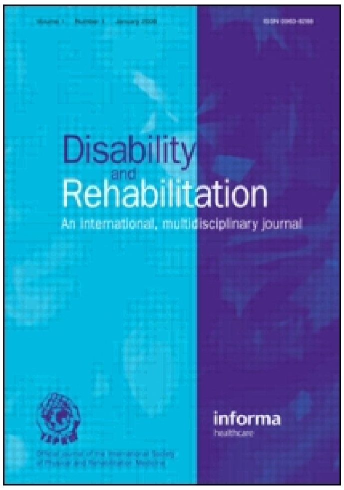

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REVIEW

Systematic review of the effectiveness of mirror therapy in upper extremity function

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Abstract

Purpose. This review gives an overview of the current state of research regarding the effectiveness of mirror therapy in upper extremity function.

Method. A systematic literature search was performed to identify studies concerning mirror therapy in upper extremity. The included journal articles were reviewed according to a structured diagram and the methodological quality was assessed.

Results. Fifteen studies were identified and reviewed. Five different patient categories were studied: two studies focussed on mirror therapy after an amputation of the upper limb, five studies focussed on mirror therapy after stroke, five studies focussed on mirror therapy with complex regional pain syndrome type 1 (CRPS1) patients, one study on mirror therapy with complex regional pain syndrome type 2 (CRPS2) and two studies focussed on mirror therapy after hand surgery other than amputation.

Conclusions. Most of the evidence for mirror therapy is from studies with weak methodological quality. The present review showed a trend that mirror therapy is effective in upper limb treatment of stroke patients and patients with CRPS, whereas the effectiveness in other patient groups has yet to be determined.

Keywords: *Mirror therapy, stroke, pain, amputation, upper extremity*

Introduction

Presenting visual feedback about motor performance to improve the effect of training is widespread in rehabilitation practice. A relative new way of using visual feedback to help patients is exploited in mirror therapy. Ramachandran [1] first used mirror therapy in patients who suffered from a phantom limb after amputation. Patients who participated in these experiments mainly experienced phantom arms that were 'paralysed' or 'frozen' in an awkward and sometimes painful position, i.e. the phantom arms could not be moved voluntary by the patients. To relieve these patients from awkward or painful feelings they were given the idea that their amputated limb was still 'alive'. To achieve this, a mirror, which showed the reflection of the intact arm, was placed in the sagittal plane. The mirror image of the intact arm gives the patient the illusion the amputated arm is resurrected: Moving the intact limb and looking at its reflection in the mirror produces visual feedback of the whereabouts of an arm at the location of the amputated arm. In this setup, some amputees with a phantom arm reported that they felt as though their phantom arm was moving. This movement relieved some of the patients from the awkward position and pain of their phantom arm. In short, the visual feedback via the mirror gives the illusion that the phantom arm is moving in response to the brain's command, suggesting that the amputated arm is 'alive' again and can be moved around [2].

On the basis of effect of visual feedback through a mirror in patients with phantom pain, mirror therapy was employed with more patient groups. The appeal of mirror therapy lies therein that it provides some

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kind of access to a body part that is otherwise not accessible. For example, in the case of phantom pain the mirror gave access to the phantom and with this access the phantom could be put in a less awkward position [3]. The fact that a phantom limb could be acted upon through mirror therapy inspired several researchers to look for more patient-groups with which mirror-therapy might work. Pathological conditions in which the patient could not get an entrance to an affected body part, as is the case with amputation, stroke, and pain syndromes, for instance, were situations for which it might be expected that mirror therapy could also work.

With the application of mirror therapy to these different types of pathological conditions, each with their own type of injury from which it emerges and underlying type of disorder, the question arose regarding the effectiveness of mirror therapy with all these different types of patients. The current article evaluated with which types of patients mirror therapy was effective. This serves at least two purposes: Information about the effectiveness of mirror therapy is relevant for the clinical practice because it can be determined for which patients this therapy might work. Second, establishing the type of patient groups with which mirror therapy is effective should allow for a better understanding of the underlying working mechanisms of mirror therapy. Understanding the working mechanisms of mirror therapy is useful in determining the (new) types of patients for who mirror therapy might be helpful. To examine the extend to which mirror therapy was effective we performed a systematic analysis of the literature into the effectiveness of mirror therapy in upper extremity rehabilitation.

Method

Literature search

The following keywords were used to search the electronical database PubMed (1970–2008): *mirror neuron, mirror therapy, nervous system diseases, upper extremity, pain*. An additional search was performed using the following Keywords: *cerebrovascular accident, stroke*. The search was limited to humans. The search strategy that was used is presented in the Appendix. In addition to searching the database also the reference lists of relevant publications were checked.

Study selection

The studies that were identified using the keywords were independently assessed by two reviewers (D. E., M. J.). The following inclusion criteria were used to include studies for the review:

- The study had to concern mirror therapy;
- The focus of the study had to be on the upper extremity;
- The study had to be a full-length publication in a peer-reviewed journal.

The reviewers decided, in a consensus meeting, whether the studies should be included in the final review. To enable the most complete view of the current literature the search was not limited by publication type or by patient group.

Methodological judgment

To assess the methodological quality of the different papers a classification of study designs as described by Jovell & Navarro-Rubio [4] was used (Table I).

Data analysis

The included journal articles were reviewed according to a structured diagram. The content of the papers were scanned for: the diagnosis, subjects (*n*, age, sex), side of lesion, time since injury, design classification, baseline measurements, intervention, outcome measurements and conclusions by the two reviewers (D. E., M. J.). The data of these categories were put into tables. Differences in opinion were resolved by discussion.

Table I. Classification of study design as described by Jovell & Navarro-Rubio [4]. This classification was used to assess the methodological quality of the included papers.

