An Alternative to Traditional Mirror Therapy

**Illusory Touch Can Reduce Phantom Pain When Illusory Movement Does Not**

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**Objectives:** There is evidence that amputation leads to cortical reorganization, and it has been suggested that phantom pain might be related to a consequently emerging incongruence of motor intention, somatosensation and visual feedback. One therapeutic approach that has the potential to temporarily resolve this visuo-proprioceptive dissociation is mirror therapy, during which amputees typically move their intact limb while observing its reflection in a mirror, which in turn evokes the illusory perception of movement of their phantom limb. However, while the action of moving the phantom relieves pain for some patients, it can actually increase cramping sensations in others. In the current study we therefore implemented an alternative version of the mirror therapy involving a visuo-tactile illusion, to explore whether it might be effective with amputees for whom the action of moving the phantom increases phantom pain.

**Methods:** We recruited six upper limb amputees who had been previously exposed to the classical mirror therapy with no or limited success, and exposed them to two differential experimental conditions involving visualization paired with either illusory movement or illusory touch of the phantom hand.

**Results:** While none of the participants benefitted from the movement condition, five participants showed a significant pain reduction during the stroking condition.

**Discussion:** Albeit preliminary, our results represent an encouraging finding of possible future clinical relevance, and indicate that such illusions can also have pain modulating effects. It has been shown that visuo-tactile illusions can be used to induce ownership of artificial hands in amputees,1 but in some cases it may only emerge after months or even years after the amputation.2 It can manifest in different ways, including burning, cramping, or tingling, and its mostly chronic nature makes it a challenging phenomenon from a clinical management perspective.

Over the past decade, numerous theoretical accounts of phantom pain have been proposed,1 and there is consensus that the phenomenon is related to plastic changes at multiple levels of the neuraxis.3 Insights into cortical contributions come from studies demonstrating postamputative neuroplastic changes in primary somatosensory and motor cortices.4,5 Specifically, it has been shown that cortical regions previously receiving input from the intact limb reorganize so as to receive input from neighboring regions, and the extent of these changes seems to be positively correlated with phantom pain intensity.5 Consistent with these observations, it has been suggested that abnormal painful sensations might be related to the incongruence of motor intention, somatosensation, and visual feedback.6 In addition to pharmacological interventions, 1 line of approaches aimed at relieving phantom pain has therefore focused on involving methods that temporarily resolve this visuo-proprioceptive dissociation. One of such techniques is the so-called mirror therapy.1,7 In its classical version, amputees move their intact limb while observing its reflection in a mirror, which in turn evokes the illusion of viewing the movement of their (contralateral) phantom limb. Repeated exposure to this procedure has been found to successfully restore voluntary movement of paralyzed phantom limbs, and consequently reduce painful clenching sensations in some cases of upper as well as lower limb amputees8–10 (but for a critical view see Moseley and colleagues11,12). Phantom pain dynamics are a heterogeneous phenomenon however, and although the action of moving the phantom relieves pain for some patients, it can actually cause an increase of cramping sensations in others. On the basis of anecdotal reports of some patients from our clinic, if this is the case, mirror therapy involving movement seems to have either no or sometimes even a negative effect on pain.

It has been shown that visuo-tactile illusions can be used to induce ownership of artificial hands in amputees,17 and in a recent study we have provided preliminary evidence that such illusions can also have pain modulating effects.18 In both of these previous studies, the visuo-tactile illusions were induced by applying tactile stimulation to specific points of the patients’ so-called “stump map” that gave rise to referred sensations in specific parts of the phantom hand and phantom digits, while the patients observed a corresponding stimulation being applied to an artificial hand. We therefore envisaged that a similar technique could be reproduced in the context of a mirror therapy setting, and that such a visuo-tactile rather than visuo-motor mirror illusion might be effective for patients whose phantom pain tends to increase as a consequence of movement.

