Modified graded motor imagery for complex regional pain syndrome type 1 of the upper extremity in the acute phase: a patient series

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Complex regional pain syndrome (CRPS) is a pathologic condition in which the painful experience is disproportionate in time and intensity in comparison with the inciting event. At present, the pathophysiology of CRPS is not well understood. Several studies have indicated that cortical reorganization plays a role in the persistence of the symptoms. A new promising approach, graded motor imagery (GMI), seems to be effective, but there are limited data for the CRPS-1 upper extremity population. The aim of this study was to demonstrate the effectiveness of a modified GMI (mGMI) protocol based on the work of Moseley to reduce pain and enhance functional capacities for a population with nonchronic CRPS-1 of the upper extremity. The following outcome measures were used to assess the clinical effectiveness: pain (short form of the McGill Pain Questionnaire), grip force (Martin vigorimeter), perception of upper extremity function (Disabilities of the Arm, Shoulder and Hand Questionnaire), and patient's global impression of change. All outcomes at T_4 were compared with the baseline data (T_0) using the Mann–Whitney test and the χ^2 test (nonparametric tests). Seven patients were recruited for the study. At the end of the mGMI (T_4), we obtained significant results for the decrease in the pain experienced in the last 7 days (visual analog scale; $P=0.046$), improvement in the affected extremity grip force ($P=0.042$), and the patient's global impression of change ($P=0.015$). However, the data of the perception of upper extremity function (Disabilities of the Arm, Shoulder and Hand Questionnaire) were not clinically or statistically significant. Our results indicate that this mGMI protocol seems to be a promising therapeutic modality to reduce pain. However, more investigations are needed to determine whether mGMI has a significant impact on upper extremity function.

Das komplexe-regionale Schmerzsyndrom (CRPS) ist ein pathologischer Zustand, bei dem die Schmerzen im Vergleich mit dem sie auslösenden Ereignis unverhältnismäßig lang andauern und stark sind. Die Pathophysiologie des CRPS ist derzeit noch unklar. Zahlreiche Studien weisen darauf hin, dass die kortikale Reorganisation eine Rolle bei der Persistenz der Symptome spielt. Ein neuer, viel versprechender Ansatz - das GMI-Programm (graded motor imagery) - scheint effektiv zu sein, wobei aber nur beschränkte Daten für die Population mit CRPS-1 der oberen Extremitäten vorliegen. Ziel der vorliegenden Studie war der Nachweis der Effektivität eines modifizierten GMI-Protokolls (mGMI) auf der Grundlage der Arbeit von Moseley zur Schmerzreduktion und Verbesserung der Funktionsfähigkeit bei einer Population mit nicht-chronischem CRPS-1 der oberen Extremitäten. Die folgenden ergebnisorientierten Messgrößen wurden zur Beurteilung der klinischen Effektivität herangezogen: Schmerzen (Kurzform des McGill-Schmerz-Fragebogens), Griffstärke (Martin-Vigorimeter), Wahrnehmung der Funktionsfähigkeit der oberen Extremitäten (Fragebogen zum DASH-Score - Behinderung an Arm, Schultern und Hand) und der globale Eindruck des Patienten von der Veränderung. Alle Ergebnisse auf T_4 wurden unter Zuhilfenahme des Mann-Whitney-U-Tests und des χ^2-Tests (nicht-parametrische Testverfahren) mit den Baseline-Daten (T_0) verglichen. Für die Studie wurden sieben Patienten rekrutiert. Nach Abschluss des mGMI (T_4) erhielten wir signifikante Ergebnisse für die in den vergangenen sieben Tagen erfolgte Schmerzreduktion (visuelle Analogskala; $P=0.046$), Verbesserung der Griffstärke der betroffenen Extremität ($P=0.042$) und der globale Eindruck des Patienten von der Veränderung ($P=0.015$). Die Daten zur Wahrnehmung der Funktionsfähigkeit der oberen Extremitäten (Fragebogen zum DASH-Score - Behinderung an Arm, Schultern und Hand) waren jedoch weder klinisch noch statistisch signifikant. Unsere Ergebnisse deuten darauf hin, dass dieses mGMI-Protokoll eine viel versprechende therapeutische Modalität zur Schmerzreduktion zu sein scheint. Um zu ermitteln, ob mGMI eine erhebliche Auswirkung auf die Funktionsfähigkeit der oberen Extremitäten hat, sind jedoch weitere Untersuchungen erforderlich.