Level	Strength of evidence	Type of study design
I	Good	Meta-analysis of randomised controlled trials
II		Large-sample randomised controlled trials
III	Good to fair	Small-sample randomised controlled trials
IV		Nonrandomised controlled prospective trials
V		Nonrandomised controlled retrospective trials
VI	Fair	Cohort studies
VII		Case–control studies
VIII	Poor	Noncontrolled clinical series; descriptive studies
IX		Anecdotes or case reports

Results

Study selection

The literature search identified 717 studies. Of these 717, 15 studies fulfilled the inclusion criteria and were included for data extraction [3,5–18]. The main reason to exclude studies was that these studies didn't involve the effects of mirror therapy, but studied the mirror neuron system. One of the included studies involves mirror therapy with patients after an amputation of the upper extremity [3]. One study involves mirror therapy with patients who suffered from deafferentation pain following amputation, partial spinal cord injury, brachial plexus lesion or traumatic peripheral nerve lesion [5]. Five studies involve the effects of mirror therapy in stroke patients [6–10]. Six involve the effects of the therapy in patients with complex regional pain syndrome (CRPS) [11–16]; one of these six is about CRPS type 1 patients and patients with phantom limb pain following amputation or brachial plexus avulsion [14], one concerns CRPS type 2 patients [16] and the other four concern only CRPS type 1 patients. The last two studies involve mirror therapy after hand surgery other than amputation [17,18]. The subject characteristics of the fifteen included studies are summarised in Table II.

Amputation

The study characteristics (design classification, the intervention, baseline/outcome measurements and conclusions) of the studies focusing on upper limb amputees are listed in Table III. The time since the amputation in the study performed by Ramachandran & Rogers-Ramachandran [3] differed from 19 days to 9 years. The treatment procedure for the 10 subjects differed among individuals. The patients who suffered from a clenching spasm of the phantom limb mainly used the mirror to unclench the arm and to be relieved from pain. In four out of five patients of the experimental group the clenching spasm could be relieved by means of mirror therapy. Besides relieving the clenching spasms Ramachandran & Rogers-Ramachandran [3] also found some additional effects as a consequence of mirror therapy including sensation referral. The intact hand was touched, scraped or dipped into water while the patients looked into the mirror. It appeared that certain modalities of sensation (related to touching, scraping, dipping and vibration) could be referred to the phantom hand but that others could not (temperature and pain). The control group existed of four healthy subjects who did not have the same experience as the experimental group. Different outcome measurements were taken, such as kinaesthetic sensations, presence of 'clenching spasm' and sensations in the phantom. Note that these outcome measurements mainly focussed on sensory function instead of motor function. The results presented in this study are only descriptive and were not statistically analysed. The study by Sumitani et al. [5] involved deafferentation pain in patients after an amputation, partial spinal cord injury, brachial plexus lesion or traumatic peripheral nerve lesion. This study used both upper and lower limb patients. The time since the deafferentation pain differed from 2 weeks until 22 years. This study did not use a control group and mirror therapy was applied in addition to conventional interventions. The total treatment period was different for each patient. The mean duration was 20.4 weeks. Mirror therapy was found to have a significant effect for reducing deep pain.

Stroke

The study characteristics of the five studies that involved mirror therapy with stroke patients are listed in Table IV. Almost all studies used chronic stroke patients (i.e. stroke occurred more than 6 months before participation of the study) except for the study by Yavuzer et al. [10] which also used subacute stroke patients (i.e. stroke occurred more than 3 months prior to participation of the study). The time since stroke was highly variable and ranged from 0.25 to 26.25 years for individual patients. Two of the studies used mirror therapy as a part of a larger therapy program [7,8].

In these five studies, 27 different outcome measurements were taken. Six different standard functional scales were used to assess the severity of the motor deficit. There were three subjective measurements undertaken: (a) Subjective comments were obtained in the study of Altschuler et al. [6], (b) Rothgangel et al. [9] undertook a process-evaluation based on the reactions of the patients and the observations of the physical therapists and, (c) they also used the patient-specific method ('Patient Specifieke Klachten Schaal' [severity of the main complaint]) to get insight in the subjective perception of performing arm and hand activities. The other outcome measures were used to assess different single aspects of motor function (e.g. grip strength, range of motion, movement times).

All studies showed a positive result of mirror therapy. Altschuler et al. [6] concluded that mirror therapy may be beneficial for at least some patients with hemiparesis following stroke. The positive result was based on a combination score given by two neurologists and subjective comments. The score

Table II. Subject characteristics of the 12 included studies.

