Motor simulation is disturbed when experiencing pain

Emiel Cracco^{1*},

Amanda Clauwaert²,

Yentl Van den Broeck¹,

Stefaan van Damme²,

& Marcel Brass¹

* Corresponding author

1. Department of Experimental Psychology, Ghent University, Ghent, Belgium

2. Department of Experimental-Clinical and Health Psychology, Ghent University, Ghent, Belgium

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Abstract

While the contributions of social processes to pain perception are well-documented, surprisingly little is known about the influence of pain on social perception. In particular, an important question is how pain modulates the processing of other people's actions. To address this question, the current study tests, using automatic imitation, the hypothesis that pain interferes with motor simulation – that is, the processing of observed actions in the motor system. Participants in both experiments performed an automatic imitation task requiring them to abduct their index or little finger while they saw someone else performing a congruent or incongruent action. Automatic imitation was measured in a pain-free context, a context where pain was coupled to movement execution (Experiment 1), and a context where pain occurred randomly (Experiment 2). The results revealed that automatic imitation, indexed by slower responses on incongruent than on congruent trials, was reduced when experiencing pain, both when pain was linked to movement execution and when it was not. Thus, the current study shows that pain leads to reduced motor processing of others' behavior, and as such has important implications for understanding the social difficulties associated with pain.

Introduction

Social and interpersonal processes play a key role in the experience and expression of pain [39,63]. For example, pain experience in children has been shown to depend on the reactions of their caregiver [11,31,66] and pain expression in both children and adults on the presence of familiar or unfamiliar others [35,37,62]. In addition, social processes contribute to the development of pain problems, as evidenced by the fact that bullying, abuse, and family conflict all correlate with chronic pain [65]. Finally, as chronic pain patients often report to have less satisfying social relations [24,28], these same social factors may also contribute to the sustainment of pain [20].

Yet, while there is now increasing evidence that others have a strong influence on how we experience pain, surprisingly little is known about how experiencing pain influences the perception of others. An important reason for this knowledge gap is that research on social perception has so far mainly focused on observing pain in others [2,48,53,61]. As a result, the opposite question of how our own pain affects social perception remains to be addressed. It is an important question, however, because social life constantly requires us to interpret and respond to what others do. Research suggests that doing so relies at least partly on motor simulation [50,51]. Specifically, this research has shown that processing observed actions involves not only visual but also motor processes [12,17,29,49]. These motor processes facilitate action recognition [3,58] as well as prediction [1,67], and as such play an important role in social interaction [16,32,38]. However, how pain influences motor simulation is still largely unknown.

Behaviorally, motor simulation can be studied by means of automatic imitation [17,33]. A well-known task to measure this phenomenon is the imitation-inhibition task [9,57]. In this task, participants have to perform a particular action while they see someone else performing

either the same (i.e., congruent) or a different (i.e., incongruent) action. The results typically reveal faster responses on congruent trials than on incongruent trials [17], indicating that the observed actions were processed motorically [7,8] and hence triggered an imitative response [17,19,33].

Here, we use automatic imitation to investigate how pain influences motor simulation. In Experiment 1, pain is linked to action execution. In Experiment 2, pain instead occurs randomly. If pain disturbs motor simulation, this should be reflected in automatic imitation. Specifically, there are two mechanisms by which pain may influence imitation. First, supported by evidence that executing painful actions elicits fear [44,45], protective processes may inhibit imitation when it would lead to pain. In this case, imitation should be reduced selectively when observing actions whose execution is associated with pain. Second, research has shown that pain shifts attention towards the own body [15,59,60]. A self-oriented focus, in turn, is known to hamper motor simulation [34,54]. As such, pain may interfere with automatic imitation by moving attention away from the other and on the self [10]. In this case, imitation should be reduced even when pain is not linked to action execution.

Experiment 1

Participants

Data of 55 participants was collected for Experiment 1 (37 females, $M_{\text{age}} = 20.91$, $SD_{\text{age}} = 3.39$, $\text{range}_{\text{age}} = 18\text{-}33$). However, two participants were excluded because their mean error rate (16.93% and 19.95%) exceeded the sample mean by $> 3 SD$. As a result, the final sample consisted of 53 participants. Participants received 5 euro in exchange for their participation, were right-handed, had normal or corrected-to-normal vision, and signed an informed consent

before the start of the experiment. The experimental procedure was approved by the local Ethics Committee and was performed in accordance with the 1964 Helsinki Declaration.

