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Moving in an Environment of Induced Sensorimotor Incongruence Does Not Influence Pain Sensitivity in Healthy Volunteers: A Randomised Within-Subject Experiment

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Abstract

Objectives: It has been proposed that in the same way that conflict between vestibular and visual inputs leads to motion sickness, conflict between motor commands and sensory information associated with these commands may contribute to some chronic pain states. Attempts to test this hypothesis by artificially inducing a state of sensorimotor incongruence and assessing self-reported pain have yielded equivocal results. To help clarify the effect sensorimotor incongruence has on pain we investigated the effect of moving in an environment of induced incongruence on pressure pain thresholds (PPT) and the pain experienced immediately on completion of PPT testing.

Methods: Thirty-five healthy subjects performed synchronous and asynchronous upper-limb movements with and without mirror visual feedback in random order. We measured PPT over the elbow and the pain evoked by testing. Generalised linear mixed-models were performed for each outcome. Condition (four levels) and baseline values for each outcome were within-subject factors.

Results: There was no effect of condition on PPT (p = 0.887) or pressure-evoked pain (p = 0.771). A sensitivity analysis using only the first PPT measure after each condition confirmed the result (p = 0.867).

Discussion: Inducing a state of movement related sensorimotor incongruence in the upper-limb of healthy volunteers does not influence PPT, nor the pain evoked by testing. We found no evidence that sensorimotor incongruence upregulates the nociceptive system in healthy volunteers.

Introduction

There is increasing evidence that a number of chronic pain conditions are characterised by functional and structural changes within the brain [1–4]. Some authors have suggested that these changes may be maladaptive and contribute, at least in part, to the maintenance of the chronic pain state [5–7]. A mismatch between the brain’s motor control and sensory systems has been suggested as one mechanism whereby maladaptive neuroplastic changes might contribute to the experience of chronic pain [8,9]. When a motor command is created, the central nervous system makes predictions of the sensory consequences of the movement and monitors the congruence between predicted and actual sensory feedback [10,11]. If incongruence is detected, it is hypothesised that pain may arise to warn of an error in information processing [8]. Pain induced disruption of cortical somatosensory representation and subsequent distortion of body perception are considered possible mechanisms underpinning the production of sensorimotor incongruence in clinical populations [8,12].

It is possible to artificially create incongruence between motor intent and the sensory feedback associated with movement using mirrors. For example, if one hand is placed in a mirror box and the other hand alongside the mirror such that its reflection appears in the space where the hidden hand should be, incongruence between motor intent, proprioception and visual feedback can be achieved by performing asynchronous bilateral wrist flexion and extension. While the intention will be to move both hands out of...
phase, such that while one is extending the other is flexing, visual feedback will show both hands moving in unison.

Several authors have attempted to experimentally test the sensorimotor incongruence hypothesis using this methodology. These studies suggest that visually mediated incongruence triggers altered sensation in healthy volunteers [13–15], fibromyalgia patients [14], symptomatic and non-symptomatic violin players [16] and patients with acute [17] or chronic [15] whiplash and there is some suggestion that these changes are more pronounced when incongruence is maximised [13,15,16]. However, the influence of sensorimotor incongruence on pain is harder to interpret. Some studies report no pain with incongruent movement in healthy volunteers [15,16] and no study to date has found a positive relationship between the intensity or frequency of pain and the extent of sensorimotor incongruence [13,14]. Furthermore, an alternative approach to inducing incongruence using tendon vibration found that vibration induced congruence created feelings of peculiarity, foreignness and swelling, but not pain or discomfort [18].

The data to date appear to suggest that sensorimotor incongruence induces various sensory changes, however the effect on pain is less clear. One possibility is that incongruence upregulates the nociceptive/pain system but not sufficiently to evoke pain. A more sensitive method would be to load the nociceptive system by applying standardised noxious stimuli, for example using pressure pain threshold testing. Our aim was to determine if sensorimotor incongruence leads to upregulation of the nociceptive/pain system to help clarify the effect incongruence has on pain. To this end we performed a randomised cross-over experiment in which healthy subjects performed synchronous and asynchronous upper limb movements with and without mirror visual feedback. We measured pressure pain threshold (PPT), and the extent of sensorimotor incongruence [13,14].

