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Impaired visual perception of hurtful actions in patients with chronic low back pain ☆

Marc H.E. de Lussanet [a,f,*,1], Frank Behrendt [b,1], Christian Puta [c,1], Tobias L. Schulte [e], Markus Lappe [a,f], Thomas Weiss [d], Heiko Wagner [b,f]

[a] Psychology, Westf. Wilh.-Univ. Münster, Fliednerstraße 21, 48149 Münster, Germany
[b] Motion Science, Westf. Wilh.-Univ. Münster, Horstmarer Landweg 62b, 48149 Münster, Germany
[c] Sports Medicine and Health Promotion, Schiller Universität Jena, Wöllnitzer Straße 42, 07749 Jena, Germany
[d] Biological and Clinical Psychology, Schiller Univ. Jena, Am Steiger 3, 07743 Jena, Germany
[e] Orthopedics, University Hospital Münster, Albert-Schweitzer-Straße 33, 48149 Münster, Germany
[f] Otto Creutzfeldt Center for Cognitive and Behavioral Neuroscience (OCC), Münster, Germany

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ABSTRACT

Visually presented biological motion stimuli activate regions in the brain that are also related to musculo-skeletal pain. We therefore hypothesized that chronic pain impairs the perception of visually presented actions that involve body parts that hurt. In the first experiment, chronic back pain (CLBP) patients and healthy controls judged the lifted weight from point-light biological motion displays. An actor either lifted an invisible container (5, 10, or 15 kg) from the floor, or lifted and manipulated it from the right to the left. The latter involved twisting of the lower back and would be very painful for CLBP patients. All participants recognized the displayed actions, but CLBP patients were impaired in judging the difference in handled weights, especially for the trunk rotation. The second experiment involved discrimination between forward and backward walking. Here the patients were just as good as the controls, showing that the main result of the first experiment was indeed specific to the sensory aspects of the task, and not to general impairments or attentional deficits. The results thus indicate that the judgment of sensorimotor aspects of a visually displayed movement is specifically affected by chronic low back pain.

☆ Short title: Chronic pain impairs visual judgments.

* Corresponding author. Psychology, Westf. Wilh.-Univ. Münster, Fliednerstraße 21, 48149 Münster, Germany. Tel.: +49 251 8334182; fax: +49 251 8334180.
E-mail address: lussanet@wwu.de (M.H.E. de Lussanet).

[1] These authors share first authorship.

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1. Introduction

Evidence suggests that high level cortical mechanisms play an important role in the body and motor representations during pain (Lotze & Moseley, 2007; Moseley, Gallace, & Spence, 2012). For example, the motor imagery of depicted hand postures causes pain and swelling of the affected limb in patients with chronic hand or wrist pain, complex regional pain syndrome (CRPS), and non-CRPS pain patients (Moseley et al., 2008b). In patients with chronic hand pain, the manipulation of visual input using binoculars during movements can alter pain and swelling of their affected limb evoked by movements (Moseley, Parsons, & Spence, 2008a). A recent study demonstrated that bilateral and unilateral back pain is associated with less accuracy in judgment of depicted left and right trunk rotations, compared to healthy controls (Bray & Moseley, 2011). Additionally, there is an altered representation of the deep postural abdominal trunk muscle at the primary motor cortex (M1) in individuals with recurrent low back pain (Tsao, Galea, & Hodges, 2008). The cortical representation of the back at the primary somatosensory cortex (S1) in response to electrical stimuli was shifted about 2.5 cm medially in chronic back pain patients compared to controls (Flor, Braun, Elbert, & Birbaumer, 1997). Furthermore, body image was distorted and two-point discrimination threshold was increased at the affected area in patients with chronic back pain (Moseley, 2008). Additionally, tactile acuity during two-point discrimination tasks at the back was decreased and related to a worse performance of voluntary lumbopelvic positioning tasks in chronic back pain patients (Luomajoki & Moseley, 2009).

These data might be interpreted in the sense that specific cognitive tasks, such as motor imagery, and sensory and motor representations of one's own body, use similar cortical resources as the processing of (chronic) pain. Possible candidates for this processing are parts of the frontal cortex and the rostral inferior parietal lobe (Apkarian, Baliki, & Geha, 2009; Lotze & Moseley, 2007; Moseley, 2003). Following this interpretation one can hypothesize that pain should also affect the visual perception of actions that involve motion of the body region affected by the chronic pain.

The visual observation of a goal-directed movement activates a complex cortical network that involves not only visual processing regions in the occipital and temporal cortex (Grossman et al., 2000; Michels, Kleiser, de Lussanet, Seitz, & Lappe, 2009; Servos, Osu, Santi, & Kawato, 2002), but also the sensorimotor representations in the brain (Buccino et al., 2001; de Lussanet et al., 2008; Saygin, Wilson, Hagler, Bates, & Sereno, 2004) which belong to the so-called mirror neuron system (Rizzolatti & Sinigaglia, 2010). These brain regions are thought to fulfill a central role during observation of movement; it is active during action execution as well as during action recognition (Buccino et al., 2001; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti & Sinigaglia, 2010). The rostral part of the inferior parietal lobe, the lower part of the precentral gyrus, and the posterior part of the inferior frontal gyrus have been found to be part of the mirror neuron system (Fogassi et al., 2005; Rizzolatti & Sinigaglia, 2010).

Some additional brain areas, such as the insula, middle temporal gyrus, and somatosensory cortex are closely connected with the areas containing mirror neurons and are also involved in information processing for mirroring and simulation (Pineda, 2008; Rizzolatti & Sinigaglia, 2010). Thus, there is a substantial anatomical overlap between the mirror neuron system, its extended areas, and regions affected by chronic pain (Apkarian et al., 2009; Baliki, Schnitzer, Bauer, & Apkarian, 2011; Rizzolatti & Sinigaglia, 2010).