Material

Painful electrocutaneous stimuli (bipolar, 50 Hz, 200 ms, instantaneous rise and fall time) were delivered using a Constant Current Stimulator (DS5; Digitimer Ltd, Hertfordshire, United Kingdom) with two pair of lubricated Medcat surface electrodes (1 cm diameter; www.medcat.be; Antwerpen, Belgium). One electrode pair was attached to the proximal phalanx of the right index finger and another pair to the proximal phalanx of the right little finger. All electrodes were attached directly to the skin surface by means of double-sided tape rings.

Stimuli and Task

The experiment was programmed in Tscope5 [56] and included a pre-test, an acquisition phase, and a post-test. In the pre-test, participants did an automatic imitation task [9,17], requiring them to abduct their right index finger when W appeared and their right little finger when P appeared. At the same time, a hand on the screen (482 x 544 pixels) also abducted its index finger, also abducted its little finger, or did not move (Figure 1). There were three trial types: neutral trials, where the stimulus hand did not move, congruent trials, where the movement performed by the stimulus hand matched the instructed response, and incongruent trials, where the movement performed by the stimulus hand did not match the instructed response. Automatic imitation in this task is defined as a congruency effect, with responses on congruent trials being faster than responses on neutral trials (i.e., facilitation effect) and

responses on incongruent trials being slower than responses on neutral trials (i.e., interference effect) [9,17].

The pre-test was followed by the acquisition phase. In this phase, one of the two responses was paired with a painful stimulus. That is, participants were instructed to abduct their right index or little finger and one of these two movements was followed in 33% of the trials by a painful electrocutaneous stimulus to the finger with which the movement was executed. To ensure that the stimulus would be linked to the movement and not to a co-occurring cue, participants could freely choose which movement to perform, but were informed that the acquisition phase would continue until their response ratio approached 50/50 to prevent avoidance behavior.

Finally, the post-test was identical to the pre-rest, except that the pain-associated movement was still followed by a painful stimulus in 25% of the trials to prevent extinction. Responses in all three phases were measured with an optical response box recording movement onset.

Procedure

Participants were tested individually in a dimly lit room. At the start of the experiment, the experimenter first attached the electrodes to the participant's right index and little fingers. Next, the pre-test instructions appeared, explaining the automatic imitation task and asking participants to respond as fast as possible without making errors. This was followed by 12 practice trials with accuracy feedback and two experimental blocks of 96 trials without any feedback. Trials were presented randomly, with the restriction that the same response cue could not appear more than 5 times in a row. There was an opportunity to take a break after each block.

Each trial of the automatic imitation task started with a picture of the hand in neutral position, together with a fixation cross, for 500 ms. This was followed by a picture of the hand abducting its index or little finger, together with the letter W or P, for 2,000 ms or until the response. Importantly, this sequence of two pictures induces an illusion of movement and has previously been shown to be equally effective in eliciting automatic imitation as videos [17]. Following the response, a black screen was shown for 1,000 ms, after which the next trial started.

The pre-test was followed by the acquisition phase. One half of the participants were told that index finger movements would be linked to a painful stimulus and the other half that little finger movements would be linked to a painful stimulus. The acquisition phase started with a staircase procedure to determine the stimulation amplitude. Participants were first presented with a stimulus of low amplitude (0.5 mA) to get familiar with the stimulation. Next, the same stimulus was presented, and participants were asked to press the right arrow key to increase the stimulation amplitude (in steps of 0.5 mA) until it reached the maximal intensity that they were willing to endure throughout the experiment. It was not possible to decrease the intensity after increasing it.

After the staircase procedure, the acquisition task started. Each trial began with a fixation cross for 500 ms, followed by the letter X for 2,000 ms or until the response, and a black screen for 1,000 ms. Participants could freely choose to abduct either their right index or right little finger as response, but were asked to roughly balance both responses. To help them achieve this goal, the response ratio was shown at the top of the screen. Following pain-related responses, there was a 33% probability to receive a painful stimulus. Furthermore, the first two pain-related responses were always followed by a painful stimulus. The task lasted for a minimum of 30 trials and continued until the response ratio was less skewed than 60:40. Afterwards, participants were asked to indicate on an 11-point Likert scale the extent to which

they expected a painful stimulus to occur after index finger responses and after little finger responses. If this revealed that they were unable to identify the pain-related finger, the acquisition task was repeated. However, all participants identified the pain-related finger on the first attempt.

