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Influence of Experimental Pain on the Perception of Action Capabilities and Performance of a Maximal Single-Leg Hop

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Abstract: Changes in an individual's state—for example, anxiety/chronic pain—can modify the perception of action capabilities and physical task requirements. In parallel, considerable literature supports altered motor performance during both acute and chronic pain. This study aimed to determine the effect of experimental pain on perception of action capabilities and performance of a dynamic motor task. Performance estimates and actual performance of maximal single-leg hops were recorded for both legs in 13 healthy participants before, during, and after an episode of acute pain induced by a single bolus injection of hypertonic saline into vastus lateralis of 1 leg, with the side counterbalanced among participants. Both estimation of performance and actual performance were smaller ($P < .01$) during pain than before and after pain. This decrease in estimation and performance during pain was apparent for hops using either leg, but it was greater ($P < .01$) for the painful leg (-10.8 ± 12.1 cm) than for the control leg (-5.5 ± 7.9 cm). Participants accurately estimated their performance in all conditions for both legs. The results provide evidence that healthy participants have the ability to update the action-scaled relationship between perception and ability during acute pain.

***Perspective:** This study demonstrates that the relationship between perceived physical ability and actual performance is effectively updated during acute muscle pain. This match between perceived ability and performance could be relevant during clinical pain assessment, with the potential to be a biomarker of transition from acute to chronic pain state.*

***Key words:** Performance, hypertonic saline, action capabilities, hop.*

The adaptation required to achieve a given behavior within constantly changing environmental constraints is an integral part of human daily life. The task-specific fit between the properties of the environment and the individual's action capabilities is known as an "affordance." Therefore, individuals perceive the properties of the world in terms of what they can do with them.[7] For instance, the affordance "stair-climbability" is related to both the characteristics of the stair (eg, riser height) and the physical capability of the individual.[38] Numerous studies demonstrate that healthy humans accurately perceive their physical capabilities for tasks such as reaching,[24] grasping,[25] jumping,[32] and walking through apertures.[10] However, the perception of action capabilities is compromised during periods of altered psychological state. For example, Graydon et al[10] reported that anxious participants underestimate their reaching, grasping, and passing ability compared to nonanxious participants, and argued that these behaviors reflect a protective mechanism. This suggests that individuals in the stressful conditions update their "safety margin" for a task, which would potentially expose them to less risk.

Considerable literature supports altered motor performance during acute experimental pain—for example,

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reduced force-generating capacity (in most[8,9,16,34] but not all studies[35]), and altered kinetics around the joint related to the painful muscle.[1,14-17,27] This alteration of performance is also observed in people with chronic musculoskeletal pain—for example, reduced force-generating capacity,[9,22,23] altered kinetics,[4] and reduced time to task failure during submaximal tasks.[28] Altered motor performance during pain may serve to reduce stress on painful tissue and/or avoid further pain.[24,37] It is unclear if the individual in pain accurately perceives this change in performance ability. If not, the individual with pain could overestimate his or her physical capabilities (ie, the function is reduced but perception in performance ability is not altered) and thus be more likely to overuse the painful part with potential for both short-term (acute injury) and long-term consequences. Alternatively, they may underestimate their physical abilities, or overestimate the physical cost of performing a movement task (eg, walking distance is overestimated in people with chronic pain[40]) and thus reduce movement/physical activity (as observed in older adults with chronic pain[11]), which may be harmful to general health in the long term.

This study used an acute pain model to investigate the effect of pain on the perception of action capabilities in healthy participants to provide a first and critical step toward understanding the unique potential for pain to modify the relationship between motor performance and perceived abilities. We hypothesized that consistent with other observations, maximal performance of the motor task would be reduced during acute pain, and that this reduction in maximal performance would be associated with reduction of the estimated ability to perform the task. Finally, as theories of the adaptation to acute pain predict changes in motor performance in and around the painful region, with little evidence (or consideration) of more generalized effects on motor performance including movement of body regions other than the painful part, we hypothesized that changes in motor performance, if present, would be confined to the painful leg. To test these hypotheses, we investigated the effect of acute experimental leg pain in healthy participants on both perception of action capabilities and performance of single-leg hops.

Method

Participants

Thirteen healthy males volunteered to participate in the study (age 28.7 ± 5.5 years; height 179.2 ± 5.3 cm; weight 73.5 ± 7.7 kg [mean ± standard deviation]). All participants indicated a preference to lead with the left leg when high-jumping. Exclusion criteria included visual or physical impairments, psychiatric or neurologic disorders, or any long-term medication use. Participants were informed of the experimental tasks before providing written consent. The experimental design of the study was approved by the Ethical Committee of Nantes Ouest IV (reference: no. CPP-MIP-002) and was conducted in accordance with the Declaration of Helsinki.