The visual perception of biological movements from moving point-light stimuli has been intensively studied since Johansson (1973). Such so-called point-light biological motion is devoid of image information but is nevertheless easily recognized. Brain imaging evidence revealed that point-light biological motion is processed by a cortical network including extrastriate visual cortical areas, ventral temporal (fusiform) areas, and the right posterior superior temporal sulcus (Grossman et al., 2000; Vaina, Solomon, Chowdhury, Sinha, & Belliveau, 2001; Michels, Lappe, & Vaina, 2005; Servos et al., 2002). Depending on the task, however, point-light biological motion may also activate premotor and parietal areas belonging to the cortical mirror-neuron system (de Lussanet et al., 2008; Saygin et al., 2004). These biological motion stimuli activate motor and somatosensory representations and

thus may evoke interactions between the visual, the motor, and the somatosensory systems (de Lussanet et al., 2008). A recent study supports the hypothesis that the primary motor cortex is involved in action observation (Alaerts et al., 2010).

On the basis of these results, we hypothesized that the perception of visually presented actions is impaired for body parts that hurt in patients with chronic lower back pain (CLBP). To test this hypothesis we used a task in which the participants had to estimate the weight of invisible manipulated objects from point-light displays. We chose to examine the judgment of lifted weight as a suitable task, since motor and sensory experiences are necessary for an accurate judgment. A point-light biological motion display of a person lifting an object is sufficient for an accurate judgment of the lifted weight by a healthy observer (Bingham, 1987; Runeson & Frykholm, 1981).

In a recent study we showed that chronic pain does indeed interfere with the judgment of lifted weight (de Lussanet et al., 2012). In that study we measured CLBP and chronic shoulder pain patients. We found that the CLBP patients could not judge the differences in manipulated weight for the trunk rotation task, whereas the shoulder patients were impaired for the judgment of the weight manipulated and transferred from one hand to the other. Thus, the impairment was specific for the affected body part. The goal of the present study was to find out whether this impairment depends on how painful the movement would be for a patient to execute and to test whether chronic pain patients are generally impaired on visual judgment tasks that involve biological motion.

In the main experiment, the point-light displays presented either bimanual lifting from the floor (referred to as "frontal lifting") or bimanual replacing from the left to the right involving a twisting of the lower back (referred to as "trunk rotation"). As the latter movement lasts longer and involves more interaction with the object, we expected that healthy controls should be better in discriminating between the lifted weights from the displays (Runeson & Frykholm, 1981). On the other hand, as the latter movement involves a trunk rotation and as such represents a more painful movement than the frontal lifting, we expected that the CLBP patients should be even worse in discrimination between the weight of the presented trunk rotation movements.

2. Methods

2.1. Participants

Eleven right-handed patients (5 females, 6 males, age = 52.6 ± 11.3 yr; $M \pm SD$) with CLBP took part in the study, together with eleven age-matched, healthy controls (7 females, 4 males age = 51.9 ± 12.1 yr, right-handed) who did not suffer from acute or chronic pain and had no history of psychiatric disorders. All patients were recruited from the outpatient clinic of the Department of Orthopedics at the University Hospital Münster, Germany. The primary inclusion criterion was a history of CLBP of more than 12 months (Table 1, Fig. 1). All patients had an orthopedic and neurologic examination by an experienced orthopedic surgeon. Individual pain drawings were also obtained to ensure that the main pain focus was on the lower back. Radiological imaging and electrophysiological examination were performed on an individual basis. Prior spine surgery was no exclusion criterion. Patients were not selected for the study if they suffered from acute neurologic deficits (paresis, incontinence), vertebral tumors, inflammatory vertebral disorders (spondylodiscitis, spondylitis, discitis) and psychiatric disorders in their medical history. All medications were recorded (Table 1). Written informed consent was obtained and all procedures were approved by a local ethics committee of the University of Münster and conformed to the Declaration of Helsinki.

2.2. Setup

Kinematic data from a healthy actor (age 33, male, without acute or chronic pain) were recorded with a high-precision 3-D video system at 50 Hz (Qualisys Motion Capture Systems). The actor either lifted a box, standing on the floor in front of him, toward his chest (referred to as "frontal lifting"), or lifted it from the floor on his right, twisted his trunk and placed it down on the floor on his left side (referred to as "trunk rotation"). The object was a box (32×27×32 cm) with side-grips for holding, of

Table 1
Characteristics of the subjects. The 11 control subjects (64% female) were 51.9 years (*SD* 12.1 years). The CLBP group were 36% females.

Patient	Gender	Age	Duration [years]	CPI[a]	4WPI[b]	Medication[c]
1	m	33	>5	30	60	Tolperison
2	m	37	>5	70	60	Me,Pa
3	m	44	*2*	0	60	Di
4	f	50	2 – 5	60	65	Duloxetin
5	f	50	>5	50	70	Ib, Di
6	m	54	>5	60	70	–
7	m	56	2 – 5	50	70	–
8	m	58	2 – 5	45	70	Ib
9	f	64	*2*	35	60	Me
10	f	64	>5	20	20	–
11	m	69	2 – 5	65	70	Me,Ib,PP
Mean ± *SD*		54 ± 11		44 ± 22	61 ± 14	

[a] CPI = Current Pain Intensity, rated on a 100 mm Visual Analog Scale (VAS) in response to the question: "How would you rate your current pain intensity?"
[b] 4WPI = 4-Week Pain Intensity rating response: "How would you rate your average pain over the last four weeks?"
[c] Reported current medications: Ib = Ibuprofen, Me = Metamizol, Di = Diclofenac, Pa = Paracetamol, PP = Pregballin + Palladon.