Finally, after the acquisition phase, the post-test started. The post-test was identical to the pre-test, except that the pain-related responses were now followed by a painful stimulus on 25% of the trials to prevent extinction. Finally, after the post-test, participants were asked to rate the unpleasantness and painfulness of the electrocutaneous stimuli on an 11-point Likert scale.

[Figure 1 about here]

Data-Analysis

All analyses were performed in R. Trials were excluded from both the reaction time (RT) and error rate (RT) analysis when no response was recorded before the response deadline (0.03%) or when the RT was faster than 100 ms (0.02%). Furthermore, trials were excluded from the RT analysis only when the response was incorrect (3.35%) or when the RT deviated from the participant's mean RT by more than 3 *SD* (1.77%). The resulting data was analyzed with a phase (pre-test or post-test) x instructed response (pain-related or pain-free) x congruency (congruent, neutral, or incongruent) repeated measures MANOVA.

If pain triggers protective inhibitory processes, automatic imitation should be selectively reduced for pain-related observed movements. In operational terms, this means that we should find a phase x instructed response x congruency interaction, with a different phase x congruency interaction depending on the instructed response. That is, on trials where the instructed response

is pain-related, congruent observed movements are pain-related and incongruent observed movements are pain-free. As such, the facilitation effect but not the interference effect should be smaller in the post-test than in the pre-test. In contrast, on trials where the instructed response is pain-free, incongruent observed movements are pain-related and congruent observed movements are pain-free, and the opposite pattern should be observed. In other words, reduced automatic imitation of pain-related observed movements should differentially affect performance on congruent and incongruent trials depending on the instructed response, allowing us to disentangle the effect of performing and observing pain-related movements.

A different pattern is expected when pain increases self-focus. In that case, automatic imitation should instead be reduced for both observed movements. That is, we should find a phase x congruency interaction, with an overall weaker congruency effect in the post-test than in the pre-test.

Results

Self Report. Participants rated the electrocutaneous stimuli as unpleasant ($M = 7.06$, $SD = 1.15$) and mildly painful ($M = 4.89$, $SD = 2.06$). Furthermore, they reported to expect painful stimuli more following pain-related ($M = 7.49$, $SD = 1.27$) than following pain-free responses ($M = 0.96$, $SD = 1.86$), indicating a successful manipulation.

Reaction Times. The RT results revealed a main effect of congruency, $F(2, 51) = 96.93$, $p < .001$, $\eta_p^2 = 0.79$, with faster responses on congruent than on neutral trials, $t(52) = -10.03$, $p < .001$, $d_z = 1.38$, and faster responses on neutral than on incongruent trials, $t(52) = -10.95$, $p < .001$, $d_z = 1.51$. As predicted, there was a significant phase x congruency interaction, $F(2, 51) = 10.16$, $p < .001$, $\eta_p^2 = 0.29$, indicating that the congruency effect was smaller in the post-test, $F(2, 51) = 118.98$, $p < .001$, $\eta_p^2 = 0.82$, than in the pre-test, $F(2, 51) = 60.13$, $p < .001$, $\eta_p^2 =$

0.70 (Figure 2a). However, there was no significant phase x instructed response x congruency interaction, $F(2, 51) = 0.19$, $p = .830$, $\eta_p^2 = 0.01$, suggesting that the effect of pain was independent of the observed movement. None of the other effects reached significance, all $F \leq 3.17$, all $p \geq 0.050$.

These results support the hypothesis that being in pain disturbs automatic imitation. However, because the post-test always followed the pre-test, it could also be that imitative responses simply decreased over time [17]. To test this, we looked at how RTs developed over blocks within each phase using a block (block 1 or block 2) x congruency (congruent, neutral, or incongruent) repeated measures MANOVA. This revealed a block x congruency interaction, $F(2, 51) = 7.31$, $p = .002$, $\eta_p^2 = 0.23$, indicating that the congruency effect was indeed reduced in block 2, $F(2, 51) = 70.79$, $p < .001$, $\eta_p^2 = 0.74$, compared with block 1, $F(2, 51) = 96.97$, $p < .001$, $\eta_p^2 = 0.79$.