The study utilised a randomised, cross-over design and was approved by the Human Research Ethics Committee of The University of Notre Dame Australia (Ref # 011007F). Participants provided informed consent by signing a written consent form and all procedures conformed to the Declaration of Helsinki.

Materials and Methods

Design and Ethics Statement

The study utilised a randomised, cross-over design and was approved by the Human Research Ethics Committee of The University of Notre Dame Australia (Ref # 011007F). Participants provided informed consent by signing a written consent form and all procedures conformed to the Declaration of Helsinki.

Participants

Thirty-five healthy volunteers were recruited from staff, their families and students at the University of Notre Dame Australia. Participants were eligible if they were right handed (determined by hand used for writing), between 18 – 60 years of age, fluent in written and spoken English and able to provide informed consent. Subjects were excluded if they had any ongoing medical complaint, had experienced any musculoskeletal pain in the past six-months, had experienced any episode of upper limb pain that had restricted work or leisure or required a visit to a health care professional in the last two years, had significant visual impairment, had previous surgery involving either upper limb, had any significant asymmetrical visual disfigurement on their upper limbs (including tattoos) or were currently taking any psychoactive medication. The participants were naive to the sensorimotor incongruence theory and blinded to the hypotheses of the study.

Procedure

Before testing, basic demographic data were collected, consent was obtained and each participant was assigned a research number. A counter-balanced random number sequence was computer-generated by an individual not involved with the study and each number was placed in consecutively numbered, sealed, opaque envelopes. After completion of the baseline assessment an independent researcher opened the envelope that corresponded to the participant’s research number and the number dictated the order in which that participant undertook the conditions.

For all movement conditions, participants were seated and the entire upper limb exposed (participants wore a sleeveless t-shirt and removed all jewellery). A height adjustable table was positioned on the participant’s left hand side and adjusted so that the subject could position their left arm on the table with the shoulder at 90° abduction, the elbow at 90° flexion and the forearm pronated. Each movement condition lasted 40 seconds. A metronome set at 1.3 Hz was used to standardise the speed of movement and the number of movement repetitions. Movement excursion was monitored in real time and feedback given to ensure range of motion remained the same within and between each condition. Immediately on completion of each condition the participant was instructed to position their left arm on the table for PPT testing. The assessor who performed the PPT testing was in the room behind a screen next to the table wearing sound cancelling headphones. On completion of each condition the assessor was tapped on the shoulder, they then removed their headphones and immediately completed the first PPT test.

There were two mirror visualisation conditions and two normal visualisation conditions. For the mirror visualisation conditions, a large mobile mirror was placed in line with the participant’s parasagittal axis with the reflective surface facing the subject’s right side. The room was set up symmetrically, with plain white walls on either side to enhance the illusion of ownership over the reflected arm. The arms were placed either side of the mirror and the participant was instructed to attend to the reflection of the right arm in the mirror. The left arm was therefore hidden from view and the reflected right arm appeared to be in the space that the left arm would normally occupy (see Figure 1). For the synchronous movement condition, both upper limbs were positioned with the thumbs facing up and simultaneous repeated flexion and extension at the shoulder were performed in time to the metronome. For the asynchronous condition the participant initially performed ten repetitions of simultaneous repeated shoulder flexion and extension and then, on instruction from a research assistant, switched to alternate flexion and extension for the remainder of the forty seconds. We adopted this strategy because in pilot testing we found that the illusion of ownership of the reflected image was reduced when the initial movements were asynchronous. Throughout the task participants were instructed to attend to the mirror and follow the reflected image of their arm as it moved. At the completion of each experimental condition, the mirror was moved to a standardised position in the room so as to ensure that the researcher performing the PPT testing was blinded to condition.

