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# Seeing and identifying with a virtual body decreases pain perception

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ABSTRACT

Pain and the conscious mind (or the self) are experienced in our body. Both are intimately linked to the subjective quality of conscious experience. Here, we used virtual reality technology and visuo-tactile conflicts in healthy subjects to test whether experimentally induced changes of bodily self-consciousness (self-location; self-identification) lead to changes in pain perception. We found that visuo-tactile stroking of a virtual body but not of a control object led to increased pressure pain thresholds and self-location. This increase was not modulated by the synchrony of stroking as predicted based on earlier work. This differed for self-identification where we found as predicted that synchrony of stroking increased self-identification with the virtual body (but not a control object), and positively correlated with an increase in pain thresholds. We discuss the functional mechanisms of self-identification, self-location, and the visual perception of human bodies with respect to pain perception.



## 1. Introduction

The sensation of pain requires a subject or an "I" of conscious experience – a "self" (Sartre, 1948). Self and pain share the location where they are experienced. Humans normally experience pain on the body surface or within their body. The self is normally also perceived within the bodily borders. Self-location (i.e. the experience that the self is localized at a position in space; normally within one's bodily borders) and self-identification (i.e. the feeling to be the owner of a body) are crucial elements of self-consciousness. Self-location and self-identification can both be clinically experimentally manipulated (Blanke and Metzinger, 2009).

Clinical neurology studies revealed that epilepsy, migraine, vascular stroke, and electrical cortical stimulation may lead to changes in self-location and self-identification during so-called out-of-body and related experiences (OBE, Blanke et al., 2004; Irwin, 1985).

Further development of the seminal observations by George Stratton made at the end of the 19th century, recently revealed that OBE-like states can also be experimentally induced and studied in healthy individuals (Stratton, 1899). The exposition of participants to conflicting multisensory (visuo-tactile) bodily cues using mirrors (Altschuler and Ramachandran, 2007) or video devices (Ehrsson, 2007; Lenggenhager et al., 2007; Mizumoto and Ishikawa, 2005) induced illusory own body perceptions in healthy participants. Altschuler and Ramachandran (2007) evoked in their study the illusion of standing outside oneself by arranging two opposing mirrors producing an image of the person standing distantly to his or her actual location. While stroking one's cheek and looking at their distant reflection at the same time, the participants reported that they had the feeling of touching somebody else and not themselves.

In a study by Lenggenhager et al., a video camera was placed behind the participant and relayed to a head-mounted display. In this way, the subject sees his own body in front of him (Lenggenhager et al., 2007). Tactile stimulation (stroking) was applied on the participant's back and the visual information related to this stimulation was systematically manipulated by displaying it as either synchronously or asynchronously (with a temporary delay) on the virtual body. During synchronous stroking of the virtual body, but not of a virtual control object, participants felt illusory self-identification (as if the virtual body was their own) as well as illusory self-location (as if they were localized at a position in front of their body).

Here, we explored whether pain experience of increasingly applied pressure is altered during states of illusory self-location and self-identification. We applied an extensively used and validated experimental pain assessment to measure pressure pain threshold (Curatolo et al., 2006). Based on earlier reports of people with OBE,

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we hypothesized that participants' pressure pain threshold would increase during illusory self-location relative to baseline and in comparison with control conditions (Green, 1968). We further hypothesized that the magnitude of illusory self-location and self-identification would correlate with the increase in pressure pain thresholds.

## 2. Materials and methods

### 2.1. Participants

The study protocol was approved by the ethics committee of the Canton of Bern. Each participant gave written informed consent to the study protocol. We recruited 15 healthy volunteers (eight females, mean age: 39 years, SD ±10) among employees of the University Hospital of Bern, Switzerland. All participants were blind to the study's hypothesis. Exclusion criteria were any clinically relevant somatic disease or mental disorder. Additionally, only participants who reported no chronic pain disorder or any other acute pain during the 2 weeks prior to testing were included. We excluded participants taking pain-modulating substances such as analgesics and antidepressants regularly in the 2 weeks prior to testing. Vision was normal or corrected-to-normal. Each participant received CHF 60 (approximately USD 50) as incentive.