However, follow-up tests revealed that time (block) and pain (phase) had dissociable effects on behavior (Figure 2b). Specifically, whereas time caused RTs to increase on congruent, $t(52) = 3.21$, $p = .002$, $d_z = 0.44$, and neutral trials, $t(52) = 2.86$, $p = .006$, $d_z = 0.39$, but not on incongruent trials, $t(52) = -0.41$, $p = .687$, $d_z = 0.06$, pain instead caused RTs to decrease on incongruent trials, $t(52) = -3.22$, $p = .002$, $d_z = 0.44$, but not on congruent, $t(52) = -0.69$, $p = .495$, $d_z = 0.09$, or neutral trials, $t(52) = -0.86$, $p = .397$, $d_z = 0.12$. In other words, as can be seen in Figure 2c, RTs on congruent and neutral trials increased over blocks within each phase and RTs on incongruent trials stayed constant within each phase but decreased between phases. These findings thus clearly indicate that the observed differences in automatic imitation between the pre- and post-test cannot be explained as changes in automatic imitation over time.

Error Rates. The ER results revealed a significant main effect of congruency, $F(2, 51) = 20.93$, $p < .001$, $\eta_p^2 = 0.45$, with more errors on neutral trials than on congruent trials, $t(52) = 4.16$, $p < .001$, $d_z = 0.57$, and more errors on incongruent trials than on neutral trials, $t(52) =$

4.89, $p < .001$, $d_z = 0.67$. The phase x congruency interaction, $F(2, 51) = 0.06$, $p = .938$, $\eta_p^2 = 0.003$, and the phase x instructed response x congruency interaction, $F(2, 51) = 0.50$, $p = .609$, $\eta_p^2 = 0.02$, were not significant. None of the other effects reached significance, all $F \geq 1.29$, all $p \leq 0.285$.

[Figure 2 about here]

Interim Discussion

Experiment 1 revealed that automatic imitation of both pain-related and pain-free observed movements was reduced when experiencing pain. This finding is inconsistent with the hypothesis that imitation is inhibited when it would lead to pain because imitation was also reduced for pain-free observed movements. While it might still be argued that there was generalization to pain-free movements [42], this seems unlikely, considering that previous research has shown that fear of pain does not generalize to other movements when it is predictably linked to the execution of one specific movement [43,46]. This is further supported by the self-report data, indicating that participants only expected pain following the pain-related but not following the pain-free response. Instead, the data are more consistent with the self-focus account. This account argues that pain leads to a self-oriented focus, and that this hampers motor simulation [10,34,54]. Given that this mechanism is unrelated to the observed movement, it can explain why automatic imitation was reduced for both pain-related and pain-free observed movements.

Nevertheless, the hypothesis that fear of pain generalized to the pain-free response as well remains a theoretical possibility. Therefore, to further distinguish between the protective inhibition and the self-focus hypotheses, we did a second experiment, in which pain was no

longer paired with movement execution but instead occurred randomly. If the results of Experiment 1 are explained by protective processes, they should disappear in Experiment 2 because such a mechanism should no longer inhibit imitation when pain cannot be prevented. In contrast, if imitation was reduced because the threat of pain caused attention to be focused on the self, the same effect should be observed even when pain is independent of movement execution.

Experiment 2

Participants

Data of 54 participants were collected for Experiment 2 (24 females, $M_{\text{age}} = 22.48$, $SD_{\text{age}} = 4.89$, $\text{range}_{\text{age}} = 18\text{-}43$). None of the participants had a mean error rate exceeding the sample mean by $> 3 SD$. Participants received 5 euro in exchange for their participation, were right-handed, had normal or corrected-to-normal vision, and signed an informed consent before the start of the experiment.

Material, Stimuli, Task, and Procedure

As in Experiment 1, one finger received painful stimulation while the other finger did not. However, now, pain was no longer coupled to response execution but could instead occur on any trial and at any possible point within those trials. Specifically, painful stimuli were administered at random time points in a randomly selected 16.67% of the acquisition trials and 12.50% of the post-test trials. Importantly, this means that participants received an equal number of painful stimuli in both experiments. All other procedures were identical to

Experiment 1, except that participants no longer had to indicate how much they expected a painful stimulus following index and little finger responses at the end of the acquisition phase. Instead, they now answered these questions at the end of the experiment. In addition, participants were also asked how much they feared a painful stimulus following index and little finger responses. As in Experiment 1, these questions were answered using an 11-point Likert scale. Finally, participants also completed the Pain Vigilance and Awareness Questionnaire [41] and the Interpersonal Reactivity Index [21]. However, this data will not be reported.

