinical recommendations and so future robust randomised controlled trials are needed in this population group.

What the study has added

There is a paucity of robust randomised controlled trials investigating sensory discrimination training as an intervention to improve sensorimotor performance in individuals with central neurological conditions. Whilst the limited available evidence appears positive, no firm recommendations can be made at this time.

Declaration of Conflict of interest

Prof. C G Ryan is a named inventor on a sensory discrimination training device that could be used to train tactile acuity in people with a range of conditions including central neurological conditions. The remaining authors have no conflicts of interest to declare.

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Appendix 1: Example initial searches using two databases

Medline:

	Sunday, March 05, 2017 10:55:34 AM	
#	**Query**	**Results**
S25	S12 AND S19 AND S24	225
S24	S20 OR S21 OR S22 OR S23	9,523,776
S23	effect* OR improv*	8,903,505
S22	outcome	1,407,605
S21	(MH "Treatment Outcome")	759,442
S20	(MH "Outcome Assessment (Health Care)")	57,333
S19	S13 OR S14 OR S15 OR S16 OR S17 OR S18	8,324
S18	sensorimotor training	308
S17	sensory re-education	39
S16	sensory reeducation	37
S15	sensory training	478
S14	sensory retraining OR somatic sensation	227
S13	discrimination training OR discrimination task	7,303
S12	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11	525,182
S11	(MH "Spinal Cord Injuries")	31,796
S10	parkinson*	107,289
S9	stroke or cerebrovascular accident or cva OR somatosensory disorder	238,605
S8	(MH "Stroke+")	102,140
S7	(MH "Multiple Sclerosis+")	49,184
S6	neurological impairment	4,206
S5	neurological conditions	3,751
S4	neurological disease	14,324
S3	(MH "Neurodegenerative Diseases") OR (MH "Motor Neuron Disease") OR (MH "Parkinson Disease") OR (MH "Dystonia") OR Dystonia	82,349
S2	neurological disorders	27,496
S1	(MH "Nervous System Diseases")	39,454

Scopus:

27/02/2017	
Query	**Results**
(TITLE-ABS-KEY ("discrimination training" OR "discrimination task" OR "sensory retraining" OR "somatic sensation" OR "sensory training" OR "sensory reeducation" OR "sensory re-education" OR "sensorimotor training")) AND ((TITLE-ABS-KEY ("Nervous System Diseases" OR "neurological disorders" OR "neurological disease" OR "neurological conditions" OR "neurological impairment")) OR (TITLE-ABS-KEY ("Multiple Sclerosis" OR "Stroke" OR "cerebrovascular accident" OR "CVA" OR "somatosensory disorder" OR "Spinal Cord Injuries")) OR (TITLE-ABS-KEY ("Neurodegenerative Diseases" OR "Motor Neuron Disease" OR "Parkinson* Disease" OR "Dystonia"))) AND (TITLE-ABS-KEY (outcome OR effect* OR improv*))	162