El síndrome de dolor regional complejo (SDRC) es una afección patológica donde el dolor experimentado es desproporcionado en tiempo e intensidad en comparación con el suceso que lo ha provocado. En la actualidad, no existe un conocimiento exhaustivo de la patofisiología de SDRC. Varios estudios han indicado que la reorganización cortical desempeña un papel importante en la persistencia de los síntomas. Existe un nuevo enfoque prometedor, las imágenes motoras graduales (GMI, por sus siglas en inglés), que parece ser efectivo, pero se dispone de un número limitado de datos sobre la población que padece SDRC-1 en las extremidades superiores. El objetivo de este estudio fue demostrar la eficacia de un protocolo

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modificado de GMI (mGMI), basado en el trabajo de Moseley, para disminuir el dolor y facilitar la mejora de las capacidades funcionales de una población con SDRC-1 no crónico de las extremidades superiores. Se llevaron a cabo las siguientes mediciones con el fin de evaluar la eficacia clínica: dolor (forma abreviada del Cuestionario del dolor McGill), fuerza de prensión (Martin vigorimeter), percepción de las funciones de las extremidades superiores (Cuestionario de discapacidad del brazo, el hombro y la mano) e impresión general del paciente sobre el cambio. Todos los resultados obtenidos en T_4 se compararon con los datos iniciales (T_0) mediante la prueba de Mann–Whitney y la prueba c^2 (pruebas no paramétricas). En el estudio participaron siete pacientes. Tras finalizar mGMI (T_4), se obtuvieron resultados significativos con respecto a la disminución del dolor experimentado en los últimos 7 días (escala análoga visual; $P=0.046$), la mejora de la fuerza de prensión de la extremidad afectada ($P=0.042$) y la impresión general del paciente sobre el cambio ($P=0.015$). Sin embargo, los datos sobre la percepción de las funciones de las extremidades superiores (Cuestionario de discapacidad del brazo, el hombro y la mano) no fueron clínicamente o estadísticamente significativos. Los resultados de este estudio indican que el protocolo de mGMI es un prometedor modelo terapéutico para la disminución del dolor. Sin embargo, es preciso llevar a cabo futuras investigaciones con el fin de determinar si mGMI influye significativamente en las funciones de las extremidades superiores.

Le syndrome de douleur régionale complexe (SDRC) est un état pathologique dans lequel l'expérience douloureuse est disproportionnée dans le temps et l'intensité par rapport à l'événement déclencheur. À l'heure actuelle, la physiopathologie du SDRC n'est pas bien comprise. Plusieurs études ont indiqué que la réorganisation corticale jouait un rôle dans la persistance des symptômes. Une nouvelle approche prometteuse, l'imagerie motrice progressive (MP), semble être efficace, mais il existe peu de données pour personnes atteintes d'un SDRC-1 au membre supérieur. Cette étude avait pour objet de démontrer l'efficacité d'un protocole IMP modifié (IMPm) basé sur les travaux de Moseley pour réduire la douleur et améliorer les capacités fonctionnelles pour une population souffrant de SDRC-1 d'une extrémité supérieure. Les mesures de résultats suivantes ont été utilisées pour évaluer l'efficacité clinique: la douleur (forme courte du questionnaire de McGill sur la douleur), force de préhension (vigorimètre de Martin), perception de la fonction du membre supérieur (questionnaire disability arm shoulder hand – sur les incapacités fonctionnelles reliées á une atteinte aux membres supérieurs) et impression globale de changement pour le patient. Tous les résultats à T_4 ont été comparés avec les données de référence (T_0) en utilisant le test de Mann-Whitney et le test chi^2 (tests non paramétriques). Sept patients ont été recrutés pour l'étude. À la fin du protocole IMGm (T4), nous avons obtenu des résultats significatifs pour la diminution de la douleur ressentie dans les 7 derniers jours (échelle visuelle analogique; $P=0.046$), amélioration de la force de préhension de l'extrémité affectée ($P=0.042$), et l'impression globale de changement pour le patient ($P=0.015$). Toutefois, les données de perception de la fonction du membre supérieur (questionnaire sur le handicap du bras, de l'épaule et de la main) n'étaient pas cliniquement ni statistiquement significatives. Nos résultats indiquent que ce protocole IMGm semble constituer une modalité thérapeutique prometteuse pour réduire la douleur. Toutefois, des recherches complémentaires sont nécessaires pour déterminer si l'IMGm a un impact significatif sur la fonction du membre supérieur. *International Journal of Rehabilitation Research* **35:138–145 © 2012 Wolters Kluwer Health | Lippincott Williams & Wilkins.**