Data-Analysis

All analyses were identical to Experiment 1, except that instructed response was no longer included as a factor in the MANOVA. Trials where a painful stimulus was provided before the response were excluded from all analyses (2.62%). Furthermore, as in Experiment 1, we excluded trials from both the RT and ER analysis when there was no response (0.44%) or when the RT was faster than 100 ms (0.00%) and only from the RT analysis when the response was incorrect (3.51%) or when the RT deviated from the participant's mean RT by more than 3 *SD* (1.77%).

Results

Self Report. In line with Experiment 1, participants rated the electrocutaneous stimuli as unpleasant ($M = 6.43$, $SD = 1.70$) and mildly painful ($M = 4.26$, $SD = 2.13$). Furthermore, compared with Experiment 1, participants reported lower pain expectation when responding with the pain-receiving finger, $t(75.88) = -4.93$, $p < .001$, and higher pain expectation when responding with the pain-free finger, $t(98.96) = 3.62$, $p < .001$, indicating that the manipulation

was successful. However, the difference between the pain-receiving ($M = 5.50$, $SD = 2.68$) and the pain-free finger ($M = 2.48$, $SD = 2.45$) was still present, $t(53) = 5.97$, $p < .001$. The same was true for fear of pain, with more pain-related fear following responses with the pain-receiving ($M = 4.85$, $SD = 2.79$) than pain-free finger ($M = 2.09$, $SD = 2.28$), $t(53) = 6.08$, $p < .001$.

Thus, the difference in pain expectation between the two responses was smaller but did not disappear in Experiment 2. To test whether this influenced the results, we divided participants in a high- ($N = 29$) and low-expectation group ($N = 25$) by means of a median split on the mean difference scores for pain expectation and fear of pain. This group variable was then included as a between-subjects factor in the RT analysis. Importantly, an analysis of the self-report data in both groups revealed that participants in the high-expectation group expected, $t(28) = 11.25$, $p < .001$, and feared, $t(28) = 10.29$, $p < .001$, pain more when responding with the pain-receiving than with the pain-free finger. Participants in the low-expectation group, on the other hand, reported no such difference for either pain expectancy, $t(24) = 0.24$, $p = .809$, or fear of pain, $t(24) = 0.51$, $p = .618$.

Reaction Times. The RT results revealed a main effect of group, $F(1, 52) = 8.46$, $p = .005$, $\eta_p^2 = 0.14$, with slower responses in the low-expectation group than in the high-expectation group, and a main effect of congruency, $F(2, 51) = 82.92$, $p < .001$, $\eta_p^2 = 0.76$, with faster responses on congruent than on neutral trials, $t(53) = -11.46$, $p < .001$, $d_z = 1.56$, and faster responses on neutral than on incongruent trials, $t(53) = -7.25$, $p < .001$, $d_z = 0.99$. Furthermore, there was again a phase x congruency interaction, $F(2, 51) = 4.61$, $p = .014$, $\eta_p^2 = 0.15$, indicating that the congruency effect was smaller in the post-test, $F(2, 51) = 66.21$, $p < .001$, $\eta_p^2 = 0.72$, than in the pre-test, $F(2, 51) = 78.52$, $p < .001$, $\eta_p^2 = 0.75$ (Figure 3a). Importantly, this phase x congruency interaction did not differ between the two groups, $F(2, 51) = 0.04$, $p = .965$, $\eta_p^2 = 0.001$, showing that the finding of weaker imitation in the post-test did

not depend on whether participants expected responses with the pain-receiving finger to be followed by pain. None of the other main effects or interactions were significant, all $F \leq 0.92$, all $p \geq .404$.

As in Experiment 1, we followed up on these findings with a block x congruency repeated measures MANOVA testing whether the phase x congruency interaction could be explained by a decrease in automatic imitation over time. The results revealed a main effect of block, $F(1, 53) = 5.51, p = .023, \eta_p^2 = 0.09$, with slower responses in the second block of each phase, but no block x congruency interaction, $F(2, 52) = 0.94, p = .398, \eta_p^2 = 0.04$ (Figure 3b). Similar to Experiment 1, this indicates that time (block) and pain (phase) had dissociable effects on behavior: whereas time led to an overall increase in RT, pain led to a weaker congruency effect (Figure 3c). As a result, the observed differences in automatic imitation between the pre- and post-test cannot be explained as changes in automatic imitation over time.