Materials and Apparatus

A rigid blue carpet (2 cm thick, 7 m long, 1 m wide) was laid on floor, with white masking tape placed across the width of the carpet to indicate the start position. A line of masking tape placed midline (perpendicular to the start line, in the middle of the carpet) extended 5 m from the start position. Participants were asked to focus on and aim for the midline when estimating their hop performance and when performing the single-leg hop task. No other visual marks were available.

To measure the participants' judgment of their perceived ability, they were asked to estimate the distance they predicted they would be able to hop by indicating "stop" as the experimenter (T.D.) moved a stick (placed transversely across the width of the carpet and with a 120-cm handle) gradually (~20 cm/sec) away from the starting line. At this point, the participants gave instructions ("farther" or "closer") to the experimenter to make minor adjustments to the stick's position in order to estimate the maximal distance they predicted they could achieve with a maximal single-leg hop, as accurately as possible. A wooden graduated ruler (3 m long, not visible to the participant) that lay on the edge of the carpet was used by a second investigator (K.T.) to measure the indicated distance.

For the single-leg hop performance, hop distance was determined using a digital camera (Casio Exilim EX-ZR100; Casio, Tokyo, Japan; sampling frequency of 120 Hz) that was aligned with the estimated hop performance but was not in the visual range of the participant. To overcome image parallax, a calibration of the camera image was performed before and after the experiment.

Procedure

Participants first performed 5 minutes of warm-up cycling on a cycle ergometer (power output = 100 W). The perception and performance tasks were then explained to the participants and they performed 3 practice hops on each leg.

A series of performance estimates and actual performance was recorded before pain, during pain (approximately 5 minutes after completion of the prepain trials, allowing time for the induction of experimental pain), and after pain had ceased (approximately 5 minutes after completion of the "pain" trial). Participants performed 6 performance estimates (3 per leg, in counterbalanced order between participants) of their own maximal single-leg hop performance during the prepain and postpain conditions, and 4 performance estimates (2 per leg) during pain. The reduced number during pain is based on time restrictions of this pain model. Maximal leg performance was defined as the maximal distance at which one could hop from 1 leg (without using the opposite leg for stability before the jump) and land on that same leg, without losing balance.[2,29,33] Participants were instructed to stand on the required leg, with the lead toe behind the starting line, and to make their judgment by considering their action capabilities at the present instant. To limit the potential for memory or visual cues to influence estimation of performance (or actual task performance), participants closed their eyes and turned away from the carpet between each performance estimate, whereas the experimenter (T.D.) returned to the starting position. After providing the series of performance estimates for both legs, participants were instructed to perform a series of 6 single-leg hop tests (3 trials per leg, in counterbalanced order between participants) during the prepain and postpain conditions and 2 single-leg hop tests (1 per leg) during pain. Participants stood in the same starting position before each hop, and at least 40 seconds of recovery was provided between 2 consecutive trials of the same leg to minimize fatigue (typically, less than 30 seconds is sufficient[33]).

Experimental Pain

Acute experimental muscle pain was induced by a single bolus injection of hypertonic saline (1 mL, 5% NaCl, 25 mm × 25 gauge needle) into the distal portion of the vastus lateralis (of the dominant or nondominant leg, with pain side counterbalanced between participants). Pain level was reported on an 11-point numerical rating scale, where 0 = no pain and 10 = most extreme pain imaginable. Once pain level was reported as at least 2/10, participants were instructed to move to the "start line" for the performance estimates to begin. Pain level was reported immediately before and following each performance estimate and hop, during the pain condition. The average of these 2 pain estimates were used for analysis. After completion of the pain trial, participants drew the region of pain experienced on their own leg, and a photograph was taken (Fig 1).