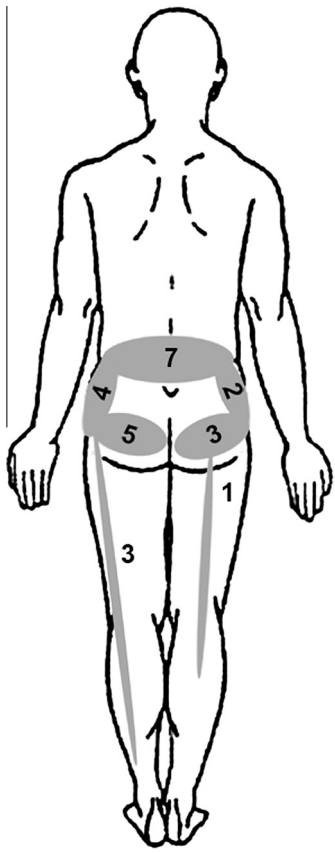

Fig. 1. Somatotopy of the pain indicated by the patients. The numbers indicate the number of patients that localized a particular region.

three different weights (5, 10 and 15 kg). The frontal lifting movements lasted 3.8 s, whereas the trunk rotation movements lasted 6.4 s. The actor made each movement several times and did not know which weight he was to lift on each trial. Only the first movements of each weight and movement type were used for the experiment. These two motion tasks were chosen since CLBP patients would consider them as painful and would therefore avoid producing these movements themselves. We also expected that the twisting movements during the trunk rotation task would convey better the object's weight because they presented a more extensive manipulation of the load.

The recordings were used in a computer program to animate point-light stimuli (white dots on a dark background) (Fig. 2). Point lights were placed on the shoulders, elbows, wrists and hand, and on the hips, knees, ankles and feet of the actor, but not on the box. Thus, the only cue to the weight of the box was in the display of the moving point-lights on the body. The actor was facing slightly away (about 10° with respect to a frontal view). A stimulus program written by one of the authors (MdL) using the standard software development tools for Macintosh OS X (XCode 3.1 and OpenGL) gave the written instruction, presented the point-light displays, and recorded the response. For this, a response display was presented on the computer screen, after the point-light display had disappeared. This response display consisted of a slider, controlled by horizontal movements of the mouse that pointed at a horizontal scale (15 cm) with ticks and the numbers 0 – 20. Once the slider had been moved, a press of the space bar confirmed his or her response and started the display for the next trial.

A MacBook 7.1 (Apple Inc.; with 13.3" display, 1280x800 pixel, 60 Hz refresh) running Mac OS X 10.6.8 was used to run the experiments and collect the data.

2.3. Assessment

To assess the severity of pain, the German version of the McGill pain questionnaire was applied, extended with additional questions regarding the pain history, as well as a pain drawing (Kiss, Müller, & Abel, 1987; Stein & Mendl, 1988) (Fig. 1, Table 1). Pain intensity assessment was performed using a visual analog scale (VAS) ranging from '0' indicating "no pain" to '10' indicating "maximal imaginable pain" (Table 1; Haefeli & Elfering, 2006; Mannion, Balagué, Pellisé, & Cedraschi, 2007). Each participant filled in the questionnaire and the informed consent form immediately before the experiment. The questionnaire included one VAS for the current pain, one for the average pain of the last four weeks, and one for the highest intensity of the last four weeks.

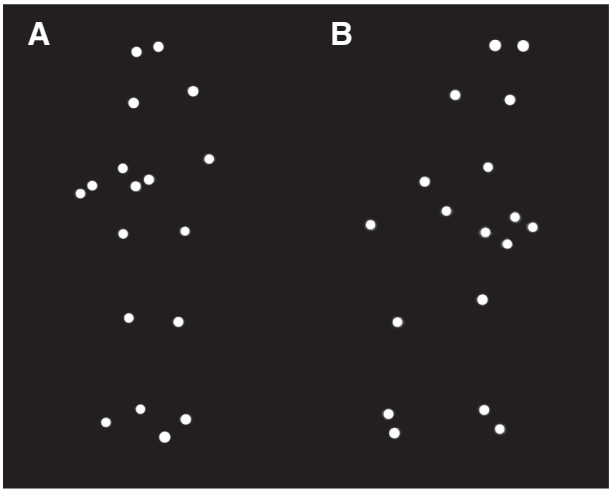

Fig. 2. Still frames taken from of the point-light-figures, presenting a frame from the frontal lifting-sequence (A), and a frame from the trunk rotation-sequence (B).

2.4. Procedure

Data were recorded in a quiet, separate room. The participants sat on a chair in front of the working desk with the laptop and the questionnaire, and were free to choose a posture that was as comfortable as possible.

Before the experiment started, each participant saw a frontal lifting sequence and a trunk rotation sequence, and was asked to describe these visual biological motion stimuli orally. All patients and controls could accurately describe the kind of movements the point-light figures performed. Participants were then instructed to estimate the lifted weight in a total of 120 sequences using the response slider. No information about the weights or the number of different weights was given to the participants. Participants were allowed to take breaks whenever they needed. The experiment took about 20 min, depending on the response time. Participants were instructed to report as accurately as possible.

The 120 sequences were the two movements, i.e., frontal lifting and trunk rotation, executed with the three different weights, i.e., 5, 10, and 15 kg, each presented 20 times in a randomized order. No feedback was given on the performance.

2.5. Analysis

Statistical analyses were performed using R (version 2.15.1, Mac OS X GUI 1.52), and by including the lmer-function of the lme4-library.

For each subject the standard deviation of the weight judgments was computed by studentizing the data (Fraser & Rousseau, 2008; Hartley, 1938). A *t*-test on the standard-deviations gave no significant difference (*SD* Control = 2.3 kg, *SD* CLBP = 2.0 kg; $t(20) = 0.59$, $p = .6$). This indicates that the two groups had the same response behavior with respect to the usage of the 0–20 kg scale. This is important because if the patient group would clearly perceive the difference between the weights but would at the same time confine their responses to a narrow range in the center of the scale they would still seem to perform poorly. The standard deviations indicate that this was not the case.