### 2.2. Experimental set-up

A mannequin's back or an object (square, white, human-sized cardboard box) was filmed from behind at a distance of 2 m and projected onto a video head-mounted display (HMD). Participants saw either the mannequin's back or the object via the HMD as if it was standing in front of them (see Fig. 1). An experimenter stood between the mannequin/object and the participant and stroked the back of the participant and the mannequin/object simultaneously during 3 min at a frequency of approximately 0.5– Hz. By using an electronic device to induce a time delay (800 ms) for video projection, participants experienced the touch of the stroking synchronously or asynchronously in comparison to the presented mannequin/object's stroking. There were thus four different conditions: mannequin/synchronous (MS), mannequin/asynchronous (MAS), object/synchronous (OS), and object/asynchronous (OAS). Delayed video projection was used in asynchronous conditions. Experimental conditions were randomized in a within-subject design. Therefore, the sequence of the four conditions differed for every subject.

### 2.3. Measurements

#### 2.3.1. Pain

Pain threshold measurements were performed by the same investigator (M.C.) by using an electronic pressure algometer (Somedic, Sweden) with a probe surface of 1 $cm^2$. The investigator was blinded to the experimental condition. A continuously increasing pressure was applied at a rate of 30 kPa/s (kilopascal/s) to the index finger of the participant's left hand up to a maximum of 1000 kPa. Participants held a stop button in their right hand and were instructed to press as soon as they perceived the pressure as painful in order to determine the pain threshold. This procedure was performed three to five times to get the participants acquainted with the procedure of the algometer. Afterwards, three measurements with 1 min intervals were performed and counted as baseline measurements, before pain thresholds were measured three times, beginning 1 min after induction of the experimental condition and with 1 min intervals between the consecutive measurements. The mean values of the three baseline measurements and the three measurements under each experimental condition were used for statistical analysis.

#### 2.3.2. Self-location

According to Lenggenhager et al., participants were asked to close their eyes and perform small steps on spot after each experimental condition (Lenggenhager et al., 2007). While stepping on spot, an experimenter moved the participant's body backwards by ~1 m. Participants were then instructed to walk with closed eyes to the position where they believed to were standing during the experiment. The drift between the starting position and the final position was measured in centimeters in the anterior–posterior axis indicating experienced self-location.

#### 2.3.3. Questionnaires

We adapted an already used questionnaire to measure self-identification (see Table 1, Botvinick and Cohen, 1998; Lenggenhager et al., 2007). Quality of pain was measured by a validated German version of the McGill pain questionnaire (see Table 2, Radvila et al., 1987). Participants were asked to rate the self-identification and pain questionnaires immediately after each experimental condition on a 7-point Likert scale (1 = totally disagree to 7 = totally agree). The rating of the questionnaires together with the setting up the HMD led to a break of ~4 min between the experimental conditions.

We assessed participants' expectation of change in pain-threshold after having finished all four experimental conditions by asking the question "I expect that the illusion of an abnormal self-location

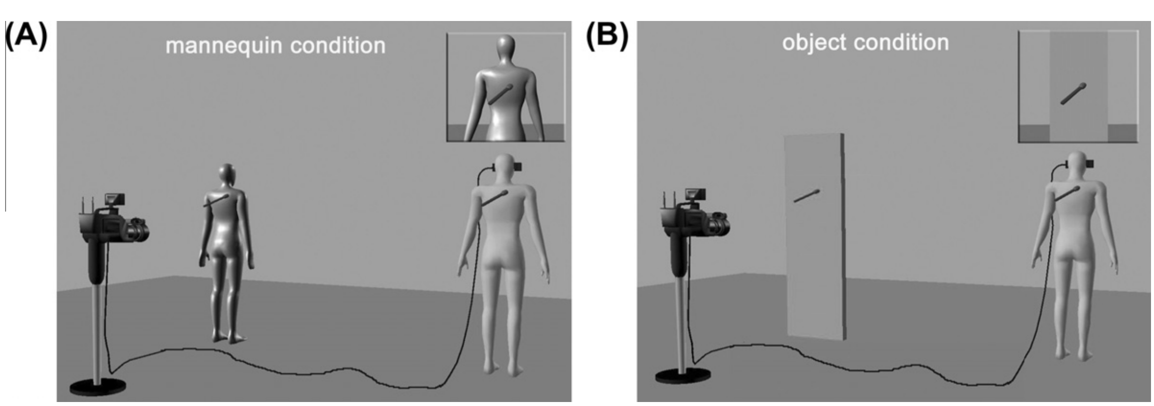


**Fig. 1.** Experimental set-up: Participant sees through a video head-mounted display the mannequin's back (A) or a noncorporeal object (B) standing in front of the participant and is stroked synchronously or asynchronously with it.

