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How a clock can change your pain? The illusion of duration and pain perception

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ABSTRACT

The intensity of experimental pain is known to be dependent on stimulation duration. However, it remains unknown whether this effect arises largely from the actual stimulus duration or is substantially influenced by the subject's perception of the stimulus duration. In the present study, we questioned this issue by misleading the perception of the duration of pain in a population of 36 healthy volunteers stimulated with a thermode. To this aim, time was signified by a clock with rotating hands in which imperceptible differences in speed rotation had been introduced. Subjects were therefore immersed in 2 comparative conditions in which time was manipulated to provide the illusion of either long or short duration of the painful stimulus. In a first condition ("full-length" clock), participants were instructed that pain would last for a complete revolution of the clock's hands, whereas in the second condition ("shortened" clock), revolution was reduced by 25%. Although the intensity and the real duration of stimulation were identical in both conditions, the intensity of pain was significantly reduced when the perception of time was misleadingly shortened by the manipulated clock. This study suggests that the perceived duration of a noxious stimulation may influence the perceived intensity of pain.

1. Introduction

Experimental studies on pain generally deliver acute painful stimuli (i.e., brief events) to normal volunteers. Intuitively, it seems logical that pain duration could influence the intensity of pain perception in a sense that the longer is the pain stimulus, the higher should be the pain perception. By manipulating the representation of time in normal volunteers during a painful stimulation, our study aimed at investigating the time dimension as a part of pain perception.

The influence of various contexts on pain intensity has been investigated previously. Emotion (i.e., seeing unpleasant pictures during painful stimuli) was found to enhance pain ratings [12] and to decrease pain threshold [19], whereas distracting the subject from pain with a cognitive task was found to reduce pain ratings [21,31]. Anxiety [24] and anticipation of pain, particularly for expected stimuli [27] have also been found to increase pain intensity. Only a few studies assessed the relationships between pain perception and time. It is generally admitted that long-duration stimuli are perceived as more painful than short stimuli for high temperatures [18]. What has been shown is that time perception was underestimated as the subjects experienced pain [13,16,28] and that pain coping strategies integrating temporal information in children can help to decrease pain rating [6], but the reverse (i.e., the effect of time perception on pain intensity) has not been investigated so far. Time perception is known to involve contextual information, and duration estimation is known to rely, for example, on stimulus size [34], velocity and speed [17], visual information [14,15], auditory clues [9], or interaction between modalities [33]. Subjective perception of time can also be distorted by emotional context [10,19] and attention [5,16,30]; we used these properties to modify subjective duration of our painful stimulations.

In the present study, we investigated how the perception of time may influence the intensity of perceived pain: by using a misleading representation of time, participants were immersed in 2 different conditions, relative to the duration of stimulations that were delivered by a heat thermode on the left leg or on the left hand. Compared with a control context in which subjects received a "full-length" nociceptive stimulation, a second context in which they were convinced that they had received a "shortened" stimulation succeeded in modulating (i.e., minimizing) pain perception. Here we present the details of this experiment showing that believing you are suffering for a shorter period of time will decrease your pain intensity.

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2. Methods

2.1. Participants

A total of 36 right-handed subjects (18 male and 18 female, age [mean ± SD] 23.2 ± 2.85 years) were included in the main study. All were free of treatment and did not practice intensive sport. They were not paid for their participation, and all provided informed consent. Twenty-four additional subjects were included in a complementary study (12 male and 12 female, age 22 ± 2.98 years). They were paid for their participation, and all provided informed consent. The local ethics committee approved the experimental protocols.

2.2. Task and procedure

Thermal stimulations were delivered by a 3 × 3-cm thermal probe (TSA-2001, Medoc). Nociceptive thresholds were determined by methods of limits. Basal temperature, set at 32 °C, rose to individual pain threshold with a slope of 1 °C/s. Subjects had to press a button as the heat temperature reached a painful level. The measure was repeated 4 times. Mean pain thresholds were 45.2 °C ± 1.46 °C in the main study (range 40.2 to 46) and 44.1 °C ± 0.68 °C in the complementary study (range 43 to 45.5). In both studies, maximal temperature was set to 47 °C to prevent skin damage.