The outliers (> 2 standard deviations from the mean) were removed from the dataset. There were 4.4% outliers, one third of which occurred in the first two of the twenty repetitions of each condition.

The main hypothesis regards differentiation between the presented loads, so we are not interested in any offsets between the individual participants. Therefore for statistical testing the offsets were removed from the data. Thus, the average weight was subtracted of the independent variable weight, and the average weight judgments were subtracted for each subject and movement kind (frontal lifting and trunk rotation).

These offset-free data were analyzed separately for each movement kind in a stepwise procedure. At first a linear model with within-factor weight and between-factor group, interaction factor Group x Weight as well as a mixed linear model with and additional random-effects factor subject. The Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) were computed for each model, showing that the random-effects models clearly had more explanatory power than the models without random effects.

Second, mixed linear models with random effects with one additional factor, either gender or age, were computed (using the anova function of R). Each of these models was compared against the random effects model without the additional factor. Each of these ANOVAs showed that neither the factor gender improved the model significantly (frontal lifting: $p = .59$, trunk rotation: $p = .45$), nor the factor age (frontal lifting: $p > .99$, trunk rotation: $p = .86$). Therefore, the factors age and gender were not included in the final analysis.

For the final analysis, an ANOVA was computed for each movement type to compare the linear mixed-effect models with and without interaction factor Group x Weight, in order to compare the performance of the two groups. In addition an ANOVA was computed for each subject group, to compare the performance on the two movement types.

As an extra control we also analyzed the normalized data. For this, the responses of each subject were normalized to the standard deviation as computed from the studentization procedure explained

above. The random effects models were also computed for these normalized data, and tested in the same manner as the non-normalized data.

Response times (RTs) comprised the duration (in s) from the start of the sequence in each trial until the moment when the participant clicked the mouse button to confirm his response. As the subjects were not instructed to respond quickly we did not expect any effect of subject group. RTs were analyzed using a repeated measures analysis of variance (ANOVA) with factors group, movement, and weight. The ANOVA results were corrected for violations of sphericity using the Greenhouse-Geisser approach for epsilon (ϵ) correction of degrees of freedom. A linear regression model was used to investigate the relationship between the outcome variables weight discrimination and pain intensity for each presented task, and also between response time and pain intensity.

3. Results

3.1. CLBP patients are impaired

If a participant would have no clue as to the weight of the lifted objects, he or she would most likely scatter his or her responses around the centre of the scale, i.e., around 10 kg, which is also the mean of the presented weights. Thus, if a subject on average gives the correct responses, it does not mean he or she could do the task. Instead, a good participant will estimate the heavier weights in each movement as more heavy than the light ones of the same movement. The important measure is therefore not the main effect of group but the interaction of group and weight.

The ANOVAs comparing the mixed effect models with and without interaction factor Group x Weight showed that the controls performed significantly better than the CLBP patients on both movement types (frontal lifting, $p = .01$; trunk rotation, $p = .003$).

The significant effects show that the groups differed in their ability to discriminate between the presented weights. This is also shown in Fig. 3. As the figure shows, the control subjects were better at discriminating the differences in the presented weights than the CLBP patients. It can further be observed in Fig. 3B that this difference in the discrimination between light and heavy weights is more pronounced for the trunk rotation task than for the frontal lifting task. This is supported by the result of the ANOVAs on each of the groups. The ANOVAs on each of the groups each compared the linear mixed, random effect models, with and without an interaction factor MovementType x Weight.

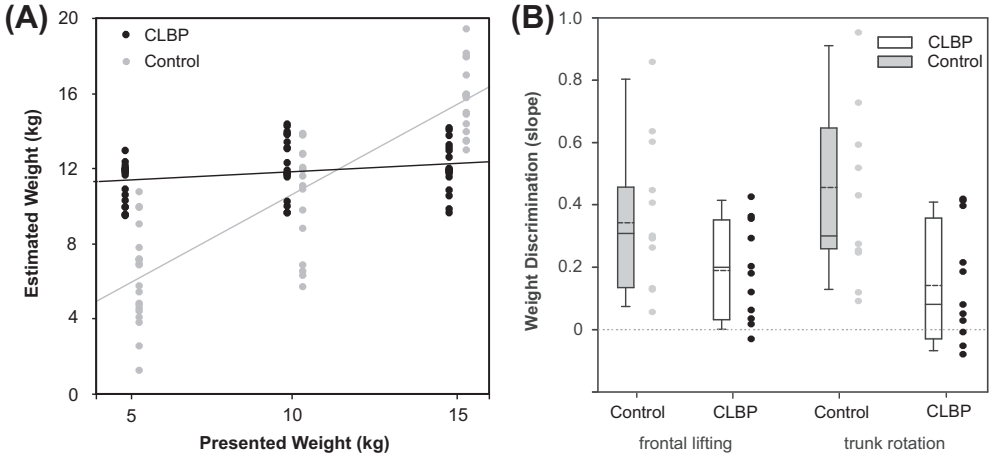

Fig. 3. (A) The recorded responses to the trunk rotation sequences of one representative patient and one matched control (20 trials per weight). Lines represent the linear regression fits (weight discrimination). (B) The weight discrimination for the frontal lifting and trunk rotation task. Zero means that there was no relation between the estimated weight and the presented weight. One indicates veridical judgment. Each participant is shown as a symbol. The group data are presented as box plots.

Whereas for the control group the model with an interaction MovementType x Weight was significantly better ($p = .0008$), but not for the CLBP patients ($p = .02$). This shows that the additional handling of the weight provided the participants of the control group with additional information, but those of the CLBP group not.

