Monitoring and enhancing visual features (movement, color) as a method for predicting brain activity level - in terms of the perception of pain sensation

The relationship between perception of pain and its measurement, using computational vision tool (Evaluation of blood supply to the brain from a video signal).

Introduction to Computational and Biological Vision

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Final project by

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We conducted a feasibility study to determine if it is possible to infer pain perception from the level of brain activity (blood flow). The evaluation of the blood flow to the brain was deduced from a video signal by using a computational vision tools to amplify and reveal very small motions and slight changes of color. Should this method be found to correlate with the subjective ‘feeling’ of pain (direct report), it may offer a new alternative simple and low cost method to quantify the subjective perception of pain, and may be used as an effective and useful research tool in studying pain perception.

I. Introduction
a. Image representations

The first step to encode a digital image is as an array of pixel intensities (Adelson, Anderson, Bergen, Bur, & Ogden, 1984). In following computational steps the image may be represented by different formats, where the format chosen impacts our ability to to process it. The choice of the format may be as critical as the algorithms applied to the data (Adelson et al., 1984).

One of the popular ways to represent an image is by its Fourier transform. However, this representation is not suitable for cases in which the spatial location of pattern elements is critical. Since visual scenes contain multiple scales features, in order to maintain those elements, as well as localization in the spatial-frequency domain, it is desirable to find representation that can nicely deal with changes of scale. A well known way to do that is to decompose the image to its bandpass components at different spatial frequencies. There are indications that such a representation is similar to the one the human visual system uses (Adelson et al., 1984).

Adelson et al. (1984) suggested a faster method than the equivalent filtering done with Fourier transform. This so called 'Pyramid' filtering is a
multiresolution representation which computes all of the convolutions with kernels having various sizes. One of the two main types of pyramid is a low-pass pyramid that uses a kernel to smooth the picture, and then reduces its resolution by discarding every second line and column. This procedure is repeated a few times. The result is a conceptual structure for representing an image at more than one resolution. The final representation of an image consists a set of lowpass or bandpass copies of the image that differ in their scales. In that way, if we will simultaneously use all of the scales we will be able to compensate for the missing information made by the analysis itself.

b. Eulerian motion magnification

Adelson et al. (1984) offered a variety of Pyramid methods for image representation. An important characteristic of these methods is that it is possible to reconstruct perfectly the original image from its pyramid representation (Adelson et al., 1984). Having a method of image analysis that transforms an input image to a representation space and a complementary method for synthesis from the representation space to an image facilitates developing schemes of the type analysis-modify-synthesis.

MIT and Cambridge researchers, developed a method that takes a video signal as input, decomposing each frame using a Pyramid representation (spatial decomposition), followed by applying temporal filtering on the sequence of decomposed frames, lastly synthesizing the output video from the sum of the Pyramid decomposition and the temporal processing. The framework of the process is shown in fig. 1.
**Figure 1.** Step 1: decomposing the frames into different spatial frequency bands. Step 2: applying similar temporal filter for the different components. Step 3: amplification by a given factor $\alpha$. Step 4: Reconstruction of the original signal (From: Wu, et al., 2012, p.2, fig.2).

Through this Eulerian spatio-temporal processing, which takes temporal changes of a sequence of frames and uses them to exaggerate the motion or the color changes in the frame sequence, we can reveal nearly invisible changes with only a standard monocular video sequences (Wu, et al., 2012).

c. **Blood flow and brain activity that is related to pain**

Based on meta-analysis of functional imaging of brain responses to pain, there is indication that there are several areas that are activated as a result of noxious stimulus. The different areas respond with activity as well as with changes in blood flow. The regions that participate in different aspect of perception of pain sensation- sensory regions such as the thalamus, primary and second somatosensory regions and the insula (that involved in the sensory discrimination of pain), posterior parietal and prefrontal cortices (cognitive attentional processing), and the ACC (reactions to pain). Furthermore, the activation of this brain areas is followed by increases in the regional cerebral blood flow (rCBF) as showed in PET imaging studies (Peyron, Laurent, & Garcia-Laerrea, 2000).
The brain’s main blood supply comes from the two main streams, the Anterior circulation (anterior carotid arteries) and the posterior circulation (Vertebral arteries). While the anterior circulation supplies the frontal lobe and parts of the temporal and parietal lobes, the posterior stream supplies almost all of the rest of the brain (Nolte, 2009).