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Introduction

Complex regional pain syndrome (CRPS) is defined by the International Association for the Study of Pain as a painful condition that is disproportionate in time and intensity compared with the inciting event (Stanton-Hicks, 2010; Sebastin, 2011). CRPS is considered as a neuropathic pain disorder that is typically expressed in an extremity after any (even minimal) injury (Bruelh, 2010). The most common initiating events are surgeries, fractures, crush injuries, and sprains (Bruelh, 2010). Notably, there is no distinct correlation between the severity of trauma and the degree of CRPS symptoms (Maihöfner *et al.*, 2010).

A distinction is made when a nerve lesion cannot be identified (CRPS-1) and when a distinct major nerve injury has occurred (CRPS-2). This distinction, however, is not without criticism. For example, bone fracture or surgery will damage peripheral nerve fibers, but CRPS resulting from these situations are almost always classified

as CRPS-1 (Marinus *et al.*, 2011). Also, around 90% of CRPS patients are categorized as CRPS-1; however, few of these patients have been investigated to detect or exclude subtle nerve injuries (Oaklander and Fields, 2009). As there is no diagnostic test to confirm the presence of CRPS, the diagnosis is made by a detailed clinical examination. The diagnosis of CRPS is made on the basis of the Orlando criteria (Merskey and Bogduk, 1994), endorsed by the International Association for the Study of Pain, or a modified version called the Budapest criteria (Harden *et al.*, 2010). Diagnosis according to the Budapest criteria is made on the basis of the grouping of signs and symptoms into four distinct categories, that is, sensory, vasomotor, sudomotor/edema, and motor/trophic nature (De Boer *et al.*, 2011; Marinus *et al.*, 2011).

The etiology of CRPS is also unclear. At present, there is no single pathophysiological mechanism that can explain the diversity and the heterogeneity of the symptoms. The clinical presentation includes a triad of symptoms including sensory (pain and hyperalgesia), autonomic (disturbances of skin temperature, color, presence of sweating abnormalities), and motor disturbances (weakness and loss of range of motion) (Maihöfner *et al.*, 2010). However, three major pathophysiological pathways have been identified: (a) aberrant inflammatory mechanisms, (b) vasomotor dysfunction, and (c) maladaptive neuroplasticity. The clinical heterogeneity of CRPS is indicative of between-subject variability in the activation of these pathways after tissue injury (Marinus *et al.*, 2011). The central nervous system undergoes functional and structural changes in individuals with persistent pain and these changes are considered to be particularly important in CRPS (Marinus *et al.*, 2011). On the basis of this paradigm, a systematic review of the literature has shown that a rehabilitation process using the mirror therapy combined with motor imagery seems promising, especially for patients with CRPS-1 (Ezendam *et al.*, 2009). The combination of mirror therapy and motor imagery is called graded motor imagery (GMI).

GMI is a comprehensive program designed to sequentially activate cortical motor networks and improve cortical organization (Moseley, 2005) and seems to be a modality of choice for the treatment of CRPS-1 (level II evidence) (Daly and Bialocerkowski, 2009). Moseley (2004, 2005, 2006) made major contributions toward the development of this intervention strategy. GMI is a treatment approach designed to 'train the brain' (Moseley, 2006) with the notion that if cortical changes are the underpinnings for pain, then reorganizing the cortex would help decrease pain (Priganc and Stralka, 2011).