Fig. 4 shows that the CLBP on average responded very close to the center of the scale, regardless the presented weight. This is consistent with our expectation if they were indeed bad at the task. The main effect of group illustrates that the control subjects generally underestimated the weights (Fig. 4). On average, the CLBP patients slightly overestimated the weights of 170 g, whereas controls underestimated the presented weights on average by 2.4 kg. The main effect of factor weight indicates that heavier weights were estimated significantly heavier than lighter ones. The weights received similar estimates in frontal lifting and trunk rotation tasks, as indicated by the lack of a main effect of Movement.

3.2. Normalized data

The normalized data were tested as described in Section 2.5. The ANOVA comparing the models for the frontal lifting movement gave a marginally significant effect ($p = .053$), whereas the ANOVA on the models for the trunk rotation movements was significant ($p = .01$).

3.3. No effect of current pain and no differences of response time

The linear regression of the weight discrimination on the current pain levels showed that the CLBP patients' disability did not depend on current pain intensity. Although the patients' current pain scores ranged from 0 to 7 (VAS), the slope was not significantly different from zero and even slightly positive for the frontal lifting and the trunk rotation task.

As all but one of the CLBP patients reported very similar pain 4-week pain intensity (4WPI) and all had been chronic for a very long time (Table 1) the data give no information as to a possible influence of these factors. An effect of pain duration is addressed in Experiment 2.

The ANOVA on RTs revealed no significant main effect for Group ($F(1, 20) = 0.14$, $p = .07$). RTs were similar between patients (Mean ± Standard error of the mean: 8.4 ± 1.6 s) and controls (7.6 ± 1.6 s). Furthermore, no significant interactions of Group × Movement ($F(1, 20) = 0.01$, $p = .09$) and Movement × Weight × Group were observed ($F(1.4, 27.1) = 1.81$, $p = .02$, $\epsilon = 0.68$). There was a significant

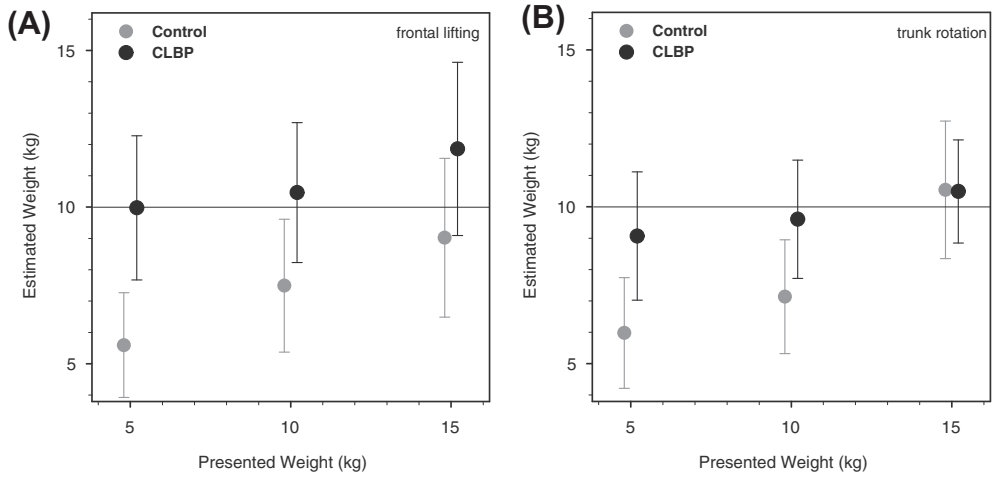

Fig. 4. Mean estimated weight judgments by CLPB patients and Controls. (A) Frontal lifting task. (B) Trunk rotation task. Error bars represent 95% confidence intervals. Horizontal line: mean of the presented weights and center of the slider.

main effect of the within-subject factor Movement ($F(1, 20) = 9.25$, $p = .006$). This main effect results from faster RTs for the frontal lifting task (7.5 ± 1.7 s) compared to the trunk rotation task (8.5 ± 2.2 s) and probably reflects that the lifting movements lasted shorter. There was a significant main effect of Weight ($F(2, 40) = 12.68$, $p < .0001$) resulting from the slower RTs for 10 kg (8.5 ± 1.7 s) in comparison to 5 kg (7.5 ± 1.5 s) and 15 kg (8.0 ± 1.6 s).

4. Experiment 2. Attention is not affected

Given the severe impact of chronic pain on the everyday life of patients, it is possible that such patients generally perform badly on the kind of psychophysical judgment task of Experiment 1. For example, attentional problems might interfere with complex visual judgment tasks. Alternatively, the deficit might be of visual, or general cognitive processing nature, and not be specific to motor judgments. To exclude such possibilities we performed a second experiment. Here, pain patients were to perform a difficult visual task involving point-light biological motion. As the task did not involve the judgment of somatosensory or motor aspects of the movement we hypothesized that the pain patients would perform as good as the normal control subjects.

4.1. Methods

Participants Twenty pain patients who were all attending the pain treatment program of the Marienhospital Hamm (Table 2). The patients were recruited in the hospital; it was stressed orally and in a written instruction that participation was fully voluntary and not part of the pain treatment. The

Table 2
Characteristics of the subjects in Experiment 2. Of the 11 chronic patients (>6months with symptoms), 55% had attended Hauptschule and 27% Realschule. Of the 21 control subjects, 43% had attended Hauptschule and 19% Realschule. CPI = current pain intensity; 4WPI = 4-week pain intensity. CPI, 4WPI: see Table 1.