Subjects received a standardized instruction that there would be 2 painful conditions and that a clock would materialize the course of time. In one condition, the hands of the clock described a complete revolution, whereas in the second condition they described only three-fourths of the revolution (Fig. 1). Subjects were instructed that in this latter condition, pain duration would therefore be reduced by 25%. In the main experiment, this instruction was reinforced by the green colour of the shortened clock and by adding a happy-face emoticon, whereas the clock with a complete revolution was filled with a red colour and associated with a sad-face emoticon. The aim of this presentation was to convince the subjects that in the context with the shortened clock, the painful stimulation was shorter compared with the context with the full-length clock. Stimulation temperature was set to the individual pain threshold +1 °C with the thermode applied on the left leg for 30 s (plateau duration, slope 6 °C/s [up] and 8 °C/s [down]). Subjects were kept blinded to the fact that stimulation temperature and duration were kept constant in both conditions. Immediately after each stimulation, the subject was asked to rate the intensity of pain on a 10-cm Visual Analog Scale. To minimize memory bias in their activity of scoring pain, subjects were asked to score their pain immediately after the temperature had returned to baseline. In a first session (passive session), 4 stimulations (2 stimulations with the full-length clock and 2 stimulations with the shortened clock) were delivered to volunteers according to a predefined sequence that was randomly ordered. To minimize the known influence of pain predictability on pain perception [26] and to exclude confounds that may relate to the chosen or the forced aspects of the decision, we replicated the experiment in a second session in which subjects were asked to choose (active session) the sequence (i.e., the order of the 4 stimulations). Thus, subjects experienced a total of 8 stimulations. The order between passive and active sessions was counterbalanced.

Then, a complementary experiment was designed to exclude the effects of colours and emoticons, and therefore, both full-length and shortened clocks were similarly represented in gray colour. The ensuing experiment was then similar to what was performed in the forced session of the main study. Two different lengths of painful stimuli applied on the dorsum of the left hand were tested (either 25 or 15 s) at the individual pain threshold or at the individual pain threshold +1 °C. Although it could be interesting to investigate the effects of time representation on innocuous stimuli, we preferred not to introduce innocuous intensities of stimulation (below pain threshold) that would have required an additional scoring and would have increased the complexity of the experiment. Subjects were asked to score their pain after the temperature had returned to baseline with a variable delay (jitter) that was introduced between the end of the stimulation and the signal for rating: 2.08 ± 1.38 s) to prepare the rating conditions of the future fMRI experiment in which stimulation should be easily dissociated from scoring.

2.3. Time perception

Throughout the main and the complementary experiments, we deliberately omitted investigating explicitly the perception of time and the perception of rotation speed of the hands of the clock by the subjects. Specifically, it would probably have been interesting to assess their own perception of time representation or to compare with a real 75% reduction of stimulus duration. However, we anticipated that orienting attention toward the representation of time and the distortions introduced here would have exposed them to the risk of giving a temporal reference, and therefore possibly the key of the illusion. At the end of the session, for the same reasons, we systematically checked with a vague but standardized question ("Did you notice anything wrong or bizarre with the