**MATERIALS AND METHODS**

**Participants**

Six upper limb amputees were recruited through the Arm Prosthesis Unit of Red Cross Hospital, Stockholm,
Swedish (location of amputation: 3 above elbow, 3 below elbow; age: 39 to 80 y, mean: 55 y; sex: 2 male, 4 female). One of the participants (P4) had undergone her amputation because of a tumor. All other participants had lost their limb due to a traumatic accident, and had no significant medical history apart from the amputation. All patients had been in contact with the clinic before our study, and the selection criteria were: (1) location of amputation, that is, upper limb either above or below the elbow; (2) presence of phantom sensations; (3) presence of phantom pain; (4) either no or limited response to previous attempts of classical mirror therapy with movement. There were no selection criteria in regard to age or time since amputation, hence these factors varied significantly across participants (Table 1). The study was approved by the Regional Ethics Review Board of Stockholm, and informed written consent was obtained from all participants.

Preexperimental Evaluations

Interview

All participants underwent an in-depth interview in order to document their medical history, the details of the accidents that led to their amputation, and their currently experienced phantom sensations (for a summary, see Table 1).

Stump Mapping

For each participant we also performed a detailed “stump mapping” (Fig. 1). To do this, we applied systematic touches to the distal portion of the stump, to determine the exact spots giving rise to referred sensations in specific parts of the phantom hand and phantom digits. These points were then marked on the stump (Fig. 1A), and the corresponding parts of the intact hand (Fig. 1B). The point eliciting the strongest referred sensations was subsequently used as a reference for the tactile stimulation during the stroking condition of the mirror experiment. We were able to individuate trigger points for all but 1 participant (P6) (for details, see Table 1).

Pain Rating Scale

During the interview conducted before the experiment, participants were asked to rate the intensity of the phantom pain they were experiencing on that particular day on a visual analogue scale from 0 to 10 (0 = no pain; 10 = very intense pain), and describe its characteristics (eg, cramping, burning, tingling). This rating was taken as the baseline score against which the effect of the individual experimental conditions was measured. The same pain rating scale was then administered before and after each experimental trial (Experimental procedures below).

Experimental Setup

The experimental setup is depicted in Figure 2. The participants sat at a table facing the experimenter, and a rectangular mirror sized 35 x 55 cm was placed in front of them. Their stump was placed behind the mirror so it was out of view, and their intact hand was placed in front of the mirror (Fig. 2A). Participants were asked to position their intact hand so that its mirror image matched the felt position of the phantom. During both the movement and stroking sessions (Figs. 2B, C), participants were instructed to look into the mirror and focus on observing the reflection of their intact hand. For the control trial conducted at the end of the experiment the mirror was covered (Fig. 2D) so that the participants could not see the reflection of their intact hand.

Experimental Procedures

Sequence of Events

Each participant underwent 1 movement and 1 stroking session (see below) consisting of 8 trials. Each trial in turn consisted of 60 seconds of stimulation (either
movement or stroking) followed by 60 seconds of rest during which the participants were asked to simply relax both their stump and intact hand. Before and immediately after each stimulation session, participants were asked to rate the intensity of their phantom pain again on the visual analogue scale. To keep the procedure consistent across participants, the movement session was always performed first. However, to keep the starting level of phantom pain consistent across conditions, after the movement session we always waited for the phantom pain level to return to baseline before performing the stroking sessions. This occurred within the timeframe of 1 minute for all participants.

**Movement Condition**

Based on previously described methods, during the movement trials participants were asked to perform mirror symmetric movements with their intact hand and their phantom hand. They were free to choose the exact type and pace of the movement, but were asked to keep both as consistent as possible throughout the trials. Most participants opted for slowly opening and closing the fist throughout all sessions (P5 added some finger tapping, and P6 added some rotating of the hand).

**Stroking Condition**

During the stroking trials, the experimenter used 2 small paintbrushes to simultaneously stroke the point of the participants' stump evoking the strongest referred sensations, and the corresponding part of the intact hand. An exception had to be made for P6 who did not have a stump map. Since she reported that her phantom pain was most prominent in the palm of the phantom hand, we opted to stroke the palm of the intact hand and an arbitrary central point on the medial side of the stump. In any case, for all participants the strokes were always applied in exact temporal synchrony, that is participants viewed the reflection of the strokes applied to the intact hand at the exact same time as they perceived the referred sensations on their phantom hand. Strokes were applied with a frequency of approximately 1 stroke/s, and the stroke length was kept between 1 and 2 cm. The overall temporal stroking pattern was kept irregular in order to avoid expectations about
the timing of the visuotactile stimulation events in the participants.