Patient	Gender	Age	Edu[a]	CPI	4WPI	Region[b]	Medication[c]
acu.a1	f	56	H	70	70	l.back	Ib
acu.06	f	49	H	20	100	u.leg	Ib
acu.11	m	63	H	10	60	l.leg	Ib
acu.15	f	39	H	80	70	l.leg	Ib,No
acu.19	f	70	H	80	90	l.back	Ib
Mean ± *SD*	80%f	55 ± 12		52 ± 34	78 ± 16		
int.07	f	50	A	50	50	neck	–
int.10	m	17	R	30	100	knee	Ib,No
int.13	f	50	R	10	40	l.back	Ib
int.14	m	61	H	20	70	l.back	Mo
Mean ± *SD*	50%f	45 ± 19		28 ± 17	65 ± 26		
chr.01	m	58	H	90	90	l.back	–
chr.02	f	46	R	80	80	l.back	Ib
chr.03	m	30	A	80	80	neck	–
chr.04	m	65	A	55	55	hip	–
chr.05	f	37	H	90	90	l.back	Ib
chr.08	f	50	R	40	40	l.back	Ib
chr.09	m	55	H	30	70	l.back	–
chr.12	m	62	H	30	50	l.back	Ib
chr.16	f	54	R	10	80	l.back	Ib
chr.18	m	68	H	40	40	l.back	MM
chr.20	f	43	H	30	85	l.back	Ib
Mean ± *SD*	45%f	52 ± 12		52 ± 28	69 ± 19		
Control	57%f	52 ± 14					

[a] Level of absolved education (low to high): H = Hauptschule, R = Realschule, A = Abitur.
[b] Primary region of indicated pain: l.back = low back, l.leg = lower leg, u.leg = upper leg.
[c] Reported current medications: Ib = Ibuprofen, No = Novalgin, Mo = Morphium, NS = Novalminsulfon, MM = Metoprolol + Metformin.

regular pain program of the Marienhospital Hamm involves physiological and psychological treatments. None of the patients had been surgically operated on the back.

All patients underwent an orthopedic and neurologic examination by an experienced orthopedic surgeon. Patients were not selected for the study if they suffered from acute neurologic deficits (paresis, incontinence), vertebral tumors, inflammatory vertebral disorders (spondylodiscitis, spondylitis, discitis) and psychiatric disorders in their medical history. Medications were recorded (Table 2). Written informed consent was obtained and all procedures were approved by a local ethics committee of the University of Münster and conformed to the Declaration of Helsinki.

Twenty-one control subjects were age- and gender-matched to the patients (Table 2). The control subjects had no history of acute or chronic pain nor any neurological defects. Effort was made to match the educational level, although we failed in this respect for the group of acute patients all of whom had the lowest level of education (Hauptschule).

Setup. The set-up was as in the first experiment. Instead of the lifting sequences of Experiment 1, a side-view of recorded treadmill walking was presented in point-lights of single frame lifetime (SFL, Beintema & Lappe, 2002; Beintema, Georg, & Lappe, 2006). The point-lights were not located on the joints but on the upper and lower segments of the arms and legs. Each point appeared just one frame, so no meaningful apparent motion was present in the stimulus. The frame duration was 16.7, 33.3, 66.7, or 133.3 ms (1, 2, 4, or 8 refreshes of the display). At any time during presentation 12 points were presented simultaneously. The presentation lasted for 1.300 s (0.94 walking cycles).

Procedure. 160 trials were presented in random order: the stimulus faced left or right, walked forward or backward, four frame durations; each kind occurring 10 times.

The task was to discriminate whether the stimulus walked forward or backward, regardless of its facing direction. This task is easy for a frame duration of 16.7 ms but very difficult for the longest frame duration.

Each participant filled in the questionnaire and was explained that he or she could break off the experiment any time. He or she was then presented a few example stimuli. All participants spontaneously and correctly identified the stimuli as human walking. Each participant was then explained the procedure and the task orally as well as by written instructions. The participant then performed some example trials on which direct feedback was given by the instructor. Finally, the participant was asked to repeat the task in his or her own words. Any potential misunderstandings were explained again by the experimenter.

Analysis. The sensitivity of each subject for each frame duration was computed from the hit rates and false alarm rates (see, e.g., Macmillan, 2002). A repeated measures ANOVA with within factor frame duration and between factor subject group was computed on the d' values (detection sensitivity). To compute d', the proportions of correct responses and false alarms are transformed to the normal distribution (Z-scores), which makes d' more suitable for statistical testing. The proportion of correct responses will be plotted as this is a more intuitive measure for visual inspection.

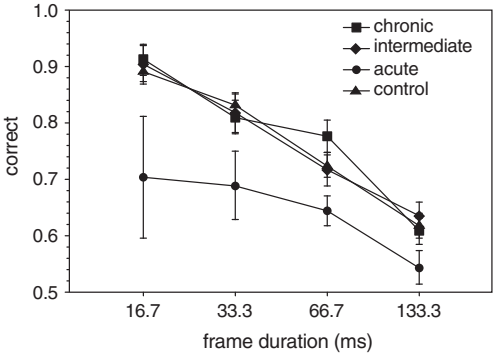

Fig. 5. Response accuracy (proportion correct responses) for Experiment 2. The data show that only acute patients but not chronic ones were impaired on a difficult visual task, conform the hypothesis. Note that chance level is at 0.5.

As the participants could only respond after the stimulus disappeared, the response duration is not an important measure. We nevertheless recorded the response durations. The ANOVA confirmed that there were no significant main effects of subject group nor an interaction between frame duration and subject group ($p > .55$).

4.2. Results

The results of Experiment 2 are presented in Fig. 5. The figure shows that the data of three of the four subject groups overlap completely. They all show the same monotonic, linear decrease in correct responses with increasing frame duration. In other words, in the easiest condition, with short frame duration as well as in the most difficult condition, the chronic and intermediate pain patients performed just as good or bad as the control group. These three groups were well matched. Unfortunately, the acute pain group was not well matched to the control group for the level of education. However, in none of the other groups was there any effect of the level of education on the performance, so it is very unlikely that the bad performance is related to education.