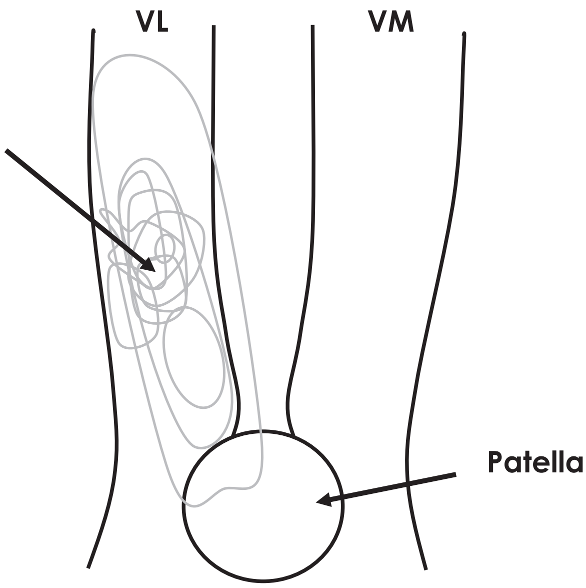

Figure 1. The location of painful injection (arrow) and area of pain (open gray circles) reported by participants on completion of pain trials are shown overlaid on a representative image of the distal thigh and knee cap (patella). VL, vastus lateralis; VM, vastus medialis.

Data Analysis

All data were normally distributed and thus values are reported as mean ± standard deviation. Statistical analyses were performed on the *average* and the *maximum* performance estimates and actual performance for each condition. The results were the same, irrespective of which measure we used, and therefore only maximum data (ie, 1 value per condition) are discussed.

Reported pain intensity was compared, using a 2-way analysis of variance with repeated measures, that is, 2 (Measure—estimates and performance) × 2 (Leg—control and painful leg). The effect of pain on both maximum estimate and actual performance was determined using a 3-way analysis of variance with repeated measures, that is, 3 (Condition—prepain, pain, and postpain) × 2 (Measure—estimates and performance) × 2 (Leg—control and painful leg). To provide additional insight into the effect of pain on the relationship between perception of action capabilities and actual performance, the ratio of perceptual estimation divided by the actual performance was calculated. A ratio of 1 indicates a perfect match, whereas a ratio greater or less than 1 indicates an over- or underestimation, respectively. These ratios were compared using a 2-way analysis of variance with repeated measures, that is, 3 (Condition—prepain, pain, and postpain) × 2 (Leg—control and painful leg).

Tukey honestly significant difference comparisons were used for post hoc tests following significant main effects. Significance was set at $P < .05$. Partial eta square ($_p\eta^2$) values are reported as measures of effect size, with moderate and large effects considered for $_p\eta^2 = .07$ and $_p\eta^2 \geq .14$, respectively.[5]

Results

Pain Intensity

The reported pain intensity during the performance estimates (5.3 ± .5/10) was slightly higher than that reported immediately following the actual hop performance (4.7 ± .4/10), main effect measure: $F(1, 12) = 8.34$, $P < .02$, $_p\eta^2 = .410$. However, there was no difference in the intensity of pain reported "between legs"—that is, reported pain intensity was similar when participants stood on their test (painful) or control (nonpainful) leg and estimated their maximal hop, and when they performed the hop on the painful and nonpainful leg, main effect of leg: $F(1, 12) = .187$, $P = .67$, $_p\eta^2 = .015$. Note that no significant measure × leg interaction was found: $F(1, 12) = .48$, $P = .50$, $_p\eta^2 = .038$.

Performance Estimates and Actual Performance

Before pain was induced, participants estimated that they could perform a single-leg hop of 194.1 ± 28.6 cm, and their maximum hop performance was 201.6 ± 24.2 cm. There was no significant main effect of measure; performance estimate vs actual performance: $F(1, 12) = .912$, $P = .36$, $_p\eta^2 = .071$, or significant interaction considering this factor (all Fs < 1.63, Ps > .22).

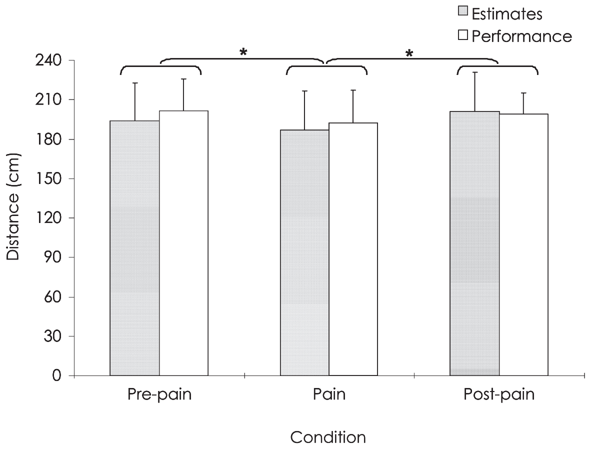

Figure 2. Both the estimation of performance ability and actual performance were reduced during acute pain compared to the prepain and postpain conditions. Error bars correspond to the standard deviation. Significant differences at $*P < .05$.