Typically, GMI consists of three phases: (a) a limb laterality recognition task, (b) an imagined limb movement task (motor imagery), and (c) mirror therapy. In the laterality recognition task, the participant has to identify a pictured hand as a left or a right limb (Swart *et al.*, 2009). The underlying premise for laterality training is that the ability to discriminate between right and left depends on an intact body schema, activates premotor cortices, and re-establishes left and right concepts in the brain (Priganc and Stralka, 2011). The second step involves asking the participant to imagine that he/she has adopted a limb posture similar to the one shown in a picture without moving the affected hand. This mental exercise would activate both the premotor cortex and the primary motor cortex (Swart *et al.*, 2009). Finally, the mirror therapy involves using a mirror box with which the participant is requested to watch the mirrored image of the unaffected hand moving in the mirror. Then, the participant moves the affected hand in the mirror box while watching the mirrored image of the unaffected hand (Priganc and Stralka, 2011). This creates the illusion that the injured hand is moving without pain. Mirror therapy is thought to provide strong positive sensory feedback into the cortex that not all movement needs to be painful (McCabe *et al.*, 2008). There is good evidence for the use of mirror therapy alone for acute CRPS-1 (McCabe *et al.*, 2003, 2004), but Moseley (2004) predicted that starting the GMI with premotor activities would reduce the risk of increased pain and help to 'train the brain' (McCabe *et al.*, 2008). In fact, a recent randomized-controlled trial demonstrated that there is good evidence indicating that GMI reduces pain and disability in relatively homogenous group of patients with chronic CRPS-1 (Moseley, 2006).

Although the current evidence is positive, Priganc and Stralka (2011) recommended that more research was needed, and studies should include more homogenous groups of patients (i.e. similar diagnoses and/or similar time since onset of CRPS) to help validate the existing literature. Future studies should also help to specify the treatment protocol in terms of duration, sequence, difficulty, and progression.

It is with this in mind that we aimed to develop and evaluate a modified GMI (mGMI) treatment protocol, based on the work of Moseley (2004, 2006). Two major changes were made to the treatment protocol used in this study: (a) integration of the mirror box into phase 2, which is to imagine the movement (motor imagery), and (b) phase 3 (mirror therapy) has been divided into two stages to create a phase 4. No previous studies using this protocol treatment have been published as yet.

The aim of this study was to demonstrate the clinical effectiveness (reducing pain and enhancing functional capacities and grip force) of this mGMI treatment protocol for nonchronic CRPS-1 of the upper extremity (UE).

Methods

Design

A pre-experimental patient series with pre–post repeated measures was conducted to evaluate the mGMI treatment

protocol. The study was performed at the Centre Hospitalier Universitaire de Sherbrooke (CHUS), a healthcare center that provides highly specialized care to the population of the Eastern Townships region in the province of Quebec, Canada, between January 2010 and October 2010. Ethics approval was obtained from the Centre de Recherche Clinique Etienne-LeBel's institutional ethics review boards at the CHUS.

Participants and recruitment

Participants were recruited on a voluntary basis from a list of patients referred to the Hand Clinic of the CHUS by plastic surgeons and orthopedists. Patients were eligible if they: (a) had a diagnosis of a UE CRPS-1 (below the elbow) according to the Budapest criteria (Harden *et al.*, 2010) for less than 6 months and (b) were at least 18 years of age. Patients were excluded if they had (a) been diagnosed with other neurologic, psychopathology, or motor disorders, (b) any other UE pathology, (c) pain before the development of CRPS in the affected limb, (d) visual impairments, and (e) received a sympathetic block in the 4 weeks before the beginning of the mGMI. Patients included were not allowed to start another therapeutic approach during this time frame. They were advised to continue their prescribed pain medications.

Independent variable: modified graded motor imagery

Our mGMI treatment included four phases that required 1–3 weeks each. Phase 1, identification of hand laterality: when presented on the screen, the participant must determine spontaneously whether it is an upper limb of the right or the left side. During this time, he must not move his hands. Phase 2, imagined hand movements: while watching the reflection of the nonaffected limb in the mirror, the participant must imagine performing the movement presented on the screen and return to the resting position. For each image presented by the software on the screen, the participant must repeat the process three times. If some pictures would induce pain, the participant was asked to imagine the movement presented on the screen while watching the nonaffected limb and not the reflection in the mirror. The affected and nonaffected limb remains immobile during this phase. Phase 3, mirror therapy with mobilization of the nonaffected hand: during this phase, the participant must execute the movement demonstrated by the software by moving the nonaffected limb slowly and gently, five to 10 times, and just watching in the mirror. The limb affected remains immobile while being hidden in the mirror box. Phase 4, mirror therapy with mobilization of both hands: the participant slowly and gently performs the movements demonstrated by the software with both UE five to 10 times. The patient then observes the reflection of the UE in the mirror and imagines that it is his affected UE. Between each movement executed, the two hands must return to the resting position.