Finally, we compared the results of Experiments 1 and 2 using an experiment x phase x congruency repeated measures MANOVA to statistically confirm that both experiments yielded similar results. This revealed a phase x congruency interaction, $F(2, 104) = 13.43, p < .001, \eta_p^2 = 0.21$, but no experiment x phase x congruency interaction, $F(2, 104) = 0.92, p = .401, \eta_p^2 = 0.02$. This was supported by a Bayesian analysis with default JZS priors [52], showing that the data was 11.79 times more likely under the model without an experiment x phase x congruency interaction than under the model with an experiment x phase x congruency interaction.

Error Rates. The ER results revealed a significant main effect of congruency, $F(2, 51) = 32.16, p < .001, \eta_p^2 = 0.56$, with more errors on neutral trials than on congruent trials, $t(53) = 4.71, p < .001, d_z = 0.64$, and more errors on incongruent trials than on neutral trials, $t(53) = 7.06, p < .001, d_z = 0.96$, but no main effect of phase, $F(1, 52) = 1.56, p = .218, \eta_p^2 = 0.03$. The phase x congruency interaction, $F(2, 51) = 1.84, p = .170, \eta_p^2 = 0.07$, was not significant, and neither were any of the other main effects or interactions, all $F \leq 1.50$, all $p \geq .226$.

[Figure 3 about here]

Interim Discussion

Experiment 2 again found weaker imitation in the painful context, even though pain was administered randomly and was hence no longer linked to movement execution. These results speak against a protective inhibition mechanism and instead point towards the self-focus hypothesis. Specifically, this account argues that pain shifts attention inwards [15,59,60] and that such a self-oriented focus hampers motor simulation [10,34,54]. Furthermore, because the results of Experiments 1 and 2 could not be distinguished, this suggests that the self-focus account can also explain the results of Experiment 1, where pain was coupled to movement execution.

General Discussion

While accumulating evidence indicates that social and interpersonal processes contribute to the experience and expression of pain [39,63], very little is known about how experiencing pain influences the perception of others. Therefore, using automatic imitation, the current study investigated the effect of pain on the sensorimotor processing of others' actions. Experiment 1 measured automatic imitation when pain was coupled with movement execution and Experiment 2 when pain occurred randomly. In both experiments, imitative tendencies were reduced in painful compared with pain-free contexts. This indicates that pain, in addition to high-level social constructs such as need for autonomy, need to belong, and need for justice [36], also influences basic social processes related to the processing of others' actions.

Specifically, it shows that pain causes individuals to simulate the behavior of other people to a lesser extent.

Two competing accounts were identified to explain the influence of pain automatic imitation. According to the protective inhibition account, imitative responses that lead to pain are inhibited [44,45]. In contrast, according to the self-focus account, pain shifts attention to the self [15,59,60], and this self-oriented focus then interferes with automatic imitation [10,34,54]. Crucially, the protective inhibition account predicts that automatic imitation should be selectively reduced when observing movements associated with pain, whereas the self-focus account instead predicts that automatic imitation should be reduced regardless of the observed movement. The results revealed weaker imitation in the pain phase regardless of the type of observed movement (Experiment 1) and regardless of whether or not pain was linked to movement execution (Experiment 2). As such, they clearly favor an interpretation in terms of self-focus.

Importantly, our results cannot be explained by general motor inhibition. That is, research suggests that pain inhibits the motor cortex [26,27]. However, this should have influenced RTs rather than imitation. Similarly, our results cannot be explained in terms of decreased attention for the task [25] because this should have resulted in slower and less accurate responses in the pain compared with no-pain phase. Instead, our results are more consistent with decreased attention for the observed movements, leading to reduced automatic imitation [10,34,54].

In sum, the current study shows, for the first time, that pain disturbs motor simulation. Importantly, this was true even for pain-free observed movements and even if pain was unrelated to movement execution. Given that key social processes such as action recognition [3,13,58], action prediction [1,67], and interpersonal coordination [16,32,38] all rely on motor simulation, these results may have important implications. Specifically, they suggest that pain,

by influencing social perception, may interfere with social interaction. Applied to chronic pain, for instance, our results speculatively suggest that patients may rely more on visual than on motor processes during action observation, creating difficulties in anticipating and interpreting other people's behavior [3,58,67], and therefore complicating everyday social life.