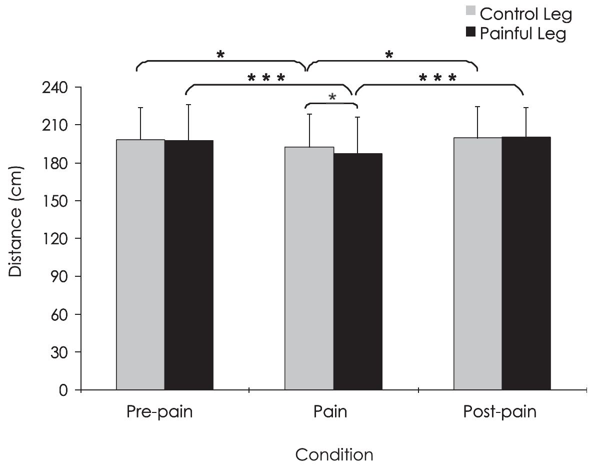

Figure 3. Performance estimates and actual performance were similar and are therefore averaged to demonstrate the reduction in these measures during the painful condition. This reduction was observed for both the legs but was greater in the painful (black) than the nonpainful (gray) leg. Error bars correspond to the standard deviation. Significant differences at $*P < .05$; $***P < .001$.

Both estimation of performance and actual performance were reduced during acute pain; main effect condition: $F(2, 24) = 8.61$, $P < .01$, ${}_{p}\eta^2 = .418$; post hoc pain versus prepain -8.1 ± 14.2 cm, that is, -4.1%, $P < .02$; pain versus postpain -10.2 ± 15.2 cm, that is, -5.1%, $P < .01$; prepain versus postpain, $P = .71$ (Fig 2). The decrease in both estimation and performance during pain was apparent for hops using either leg, but it was greater for the painful leg than for the control leg; -10.8 ± 12.1 cm vs -5.5 ± 7.9 cm for painful and control leg, interaction condition $\times$ leg: $F(2, 24) = 3.76$, $P < .01$, ${}_{p}\eta^2 = .239$; post hoc: $P < .01$ (Fig 3).

The ratio of perceptual estimation divided by the actual performance was $.96 \pm .11$, $.96 \pm .09$, and $1.00 \pm .12$, for prepain, pain, and postpain, respectively. The ratio was not affected by condition: $F(2, 24) = 1.365$, $P = .275$, ${}_{p}\eta^2 = .102$; or leg: $F(1, 12) = .475$, $P = .504$, ${}_{p}\eta^2 = .083$. In addition, no significant interaction condition $\times$ leg: $F(1, 12) = .715$, $P = .478$, ${}_{p}\eta^2 = .056$, was observed.

Discussion

The aim of the present study was to determine if acute pain alters the relationship between perceived ability and actual performance in healthy participants. In support of our first hypothesis, the performance of the single-leg hop was reduced during acute pain. In support of our second hypothesis, there was no change in the relationship between perceived ability and actual performance such that participants' perception of their ability to hop was adjusted in a manner that was concordant with their change in performance. As both the actual performance and estimation of performance were reduced in a similar manner, this indicates that the task-specific perception of action capabilities was unchanged during acute pain. This means either that the healthy individuals accurately estimated the reduction in their ability to perform the task during acute pain or that they adjusted their actual performance on the basis of an estimated/expected reduction in ability. This study cannot distinguish which of these alternatives explains the results. In contrast to our third hypothesis, there was also a reduction in both the task performance and estimation of performance when the task was performed with the nonpainful leg. However, this reduction was smaller than that observed for the painful side. This provides evidence of a more subtle generalized change in motor performance and perception of motor performance that does not necessarily relate to the immediate location of pain, but with lesser magnitude.

Various studies have shown that task performance is altered during experimental pain (eg, reduced torque during maximal voluntary contractions[8,9,16,35] and altered kinetics during movement tasks[1,13-15,17,27]). This reduction in maximal performance is thought to relate to either a reduction in total motor drive (eg, generalized inhibition of the muscles in or near the painful site; see review[26]), which is not supported by all studies,[22] or a change in the manner in which the force is generated. With respect to the latter, reorganization of the control of movement such as a redistribution of muscle activity within and between the muscles used to perform the task has been hypothesized (see review[18]). This is the first study to test and demonstrate reduced maximal performance in a dynamic, multijoint task (ie, distance of a single-leg hop) during acute pain.