**Table 1**
Mean differences between baseline pain threshold measurement and experimental setting and mean drift (±SE).

| | Mannequin/ synchronous | Mannequin/ asynchronous | Object/ synchronous | Object/ asynchronous | Repeated measures ANOVA *p*-value |
|---|---|---|---|---|---|
| Pain threshold (kPa) ± SE | 56.1 ± 21.0 | 36.3 ± 21.5 | 12.4 ± 13.6 | 6.8 ± 19.1 | .030 |
| Drift (cm) ± SE | 19.6 ± 5.9 | 8.6 ± 3.1 | 6.5 ± 4.4 | 6.4 ± 5.3 | .012 |

**Table 2**
Questions of the global-attribution questionnaire.

| |
|---|
| (1) It seemed as if I were feeling the touch of the highlighter in the location where I saw the body of the mannequin touched |
| (2) It seemed as though the touch I felt was caused by the highlighter touching body of the mannequin |
| (3) I felt as if the body of the mannequin was my body |
| (4) It felt as if my (real) body was drifting towards the front (towards the body of the mannequin) |
| (5) It seemed as if I might have more than one body |
| (6) It seemed as if the touch I was feeling came from somewhere between my own body and the body of the mannequin |
| (7) It appeared (visually) as if the body of the mannequin was drifting backwards (towards my body) |

leads to an increase in pressure pain threshold". This question was also rated on a 7-point Likert scale: 1 = totally disagree, 7 = totally agree.

### 2.4. Statistical analysis

Data were analyzed using SPSS statistical software package (version 15.0). Level of significance was set at $p < 0.05$ (two-tailed). Normal distribution of data was tested by the Kolmogorov–Smirnov test. Pain threshold and drift data showed a Gaussian distribution; therefore, we applied a $2 \times 2$ repeated-measures ANOVA (with the within factors Character (mannequin/object) and Stroking (synchronous/asynchronous)) to analyze the change in drift (measurement of self-location) and pain-threshold with the experimental condition. Because questionnaire scores were not normally distributed, we applied non-parametric Friedman ANOVAs for dependent samples to test whether self-identification and quality of pain measures would differ between the four experimental conditions. Post hoc analysis applied Wilcoxon matched pair test to identify differences between the individual experimental conditions. Pearson correlation analysis was used to estimate the relationship between two normally distributed variables.

## 3. Results

### 3.1. Pressure pain threshold

Mean baseline pressure pain threshold was 336.4 kPa (STE ±25.6 kPa). The $2 \times 2$ repeated-measures ANOVA showed a significant main effect for Character ($F(1, 14) = 7.23$, $p = 0.018$) with increased pain thresholds for the conditions where the mannequin was shown (MS/MAS) compared to showing the object (OS/OAS). There was neither a main effect for Synchrony ($F(1, 14) = 1.12$, $p = 0.31$) nor an interaction effect between Character and Synchrony ($F(1, 14) = 0.76$, $p = 0.56$). Fig. 2 illustrates the increase in pain threshold as compared to baseline for each experimental condition.

### 3.2. Self-location (drift)

The $2 \times 2$ repeated-measures ANOVA showed a significant main effect for Character ($F(1, 14) = 0.84$, $p = 0.007$). There were larger drifts in the conditions that showed the mannequin (MS/MAS) compared to the showing of the object (OS/OAS). There was no main effect of Synchrony ($F(1, 14) = 2.83$, $p = 0.11$) nor an interaction effect between Character and Synchrony ($F(1, 14) = 2.41$, $p = 0.14$). Fig. 3 illustrates the drift for each experimental condition.

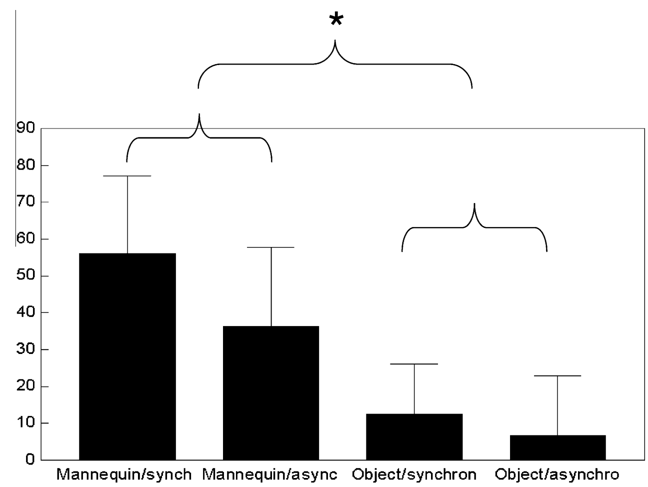


**Fig. 2.** Mean increases of pain thresholds (kPa) for the four experimental conditions (±SE) as compared to baseline threshold: Mannequin/synchronous stroking, mannequin/asynchronous stroking, object/synchronous stroking, and object asynchronous stroking (*$p < 0.05$).