Authors	Diagnosis	Subjects (n, age in years (mean ± s.d. (range)), sex)	Side of lesion	Time since injury in years (mean ± s.d. (range))
Amputation				
Ramachandran & Rogers-Ramachandran [3]	Upper limb amputees	Experimental group: $n = 10$, age = 40.60 ± 16.85 (23–73), sex = 7 m, 2 f, 1 unknown	Experimental group: 5 left, 5 right	Experimental group: 2.43 ± 3.40 (0.05–9.00)
		Control group: $n = 4$, age = unknown, sex = unknown	Control group: healthy subjects	Control group: –
Sumitani et al. [5]	Limb amputees, partial spinal cord injury, brachial plexus lesion, traumatic peripheral nerve lesion	$n = 22$, age = 48.36 ± 16.28 (17–75), sex = 16 m, 6 f	12 left, 10 right	4.81 ± 7.48 (0.04–22.27)
Stroke				
Altschuler et al. [6]	Chronic stroke patients	$n = 9$, age = 58.22 ± 6.42 (53–73), sex = 5 m, 4 f	1 left, 8 right	4.84 ± 8.18 (0.50–26.25)
Sathian et al. [7]	Stroke patient with profound sensory deficits contralateral to a subcortical infarct	$n = 1$, age = 57, sex = m	1 left	±0.50
Stevens & Stoykov [8]	Chronic hemiparesis after embolic middle cerebral artery stroke	$n = 2$, age = 76 & 63, sex = 1 m, 1 f	1 left, 1 right	1.16, 6.16
Rothgangel et al. [9]	Stroke patients	*Daycare treatment groups*: Experimental group: $n = 3$, age = 73 (62–87) (median), sex = unknown	*Daycare treatment groups*: Experimental group: 0 left, 3 right	*Daycare treatment groups*: Experimental group: 1.00 (0.75–1.25) (median)
		Control group: $n = 3$, age = 80 (72–81) (median), sex = unknown	Control group: 1 left, 2 right	Control group: 1.00 (0.42–1.50) (median)
		Clinical rehabilitation groups	Clinical rehabilitation groups	Clinical rehabilitation groups
		Experimental group: $n = 5$, age = 79 (49–87) (median), sex = unknown	Experimental group: 1 left, 4 right	Experimental group: 0.58 (0.25–1.17) (median)
		Control group: $n = 5$, age = 76 (73–86) (median), sex = unknown	Control group: 3 left, 2 right	Control group: 0.58 (0.42-2.00) (median)
		In total there were 6 males and 10 females how divided among the groups is unknown		

(*continued*)

Table II. (*Continued*).

Authors	Diagnosis	Subjects (n, age in years (mean ± s.d. (range)), sex)	Side of lesion	Time since injury in years (mean ± s.d. (range))
Yavuzer et al. [10]	Stroke	Experimental group: $n = 17$, age = 63.2 ± 9.2 (49–80) sex = 9 m, 8 f	Experimental group: 7 left, 10 right	Experimental group: 0.45 ± 0.24 (0.25–1.00)
		Control group: $n = 19$, age = 63.3 ± 9.5(43–79), sex = 10 m, 9f	Control group: 8 left, 11 right	Control group: 0.46 ± 0.21 (0.25–1.00)
CRPS1				
McCabe et al. [11]	CRPS1	$n = 8$, age = 33.00 ± 5.93 (24–40), sex = 3 m, 5 f	6 left, 2 right	1.10 ± 1.11 (0.06–3.00)
Moseley [12]	CRPS1	Experimental group: $n = 7$, age = 35.00 ± 14.74 (20–62), sex = 2 m, 5 f	Experimental group: 4 left, 3 right	Experimental group: 0.97 ± 0.35 (0.63–1.67)
		Control group: $n = 6$, age = 38.17 ± 13.79 (18–56), sex = 2 m, 4 f	Control group: 4 left, 2 right	Control group: 1.25 ± 0.36 (0.82-1.69)
Karmarkar & Lieberman [13]	CRPS1	n = 1, age = 63, sex = f	right	unknown
Moseley [14]	CRPS1 and phantom limb pain as a consequence of amputation or brachial plexus avulsion injury	Experimental group: $n = 25$, age = 41.04 ± 14.10 (18–62), sex = 10 m, 15 f	Experimental group: 16 left, 9 right	Experimental group: 1.15 ± 0.82 (0.08–2.50
		Control group: $n = 25$, age = 41.08 ± 13.68 (20–61), sex = 8 m, 17 f	Control group: 12 left; 13 right	Control group: 1.01 ± 0.66 (0.08–2.17)
Tichelaar et al. [15]	CRPS1	n = 3, age = 23, 42, 46, sex = 1 m, 2 f	2 left, 1 right	2.50, 0.67, 9.00
CRPS2				
Selles et al. [16]	CRPS2	n = 2, S1 = 36 years, female S2 = 33 years, female	S1 = right hand at wrist level, S2 = right hand	S1 = 0.50, S2 = 3.00
Hand surgery				
Rosén & Lundborg [17]	Patients after hand surgery	$n = 3$, age = 26, 58, 38, sex = 2 m, 1 f	0 left, 3 right	1.00, 3.00, 0.08
Altschuler & Hu [18]	Fractured distal radius	$n = 1$, age = 39, sex = f	Left	0.33

m, male, f, female; MCA, medial cerebral artery; CRPS1, complex regional pain syndrome type 1; CRPS2, complex regional pain syndrome type 2. Range of the age and time since lesion are listed when available through the papers.

Table III. Study characteristics of the mirror therapy performed with patients after an amputation.

Authors	Baseline measurements	Intervention	Outcome measurements	Conclusion
Ramachandran & Rogers-Ramachandran [3]; methodological score*: 'level VIII'	Neurological evaluation and 'mental status' examination	Mirror therapy. At first the patient had to place his unimpaired arm on one side of the mirror in the mirror box and the phantom on the other side. The unimpaired arm had to be moved gradually until its mirror image matched the felt position of the phantom. After this the patient had to close his eyes and perform mirror symmetric movements. The patient then opened his eyes and looked in the mirror while performing the same task. Not all patients performed the same protocol after this and some patients took the mirror box home	Kinaesthetic sensations	The referral of sensations from the unimpaired arm to the phantom can emerge in the adult human brain in less than 3 weeks. This implies that new pathways are precisely organised and functionally effective
			Presence of 'clenching spasms'	The mirror box may provide a useful new tool for exploring inter-sensory effects in phantom limbs
			Sensations in the phantom	The finding of immediate restoration of vivid illusory movements in the phantom using a mirror; including the 'opening' of a tightly clenched phantom fist, demonstrates that 'modules' concerned with vision and proprioception must interact to a much greater extent than previously assumed The finding that the body image of one particular patient was permanently altered demonstrates the tremendous ability of neural connections in the adult human brain and it may have some therapeutic implications for stroke rehabilitation
Sumitani et al. [5]; methodological score*: 'level IV'	Before each MVF procedure: Dichotomous measurement of phantom limb awareness (presence/absence) Motor imagery of affected limb (willed/involuntary movements/immobilised/absence) NRS measurement Subjective descriptions of qualities of deafferentation pain	Daily mirror therapy treatment. 10 min. exercise of unaffected limb and simultaneously perform similar exercise or imagined movements of the affected limb. The duration of the intervention was individualised (mean 20,4 $\pm$ 23,8 s.d. weeks).	After each MVF procedure: Dichotomous measurement of phantom limb awareness (presence/absence) Motor imagery of affected limb (willed/involuntary movements/immobilised/absence) NRS measurement Subjective descriptions of qualities of deafferentation pain	MVF treatment is a promising therapeutic approach to certain types of deafferentation pain. Pain alleviating effect of MVF promisingly corresponds with the emergence of willed visuomotor imagery of the affected limb. It was more effective for reducing deep pain than superficial pain.