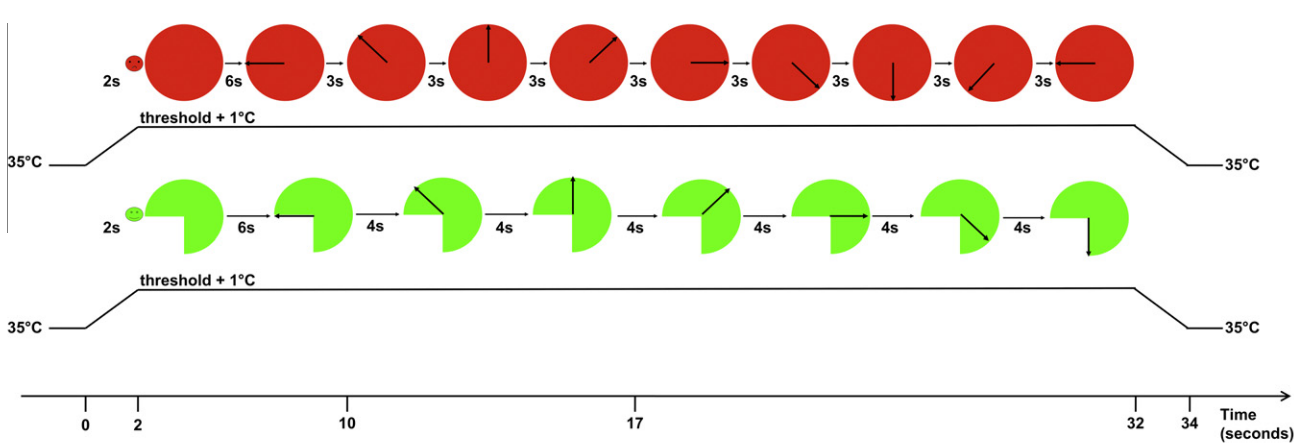

Fig. 1. Experimental design. In the 2 conditions, the clock with the emoticon was first presented for 2 s corresponding to the delay for the temperature to reach the plateau, then the first hand position on the clock was presented for 6 s. In the shortened-length condition, green clock with a happy-face emoticon, the hand moved every 4 s, in the full-length condition, red clock with a sad-face emoticon, the hand moved every 3 s. After 30 s, the temperature decreased to 35 °C (baseline) and the clock was removed.

clocks or the experiment?") that they did not recognize the illusion and that they were really misled.

2.4. Statistical analyses

Statistical analyses were conducted on SPSS (version 16.0.2, SPSS, Inc., Chicago, IL) with parametrical tests. Pain intensity ratings were normally distributed in the 2 × 2 conditions and sessions (Kolmogorov–Smirnov $Z < 0.71$, $P > .05$). Repeated-measures analysis of variance tests were conducted on mean pain ratings. We defined 2 within-subject factors: condition (shortened or full-length) and session (passive or active) in the main study, condition (shortened or full-length) and temperature (pain threshold or pain threshold +1 °C) in the complementary study. These analyses allowed us to test the main effect of condition, as well as the condition by session/temperature interactions. Student paired t tests were used for post hoc analyses, and P values were corrected for multiple comparisons with the Bonferroni correction, when appropriate ($P_{(corr)}$). To verify whether the illusion was maintained for the short time duration, the 15-s session was analyzed with Student paired t test because these conditions were only manipulated by the condition factor (shortened or full length).

When necessary, the pain intensity rating obtained in different sessions in the conditions of the full-length clock were averaged together, as well as the pain intensity rating obtained in the conditions of the shortened clock. Results are reported in the text as the mean ± SD and in Fig. 2A and B as the mean ± SEM. The significance criterion was set at $P < .05$.

3. Results

3.1. Main study, 30-s duration

A main effect of condition (shortened-length clock vs. full-length clock) was found ($F_{1,35} = 7.778$, $P = .008$) (Fig. 2A) and showed that the shorter the stimulus seemed to be, the lower was the intensity of pain (mean pain score ± SD for full-length clock: 5.25 ± 1.86, shortened clock: 4.71 ± 2.14). No significant effect of session (passive session vs. active session) was found ($F_{1,35} = 0.238$, $P = .629$) and showed that the selection mode of conditions had no significant effect on pain intensity scores (passive: 5.03 ± 1.90, active: 4.93 ± 2.14). No significant interaction was found between selection mode and perceived duration ($F_{1,35} = .001$, $P = .978$). Detailed results showed a significant effect of condition for both passive (full-length clock: 5.30 ± 1.89, shortened clock: 4.76 ± 2.11; $T = 2.524$, $P = .016$) and active sessions (full-length clock: 5.20 ± 2.25, shortened clock: 4.65 ± 2.29; $T = 2.169$, $P = .037$). Magnitude of pain modulation in the chosen sessions was correlated with those of the forced sessions (mean differences in pain scores: 0.55 ± 1.52 and 0.54 ± 1.29, respectively; $R = 0.394$, $P = .018$).