Control Trial
The control trial was performed after the exact same procedure as the one adopted during the stroking trials, except that the mirror was covered with a cloth so that the participant did not receive any visual feedback on the stroking performed on the intact hand.

Questionnaire
At the end of the experimental sessions involving pain rating we repeated 1 additional trial of the movement and the stroking conditions, after each of which participants were asked to fill out a questionnaire consisting of 4 statements aimed at capturing the subjective experience of the experimental effects. Two of them were “illusion statements” aimed at capturing the extent to which the participants felt that the hand they saw in the mirror was their contralateral hand (ie, their amputated hand), whereas the remaining 2 were “control statements” aimed at capturing the participants’ suggestibility and task compliance. The order of the questions was randomized, and participants were asked to affirm or deny each statement on a 7-point Likert scale (+3 = strongly agree; −3 = strongly disagree; Fig. 6).

Data Analysis
None of the acquired pain rating and questionnaire data was normally distributed (Shapiro-Wilk test), and therefore analyzed using nonparametric statistics (Wilcoxon signed rank tests). All analyses were based on a priori hypotheses, and hence consisted of planned comparisons with no post hoc corrections. For all analyses, z was set to 0.05. Questionnaire data are reported descriptively.

RESULTS

Individual Pain Rating Data

“After” Ratings
The individual poststimulation pain ratings for both the movement and stroking conditions are displayed in Figure 3. As can be seen from the graphs, overall we did not observe any beneficial effect of the movement condition. With the exception of P4 who showed a slight (0.5 point) decrease with respect to baseline, all other participants showed either no effect or even some increase in pain. On questioning, the participants reported that this mainly reflected the fact that the mere action of moving the phantom as such tended to promote cramping sensations. In contrast, overall we observed a beneficial effect of the stroking condition. With the exception of P6 who did not respond to the stroking, all other participants showed varying extent of pain decrease.

“Before” Ratings Versus “After” Ratings
Figure 4A displays the difference between the individual mean ratings before versus after the movement and stroking trials (the before ratings for all participants are provided in the Appendix). For the movement condition, 3 of the participants (P2, P4, and P6) showed no effect (movement average rating before vs. movement average rating after—Wilcoxon signed rank test: P2: z = 0.000, P = 1.000; P4: z = −1.857, P = 0.063; P6: z = −0.577, P = 0.564), and for 3 participants (P1, P3, and P5) there was in fact a significant increase in pain ratings (Wilcoxon signed rank test: P1: z = −2.714, P = 0.007; P3: z = −2.000, P = 0.046; P5: z = −2.060, P = 0.039). For the stroking condition, 4 of the participants (P1, P2, P4, and P5) showed no significant decrease in pain ratings (stroking average rating before vs. stroking average rating after—Wilcoxon signed rank test: P1: z = −2.070, P = 0.038; P2: z = −2.565, P = 0.010; P4: z = −2.588, P = 0.010; P5: z = −2.414, P = 0.016). One participant (P3) showed no statistically significant difference (Wilcoxon signed rank test: P3: z = −1.890, P = 0.059), but not because of the absence of pain reduction. As can be seen in Figure 4B, P3’s overall pain reduction was actually the most pronounced of all. In fact, after the first few stroking trials, her pain levels progressively decreased and never actually returned back to baseline levels during the 60-second resting periods. Hence, since the mean preratings decreased substantially in their own right, the difference between preratings and postratings as such was not significant. The remaining participant (P6) however, showed no effect (Wilcoxon signed rank test: P6: z = −1.732, P = 0.083).

FIGURE 3. Time course of pain ratings. For each of the 6 participants (P1 to P6), the graphs display the pain ratings provided at baseline (B) and after each of the 8 trials of the movement and stroking conditions (1 to 8) of the mirror experiment.
Baseline Versus Final Rating

Figure 4B displays the difference between the individual baseline rating and the final rating. No statistics are reported since the data were limited to 1 rating for each time point for each participant. However, as can be seen from the graph, for all participants but P6 the final pain rating was markedly decreased compared to baseline in the stroking but not in the movement condition.