*According to Jovell & Navarro-Rubio [4] (table I).
MVF, mirror visual feedback; NRS, numerical rating scale of pain (0 = no pain, 10 = severe pain); sd, standard deviation.

Table IV. Study characteristics of the mirror therapy performed with stroke patients.

Authors	Baseline measurements	Intervention	Outcome measurements	Conclusion
Altschuler et al. [6]; methodological score* : 'level III'	Assessment by two blinded neurologists of a videotape showing all of the cardinal movements made by the patients.	Mirror therapy. Random assignment to the mirror or transparent plastic (control) condition. After 4 weeks patients crossed over to the other treatment for the next 4 weeks. Total duration of the intervention period was 8 weeks. A session was performed for 15 min, twice a day, 6 days/week, moving both hands or arms symmetrically (moving the impaired arm as best as they could) while watching the unimpaired arm move in the mirror or the impaired arm through the clear plastic	Patients were videotaped at 2, 4, 6 and 8 weeks and progress was assessed by two blinded neurologists assessing the patients' movement ability in terms of ROM, speed and accuracy using a -3 to $+3$ scale (0 representing no change) Subjective comments were also obtained from the patients	Both neurologists found that substantially more patients improved on mirror than on control Mirror therapy may be beneficial for at least some patients with hemiparesis following stroke
Sathian et al. [7]; methodological score* : 'level IX'	Pre-test: Grip strength Release time Max. shoulder flexion Max. shoulder abduction Max. shoulder external rotation Functional reach Cup to mouth time Time to drape towel over shoulders Time to pick up pen Time to fold towel in quarters Spasticity (Asworth grade)	Mirror therapy in combination with 'motor copy' strategy and 'forced use'. The patient had to perform synchronous bimanual movements in a mirror-box while looking at his unimpaired left arm and its reflection in the mirror. The patient started with weekly physical therapy visits that were used to direct and monitor a home program. Initial therapy involved use of the mirror to facilitate a 'motor copy' strategy. Later the therapeutic strategy progressed to 'forced use' of the impaired arm in daily activities	Post-test: Grip strength Release time Max. shoulder flexion Max. shoulder abduction Max. shoulder external rotation Functional reach Cup to mouth time Time to drape towel over shoulders Time to pick up pen Time to fold towel in quarters Spasticity (Asworth grade)	The use of a mirror was beneficial in the rehabilitation of this patient. The mirror was a critical factor in facilitating use of more established strategies such as motor copy and forced use. The end result was increased functional use of the impaired upper limb
Stevens & Stoykov [8]; methodological score* : 'level IX'	Three subtests from the Jebsen Test of Hand Function FM-UEMFT Grip strength ROM wrist extension ROM wrist flexion ROM wrist pronation ROM wrist supination Arm and hand dimensions of the Physical Impairment Inventory of the CMSA	Motor imagery training in which two tasks were performed during 4 weeks, 3 sessions/week, each session took ± 1 hour. Task 1 (± 25 min) – computer-facilitated imagery. Focused on wrist extension and wrist pronation-to-supination of the impaired limb. Computer generated movies provided visual cues, subjects had to imagine performing the movements that were depicted by the movie. The movements were shown from 3 angles and at 4 different speeds Task 2 (± 30 min) – mirror box-facilitated motor imagery. At week 1: focus on learning to identify the reflected hand as own impaired limb moving around freely. At week 2 + 3: simple object manipulation tasks. At week 4: complex object manipulation tasks.	Performed at 1 wk, 2.5 wk and 4 wk after the start of the intervention. Follow-up measurement at 1 month and 3 months after treatment termination: Three subtests from the Jebsen Test of Hand Function FM-UEMFT Grip strength ROM wrist extension ROM wrist flexion ROM wrist pronation ROM wrist supination Arm and hand dimensions of the Physical Impairment Inventory of the CMSA	Performance of the impaired limb improved after the imagery intervention, indicated by increases in assessment scores and functionality and decreases in movement times. The improvements over baseline performance remained stable over a 3-month period. These results demonstrate the potential for using motor imagery as a cognitive strategy for functional recovery from hemiparesis. The intervention targets the cognitive level of action processing while its effects may be realised in overt behavioural performance

(continued)

Table IV. (*Continued*).

