Temporal dynamics of acute pain perception

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INTRODUCTION

There are no systematic studies of the temporal properties of pain perception. Here we describe a new thermal stimulator, coupled to a pain rating device, that allows fast and accurate determination of dynamics of pain perception. We describe initial results regarding temporal dynamical properties of acute pain in normal subjects, and linear and non-linear models for pain perception.

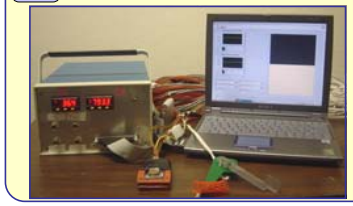
METHODS

•The study of pain perception dynamics requires fast and reproducible stimulus delivery, accurate determination of skin state, and fast documentation of perception. A novel two-channel thermal stimulator, coupled to a finger-span device was specially developed for these studies (Fig. 1). The thermal stimulator presents hot and cold stimuli with varying rise and fall rates (as fast as 15 °C/s). The stimulus sequence, duration and rate are independently controlled. At the same time, a continuous rating of the subject's perceived pain, is recorded by a finger-span device. Visual stimuli that mimic the intensity and duration of the thermal stimuli are used as control. The unit is MR compatible, enabling use in fMRI studies.

•Six healthy volunteers participated in the study. Subjects were first trained on the finger-span device using a visual tracking paradigm. They then used the finger-span device to assess intensity of pain for thermal stimuli.

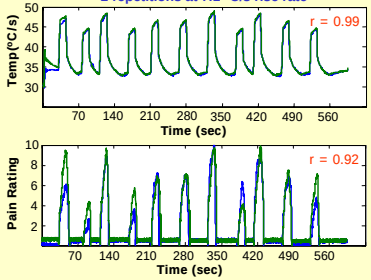
•Thermal stimuli of 3 different intensities with rise rates 7.1 or 14.2 oC/s, were presented in random combination at random inter-stimulus intervals (ISI). Stimuli were applied either on the arm or the foot. Multiple trials were done per subject.

1 Thermal stimulator prototype



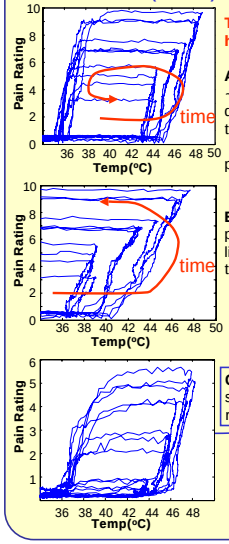
RESULTS

2 Example responses & repeatability



Time-course for temperature pulses and related pain ratings. Temperature measured at the skin and pain ratings are highly reproducible (see correlation coefficients in panels). In contrast correlation between temperature and pain ratings is poor (r = 0.6). These properties hold for different rise rates, body positions, and inter-stimulus intervals.

3 Hysterisis of pain perception



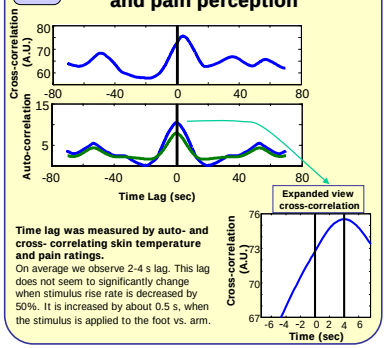
There is a 8 °C hysterisis.

A. Threshold to pain is ~45 °C and seems dependent on applied temperature. Threshold to end of pain is ~36 °C.

B. Supra-threshold perception seems linearly related to skin temperature.

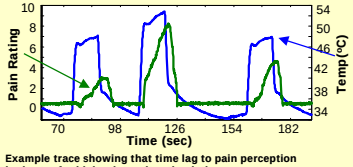
C. Averaging over 5 subjects shows similar results.

4 Time lag between stimulus and pain perception



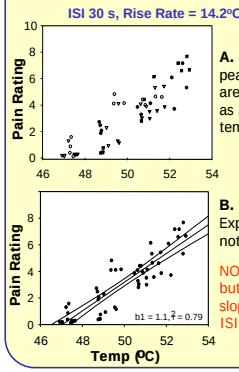
Time lag was measured by auto- and cross- correlating skin temperature and pain ratings. On average we observe 2-4 s lag. This lag does not seem to significantly change when stimulus rise rate is decreased by 50%. It is increased by about 0.5 s, when the stimulus is applied to the foot vs. arm.