3.2. Complementary study: colourless sessions, 25-s duration

Regarding the main study in which thermal pain stimulations lasted 30 s, a main effect of condition (shortened-length clock vs. full-length clock) was found ($F_{1,23} = 12.214$, $P = .002$ [Fig. 2B]; mean pain score ± SD for full-length clock: 5.23 ± 1.79, shortened clock: 4.88 ± 1.67). A positive main effect of temperature (pain threshold vs. pain threshold +1 °C) on pain intensity ratings was found ($F_{1,23} = 78.873$, $P < .001$; mean pain score ± SD for pain threshold: 4.15 ± 1.52, pain threshold +1 °C: 5.96 ± 1.44).

A significant interaction was found between condition and temperature ($F_{1,23} = 5.014$, $P = .035$). Detailed results showed that pain intensity ratings were significantly lower in the shortened than in the full-length conditions when thermal stimulation was set to pain threshold +1 °C (full-length clock: 6.24 ± 1.47, shortened clock: 5.68 ± 1.39; $T = 3.139$, $P_{(corr)} = .01$). In the conditions with stimulation intensity set to pain threshold instead of pain threshold +1 °C, pain intensity did not differ significantly between condition (full-length clock: 4.22 ± 1.50, shortened clock: 4.09 ± 1.57; $T = 1.726$, $P_{(corr)} = .196$).