Authors	Baseline measurements	Intervention	Outcome measurements	Conclusion
Rothgangel et al. [9]; methodological score* : 'level III'	Primary measurements: ARAT PSK Secondary measurement: MAS	2 experimental groups (1 daycare treatment group and 1 clinical rehabilitation group) received standardised exercise therapy with mirror therapy, 2 control groups (1 daycare treatment group and 1 clinical rehabilitation group) only received standardised exercise therapy. Patients received no co-intervention during the experiment and were instructed not to practice at home. Total intervention duration was 5 weeks, in which the daycare treatment group received therapy 2 times per week, 2x/day for 30 min. Clinical rehabilitation group received therapy 4 times per week, 2x/day for 30 min. Standardised exercise therapy: 10 min – tonus inhibiting or stimulating exercises; 10 min – functional exercises with different objects; 10 min – practicing fine motor skills. Both arms moved and it was important that both arms moved synchronous. A physical therapist facilitated movements of impaired upper limb when necessary. The experimental groups focused on the mirror during all movements.	Same measurements as baseline measurements were taken after 2,5 weeks after the start of the treatment period, after 5 weeks at the end of the treatment period and a follow-up measurement was undertaken at 10 weeks after the start of the treatment period. In addition a process-evaluation was undertaken during and at the end of the treatment period to assess the practical applicability and feasibility. The reactions of the patients and the observations of the physical therapists were collected.	Mirror therapy shows positive changes in hand and arm function of chronic CVA patients. During the 10 week follow-up phase there was no decline regarding hand and arm function.
Yavuzer et al. [10]; methodological score* : 'level III'	Brunnstrom stage (hand) Brunnstrom stage (UE) MAS FIM	Both the mirror group and control group participated in a conventional stroke rehabilitation program, 5 days a week, 2-5 hours a day, for 4 weeks. For the same period, the mirror group received an additional 30 minutes of mirror therapy and the control group performed the same exercises using the non-reflecting side of the mirror. Patients were seated close to a table on which a mirror was placed vertically. The involved hand was placed behind the mirror. Bilateral movement was stimulated.	Brunnstrom stage (hand) Brunnstrom stage (UE) MAS FIM	In the group of stroke patients, hand function improved more after mirror therapy in addition to a conventional rehablitation program compared with control treatment (after 4 weeks and 6 month follow-up). Mirror therapy did not affect spasticity

*according to Jovell & Navarro-Rubio [4] (Table I); ROM, range of motion; ARAT, action research arm test; PSK, patiënt specifieke klachten schaal; MAS, modified ashworth scale; F; FM-UEMFT, Fugl-Meyer upper extremity motor function test; CMSA, Chedoke-McMaster stroke assessment; UE, upper extremity; FIM, functional status component of the uniform data system for medical rehabilitation.

represented change based on range of motion, speed and accuracy. Which component really was affected by mirror therapy was unclear in this study. The results of this score were not statistically analysed. Sathian et al. [7] used mirror therapy to facilitate other forms of therapy, namely a 'motor copy' strategy and 'forced use'. The authors state that the employment of the mirror was the critical factor in facilitating the use of these strategies. The results were not statistically analysed. Because this is a case study and no control case was presented it remains unclear whether the mirror really was the critical factor. In the study performed by Stevens and Stoykov [8] mirror therapy was used as a part of a motor imagery program which consisted of two tasks. Two patients participated and both improved after the therapy program. The program had a positive result for the functional recovery from hemiparesis assessed by different functional outcome measurements. The results of these different outcome measurements were not statistically analysed. Rothgangel et al. [9] undertook a pilot-study in two different groups of stroke patients. One group received daycare treatment and the other group received clinical rehabilitation. In both groups mirror therapy was found to be effective, with the clinical rehabilitation group showing more progress than the daycare treatment group. However, these differences were not statistically tested. Yavuzer et al. [10] performed mirror therapy using a mirror and bilateral movements in addition to a conventional stroke rehabilitation program. The experimental group received mirror therapy and the control group had to perform the same therapy but without using the reflecting side of the mirror. Mirror therapy seems to have a significant effect in terms of motor recovery and hand-related functioning. There was no significant effect found on spasticity.

Complex regional pain syndrome

Complex regional pain syndrome type 1. The study characteristics of the five studies that involved mirror therapy with complex regional pain syndrome type 1 (CRPS1) patients are listed in Table V. Three of these studies involved mirror therapy with both upper and lower limb patients [11,14,15]. The other two studies involved only upper limb patients [12,14]. One study by Moseley [14] involved mirror therapy with both CRPS1 patients and patients who suffer from phantom limb pain as a consequence of amputation or brachial plexus avulsion injury. Both studies of Moseley [12,14] used mirror therapy as a part of a motor imagery program. In the 2004 study, he used a very restricted group of CRPS1 patients; the patients had developed CRPS1 as a result of a non-complicated wrist fracture. The patients were chronic CRPS1 patients (≥6 months after injury). The motor imagery program had a significant effect for these patients. In the 2006 study, Moseley showed that the program had a significant effect for a more general CRPS1 population and also for patients who suffered from phantom limb pain. Because the mirror therapy in these two studies is a part of a larger therapy program it is difficult to determine whether the mirror therapy was the factor that caused the positive outcome. It could be that other parts of the program or the total program caused the positive effects found by Moseley. The study of McCabe et al. [11] examined mirror therapy with the use of a mirror. In this study mirror therapy was effective in patients with early CRPS1 (≤8 weeks) and with intermediate CRPS1 (≤1 year). In patients with chronic CPRS1 (≥2 years), the treatment was not effective. The mirror therapy had an immediate analgesic effect in early CRPS1 and led to a reduction in stiffness in intermediate CRPS1. These effects were not statistically analysed. In this study, both patients with upper as lower limb CRPS1 were included. The positive effects were present in both lower as upper extremity patients. The patients where the mirror therapy was ineffective all concerned lower limb patients. The patient in the study by Karmarkar and Lieberman [13] experienced immediate and dramatic improvement in range of motion and pain of the affected upper limb while using mirror therapy. This effect was not statistically tested. Tichelaar et al. [15] used cognitive behavioural therapy combined with mirror therapy in three patients. Two of these patients suffered from CRPS1 of the lower limb and mirror therapy had a beneficial effect in these cases and one patient suffered from CRPS1 of the upper limb and mirror therapy wasn't effective at all. The results of this study were not statistically analysed.