The mGMI was carried out using a software and a mirror box. The participant performed the therapy at home for 10 min per session, three sessions a day, and 6 days a week. The occupational therapist performed a weekly follow-up (phone call) to answer the participant's questions and to adjust the progression if necessary. Each phase of the protocol included four levels of difficulty (to imagine hand position) and four levels of image display speed. If an increase of more than 2/10 in pain intensity occurred during the mGMI protocol, the exercises had to be stopped and the participant had to note after how long the pain had started. If this occurred, the participants had two options for the following session's exercises: (a) passing over the image that caused the pain or (b) perform the exercise for recorded time minus 1 min.

An in-person appointment took place at the clinic at every change in mGMI phase. The participant progressed to the next phase when exercises did not cause an increase in pain. The occupational therapist evaluated the patient's condition before each new phase. For this study, the progression of the mGMI was similar for every participant. Every participant had their follow-up appointment and their change of phase every 2 weeks.

Outcomes measures

Clinical pain

The short form of the McGill Pain Questionnaire (SF-MPQ) (Melzack, 1987) was used to assess the qualitative and quantitative aspects of pain. The first part consisted of evaluating the qualitative aspect by selecting the adjectives that best qualified the pain during the last week. The main component of the SF-MPQ consists of 15 descriptors (items 1–11 sensory; items 12–15 affective), which are rated on an intensity scale as 0 = none, 1 = mild, 2 = moderate, and 3 = severe. The total score of the qualitative aspect of pain is obtained by adding the scores of the 15 descriptors. The second part was used to assess the pain intensity experienced in the last 7 days with a visual analog scale (VAS; 0 mm = no pain and 100 mm = worst possible pain). The SF-MPQ also includes the present pain intensity (PPI) assessed by a verbal rating scale (0 = no pain and 5 = excruciating).

Perceived function of the upper limb

Disabilities of the Arm, Shoulder and Hand (DASH) Outcomes Measures is a 30-item self-report questionnaire designed to measure physical functions and symptoms in patients with any musculoskeletal disorders of the upper limb (Durand *et al.*, 2005). The total DASH was obtained by following a specific algorithm and ranged from 0 to 100, where a higher score indicates greater disability.

Grip force

The grip force was evaluated using a Martin vigorimeter (Thorngren and Werner, 1979). The participants

squeezed the vigorimeter three times with each hand and the average of those three results was calculated to obtain the grip strength for each hand.

Patient's global impression of change

Patient's global impression of change scale (PGIC) is a seven-point Likert scale, ranging from very much improved to very much worse, to assess how much the patient's condition had improved or worsened (Dworkin *et al.*, 2005).

Other variables

We also collected sociodemographic data (i.e. age, sex, ethnicity, education level, civil status, works status, etc.) and medical information related to the event such as the affected hand, current medication, medical investigation, and previous treatments.

Data collection

Data were collected at baseline (T_0) and after each phase of the mGMI (T_1–T_4). We collected the data at T_0 and at the end of each of the four phases of mGMI (T_1–T_4), except PGIC, which was not collected at T_0, and the DASH Questionnaire, which was collected at T_0 and T_4. Detailed information is presented in Table 1.

Data analysis

Descriptive statistics (mean, SD) were used to describe sociodemographic data at baseline. All outcomes at T_4 (SF-MPQ, grip force, DASH, and PGIC) were compared with the baseline data (T_0) using the Mann–Whitney test and the χ^2 test (nonparametric tests) because of the relatively small number of patients included in this study and as visual inspection of the histograms did not allow us to assume that the data were normally distributed. Significance was set at *P*-value of less than 0.05. Statistical analysis was performed using SPSS software version 18.0 for Windows (SPSS, Chicago, Illinois, USA).