The normal visualisation conditions were identical except that no mirror was used and the participant attended to their actual left arm during the performance of either synchronous or asynchronous upper limb movements. The mirror was left in the standardised position throughout testing. A fifteen-minute washout period separated conditions.
Outcome Measures

Pressure Pain Threshold. We defined PPT as the minimal amount of force where a sense of pressure first changes to pain [19]. PPT was measured using a hand-held pressure algometer (Wagner instruments, Greenwich, CT, USA) consisting of a 1 cm² round rubber disk attached to a pressure gauge, which displayed force digitally in increments of 0.1 N/cm². The testing protocol outlined by Chesterton et al [20] was used, including an initial training period to ensure standardisation of rate of force development. This protocol has demonstrated excellent reliability (ICC 0.91) [20]. Weekly calibration of the algometer, and of the tester’s rate of force development, was undertaken. All testing was carried out by the same assessor who was blind to movement condition.

Prior to formal testing, the procedure and testing approach were explained. Fifteen test runs on the leg and one test run over the lateral epicondyle of the right arm allowed familiarisation with the procedure. For formal data collection, a point on the left forearm, 2 cm distally and medially to the lateral epicondyle of the humerus in the belly of the wrist extensor muscles was localised by palpation and marked with a felt-tipped pen [19]. This mark established the site for all testing. We chose to test over a muscle unlikely to be

Figure 1. Experimental set up. A: asynchronous movements with mirror. B: synchronous movements with mirror. C: asynchronous movements without mirror. D: synchronous movements without mirror.

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Sensorimotor Incongruence and Pain Sensitivity

The Effect of Movement Condition on Pain Intensity. To determine if moving in an environment of induced sensory-motor incongruence influenced the intensity of local pain that results from PPT testing, the pain intensity scores obtained post PPT testing of each subject were analysed using a generalised linear mixed model similar to that described above. Baseline pain intensity scores were used as a covariate in this analysis.

Results

Participant Characteristics

The average age of participants was 27 years (SD 11), 31% were male. The average height was 173 cm (SD 9) and average weight 73 kg (SD 15).

Methodological Checks

All 35 participants completed all phases of the study and there were no missing data. The repeatability (ICC) of PPT readings for the elbow determined for the three repeated measures collected at baseline was 0.95 (95% CI: 0.93-0.96). Twelve out of 35 times (34%), the observer correctly identified the maximal incongruence condition as the experimental condition. This was not statistically significant (p = 0.219) when compared to the expected proportion of 25%. There was no order effect of movement condition on average PPT (p = 0.307), the first PPT measurement (p = 0.587) or pain intensity (p = 0.151).

Baseline Assessment

The mean (SD) baseline values of the three outcome measures were: PPT = 34.6 (27.56); first PPT = 36.46 (27.85) and pain intensity = 0.94 (1.14).

The Effect of Movement Condition on PPT

Table 1 shows the mean and standard deviation (SD) of the PPT measure for all 35 subjects after each condition. The generalised linear mixed model analysis showed no statistically significant difference for each bivariate comparison of condition (p = 0.887), indicating that there was no difference in PPT between the different movement conditions. The mean difference (and 95% CI) in PPT scores between the experimental condition and each of the control conditions is given in Table 2.

The mean and SD of the first PPT, recorded immediately after each condition, can also be found in Table 1. The results of the sensitivity analysis using only the first PPT test yielded the same results. There was no statistically significant difference found for the bivariate comparisons of condition (p = 0.867), demonstrating that there was no difference in PPT taken immediately post movement between the different movement conditions. The mean difference (and 95% CI) in first PPT scores between the experimental condition and each of the control conditions is given in Table 2.