In these five studies, 17 different outcome measurements were used. Three of these measurements were scales to assess the amount of pain in the affected limb. Seven of the measurements were clinical assessments to define the severity of CRPS1 or to define the signs and symptoms of the stump or phantom limbs for amputees. Three of the measurements were related to the performance of the different tasks in the studies of Moseley [12,14], i.e. response time, movement time and frequency of training. Two measurements concerned the temperature and circumference of the affected limb in CRPS1. One outcome measure was a subjective assessment about mirror box therapy and about the affected limb. The last measurement was a scale to define the functional level of the patients.

Complex regional pain syndrome type 2. The study characteristics of the study that involved mirror therapy with Complex regional pain syndrome type 2 (CRPS2) patients are listed in Table V. This case study concerned two patients with CRPS2 [16]. In CRPS2, a local origin for the pain in generally assumed in contrast with CRPS1 where a clear peripheral etiology for pain is lacking. In these two patients, mirror therapy had a positive effect. For the first patient pain was relieved during and immediately after mirror therapy, but the overall level of pain did not decrease. For the second patient, mirror therapy caused a systematic overall decrease in pain. The authors state that mirror therapy in CRPS2 is worthy of further exploration.

Hand surgery

The study characteristics of the studies with the patients after hand surgery other than amputation are listed in Table VI. In the study by Rosén and Lundborg [17] mirror therapy was applied in combination with traditional hand training and was a successful part of the treatment program in the three included subjects. On these three patients, different outcome measurements were taken. Most measurements concerned motor function. The results of these measurements were not statistically analysed. Following Rosén and Lundborg, Altschuler and Hu [18] also applied mirror therapy to a patient after hand surgery other than amputation. This patient had a fractured wrist. Conventional treatment had no effect and mirror therapy was started. The patient performed mirror therapy in combination with electrical stimulation to the left wrist extensors for 2–3 times per week and besides that also practiced at home 5–6 times per week. At the end of the treatment active wrist extension was 30°. The results of this study were not statistically analysed.

Discussion

In the present review, 15 studies were qualitatively analysed to investigate the effects of mirror therapy on the impaired motor function and pain reduction of the upper limb. As much as five different patient categories were studied: amputation of the upper limb, stroke, CRPS1 and CRPS2 and hand surgery other than amputation.

Mirror therapy is still in its early stages, therefore only a small number of studies could be included in this review. The methodological quality of the included studies is variable. The highest methodological score according to Jovell and Navarro-Rubio [4] (Table I) of the studies in this review is level II, which corresponds to a good strength of evidence. Only five of the 15 included studies were randomised controlled trials (RCTs) of which four were small-sample RCTs. The remainder of the studies had a poor strength of evidence and concerned descriptive studies or case reports. The studies on amputation and hand surgery other than amputation all had a weak methodological quality, hence, these studies were not used to draw conclusions regarding the effectiveness of mirror therapy. Our conclusions on the effectiveness of mirror therapy, as explained in the following, were drawn using only three studies in stroke patients [6,9,10] and two studies with CRPS1 patients [12,14].

Note that although all of these five studies are RCT's and those studies have a high methodological score relative to the other studies, there are still aspects of these studies that possibly bias the results. For instance, the number of participants in the studies is small. An other factor that may have biased the results was that the time spent at training with the mirror box was not similar in all studies; in some of the studies the patients could take the mirror box home and practice whenever they wanted to, which made that the intensity of the therapy could not be controlled. Finally, in some of the studies mirror therapy was performed in combination with other therapy forms, which made it difficult to determine which part of the therapy contributed to the reported effects.

The potential of mirror therapy in CRPS1 patients was recognised based on the fact that characteristics of CRPS pain (burning, cramping, mislocalisation) are also observed with phantom pain [cf. 11; cf. 14]. Since mirror therapy seemed effective with phantom pain [3], it was thought that this therapy might also work with CRPS1. The two studies of Mosely [12,14] showed that mirror therapy was effective for chronic CRPS1 patients. Importantly, in the studies of Moseley mirror therapy was combined with a motor imagery program, hence, it could be that it was this combination of motor imagery and mirror therapy that caused the positive effect. Therefore, it is difficult to determine the role of mirror therapy in CRPS1 rehabilitation.

With regard to the working mechanisms of mirror therapy in CRPS1 patients, Moseley suggested that a possible explanation for the positive effect of mirror therapy are sequential activation of cortical premotor and motor networks, or sustained and focussed attention on the affected limb, or both. The attention a patient pays to the affected limb in mirror therapy might reverse the disuse of the limb. The forced attention of the limb in the mirror therapy might activate neuromotor networks, which might relieve the pain [14]. Despite that the

Table V. Study characteristics of the mirror therapy performed with patients with complex regional pain syndrome.