5 Time lag is also a function of stimulus temperature



Example trace showing that time lag to pain perception is shorter for higher intensity stimulation.

6 Peak pain perception is a linear function of peak skin temp.

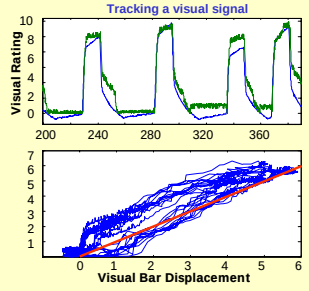


A. Peak pain ratings and peak skin temperatures are shown for 5 subjects as a function of peak temperature.

B. Best fit is linear. Exponential curve does not improve fit.

NOTE: Similar results, but with a less steep slope were obtained for ISI = 120 s.

7 Visual rating of a signal that mimics the thermal stimulus does NOT show hyesterisis



This task controls for perceptual and motor components of pain ratings. Fast rises and falls are tracked very accurately.The only mismatches are in the slow returns, and the undershoot which is an artifact of presentation.

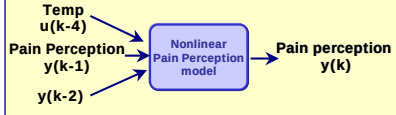
8 Non-linear model (NeuroFuzzy)

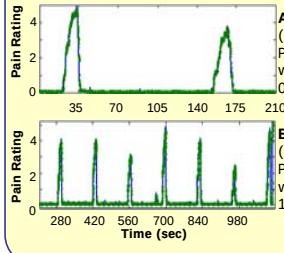
Rule base (example)

IF TEMP(k-4) IS cold AND Perception(k-1) IS small
AND Perception(k-2) IS small
THEN Perception(k) = p1*Y(k-1) + q1*Y(k-2) + r1*u(k-4)+s1

IF TEMP(k-4) IS cold AND Perception(k-1) IS small
AND Perception(k-2) IS large
THEN Perception(k) = p2*Y(k-1) + q2*Y(k-2) + r2*u(k-4)+s2

...





A. Training Data (blue) and ANFIS Prediction (green) with RMSE = 0.6623

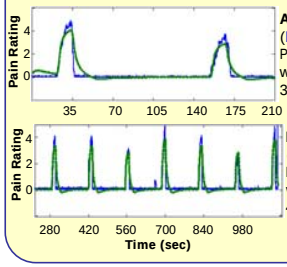
B. Checking Data (blue) and ANFIS Prediction (green) with RMSE = 1.073

9 Linear model (ARX)

$$y(k)=a1*y(k-1)+a2*y(k-2)+a3*y(k-3)+a4*y(k-4)+a5*y(k-5)+a6*y(k-6)+a7*y(k-7)+a8*y(k-8)+a9*y(k-9)+b10*u(k-10)$$

where a_i and b10 are linear parameters determined by least-squares methods.

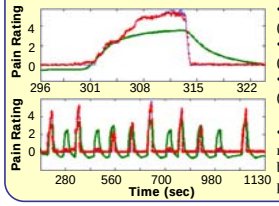
a1= 0.6033 a2= 0.3089 a3= 0.03151 a4= 0.03536 a5= 0.06668 a6= 0.01674 a7= 0.05532 a8= 0.08954 a9= 0.05984 b10= 0.08523



A. Training Data (blue) and ARX Prediction (green) with RMSE = 3.6826

B. Checking Data (blue) and ARX Prediction (green) with RMSE = 4.452

10 Comparison between linear and nonlinear model with new data sets



•Real perception (blue)
•ANFIS prediction (red)
• ARX prediction (green)

•Note that the ANFIS model provides a far better fit for the actual pain perception

CONCLUSIONS

- The dynamical properties of pain perception seem very different from the classic static measures of pain.
- A robust time lag is reproducibly observed.
- Supra-threshold perception seems linear.
- A linear model for pain perception results in large prediction errors.
- A non-linear fuzzy-neural net model very robustly captures pain perception dynamics.
- This novel approach provides a whole set of new tools with which human pain perception can be studied.

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