Moreover, in addition to having an indirect influence via motor simulation, reduced imitation may also have important consequences in itself. Indeed, imitation is known to have important prosocial benefits. For example, Chartrand and Bargh [14] found that people who were imitated by someone liked that person more and rated the interaction as smoother. This has been confirmed in subsequent research [40,55] and extended from the imitated to the imitating person [55] as well as from ratings to both helpfulness [4] and generosity [4,5]. Albeit speculative, this could have important implications for understanding the social difficulties associated with chronic pain. That is, chronic pain patients often report having fewer satisfying social interactions [24,28] and stigmatization by society [22]. While these problems are likely to be multifaceted, our findings suggest that reduced imitation may be a contributing factor. Specifically, if chronic pain patients imitate less, this could make them less likable [14], leading to increased discounting of their pain [23], and ultimately to stigmatization [22]. Nevertheless, this remains, at present, a hypothesis and will require further testing with chronic pain samples [64] and more ecologically valid measures of imitation [30].

An important limitation of the current study is that pain was manipulated in two phases, with the pain phase always following the non-pain phase. As a result, the finding of reduced automatic imitation in the pain phase may have simply reflected a decrease in imitation over time [17]. This seems unlikely, however, considering that time and pain had dissociable effects on behavior: whereas time led to an increase in RTs, pain led to a decrease in the congruency effect. Such a slowdown over time is likely to reflect a decrease in motivation. Yet, in Experiment 1, this slowdown was only visible on congruent and neutral trials. There are two

possible reasons for this pattern. First, incongruent RTs may have reached a ceiling effect. Second, the decrease in motivation may have led to a decrease in attention. As attention is known to modulate automatic imitation [6,18], this could then have canceled out the slowdown on incongruent trials. In any case, the fact that RTs in both experiments returned to baseline after interrupting the imitation task with the acquisition task supports a motivational interpretation (Figures 2c and 3c). Moreover, regardless of the mechanism, the finding that the between-phase (i.e., pain) effect differed from the within-phase (i.e., time) effect clearly shows that pain and not time caused automatic imitation to become weaker in the pain phase.

A second limitation is that some participants in Experiment 2 still expected painful stimuli more after responses with the pain-receiving finger than after responses with the pain-free finger, even though these stimuli occurred randomly. There are at least two possible reasons for this expectation bias. First, the leading nature of the questions, together with the lack of reliable information about the occurrence of the pain stimuli, may have caused participants to rely on other, incidental, information in their self-report, such as which finger received pain. In this view, the elevated pain expectation for responses with the pain-receiving finger in Experiment 2 may have been a response bias rather than a perceptual bias. Second, people may have a general tendency to expect pain following movements of body parts that hurt, even when the pain is unrelated to movement. Regardless of the reason, when we compared participants with an expectation bias to participants without such a bias, the results were identical, suggesting that this cannot explain our results. Indeed, already in Experiment 1, pain was found to be independent of whether the observed movement was pain-related or not. Experiment 2 simply extends this finding by showing that pain does not have to be linked to movement for these effects to occur.

To conclude, the current study shows that being in pain reduces automatic imitation, both when pain is linked to movement (Experiment 1) and when it is not (Experiment 2). This

shows that pain can influence basic social processes related to perceiving others' actions and as such may contribute to a better understanding of the social difficulties often associated with pain.

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Figure legends

Figure 1. Procedure of Experiment 1. In the pre-test and post-test, automatic imitation was measured. In the post-test, one of both responses was sometimes followed by a painful stimulus. This association was learned in the acquisition phase. In this phase, participants could freely choose to abduct either their index or little finger, and one of both movements was occasionally followed by a painful stimulus. Experiment 2 was identical to Experiment 1, except that the painful stimuli were no longer paired with one particular response but instead occurred randomly.

Figure 2. Reaction time results of Experiment 1 separately for (a) phase, (b) block, and (c) blocks and phases. Error bars are standard errors of the mean (SEMs) corrected for within-subject designs [47].

Figure 3. Reaction time results of Experiment 2 separately for (a) phase, (b) block, and (c) blocks and phases. Error bars are standard errors of the mean (SEMs) corrected for within-subject designs [47].