The ANOVA confirms these results: There were significant main effects of subject group ($F(3,164) = 4.1$, $p = .01$), of frame duration ($F(3,164) = 67.5$, $p < .0001$), and no significant interaction. A Fisher's PLSD post-hoc test showed that the acute patient group differed significantly from all other groups ($p < .04$), whereas all other groups did not differ significantly from each other ($p > .4$).

5. Discussion

The goal of the present study was to find if weight perception from visually presented actions involving the back, is impaired in CLBP patients. The main finding was that CLBP patients were unable to distinguish the differences in weight of an invisible box moved by the point-light actor. We thus found that CLBP is indeed associated with a reduced ability to discriminate between the different weights handled in point-light biological motion displays. This is fully consistent with recent findings (de Lussanet et al., 2012).

The second prediction, that the difference between controls and CLBP patients is more pronounced for trunk rotation than for frontal lifting, was also confirmed by the results.

Third, Experiment 2 showed that chronic pain patients are not generally impaired in visual discrimination tasks involving visually presented point-light biological motion. By contrast, acute pain did interfere with the task, at least in the small sample involved in this experiment. Thus, Experiment 2 indicates that acute pain may interfere with the performance on a difficult visual task, but in chronic pain patients there clearly was no such interference.

In the Introduction we listed findings that the observation of actions recruits sensorimotor regions in the brain. We argued that there is evidence that this activity reflects sensorimotor experience (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006) and that this is essential for understanding the detailed sensory and motor aspects of a seen action (Jackson, Warren, & Abernethy, 2006; Renden, Kerstens, Oudejans, & Cañal-Bruland, 2012). Further, we listed evidence that the same sensorimotor structures in the brain are involved and affected in CLBP. On the basis of this anatomical overlap we formulated our hypothesis, that the judgement of sensorimotor aspects of a seen action of the back should be impaired. A crucial prerequisite though is that there is not only mere anatomical overlap. Instead, the hypothesis requires that sensorimotor mechanisms should be affected by CLBP.

Indeed there are many findings that associate specific changes in sensorimotor control with CLBP. These changes occur at various levels, including the sensorimotor cortex. Also, it is known that CLBP patients are more attentive to pain-related stimuli. It has been found repeatedly that patients with CLBP show an increased attention for pain-related stimuli, but an increased attention does not necessarily lead to better performance. CLBP is associated with pathophysiological changes at various levels of sensorimotor control. At the cortical level, CLBP is associated with functional reorganization in somatosensory and motor regions (Flor et al., 1997; Strutton, Theodorou, Catley, McGregor, & Davey, 2005; Tagliazucchi, Balenzuela, Fraiman, & Chialvo, 2010; Tsao, Druitt, Schollum, & Hodges, 2010;

Wand et al., 2011). Changes have also been observed on a behavioral level, during stimulus anticipation (Flor, Knost, & Birbaumer, 2002; Moseley, Nicholas, & Hodges, 2004), and in motor behavior (Martel, Thibault, & Sullivan, 2010; MacDonald, Moseley, & Hodges, 2009; MacDonald, Moseley, & Hodges, 2010). Chronic low back pain, especially the non-specific types, might be associated with a general hypersensitivity in CLBP patients, rather than being solely a problem of the spine and the low back region (Puta et al., 2012). Taken together, these findings strongly suggest that the cortical somatosensory and motor representations of the low back are indeed suppressed in CLBP patients. Given the suppression of these mechanisms it is likely that they are not only unavailable for active movement execution, but also for the recognition of visually presented actions.

The control subjects were not perfect in their judgments of manipulated weight. On average they judged about 50% of the actual difference between the lowest and highest weights, which is much lower than found by Runeson and Frykholm (1981), but comparable to the performance of healthy subjects in other studies with point-light stimuli (Bingham, 1987; Runeson & Frykholm, 1983; Shim, Carlton, & Kim, 2004) as well as with filmed stimuli (Bingham, 1987; Bosbach, Cole, Prinz, & Knoblich, 2005; Poliakoff, Galpin, Dick, & Tipper, 2010). In the paradigm of Runeson and Frykholm the subjects saw a reference movement from the middle of the range and point-light markers were present on the lifted object, which may have caused the particularly good performance in that study. On the basis of this literature we predicted that the healthy controls should be better if the presented movement lasts longer and if the interaction with the object is more extensive. This was indeed that case as can be seen in Fig. 3B, which shows that the controls discriminated the weights better in the trunk rotation task than in the frontal lifting task.

An interesting question is what properties in a stimulus help to judge the weight. Little can be learned from the literature, but Runeson and Frykholm (1981) reported that it helps if the actor does not know what to expect, whereas they showed in Runeson and Frykholm (1983) that observers tend to notice it when the actor tries to fool them to mimic a different weight. One factor that does appear to be important is the length of the sequence and the amount of handling with the weight by the actor (cf. frontal lifting versus trunk rotation). Another factor that one might expect to be important is the view from which the movement is presented (i.e., frontal or profile). To test this we did a control experiment for which one recorded actor lifted a box containing four different weights each five times in two different manners (i.e., with or without strong bending of the knees). The order of the loads was randomized and unpredictable for the actor. Four participants (two male) judged the weight lifted in all recordings, presented in profile view and in frontal view. The participants judged different movements differently. Especially the first recordings of each weight were judged very accurately. Importantly though, it was completely irrelevant in which view a movement was presented. This was so for each individual subject and each individual recorded movement. We take this as additional evidence that the observers' sensorimotor experience is important in this task, because frontal and profile views look very different, whereas sensorimotor experience is view-independent.