The Effect of Movement Condition on Pain Intensity

Table 1 shows the mean and SD for pain intensity associated with PPT testing of the 35 subjects after each condition. The analysis showed no statistically significant difference for the bivariate comparison of condition (p = 0.771), signifying no difference in pain intensity across the four movement conditions. The mean difference (and 95% CI) in pain intensity scores between the experimental condition and each of the control conditions is given in Table 2.
Discussion

The aim of this study was to investigate whether moving in an environment of induced sensorimotor incongruence leads to upregulation of the nociceptive system. We artificially created incongruence between motor intent and the sensory feedback associated with movement, by asking participants to perform repeated asynchronous arm movements with mirror visual feedback and then measured the pressure pain threshold over the elbow and the pain intensity experienced at the completion of PPT testing immediately after this movement task. We also assessed participants immediately after asynchronous movement without a mirror, synchronous movement without a mirror and synchronous movement with a mirror, to control for the confounding influences of arm movement, asynchronous movement and visualisation of the reflection of the arm. Contrary to our hypothesis, PPT was not reduced during the incongruent condition, and in fact was near identical after each of the four movement stages. A sensitivity analysis in which we used only the first PPT test (recorded immediately on movement cessation) returned the same result. Furthermore, the self reported pain intensity felt after PPT testing was the same across all four conditions. Using a highly reliable and sensitive measure of pain sensitivity we found no evidence of upregulation of the nociceptive system. We artificially created sensorimotor incongruence to the experience of pain is inconsistent whether the arms were moved asynchronously (maximal incongruence) or synchronously (minimal incongruence) [13,14]. It is possible that methodological issues contributed to the report of pain in these studies, particularly the influence of suggestion over participant’s responses, as there was no blinding of assessors [21].

In more recent and methodologically rigorous studies artificially inducing sensorimotor incongruence have produced numerous sensory changes but minimal reported pain in healthy pain free controls [15,16,18,22]. When visual feedback from the moving limb is manipulated in clinical populations, it seems that reports of pain are more common than in healthy participants [14,15,17]. However, as with the healthy population, there appears to be no difference in reported pain between conditions of minimal and maximal incongruence [14]. Our findings are in agreement with the more recent and methodologically robust studies which have found minimal reports of pain when sensorimotor incongruence is induced in healthy volunteers [15,16,18,22]. The current results also seem consistent with the recent investigation, by two independent research groups, using a blinded randomised design, which showed that the rubber hand illusion, which introduces a mismatch between proprioceptive and visual feedback, does not modulate experimentally induced thermal pain in healthy volunteers [23].

Although the evidence is building that sensorimotor incongruence does not produce pain in a healthy nervous system, it remains possible that it does produce pain in a pathological nervous system, such as might be found in someone with chronic pain [24,25]. This position would be consistent with the contrasting effects of magnifying the visual image of a painful body part, which has an analgesic effect in healthy volunteers experiencing experimentally induced pain [26] but increases pain in patients with CRPS who are moving their painful limb [27]. Alternatively, perhaps the mounting evidence against the sensorimotor incongruence idea in

Table 1. Mean (SD) of each outcome measure across each condition (after adjusting for baseline values).

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Condition</th>
<th>Asynchronous Mirror (n = 35)</th>
<th>Synchronous Mirror (n = 35)</th>
<th>Asynchronous No Mirror (n = 35)</th>
<th>Synchronous No Mirror (n = 35)</th>
<th>Test for difference: p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average PPT (SD) N/cm²</td>
<td>33.2 (28.60)</td>
<td>31.5 (25.18)</td>
<td>32.6 (29.85)</td>
<td>31.2 (25.06)</td>
<td>0.887</td>
<td></td>
</tr>
<tr>
<td>First PPT measurement (SD) N/cm²</td>
<td>34.8 (29.80)</td>
<td>32.5 (24.12)</td>
<td>34.1 (30.97)</td>
<td>32.8 (25.66)</td>
<td>0.867</td>
<td></td>
</tr>
<tr>
<td>Pain Intensity after PPT testing (SD) NRS/10</td>
<td>1.4 (1.36)</td>
<td>1.2 (1.36)</td>
<td>1.5 (1.52)</td>
<td>1.3 (1.28)</td>
<td>0.771</td>
<td></td>
</tr>
</tbody>
</table>