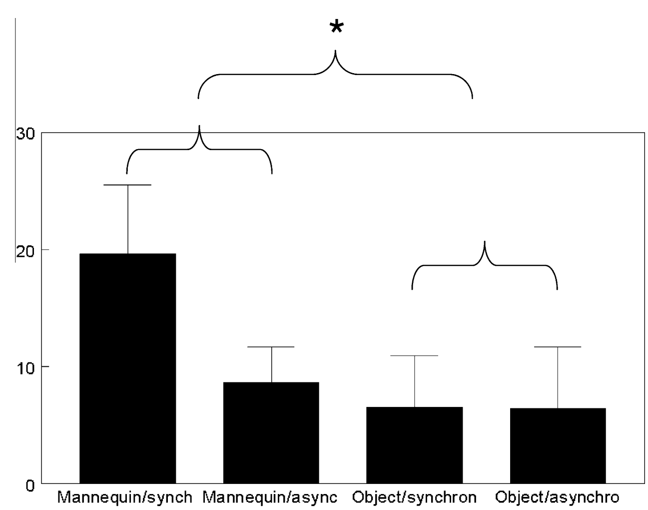


**Fig. 3.** Mean drift (in cm) for the four experimental conditions (±SE): Mannequin/synchronous stroking, mannequin/asynchronous stroking, object/synchronous stroking, and object asynchronous stroking (*$p < 0.05$).

### 3.3. Self-identification questionnaire

A Friedman-ANOVA for nonparametrical data revealed a significant effect for questions 1–3 (Table 1). Further analyses (Wilcoxon matched pair test) for question 1 showed that for both Characters the ratings were higher in the synchronous than in the asynchronous condition (mannequin $Z = 2.6$, $p = 0.01$; object $Z = 2.8$, $p = 0.005$), while the two synchronous conditions and the two asynchronous conditions did not significantly differ from each other. The same pattern was observed for question 2 (mannequin $Z = 2.1$, $p = 0.04$; object $Z = 2.7$, $p = 0.008$). For question 3 (self-identification) a significant difference between synchronous and asynchronous stroking was only revealed in the mannequin condition ($Z = 2.7$, $p = 0.008$), but not in the object condition.

### 3.4. Correlation between pressure pain threshold and self-identification questionnaire

For question 3 (showing an interaction effect between object and synchrony) we calculated a correlation between scores and pain threshold. We used the difference between the synchronous and asynchronous condition and performed this analysis separately for the mannequin and the object condition.

We found a significant correlation between the difference in the synchronous versus asynchronous ratings of question 3 and higher pain threshold in the mannequin condition ($r = 0.55$, $p = 0.03$), but not in the object condition.

The latter suggests that the more a participant self-identified in the synchronous (as compared to the asynchronous) condition with the mannequin the higher the pain threshold in the synchronous compared to the asynchronous condition. There were no significant correlations between scores of question 1 and 2 and change in pain threshold for the mannequin and object conditions (all $p$-values >0.41).

### 3.5. Pain questionnaire and participants' expectations to study hypothesis

Participants described the quality of pain during the measurement of pressure pain threshold mainly as compressing, clamping and dull. Participants perceived a minor-to-moderate intensity of pain. Table 3 shows the five most intensely experienced pain qualities for each condition.

On average, participants agreed to the principal study hypothesis that abnormal self-location would lead to an increase in pain threshold (Mean 5.3 ± 1.8). The extent of the participant's agreement to the study hypotheses did not significantly correlate with changes in pain threshold and drift.