In contrast to the healthy controls, the CLBP patients were not better at discriminating the weights in the trunk rotation task than in the frontal lifting task (Fig. 3B). This shows that the CLBP patients were "resistant" to better visual information: in contrast to the controls the patients performed slightly worse on the trunk rotation displays than on the frontal lifting displays. In other words, although they could recognize the action that was represented by the display, they were specifically unable to access information regarding body (back)-related aspects of the action.

One interpretation of our results might be that the inability to discriminate the weight handled in a visually presented action is due to an inability to move. We do not favor such an explanation. Recently, in a comparable experiment to ours, patients suffering from Parkinson's disease had to judge the lifted weight (a hand-held container), from a short movie of a human arm (Poliakoff et al., 2010). Poliakoff et al. found that the Parkinson's patients could judge the lifted weight just as well as healthy controls. The motor control system involves the basal ganglia, cerebellum and spinal mechanisms. Since Parkinson's disease is caused by a malfunctioning of the basal ganglia, it can be expected that the cortical mirror neuron system is intact. Thus, it seems likely that the bad performance of the CLBP patients in the present study is due to cortical mechanisms.

One might also argue that the patients were so much distracted by the pain that they were unable to concentrate sufficiently on the task. For example deficits in selective attention have been found in

chronic pain patients (Grisart & Plaghki, 1999). However, Grisart and Plaghki only found any effects in the high-current-pain group but not in the low-current-pain group. Following the definition of Grisart and Plaghki, the patients of our experiments all belonged to the low-current-pain category. The results of the second experiment strongly support this: in a visual task that did not require fine sensorimotor judgments that chronic patients performed just as fast and accurate as the normal controls over the whole range of task difficulty. Instead, the acute group were clearly impaired on this experiment, which might well be due to attentive problems. This result is consistent with earlier studies. These studies found that pain-related stimuli tend to attract attention more strongly in patients with chronic musculo-skeletal pain than in controls, whereas the patients had no attentional deficits (Apkarian et al., 2004; Peters, Vlaeyen, & Kunnen, 2002; Roelofs, Peters, Fassaert, & Vlaeyen, 2005).

Other studies have indicated that chronic pain patients need more attention for making movements (Geurts & Mulder, 1994; Johnston, Atlas, & Wager, 2012; Lamoth, Stins, Pont, Kerckhoff, & Beek, 2008), and that pain-related stimuli attract more attention (Haggman, Sharpe, Nicholas, & Refshauge, 2010). On first blush one might come to a hypothesis that is opposite to ours, namely that this increased attention should improve the performance of pain patients for the weight judgment task. However, since the improved attention is most likely related to the impaired sensorimotor mechanisms and fear-avoidance behavior, this alternative hypothesis is not supported by the facts.

In defining our hypothesis, we built upon this background. First, notice that the task was not an attentional one: There was just one stimulus, just one, clearly defined, task, and no time pressure. Second, the stimuli may have evoked pain-associations in the patients, but such associations are not at all informative in the sense of the lifted weight because they rather enhance the fear of movement and the fear-avoidance behavior. Crucially, to perceive lifted weight from mere point-lights, one can only rely on one's sensorimotor experience with the lifting of various weights. Consequently, there is no way a pain association could be of help in this task, since a negative association should suppress the recruitment of sensorimotor experience.

5.1. Mechanism

Imaging studies have identified many regions in the brain that are related to chronic pain, such as the anterior cingulate, insular, and somatosensory cortex (Apkarian, Bushnell, Treede, & Zubieta, 2005; Baliki et al., 2011). Elsewhere in this issue we show that the judgment task of Experiment 1 recruits these brain regions in healthy subjects (Ritter, de Lussanet, & Weiss, 2013). These findings suggest that chronic pain might interfere with higher cognitive processes. The present experiment was designed to recover such an interference. Experiment 2 suggests that this interference did not take place at the level of visual perception nor at the response level as these were completely normal (although acute pain did affect the performance in Experiment 2). Then, if the chronic pain comes along with cortical changes, in which manner do these changes affect the perception of presented weight?

It is known that chronic pain leads to major changes in the mapping of somatosensory and motor regions (S1: Flor et al., 1997; motor cortex: Tsao et al., 2008). Further, behavioral studies have found that chronic pain usually evokes a profound increase in kinesiophobia (Roelofs, Goubert, Peters, Vlaeyen, & Crombez, 2004; Trost, France, & Thomas, 2008, 2009; Vlaeyen & Crombez, 1999), as well as changed and delayed reflexes (Leinonen, Kankaanpää, Hänninen, Airaksinen, & Taimela, 2002; MacDonald et al., 2009; van Dieën, Cholewicki, & Radebold, 2003).

Thus, it can be hypothesized that pain leads to a dynamic suppression of motor mechanisms, on a somatosensory or a motor level of representation (or both). This suppression in turn evokes the suppression of the mirror neuron mechanisms in these regions. Alternatively, chronic pain patients might relearn the kinematic ranges for the affected body part to the limited range of the affected body (Moseley et al., 2012; Moseley & Brugger, 2009). By this, the presented movements could not be judged against one's own sensorimotor experience. Consistently, chronic pain did not interfere with the visual recognition of human actions (the CLBP patients could recognize the point-light actions), but only with motor and sensory aspects that are hard to distinguish visually, such as the lifted weight. In line with this interpretation, patients with chronic back pain have been shown to perform badly in an implicit motor imagery task which consists of left/right trunk rotation positions, based on a picture bank of 56 photographs (Bray & Moseley, 2011). The current study adds to the findings of

Bray and Moseley, in that it used real actions and a display without any figurative information (i.e., point lights).

5.2. Conclusion

Chronic pain interferes with sensorimotor judgments but not with visual judgments. This impairment is body part specific and depends on how these body parts move in the visual display. As the processing of pain and the visual judgments of such movements both recruit anterior cingulate, insular and somatosensory regions, it is likely that changed activities in these regions due to chronic pain also underly the impaired visual judgments.

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