Group Pain Rating Data

“Before” Ratings Versus “After” Ratings

Figure 5A displays the difference between the group mean ratings before versus after the movement and stroking sessions. For the movement condition, there was a small but statistically significant increase in pain ratings at the group level (movement average rating before vs. movement average rating after—Wilcoxon signed rank test: \( z = -2.558, P = 0.011 \)). For the stroking condition, there was a significant decrease in pain ratings at the group level (stroking average rating before vs. stroking average rating after—Wilcoxon signed rank test: \( z = -2.552, P = 0.011 \)).

Baseline Versus Final Rating

Figure 5B displays the difference between the group baseline ratings and the group final ratings. For the movement condition, there was no significant difference (movement average baseline ratings vs. movement average final ratings—Wilcoxon signed rank test: \( z = -1.289, P = 0.197 \)). For the stroking condition in contrast, there was again a significant decrease in pain ratings (stroking average baseline ratings vs. stroking average baseline ratings—Wilcoxon signed rank test: \( z = -1.997, P = 0.046 \)).

Control Trial

We performed 1 single control trial for the stroking condition. During this trial the mirror was occluded with a cloth, so as to prevent the participant from seeing the reflection of their own hand. None of the participants reported any pain modulating effect of this purely somatosensory stimulation (see Appendix for individual ratings).

Questionnaire Data

Next we examined to which extent both the movement and stroking conditions induced the participants to experience that they were actually “looking at their phantom hand”, that is to feel that the hand they saw in the mirror was part of their own body. For this purpose, after the pain rating sessions we repeated 1 additional trial of the movement and the stroking conditions, after each of which participants were asked to rate 4 questionnaire statements (2 illusion statements and 2 control statements) so as to reflect their subjective experience of seeing the phantom hand in the mirror. The individual ratings for all participants are depicted in Figure 6. For the movement condition, all but P2 reported illusory ownership of the hand they saw in the mirror, that is, they affirmed feeling as if the hand they saw in the mirror was their own contralateral hand. Four participants reported to experience feelings of agency over the hand they saw in the mirror, that is, they affirmed feeling as if the movement they saw was directly performed with their contralateral (phantom) hand. For the stroking condition, all participants reported illusory ownership of the hand they saw in the mirror, that is, they affirmed feeling as if the touch they saw was directly given to their contralateral (phantom) hand. None of the participants affirmed any of the control statements in either of the experimental conditions. On a group level, for both the movement and the stroking conditions there was a significant difference between the mean rating given to the illusion statements and the mean rating given to the control statements (illusion statements mean score vs.

FIGURE 4. Individual data. The graphs display individual data for each participant. A, The plot depicts the difference between the mean pain ratings before versus after the trials of the movement and stroking conditions. B, The plot depicts the difference between the baseline rating and the final rating of the movement and stroking conditions. The error bars represent SDs. * indicates a significant difference (\( P < 0.05 \)).

FIGURE 5. Group data. The graphs display group data. A, The plot depicts the difference between the mean pain ratings before versus after the trials of the movement and stroking conditions. B, The plot depicts the difference between the baseline rating and the final rating of the movement and stroking conditions. The error bars represent SDs. * indicates a significant difference (\( P < 0.05 \)).
control statements mean score—Wilcoxon signed rank test: movement: \( z = -1.997, P = 0.046 \); stroking: \( z = -2.214, P < 0.027 \), indicating that participants did in fact experience ownership sensations over the hand they saw in the mirror. There was no significant difference between the mean ratings given to the illusion statements in the movement and the stroking condition (movement condition illusion statements mean score vs. stroking condition illusion statements mean score—Wilcoxon signed rank test: \( z = 0.535, P = 0.593 \)), indicating that the 2 types of multisensory stimulation evoked equivalently strong ownership sensations.

Duration of the Experimental Effects

For the movement condition, any observed increase in pain due to the movement of the phantom during the experimental trials returned to baseline within 1 minute. For the stroking condition, for all but 1 participants the beneficial effects were short lived as well, with the pain returning back to baseline within a time frame of 1 to 5 minutes. The exception to this observed pattern was P3, whose pain relief actually lasted for 4 hours.