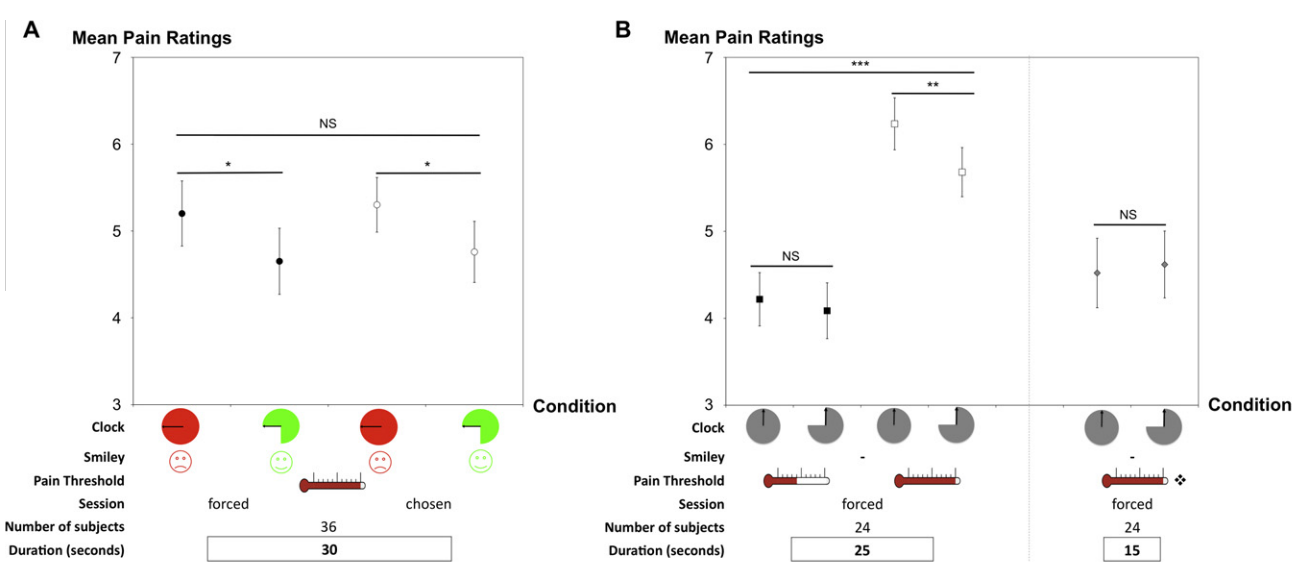

Fig. 2. (A) Main study. Mean pain ratings from 36 subjects were obtained in 2 sessions by 2 conditions. Full-length condition corresponds to a red, full-length clock with a sad-face emoticon, and shortened condition corresponds to a green, three-fourths-full clock with a happy-face emoticon. During the whole experiment, stimulation temperature was set to pain threshold +1 °C and duration was set to 30 s. In both the chosen and the forced sessions, shortened stimulations were perceived as significantly less painful than full-length ones. Mean pain ratings (±SEM) during chosen sessions did not differ from those recorded in forced sessions. (B) Complementary study. Mean pain ratings from 24 subjects were obtained in 2 sessions. Full-length condition corresponds to a full-length clock, and shortened condition corresponds to a three-fourths-full clock, both gray. In one session, stimulation duration was set to 25 s and temperature to pain threshold or pain threshold +1 °C. In the other session, stimulation duration was set to 15 s and temperature to pain threshold +1 °C (❖ except for 6 of 24 subjects, who would not support the repetition of stimulations at pain threshold +1 °C). Shortened stimulations were perceived as significantly less painful (mean pain ratings ± SEM) than full-length ones only for longer conditions at pain threshold +1 °C. Statistically significant difference: $^{*}P < .05$, $^{**}P < .005$, and $^{***}P < .001$. NS = nonsignificant.

3.3. Complementary study: colourless sessions, 15-s duration

In the conditions with a duration of 15 s of stimulation instead of 25 s, in 6 of the 24 subjects the stimulation set to pain threshold +1 °C was unbearable and they were therefore stimulated at pain threshold. Pain intensity scores were not different in these 6 subjects as compared with the 18 subjects stimulated at pain threshold +1 °C (full-length clock: 4.97 ± 2.68 and 4.37 ± 1.73, $T = -0.64$, $P = .53$; shortened clock: 5.58 ± 2.2 and 4.30 ± 1.72, $T = -1.49$, $P = .151$ in the 6 and the 18 subjects, respectively). In these 24 subjects, pain intensity did not differ between the full-length clock and the shortened clock (4.52 ± 1.96 and 4.62 ± 1.88, respectively; $T = 0.608$, $P = .549$).

The magnitude of pain modulation between full-length and shortened conditions were not significantly different in the 25-s conditions as compared with the 30-s sessions (mean differences in pain scores: 30 s: 0.55 ± 1.18, 25 s: 0.56 ± 0.87; $T = -1.249$, $P = .217$). These results were obtained even though colour and emoticons were present in the 30-s conditions but not in the 25-s conditions. The magnitude of pain modulation was significantly higher in the 25-s sessions (at pain threshold +1 °C) than in the 15-s sessions (mean differences in pain scores: 25 s: 0.56 ± 0.87, 15 s: −0.098 ± 0.79; $T = 2.35$, $P = .012$).

3.4. Time perception

Throughout the main and the complementary experiments, none of the subjects realized that the differences in stimulation duration were an illusion.