Results

Participants' characteristics

Initially, eight patients took part in the study but one was excluded after 2 weeks as he developed a severe infection. Therefore, seven patients completed the study. Our sample consisted of six women and one man, with a mean age of 45 ± 9.36 years. Participants were all French-speaking and white. Five participants had a high school degree of education, one participant had a college degree of education, and one had a university degree of education. Most patients developed CRPS-1 after a trauma. Three participants had a fracture of the radius, two participants had a laceration of the tendons of the hand, one participant had a decompression of the median nerve, and one participant developed CRPS after a minor sprain (Table 2).

Table 1 Data collection time as a function of the assessments

	At baseline		Follow-up		
Assessments	T_0	T_1	T_2	T_3	T_4
SF-MPQ	X	X	X	X	X
Grip force	X	X	X	X	X
DASH	X	–	–	–	X
PGIC	–	X	X	X	X

DASH, Disabilities of the Arm, Shoulder and Hand Questionnaire; PGIC, patient's global impression of change; SF-MPQ, short form of McGill Pain Questionnaire; T_1–T_4, follow-up after each stage of modified graded motor imagery.

Outcomes

Clinical pain

There was a tendency toward decreased qualitative aspect of pain, evaluated using the SF-MPQ (items 1–15), between T_0 and T_4 (17.29 ± 11.63 vs. 7.17 ± 7.68; $P = 0.058$; Table 3). For the pain intensity assessed with VAS, a statistical difference was found between T_0 (43.86 ± 22.36) and T_4 (20.50 ± 23.31) in the last 7 days ($P = 0.046$; Table 3 and Fig. 1). No decrease in PPI was found between T_0 and T_4 (1.43 ± 0.79 vs. 0.67 ± 0.82; Table 3).

Perceived function of the upper limb

No difference was found between T_0 and T_4 for the UE function perception evaluated using the DASH Questionnaire ($P = 0.138$; Table 3). The average difference was 8.99 points between T_0 and T_4, whereas the minimal clinically significant difference for the DASH was 10.2 (Roy *et al.*, 2009). Thus, mGMI did not have a statistically and clinically significant positive impact on perception of the UE function.

Grip force

Grip force for the affected extremity showed a statistical increase (11.78 ± 9.02 at T_4 vs. 28.90 ± 13.10 at T_0; $P = 0.042$; Table 3 and Fig. 2).

Patient's global impression of change

As shown in Table 4, none of our participants reported a worsening of his/her condition during the treatment. As the mGMI treatment progressed, patients reported a perception of improved condition. During the mGMI (T_1, T_2, T_3), most participants had a minimal improved perception of change. After the four phases of mGMI (T_4), 50% of participants reported a 'much improved condition' and 33% reported a 'very much improved condition'. This perceived improvement was statistically significant ($P = 0.015$). Moreover, the global impression of change was also clinically significant as at least 33% of the participants reported a 'much better' improvement for the PGIC, which meets the minimal clinically important difference associated with this concept (Salaffi *et al.*, 2004).

Discussion

The aim of this study was to evaluate an mGMI treatment protocol, based on the work of Moseley

Table 2 Participants' characteristics

Sex, age (years)	DomH, AffH	Medication	Therapeutical consultations	Working status	Preceding trauma
F, 57	R, L	Acetaminophen, codeine	OT, PT, ortho, anesth	Sick leave	Radius fracture
F, 34	R, L	Morphine (hydromorphone)	OT, PT, ortho	Sick leave	Radius fracture
F, 53	R, R	None	OT, PT, plast	Progressive back to work	Decompression median nerve
F, 54	R, R	Morphine, anti-inflammatory	OT, PT, ortho, psycho	Progressive back to work	Radius fracture
F, 41	R, L	None	Pain clinic, OT, chiro, neuro, anesth, psy, MT, kin	Retired	Minor sprain
F, 37	R, L	None	OT, plast	Sick leave	Tendon laceration
M, 39	R, R	None	OT, PT, ortho	Sick leave	Tendon laceration