PPT = Pressure pain threshold
NRS = Numerical rating scale
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Table 2. Mean differences and 95%CI for each outcome measure.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Asynchronous Mirror – Asynchronous No Mirror</th>
<th>Asynchronous Mirror – Synchronous No Mirror</th>
<th>Asynchronous Mirror – Synchronous Mirror</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average PPT (95% CI) N/cm²</td>
<td>0.64 (−5.01 – 0.63) p = 0.822</td>
<td>2.00 (−3.64 – 7.63) p = 0.484</td>
<td>1.70 (−3.94 – 7.33) p = 0.552</td>
</tr>
<tr>
<td>First PPT measurement (95% CI) N/cm²</td>
<td>0.70 (−5.39 – 0.80) p = 0.820</td>
<td>1.95 (−4.13 – 8.02) p = 0.527</td>
<td>2.28 (−3.80 – 8.36) p = 0.459</td>
</tr>
<tr>
<td>Pain Intensity after PPT testing (95% CI) NRS/10</td>
<td>−0.15 (−0.80 – 0.50) p = 0.646</td>
<td>0.10 (−0.55 – 0.75) p = 0.756</td>
<td>0.18 (−0.47 – 0.83) p = 0.593</td>
</tr>
</tbody>
</table>

Effect sizes are given for the experimental condition (asynchronous mirror) in comparison to each control condition.
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healthy volunteers also applies to patients. The most robust studies in whiplash patients support this position [15,17] and in participants with fibromyalgia, a condition characterized by heightened pain sensitivity, neither the report of pain nor any other sensory symptoms appear to be greater in the condition of maximal sensorimotor incongruence [14]. If this is the case, it appears important to revisit the proposed mechanism of treatments for chronic pain such as mirror therapy.

Mirror visual feedback therapy seems to reduce pain in some chronic limb pain states [28,29] (see [30] for review and [31] for meta-analysis) and preliminary data suggest that visualisation of the back during movement reduces pain in low back pain patients [32]. These effects have been interpreted to possibly reflect improved sensory acuity of the affected area and re-establishment of the normal pain-free relationship between sensory feedback and motor intention [33]. Both tactile [34] and proprioceptive [35] acuity are enhanced with visualisation of the area, and it seems plausible that these and other perceptual impairments could be rectified by mirror visual feedback and thus help normalise the relationship between actual and intended movement. Perhaps however, the effect is unrelated to sensorimotor incongruence. Other mechanisms have been proposed – it is possible that the illusion created by the mirror of a painful limb that now looks normal may result in the brain rejecting nociceptive input as spurious because there is no other evidence that the limb is in danger [36] – that is ‘all is as it should be’ [24]. Perhaps the appearance of a normal limb in place of the painful one reduces the anxiety and fear of movement and the threat value associated with use of the painful area [33]. It is also possible that cross-modal inhibition, or an increased sense of bodily ownership and control, imparts the effect [37]. Finally, perhaps mirrors just offer a very engaging and almost ‘magical’ distraction.

Our findings suggest that a mismatch between movement intent and feedback might not contribute to clinical pain states; however it is important that the results of the current study are interpreted with regard to the design limitations. Firstly, the perception of threat is an important component of construction of the pain experience [38]. The experimental production of sensorimotor incongruence we used probably lacked a threatening context as there is a plausible and short-lived reason for the mismatch in our experiment. Therefore, the results of the current study are interpreted with regard to the design limitations. Firstly, the perception of threat is an important component of construction of the pain experience [38]. The experimental production of sensorimotor incongruence we used probably lacked a threatening context as there is a plausible and short-lived reason for the mismatch in the condition of maximal sensorimotor incongruence than when participants performed conditions involving less or no sensorimotor incongruence. The inability to detect any upregulation of the nociceptive system might have in clinical pain states and strongly suggests that the current work should be replicated in patient populations to further clarify this issue.

Author Contributions

Conceived and designed the experiments: BMW LS PJG MKB NEO GLM. Performed the experiments: BMW LS PJG. Analyzed the data: MKB BMW LS. Wrote the paper: BMW LS PJG MKB NEO GLM.

References


Sensorimotor Incongruence and Pain Sensitivity