**Table 3**
Five most common perceived pain descriptions for the four experimental conditions on the McGill pain questionnaire (value of intensity: 1 = minor, 5 = intolerable).

| | Mannequin/ synchronous | Mannequin/ asynchronous | Object/ synchronous | Object/ asynchronous |
|---|---|---|---|---|
| Rank 1 | Pressing | Pressing | Pressing | Dull |
| Value | 2.3 +/−1.0 | 1.5 +−/1.4 | 1.9 +/−1.3 | 1.3 +/−1.0 |
| Rank 2 | Pricking | Dull | Dull | Pressing |
| Value | 1.1 +/−1.4 | 1.5 +/−1.4 | 1.6 +/−1.2 | 1.3 +/−1.2 |
| Rank 3 | Dull | Cramping | Cramping | Cramping |
| Value | 1.0 +/−1.0 | 1.3 +/− 1.5 | 1.4 +/−1.5 | 1.0 +/−1.1 |
| Rank 4 | Pinching | Pulsing | Pinching | Cramping |
| Value | 0.9 +/−1.2 | 0.7 +/−1.0 | 1.1 +/−1.4 | 1.0 +/−1.1 |
| Rank 5 | Drilling | Stabbing | Stabbing | Stabbing |
| Value | 0.9 +/−1.3 | 0.6 +/−1.1 | 0.9 +/−1.2 | 0.9+/−1.2 |

## 4. Discussion

We found that visuo-tactile stroking of a virtual body but not of a control object led to increased pressure pain thresholds. This increase was not additionally modulated by the synchrony of stroking (as we – based on previous work – expected (Aspell et al., 2009; Lenggenhager et al., 2007, 2009). Changes in self-location mimicked these increases in pain threshold and revealed a main effect of Character, but not of Stroking or an interaction between both factors. This observation, however, differed for self-identification which was measured by questionnaires. Our data also show that the synchrony between visual and tactile stroking systematically increased self-identification in the mannequin (or virtual body), but not in the object condition. Additional correlation analysis found that this increase in self-identification was associated with an increase in pain threshold. To sum up, the present data show two main findings: Firstly, seeing synchronous or asynchronous stroking of a virtual body with respect to the application of tactile stimulation to the back of one's body are both associated with significant increases in pain thresholds, which was not the case when the touch was seen on a object. This finding confirms earlier observations that seeing a human body increases pain thresholds (see Longo et al., 2009 for similar findings when seeing a body part). The data additionally reveals that the magnitude of the perceived strength of pain (being applied by pressure) is directly linked to the magnitude of self-identification with a seen body, but not to self-location (Lenggenhager et al., 2007).

Other research using the rubber hand illusion found changes in skin conductance (recorded from the participants' hand) when the rubber hand was approached by potentially harmful or painful visual stimuli (Armel and Ramachandran, 2003; Ehrsson et al., 2007). Comparable changes in skin conductance were also observed in an illusion closely related to the full body illusion that was tested in the present study (Ehrsson et al., 2007). Studying the link between pain and the bodily self, it has also been reported that when upper-limb amputees see their real arm/hand superimposed on the amputated arm/hand in a mirror, they may report relief from phantom pain (Maclachlan et al., 2006; Ramachandran and Rogers-Ramachandran, 1996). Other studies reported a reduction of phantom pain for amputees by controlling a virtual limb in immersive virtual reality (Sato et al., 2010; Cole et al., 2009; Murray et al., 2007) or a decrease of the skin temperature in the real hand during the rubber hand illusion (Moseley et al., 2008a).

To the best of our knowledge, however, the perception of painful stimuli that are directly applied on the participants' body has not been previously investigated during the manipulation of the bodily self. The present study tested this directly and reveals that pain thresholds can be altered by manipulating multisensory (visuo-tactile) bodily input. We also found an increase in pressure pain thresholds during both body conditions that did not depend on the synchrony of stroking. Although participants did not report any differences in pain qualities during the different experimental conditions, pain threshold increased by 16% from baseline in the synchronous stroking condition. This effect can be considered as clinically relevant. To compare our results, we have previously found an increase of 17% in pain pressure tolerance threshold after infusion of the potent opioid remifentanil at a target plasma concentration of 1 ng/ml, a dose which also resulted in detectable sedation (Luginbühl et al., 2003). It might be possible that the increase in pressure pain threshold was partly influenced by participants' expectations. As we did not measure participants' expectation before the measurements, but only at the end of the study, one can argue that participants' answers reflect their observation rather than their expectation. Participants' agreement of the study's hypothesis (i.e. abnormal self-location would lead to an increase in pain threshold) did neither correlate with the induced changes in pain threshold nor the extent of changes in drift. This indicates that the observed increase in pain threshold cannot be explained by expectation alone. It can also be argued that the application of noxious signals to the body may alter illusory self-location per se. This is, however, not very likely, because studies of the rubber hand illusion (RHI) paradigm on pain perception showed that nociceptive visuo-tactile stroking induces changes in hand ownership comparable to visuo-tactile stroking alone (Capelari et al., 2009). Thus, applying noxious signals to the hand did not inhibit the rubber hand illusion as also shown in the present study.