Authors	Baseline measurements	Intervention	Outcome measurements	Conclusion
CRPS1				
McCabe et al. [11]; methodological score*: 'level VIII'	Pain VAS IRT Both measured on presentation according to an assessment protocol that consisted of 2 control phases (using no device and viewing a non-reflective surface) and an intervention phase (viewing a mirror)	Mirror therapy. Subjects were directed to use the mirror as frequently as they wished for a period of 6 weeks. The maximum time for each period of mirror therapy was 10 min. Patients had to perform flexion-extension cycles of the relevant body parts with their unimpaired limb and, if possible, with their impaired limb in a symmetric way. The ROM and speed of these exercises was dictated by the subject's pain	Pain VAS IRT Measured at the end of the 6 week treatment period. A daily diary was used to record frequency of mirror use and pain severity between assessments	In early CRPS1 visual input from a moving, unimpaired limb re-establishes the pain-free relationship between sensory feedback and motor execution. Trophic changes and a less plastic neural pathway preclude this in chronic disease
Moseley [12]; methodological score*: 'level III'	NPS Finger circumference Measured at the start of the treatment- or control period	Experimental group: motor imagery program consisting of 3 stages, each of 2 weeks duration Stage 1 – recognition of hand laterality. 56 pictures of a right or left hand were shown and patients had to respond as quick and accurate possible by pressing a button at the moment they recognised the hand to be right or left. Patients were advised to perform the task 3 times (10 min) each waking hour. Stage 2 – imagined hand movements. 28 pictures of the impaired hand were randomly shown. Patients had to imagine that their own hand was moving to adopt the posture shown in the picture, three times. The emphasis was on accuracy. Patients were advised to perform the task three times every waking hour ($\pm$15 min.) Stage 3 – mirror therapy. With the use of a mirror box patients had to adopt the posture shown in 20 pictures of the unimpaired arm with both arms slowly and smoothly. The emphasis was on watching the reflection of their unimpaired hand in the mirror. Patients were advised to perform the task 10 times each waking hour and to stop if they had an increase in pain Control group: these patients had to maintain their ongoing management, which consisted mostly of 2-3 sessions of physical therapy per week	NPS Finger circumference These two measurements were performed at 2, 4 and 6 weeks after the start of the treatment- or control period and a follow-up measurement was performed at 12 weeks Of the experimental group the following additional measures were taken as outcome: Response time to recognise the impaired hand (stage 1) Time at which each trial was performed (stage 2) Diary of training (stage 3)	This study supports a motor imagery approach to chronic CRPS1. The results uphold the hypothesis that a motor imagery program initially not involving limb movements is effective for CRPS1 and support the involvement of cortical abnormalities in the development of this disorder.

(*continued*)

Table V. (*Continued*).

Authors	Baseline measurements	Intervention	Outcome measurements	Conclusion
Karmarkar & Lieberman [13]; methodological score*: 'level IX'	ROM	Mirror box therapy	ROM Pain scores (unspecified)	Mirror box therapy had an immediate and dramatic improvement in the ROM of the affected hand and a reduction in pain scores of more than 50%. After 1 trial mirror box therapy proved to be very useful in the patient with CRPS1
Moseley [14]; methodological score* : 'level II'	Undertaken at prerandomisation. Questionnaires: Function NRS MPQ Pain VAS Clinical assessment: Diagnostic criteria for CRPS1 Symptoms and signs of hyperalgesia and allodynia of the stump for amputees Symptoms of swelling and temperature changes in the phantom limb Symptoms of motor disorders of the phantom limb	Experimental group: motor imagery program consisting of 3 stages, each of 2 weeks duration. Stage 1 – limb laterality recognition. Patients saw pictures and had to respond by pressing a left or right pressure-sensitive button according to whether the picture showed a left or right limb. Stage 2 – imagined movements. Pictures of both limbs were randomly presented and patients had to imagine twice adopting the posture shown with a smooth and pain free movement. Stage 3 – mirror movements. With the use of a mirror box patients were advised to twice adopt the posture shown with both hands, using smooth and pain free movements. Within all three stages the training load was increased by showing postures of limbs that were more painful to adopt. And patients had to train at home every waking hour Control group: medical/ physiotherapy management. These patients received a 6 week physiotherapy program and maintained usual medical care. The physiotherapy program did not contain treatments similar to those used in the experimental group. It consisted of at least 1 treatment/week and a home program that involved a training load comparable to that in the motor imagery program (i.e. hourly training)	Undertaken at 6 weeks after completion of the treatment period. Questionnaires: Function NRS MPQ Pain VAS Clinical assessment: Diagnostic criteria for CRPS1 Symptoms and signs of hyperalgesia and allodynia of the stump for amputees Symptoms of swelling and temperature changes in the phantom limb Symptoms of motor disorders of the phantom limb Of the experimental group the following additional measures were taken as outcome: Response time to recognise the impaired hand (stage 1) Time at which each trial was performed (stage 2) Diary of training (stage 3) At 6 months follow-up function NRS and pain VAS were also undertaken	Graded motor imagery reduced pain and disability in a wider CRPS1 population and in those with phantom limb pain after amputation or brachial plexus avulsion injury. The following results support this position: 1) pain decreased and function increased for the motor imagery group, this effect was significant; 2) NNTs for response to treatment at 6 months of about 3

(*continued*)

Table V. (*Continued*).

Authors	Baseline measurements	Intervention	Outcome measurements	Conclusion
Tichelaar et al. [15]; methodological score*: 'level IX'	ROM (dorsal/palmar flexion or dorsal/ plantar flexion) muscle strength allodynia (upper border of the area was measured) hyperalgesia (upper border of the area was measured) position of hand or foot in which patient was most comfortable at rest subjective assessment about mirror box therapy and about the affected limb Quantitative aspects of pain VAS, measured: At rest After testing ROM After testing ROM After testing muscle strength After testing muscle strength After testing allodynia After testing hyperalgesia	CBT (cognitive behavioural therapy) combined with mirror box therapy aiming at regaining limb function and pain reduction. Week 1 – all analgesics were gradually reduced or stopped (detoxification) Week 2 – mirror box therapy was introduced as add-on to the desensitisation therapy, 3 times per day for 2 cycles of 5 min. Week 3 – mirror box therapy 5 times per day for 2 cycles of 5 min.	Same measurements as the baseline measurement. Performed once a week during therapy and at follow-up after the clinical phase Patient 1 – follow-up after 14 weeks Patient 2 – follow-up after 8 weeks Patient 3 – follow-up after 5 weeks	Case 1 improved i.e. he experienced less pain without using any medication and could walk a little distance without using elbow-crutches. Case 2 improved less. She experienced less pain but mobility did not improve. Case 3 improved not at all.
CRPS2				
Selles et al. [16]; methodological score* : 'level IX'	Pain VAS	Mirror therapy. A mirror was placed vertically on the table in front of the patient. Painful hand hidden behind the mirror, non-painful hand positioned so that the reflection of the hand was superimposed on the painful one. Patients had to practice 3-5 times each day for 15 minutes. First 5-10 min. unilateral movements. After that 5-10 min. bilateral movements. S1 trained for 3 weeks S2 trained for 5 months	Pain VAS	The presented cases demonstrate that the use of mirror therapy in patients with CRPS2 is worthy of further exploration as a potential treatment modality in patients with CRPS2.