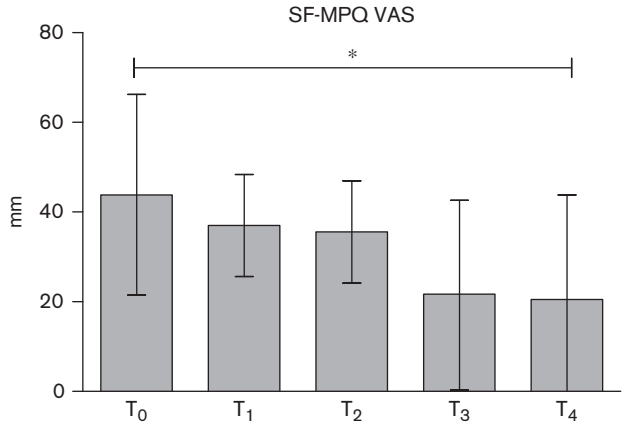
AffH, affected hand; anesth, anesthesis; chiro, chiropractor; DomH, dominant hand; F, female; kin, kinesitherapist; L, left; M, male; MT, massage therapist; neuro, neurologist; ortho, orthopedist; OT, occupational therapist; plast, plastic surgeon; psy, psychiatrist; psycho, psychologist; PT, physical therapist; R, right.

Table 3 Short form of the McGill Pain Questionnaire, grip force, and Disabilities of the Arm, Shoulder and Hand Questionnaire results at baseline (T_0) and at the end of modified graded motor imagery (T_4)

Assessments	T_0	T_4	$\triangle T_0 - T_4$	*P*-value
SF-MPQ QD (items 1–15)	17.28 (11.63)	7.16 (7.68)	10.09	0.058
SF-MPQ VAS	43.86 (22.36)	20.50 (23.31)	23.36	0.046
SF-MQP PPI	1.43 (0.79)	0.67 (0.82)	0.76	0.102
Grip force (mmHg)	11.78 (9.02)	28.90 (13.10)	17.12	0.042
DASH	40.97 (12.29)	31.98 (16.97)	8.99	0.138

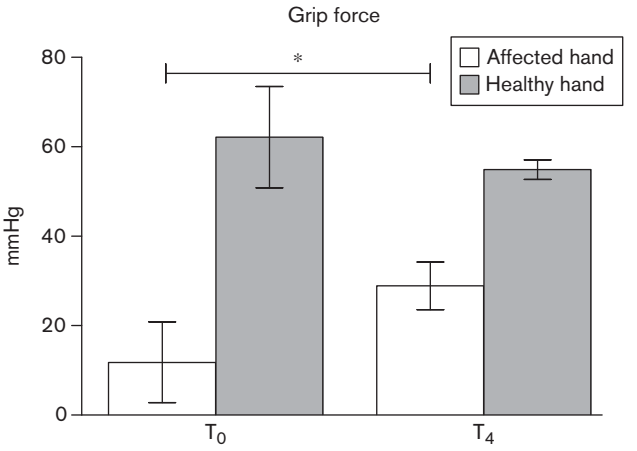
The values are given as mean (SD).
DASH, Disabilities of the Arm, Shoulder and Hand Questionnaire; PPI, present pain intensity; QD, qualitative descriptors; SF-MPQ, short form of the McGill Pain Questionnaire; VAS, visual analog scale.

Fig. 1



Means (columns) and SD (error bars) of the score of visual analog scale (VAS) of the short form McGill Pain Questionnaire (0–100 mm) at baseline (T_0) and at the end of the four phases (T_1–T_4) of the modified graded motor imagery (*P=0.046).

Fig. 2



Grip force results at baseline (T_0) and at the end of modified graded motor imagery (T_4) (*P=0.042).

Table 4 Impression of change reported by participants at each follow-up (patient's global impression of change scale)

	Follow-up			
PGIC descriptors	T_1 (%)	T_2 (%)	T_3 (%)	T_4 (%)
Very much improved	–	–	–	33
Much improved	–	43	43	50
Minimally improved	57	57	57	17
No change	43	–	–	–

Minimally/much/very much worse are not shown; no participant had a worsening of his/her impression of change.
PGIC, patient's global impression of change.

(2004, 2006), that reduces pain and enhances functional capacities and grip force in patients with nonchronic UE CRPS-1. Our results show that this mGMI significantly reduces pain intensity in our CRPS-1 population. The mean reduction in pain intensity (23.4 mm) obtained with a VAS is comparable with the results of Moseley (2006). Moseley (2006) showed a 23.4 mm decrease in average pain for their GMI protocol. However, we found no significant reduction in pain using the PPI score included in the SF-MPQ. This may be attributed to the fact that the VAS is much more sensitive to change (Turk and Melzack, 2011).