DISCUSSION

In the current study we implemented an alternative version of the mirror therapy involving a visuotactile illusion, to explore whether it might be effective with amputees for whom the action of moving the phantom increases phantom pain. We recruited 6 upper limb amputees who had been previously exposed to the classical mirror therapy with no or limited success, and exposed them to 2 differential experimental conditions involving visualization paired with either illusory movement or illusory touch of the phantom hand. None of the participants significantly benefitted from the movement condition, with 3 participants actually experiencing a worsening of cramping sensations. In contrast, 5 participants showed a significant pain reduction during the stroking condition. At the group level, these results were reflected by a significant increase in phantom pain in the movement condition, and a significant decrease in phantom pain in the stroking condition. For 4 participants the beneficial effect was only short lived with the pain returning to baseline levels within 5 minutes, but for 1 participant the pain relief actually lasted for 4 hours.

The only participant who did not respond to the stroking condition (P6), was also the only one for whom we were not able to find any spots on the stump triggering–referred sensations in specific parts of the phantom hand. Hence, in her case we had to simply stroke an arbitrary point on the stump as opposed to a precisely targeted location with respect to the intact hand. This is of particular interest because it suggests that a stump map, even if consisting of only a single trigger point, and stroking according to an exact match between this point and the corresponding point on the intact hand, is necessary for the induction of illusory touch on the visualized phantom. It is also in line with the findings of Ehrsson and colleagues who used...
visuotactile stimulation to induce ownership sensations of an artificial hand in amputees, observing that patients with stump maps had higher ownership ratings than patients without.

There was an interesting link between the pain ratings, and the subjective reports of experienced ownership and referral of touch in the questionnaire. Here again we observed that P6, who did not experience any pain modulation during the stroking condition, was also the only participant who did not affirm experiencing any referral of touch from the visualized phantom (ie, she did not feel as if the touch she saw was directly given to her phantom hand). This suggests that referral of touch is necessary for the stroking condition to have a pain modulating effect. On an additional interesting note, P6 did actually affirm that by merely looking at the mirror reflection she felt like she was looking at her phantom hand. This sensation was however disrupted as soon as she experienced the stroking, which due to the absence of a stump map elicited a visuotactile mismatch. This observation confirms again how the central integration of precisely matched visual and tactile signals seems to be crucial for triggering and maintaining the present mirror illusion, just as for the previously reported illusory ownership of an artificial hand in amputees.11,19

Covering the mirror and consequently eliminating visual feedback has been found to be an effective control manipulation for the classical mirror therapy, in that it abolishes its pain modulating effects.12 Hence, we designed our control condition according to the same strategy in order to assure that the pain relief we observed was not merely driven by the effect of tactile stimulation of the stump. Because of time constraints, we were able to perform only 1 single control trial with each participant, and are therefore limited to reporting the results only in a descriptive fashion. In any case however, based on the participants’ reports neither of them experienced any pain modulation during the covered mirror trial. On questioning, the participants described simply perceiving 2 clearly distinguishable touches on the stump and the intact hand, which did not lead to a “fused” percept like the one evoked through the visual feedback at any stage. Of course, we cannot rule out that several repetitions of purely tactile stimulation may have eventually led to some degree of pain modulation as well, and it would certainly be of interest for future studies to investigate this possibility. However, the immediacy of pain relief observed in the stroking condition with the overt mirror strongly indicates that the combination of visual and tactile stimulation and the elicitation of the illusion that the hand in the mirror is part of one’s own body are crucial to drive the effect.

Finally, we would like to acknowledge 1 further limitation of the covered mirror condition as such. Although the covered mirror condition controls for the stimulation component of the stroking condition, it does not control for potential negative placebo effects as the covered mirror clearly represents a nonstandard treatment. An interesting alternative to be explored in future studies would be more subtle control conditions, such as stroking with temporal asynchrony or spatial mismatch with respect to the stump map.

So what could be the mechanisms underlying the pain modulating effect of the stroking condition? As mentioned in the introduction, there is evidence that amputation leads to cortical reorganization,2 and it has been suggested that phantom pain sensations might be related to a consequently emerging incongruence of motor intention, somatosensation, and visual feedback.10 Hence, as has been proposed for the visualized movement of the phantom in the traditional mirror therapy, we believe that the visualized touch on the phantom also entails a temporary resolution of this visuo-proprioceptive dissociation. On a neural level, it can be hypothesized that the mere illusion of “seeing the phantom” as such may be reflected by activity in multisensory areas including the premotor and intraparietal cortex, which are known to be involved in the integration of congruent visual, tactile, and proprioceptive signals in healthy individuals.20,21 Whether the concomitant pain modulation in amputees is accompanied by additional modulations in primary sensory and motor areas remains to be explored. It is known for example, that sustained sensorimotor training can reverse alterations to sensory and motor maps to varying degrees in diverse cases of trauma-induced cortical changes.22 Although actual structural changes involving axonal sprouting and permanent alterations in synaptic strength take days or weeks to develop,12,23 initial more subtle changes to synaptic sensitivity can be related to an unmasking of previously existing connections and take place within minutes or even seconds.24 Hence, it can be speculated that the short-term effect of brief sessions of mirror therapy such as the ones described in this study, might be related to modulations of this nature.