Although the reduction in performance might be explained by an actual reduction in maximal ability to perform the task (eg, inability to exert maximal effort), the maximal performance might also be reduced as a protective mechanism, whereby individuals in pain moderate their performance (and estimation of performance ability) to increase the "safety margin" for the task to expose their system to less risk. This is supported in part by the smaller, but significant, reduction in performance and performance estimation in the nonpainful leg. In that case, the individual may still reduce the maximal performance to increase the safety margin, as a contribution from the painful leg is required to stabilize the individual if he or she were to lose balance with hopping. Reduction of the actual performance (use of a more conservative strategy that is less than the true maximum potential) would lessen the chance of loss of balance, and thus reduce the possibility to need to use the painful region (for balance).

The second key finding is that participants accurately predicted their decrease in performance ability during acute pain (or they performed in a way that they had predicted). This provides evidence that the presence of experimental pain did not alter the critical cognitive updating process, and that an adequate protective mechanism was maintained to meet the painful context. This is in line with our understanding that the (re)calibration of perceived action capabilities is dynamic and can evolve both rapidly (reviewed in[6]) and over longer time scales—for example, in people with chronic pain[40] and in older adults.[12,30] For instance, people with chronic low back pain estimated a larger distance to walk to a target than pain-free controls,[40] which is argued to be associated with the perception of greater effort required to achieve this distance. This supports the idea that individuals perceive the environment in terms of the costs of acting within it. Overall, these results highlight a (re)calibration of action capabilities during painful episodes.[20] This process may be interpreted as a change in pain function that relates performance estimation to the requirements that the environment imposes on the patients who are living with chronic pain. Further work is necessary to determine the effectiveness of this process in different clinical populations.

Finally, contrary to our expectations, the present study results highlight an influence of pain on both perceived action capabilities and performance that is not specific to the action being performed local to the site of pain. We observed a decrease in estimation and performance of the maximal hop, for both the painful and the nonpainful leg (albeit greater reductions on the painful side), during pain (Fig 2). It is possible that the presence of pain in an unrelated region diverts attention from the experimental task, and that this reduction in attention to the task may compromise performance.[19] This has been shown for other distractors, not related to pain. For example, distraction by points of light while climbing on a high traverse reduces both perceived and actual performance.[31] It is also possible that the reduced performance in the nonpainful leg is related to a protective mechanism (as discussed above). Finally, consistent with the muscle-based perception and the tensegrity hypothesis,[3] generalized effects of altered motor ability in one region may affect performance ability in an unrelated muscle. For example, a handgrip fatiguing task has been shown to alter the maximal force-generating capacity of plantar flexor muscles.[21] Again, we can argue from these unexpected findings that an acute muscle pain (induced in healthy young participants) does not alter the necessary updating process of their motor capabilities, as both performance ability and perceived ability changed in parallel. Further research is required to test this assumption of shared processes for top-down control of (selecting and recalibrating) the perception of performance ability and motor adaptation to pain.[36]

The within-subject study design allowed us to explore the potential for acute experimental pain to alter maximal performance ability, perception of maximal performance ability, and the relationship between these measures with a modest (n = 13) sample size. Effect sizes were moderate to large for the primary outcome measures used in this study, which is likely to be enhanced by the homogeneity (young, fit males) of the participants. Larger sample size may be required in future studies if a more heterogeneous participant group is included (ie, in relation to pain beliefs, duration, and effect of clinical pain conditions).

Conclusion

This experiment was conducted to determine whether acute muscle pain influences the relationship between perceived ability and actual performance in healthy participants. We provide evidence that healthy individuals effectively update the perception of their action capabilities during acute pain; that is, the short-term reduction in motor performance during acute experimental pain is associated with a recalibration of perception of movement capabilities. Evidence that the reduced performance (and perception of performance ability) occurs both local and contralateral to the painful site provides some evidence that the reduction in performance is not necessarily related to reduced motor potential, but rather increasing the "safety margin" of the task. The potential for an individual in pain to modify his or her performance ability to increase a "safety margin" is particularly relevant when measures such as the single-leg hop test are used in clinical pain studies to determine progression and/or recovery from lower limb pain conditions.[39] This is because, independent of any functional alteration present in clinical populations, the acute nociceptive stimulation (in combination with the individuals' cognitive processes associated with this experience) is sufficient to induce a reduction in task performance; that is, reduced single-leg hop may be associated with current pain (and potentially pain-related cognitions) rather than actual functional capability.

This study provides a first step toward understanding the potential for pain to modify the relationship between motor performance and perceived abilities. It is now critical to determine if the perception process of action capabilities is updated in a similar way in more diverse samples of people with differing pain cognitions, and in people living with clinical pain. We argue that it is possible that an alteration in perception of action capabilities could be relevant during clinical pain assessment, with the potential for this measure to be an early biomarker of the transition from an acute to chronic pain state.

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