The most significant clinical reduction in pain intensity (VAS) was observed between phases 2 and 3 (phase 2: 37 mm, phase 3: 19 mm), which corresponds to the mirror therapy with mobilization of the nonaffected hand; however, this difference was not statistically different

($P = 0.15$) (Fig. 1). McCabe *et al.* (2003) demonstrated in early CRPS-1 that visual input (mirror therapy with the use of a mirror box) from a moving unaffected limb re-establishes the pain-free relationship between sensory feedback and motor execution. It seems that the mirror therapy plays an important role in the GMI (Moseley *et al.*, 2008). The most robust trial of mirror therapy undertaken so far concludes that mirror therapy *per se* is probably no better than motor imagery for immediate pain relief, although it is arguably more interesting and might be helpful if used regularly over an extended period (Brodie *et al.*, 2007). This mGMI acknowledges this fact by incorporating mirror therapy in motor imagery (phase 2) and extends the use of mirror therapy with its phase 4.

According to the DASH Questionnaire, the perceived functional capacities of the UE increased between T_0 and T_4, but the results were not statistically or clinically significant. We expected that those would have been improved, as Moseley (2006) demonstrated with the task-specific numerical rating scale (NRS). In this assessment, patients were asked to select five activities or tasks that they regularly performed before their injury but now found difficult to perform because of pain. They scored their level of difficulty with an 11-point NRS. In our study, we used the DASH Questionnaire. It has the advantage of being a standardized outcome measure but also has the disadvantage to be less representative of the individual capabilities of each patient as some activities were not previously performed by patients in comparison of the task-specific NRS that were selected by the participants. However, the DASH Questionnaire is a standardized tool that allows a better generalization between participants. The real functional activities could also have been underestimated by the patients, especially as these patients are known to experience fear and avoidance behaviors (De Jong *et al.*, 2005).

However, the results showed that the grip strength increased significantly after our mGMI protocol. Even though the grip force of the affected limb almost doubled, it remained 50% below the strength of the nonaffected limb. This may be why, even though the grip force significantly increased, the results of the DASH Questionnaire were not significant. Moreover, it should be kept in mind that the mGMI does not focus on the improvement of functional capacities; training on this specific component can then be carried out when pain has significantly subsided, after the four phases of the mGMI.

Strengths and limitations

First, we took into consideration the promising literature findings on GMI and mirror box therapy (McCabe *et al.*, 2003, 2008; Moseley, 2004, 2005, 2006; Brodie *et al.*, 2007; Moseley *et al.*, 2008; Daly and Bialocerkowski, 2009; Ezendam *et al.*, 2009; Priganc and Stralka, 2011) to maximize the efficacy of our experimental intervention. All patients complied with the different phases of the treatments. Our inclusion criteria were very specific, and our sample can be considered highly homogenous. We included only patients with diagnosed upper-limb CRPS-1 which were non-chronic; for this reason, we can only assume the generalizability of our results to this population.

Our study has some limitations such as the small sample size and the fact that it was a noncontrolled clinical series (level VIII) (Jovell and Navarro-Rubio, 1995). We recruited our participants from only one health establishment, which yields a selection bias. Finally, we did not control for the pharmacological treatment that participants received in parallel to the mGMI. We recorded them, but did not take them into consideration in our statistical analysis. Future studies should consider verifying medication usage during mGMI.

Conclusion

Our mGMI seems to be effective to reduce pain and enhance grip strength in patients with non-chronic CRPS-1 of the UE. However, despite the fact that participants observed a positive improvement in their condition according to the PGIC, we did not observe significant changes in their functional capacities. Taken together, these results indicate that mGMI seems to be a promising and effective therapeutic modality to treat this population, which has a high risk of chronicity. Although further studies with a larger sample size and a control group are needed to replicate our findings, it appears essential to study new therapeutic approaches to maximize clinical outcomes with the mGMI, notably to improve the functional capacities. Also, other treatment strategies could be combined to maximize the effect. Considering the positive results obtained from this pilot study, we will continue to study our mGMI protocol in a controlled clinical trial.

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Conflicts of interest

There are no conflicts of interest.

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