In sum, in the current study we explored an alternative version of the mirror therapy using visuotactile instead of visuomotor stimulation, showing that this technique can be effective for amputees who experience increased phantom pain sensations as a consequence of movement. Albeit preliminary, our results represent an encouraging finding of possible future clinical relevance. The fact that for 1 participant the pain relief lasted for 4 hours is particularly promising, and suggests that prolonged and systematic training with this technique may in fact have the potential to lead to long-term pain reduction effects for some patients. While highlighting the selective effect of the stroking condition in our group of participants however, we also want to stress that we do not by any means intend to put the general effectiveness of the classical movement version into question. The patients of the current study who experienced increased pain during the movement trials, also reported that the mere action of attempting to move their phantom outside the context of the mirror therapy was typically associated with fatigue, discomfort, and increased phantom pain. It is therefore not surprising that for these patients mirror therapy involving numerous sessions of movement is counterproductive. Hence, the main point we want to make is that different versions of mirror therapy seem to be appropriate for amputees with different types of phantom sensations. While the movement version is undoubtedly effective for reinstalling voluntary movements of paralyzed phantoms and release comitant clenching sensations,14 the stroking version can be used with patients who on the contrary can voluntarily move their phantom but who tend to experience a concomitant increase in cramping sensations.

The treatment of phantom limb pain is notoriously challenging, and the mechanisms underlying pain relief when it occurs are complex and not yet fully understood.26 Even though the general effectiveness of mirror therapy has been questioned,15,16 there are a number of published studies complemented by anecdotal evidence from clinical
practice suggesting that at least for some amputees it can indeed have a very positive effect. We therefore believe that mirror therapy, especially when carefully tailored to the specific characteristics of the phantom pain experienced by patients such as in the current study, can be a valuable complement to standard pharmacological, physical, and psychological interventions, as it is noninvasive, easy to administer, and inexpensive.

On this note, we would like to briefly draw attention to mirror therapy in relation to other neurocognitive treatment approaches, specifically those employing motor imagery. It has been shown that mentally simulating a movement of the phantom can reduce phantom limb pain. Although the exact causal mechanisms underlying this effect remain unknown, it has been proposed that it might be driven by a temporary reduction of maladaptive cortical reorganization of motor areas. Similarly, classical mirror therapy has an explicit motor component that is likely to engage movement simulation mechanisms in motor regions. This fact raises the question as to which extent the analgesic effects associated with the classical mirror therapy are due to the perceptual mirror illusion or the motor component per se. Our current study is informative in this regard. In the stroking condition participants were completely passive, without being instructed to perform or imagine any movement of their phantom. The fact that we found pain reduction in this condition, supports the hypothesis that the mirror illusion in itself promotes phantom pain reduction by diminishing the incongruence between visual, tactile, and proprioceptive representations, and shows that this can occur independently of phantom limb movement or motor imagery.

In conclusion, our study sets the scene for a number of interesting future questions to be addressed. Behavioral investigations of interest include for example longitudinal studies with larger patient groups looking at the effects of repeated and prolonged training, studies comparing the effectiveness of movement and stroking in participants who respond to both, and studies examining the respective role of visual, tactile, and motor feedback in more detail. From a neuroimaging perspective, studies shedding light on the exact localization and nature of temporary and potentially also long-term cortical modulations associated with the beneficial effects of the visuotactile mirror illusion, would be of particular relevance.

ACKNOWLEDGMENTS

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APPENDIX

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Table A1 For each participant the table displays the baseline pain rating, the before and after ratings for each individual trial of the movement and stroking and conditions, and the before and after ratings of the control trial.
REFERENCES