Why did self-location and pain threshold not show a significant interaction between character and synchrony of stroking as predicted by us and as observed for self-location in our previous studies (Lenggenhager et al., 2007, 2009)? Our data on pain perception may suggest that the bodily self – as tested here based on visuo-tactile conflicts – influences pain perception differently than it influences tactile perception (Aspell et al., 2009). This suggestion is based on the present observation that pain thresholds were not modulated by stroking and did not show a modulation that depended on both experimental factors. Several mechanisms may account for this. Firstly, the co-application of painful stimulation may – in addition to the tactile stroking – have altered the effects previously observed during synchronous and asynchronous visuo-tactile stroking on the drift (self-location); this may also have affected the modulation of pain perception, i.e. leading to a decrease of the effects of synchrony and the interaction. Secondly, the application of a painful stimulus may have led to a shift of attention towards one's own body and thus altering the manipulation due to the synchrony of stroking on drift as well as on pain thresholds. This attentional shift towards the own body (backward drift) may have altered the generally found forward drift during synchronous versus asynchronous stimulation, although both conditions lead to a forward drift. These mechanisms may counteract the selectivity of illusory changes with respect to self-location as well as pain thresholds. Furthermore the visuo-tactile delay varied between the present and previous work (e.g. Lenggenhager et al., 2007). Studies on visuo-tactile integration have also shown that the delay of the visual and tactile stimulus is important for body representation and bodily self-consciousness (Aspell et al., 2009). Independent from these technical aspects, it may be that the different functional mechanisms between pain and tactile perception (as tested in Aspell et al. (2009)) described at the neuroanatomical, neurophysiological, and psychological level (i.e. Craig, 2002) may lead to the observed differences. Future research is needed to determine whether the observed results on pain reflect the above-mentioned technical differences, attentional mechanisms, or reflect differences between pain and touch systems.

Despite these open questions, our data corroborate anecdotal reports of altered pain perception during the experience of disembodiment in healthy subjects and in patients with neurological disease. This may also be useful in order to develop novel behavioral pain treatments (Röder et al., 2007). With respect to disembodiment, it has been reported that people with OBE experience changes in pain level and pain quality (Bünning and Blanke, 2005; Green, 1968; Irwin, 1985). These changes in pain experience are associated with a wide range of pain characteristics and were reported to involve the experienced intensity or quality as well as the person's attitude towards pain. These subjective changes – that have not been subjected to quantitative analysis in previous work – were mainly associated with a decrease in the intensity of pain. The present data show that the strength of self-identification with the virtual body positively correlated with the increase in pain thresholds pointing to at least partly comparable mechanisms in people with pain during OBE (Green, 1968). Changes in self-identification (as quantified by question 3) depended on synchrony and the shown object, leading – as predicted – to strongest changes in the mannequin/synchronous condition, also correlated with changes in pain thresholds. As changes in the present study in self-location did not correlate with changes in pain thresholds, we suggest that self-identification (or owning and identifying with a body) rather than self-location (where we experience our body to be) modulates humans' experience of pain.

Finally, the small sample size of $N = 15$ is a limitation of the present study. Due to lack of power the difference between thy synchronous/asynchronous stroking condition with regard to pain/drift may have not reached statistical significance. Although the increase in pressure pain threshold and drift were highest in the mannequin/synchronous stroking condition, this increase was not strong enough to reach statistical significance. Greater statistical power might have revealed significant effects of synchrony. Future research is necessary to elucidate the role of the different mechanisms and its effects on self-location and pain thresholds.

A possible perspective that arises from our findings is the development of therapeutic behavioral procedures as a clinical tool to alleviate pain either alone or in combination with other pain treatments (Raz and Shapiro, 2002; Röder et al., 2007). Moseley reported an intriguing way to alleviate chronic pain perception by using binoculars to create a multisensory conflict (Moseley et al., 2008b). Patients with chronic arm pain watched their affected limb using binoculars while performing a standardized repertoire of hand movements. Thus, pain intensity as well as swelling of fingers was decreased or increased when these patients watched their limb through inverted binoculars that minimized or magnified the size of limb.

Future studies need to evaluate whether changes in pain perception following multisensory conflicts – as tested here – or in other multisensory conditions may offer novel therapeutic interventions for chronic pain patients (Moseley, 2005, 2008).

## Conflict of interest

None declared.

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