4. Discussion

In this study, we succeeded in creating an illusion of shortened painful stimulation by a misleading materialization of time. For given temperatures and fixed duration of stimuli, a simple illusion on the time course made the pain perception less intense. By convention, in what follows, consistent with the instructions given to participants, we will discuss our results as lowered pain in shortened clock conditions rather than increased pain in full-length clock conditions. These results are in agreement with the finding that long stimuli (30 s) are generally more painful than short stimuli (5 to 15 s) [18] at high temperatures and suggest that subjects' perception of time has actually been misled by the context of the experiment. Although many other modulations of pain or pain illusions have been demonstrated previously, it is always fascinating to observe that previously unexplored and natural situations can reduce pain intensity. Attentional [8,11,20,22,32], emotional [12], diversion [31], anticipation [24,27], memorization [3], or sensory illusions [4,7] are nonexhaustive examples of what the nervous system can do to change pain perception. Hypnotic suggestion has been reported to modulate pain perception [25], and shortening the perception of time duration with hypnosis can alleviate acute or chronic pain [2]. Conversely to instrumental and drug therapies, the main interest of these modulations is that they recruit endogenous resorts. This is particularly relevant for the comprehension of time appraisal in painful situations because it is clear from these results that the contextual estimation of time may change pain intensity. It seems possible that the enhancement of pain ratings that is reported here over a 30-s duration in a condition that is expected to be long, as compared with a shortened condition, would be a mechanism of importance in how the subject's relation with time during a painful episode can influence pain intensity ratings. According to this interpretation, the modulation of pain intensity by time representation was not found for shorter pain conditions (i.e., 15 s), consistent with a low influence of time effect for acute or short painful stimuli compared with longer ones. As suggested previously by others [1], chronic pain states could be explained by pernicious loops among pain perception, duration of pain, and additional cognitive factors. Although our study did not apply to patients with chronic pain, the short-term modulations reported here emphasized the importance of duration on the perception of a painful state. Later on, other processes such as emotion could further amplify these processes because time has been shown to be overestimated in cases of negative emotions as compared with positive emotions [10,19,29]. Alternatively, the modulations reported here may be viewed from the inside of the subjects as an equivalent of temporal summation: with the distortion of the temporal reference, stimuli of presumed longer duration were associated with stronger pain. These results may appear as a replication of another study showing a temporal summation of phasic stimuli of between 10 and 30 s with a maximal effect for high temperature [18]. Increased pain intensity was reported here for 25 s as compared with 10 s, with a similar enhancement for pain intensity observed for the highest intensities of stimulations (pain threshold +1 °C) but not for lower intensities (pain threshold). However, conversely to the study by Koyama et al. [18], our paradigm was designed to test temporal manipulation rather than temporal summation; therefore, stimuli were tonic rather than phasic and constant rather than repetitive.

A second aspect of the study was that pain modulation by time perception was not influenced by the visual aspects associated with time representation, such as colours and emoticons. If we consider similar duration of pain stimulation (i.e., 30 and 25 s) and similar thermal intensities (pain threshold +1 °C), the complementary study replicated findings from the main study in a different population of volunteers, suggesting a reliable effect of time representation on pain intensity that prevails over these cosmetic details. It is not possible on the basis of these data to conclude whether the speeds of the hands or the angular degrees completed (or both) are the most important pieces in the representation of time. On the basis of previous literature, the temporal frequency of visual stimuli plays an important role in estimating duration [17]. In other words, when temporal frequency (as velocity and speed) increases, time overestimation increases, at least for short durations of stimuli (200 to 1000 ms). If we extrapolate these data to our experiment, it would mean that the higher temporal frequency and speed of the full-length clock would have enhanced the apparent length of stimuli as compared with the shortened clock, and therefore would have enhanced the illusion. Because in both experiments (main and complementary studies), the common denominator was the representation of time by the clock, these results suggest a direct modulation of pain perception, regardless of colours and emoticons that may have a conditioning power. Interestingly, the complementary study demonstrated that this modulatory effect survived neither to shorter duration (15 s) of pain stimulation, nor to lower thermal intensities (pain threshold instead of pain threshold +1 °C). This may be caused by a specific effect of time representation on high pain intensities, as suggested previously by others [18], but also on relatively long painful stimulations, consistently with what has been shown for temporal summation [18].

A third aspect of the study was that pain modulation by time perception was not influenced by whether the decision was forced or chosen. In a previous experiment investigating 2 contexts that differ for their pain controllability, it was also found that pain intensity was not different [26]. Thus, it seems that perception of time prevails over other aspects of pain perception, such as whether pain was forced or chosen, a situation that is very close to that of pain controllability.

Finally, our study raises the question of a conditioning effect because the participants were actually instructed that pain was reduced for the shortened clock as compared with the full-length clock. In addition to these instructions, both the colour of the clocks and the associated emoticon were indexes that may theoretically have conditioned their response to pain in the main experiment. Colour conditioning/anticipation has been successfully reported to modulate pain intensity [23,24]. Although these aspects associated with materialization of time may have contributed to the present results, the complementary study suggests that perception of time, even misled, prevails over other aspects such as conditioning or anticipation. The pattern of brain activations associated with the modulations of pain intensity by the perception of stimulus duration will be precised in an (ongoing) fMRI study replicating this experimental paradigm.

Conflicts of interest statement

The authors declare that there are no conflicts of interest in the publication of the article.

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