*According to Jovell & Navarro-Rubio [4] (Table I); VAS, visual analogue scale (0, no pain; 10, pain as bad as it could be); IRT, infrared thermography; ROM, range of motion; NPS, neuropathic pain scale; function NRS, patient-specific task-related numerical rating scale; MPQ, McGill pain questionnaire; NNT, number needed to treat; CRPS1, complex regional pain syndrome type 1; CRPS2, complex regional pain syndrome type 2.

Table VI. Study characteristics of the mirror therapy performed with patients after hand surgery other than amputation.

Authors	Baseline measurements	Intervention	Outcome measurements	Conclusion
Rosén & Lundborg [17]; methodological score* : 'level IX'	On all three patients the baseline measurements were different, e.g. grip strength, active ROM, SWM	All patients used mirror therapy combined with traditional hand training	On all three patients the outcome measurements were different, e.g. grip strength, active ROM, SWM, and STI test	Mirror therapy works in these three case and these examples demonstrate new applications of the mirror therapy
Altschuler & Hu [18]; methodological score* : 'level IX'	Active ROM	Mirror therapy combined with electrical stimulation to the left wrist extensors. Bilateral movements were requested. Duration: 15 min. 2–3 times per week. Patient also practiced at home without electrical stimulation for 15 min. 5–6 times per week	Active ROM	Active wrist extension was impossible until mirror therapy started. The authors think that the recovery of functionally useful and maintained active wrist extension can be attributed to mirror therapy

*According to Jovell & Navarro-Rubio [4] (Table I); ROM, range of motion; SWM, Semmes-Weinstein monofilaments to test the perception of touch/pressure; STI test, shape texture identification test.

underlying working mechanism is not clear yet, the effects of mirror therapy with CRPS1 patients are relevant for rehabilitation because these patients seem to be locked in a vicious circle of pain and disuse. Mirror therapy seems to be a possibility to break through this vicious circle, which opens up opportunities for rehabilitation for patients with CRPS1. However, more systematic research is needed before definite conclusions regarding mirror therapy in CRPS1 patients can be drawn [19].

Three studies reported a positive effect of mirror therapy on motor function after stroke. Within stroke patients, the sensomotoric coupling is often disturbed, which might compromise task-intrinsic feedback. Therefore, to recover motor function stroke patients may be more dependent on augmented feedback [20]. This augmented feedback might be delivered in the form of visual feedback through mirror therapy [6–9]. A possible working mechanism of mirror therapy in stroke patients is based on the fact that in mirror therapy movement of the unimpaired upper limb is used to improve the motor control of the impaired limb. This bilateral movement suggest a bilateral transfer as an origin of the effects of mirror therapy.

Moreover, there is evidence that both the motor activity and the perceptual activity in mirror therapy modulate the excitability of M1, pointing at a mechanism that might explain effectiveness of mirror therapy [21–24]. During mirror therapy, there are two sources of changes in ipsilateral M1 excitability [cf. 21], that is, through action performance activating M1 ipsilateral and through observation of that action activating M1 contralateral. The simultaneous changes in excitability of M1 in mirror therapy might result in neural reorganisations appropriate for functional recovery. This is hypothesised as a possible mechanism by which mirror therapy can work with stroke patients. Garry et al. [21] found a trend in their data supporting this idea; the results showed that looking at the moving hand facilitates excitability of ipsilateral M1 compared to looking at the inactive hand or a dummy position. However, the difference between looking at the active hand and looking at the mirror reflection did just not reach a conventional significance level.

In summary, the interaction within M1 between the mechanisms mediating the excitability as a consequence of movement and the mechanisms mediating the excitability as a consequence of observation might serve as a hypothesis to explain for the improved functional recovery with the use of mirror therapy in stroke patients. Would this hypothesis hold in future studies, it indicates that the benefits of mirror therapy are not just a result of motor training but of the mutual interactions between perceptual and motor activity at the cortical level. Of course, this hypothesis deserves further studying but it might be an interesting starting point to increase our understanding of the workings of mirror therapy in stroke patients.

To conclude, mirror therapy seems to be effective mainly for patients with CRPS1 and stroke patients – but note that it is currently impossible to establish the individual benefit of mirror therapy in CRPS1 patients [19]. However, the proposed working mechanisms of mirror therapy differed in those two patients groups. All in all, the current systematic literature review has shown that the use of mirror therapy in rehabilitation seems promising, especially for CRPS1 patients, when combined with motor imagery, and for stroke patients, while the effectiveness in other patient groups has yet to be determined.

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Appendix – PubMed search strategy

1. Mirror 'neuron' [MeSH]
2. Mirror therapy
3. 'Nervous system diseases' [MeSH]
4. 'Upper extremity' [MeSH]
5. 'Cerebrovascular accident' [MeSH]
6. Stroke
7. Pain
8. Nos. 1 and 3
9. Nos.1 and 4
10. Nos. 2 and 3
11. Nos. 2 and 4
12. Nos. 2 and 5 or 6
13. Nos. 2 and 7

MeSH, medical subject headings.

The search was limited to humans and there were no limits set for publication type.