Noxious stimulus showed activation and increased blood flow mainly at the anterior cingulated cortex (ACC). Increased rCBF occur also at the posterior parietal and prefrontal cortices, as those regions refer to the higher cognitive processes that comes along with the sensation of pain (attentional and memory networks that are activated from the stimulus). Areas that were also activated by acute pain, and showed increases in rCBF during analgesic procedure are the thalamus and anterior cingulate (Peyron et al., 2000).

d. Pain perception and regulation

Emotional state has an important key-role on the perception of pain (Tracey, 2008). Accordingly, researchers showed significant improvements in pain levels, mood, and other psychiatric symptoms as a result from a mindfulness-based stress reduction therapy (MBSR) with comparison to control group (Shapiro & Carlson, 2009). The MBSR manipulation induces the inside awareness, that allows an increase in adaptive thoughts and emotions and a decrease in maladaptive ones (Rapgay & Bystrisky, 2009 as in Chiesa & Malinowski, 2011). Therefore, mindfulness-based manipulation may cause alteration in perception of pain sensation.

e. Current research

"Pain is a conscious experience, an interpretation of the nociceptive input influenced by memories, emotional, pathological, genetic, and cognitive factors“ (Tracey, 2008). In other words, pain is a subjective experience, and as such it is difficult to evaluate objectively.
Most of the research in this field focuses on the regions and structures of the brain that activates while it occurs. Tracey and Mantyh (2007) define this cerebral activation as “pain signature” of individualized neural activation while experiencing pain. Other researches define it as general 'pain matrix' include 'lateral components’- sensory-discriminatory areas (S1, S2, thalamus, and posterior parts of the insula), and ‘medial components’- affective-cognitive-evaluative (anterior parts of insula, ACC, and prefrontal cortex) (Tracey, 2008).

This research focuses on the perception of pain sensation, i.e. what the subject eventually feels, and suggests a way of assessing that feeling. While perceiving a painful stimulus, the system is getting into hyper activity. As a result, the brain needs more oxygen thereby increasing the blood flow towards the regions that worked intensively, the cognitive, somatosensory and emotional networks. Monitoring the changes in the blood flow, may give us schematic but robust prediction for the level of activity in the brain. This, in turn, may help us to conclude upon complex or decentralized processes such as pain.

The Eulerian magnification algorithm, as described above, will be used to monitor and amplify the blood flow through the patient’s faces (i.e. the redness of the face) and the blood flow through the main arteries to the brain (i.e. the vibrating of the Anterior and Posterior circulations main arteries). The more blood will flow through the arteries per time unit (milliseconds) will imply that more blood supply was needed by the brain (i.e. more oxygen needed), thus indicating higher level of brain activity.

From this indication of the brain activity, we will try to infer the perception of pain sensation of the patient. Therefore, this research may yield a method to a relative simple and low-cost indication for ‘feeling’ pain, and as such, could be efficient for pain related researches.

In this experiment, the subjects will be exposed for two pain inflicting stimuli. Their responses will be measured using the Eulerian motion
magnification method before and after the stimuli. After the completion of the first stimulus the subject will perform a short meditation course that aims to regulate their perceived pain level scale.

f. Study hypotheses

1. Inducing a painful stimulus will increase the subject’s blood flow (e.g. darker color with each pulse and/or increased vibrations of the arteries), correlated with the subjective measure of the perception of pain caused by the stimulus. The larger the pain caused by the stimulus, the larger the blood flow.

2. The subject’s pain perception in response to the second stimulus will be decreased compared to their response to the first stimulus due to the mindfulness manipulation done between the two stimuli (The purpose of the mindfulness manipulation is to make a change and regulate the perception of pain of the subjects).

3. The larger the subject’s perceived pain to the first stimulus is ranked in their subjective pain scale, the smaller the changes in measured features between the first and the second stimulus. For larger perceived pain the subject recruits more systems as well as it is more difficult to calm the pain sensation, therefore we expect the effect of the impact of the mindfulness manipulation to be reduced, yielding similar results for both stimuli.

II. Method

In this experiment we will attempt to measure changes in the blood flow to the brain and the subjective perception of pain sensation (‘feeling’) as a result of a noxious stimulation.

The level of brain activity will be presented as the amount of blood flow, which will be monitored and calculated in two ways. First, by the color of
the subjects’ face: the redness of the subject’s face, in comparison to the resting state. Second, by the motion: the vibration of the two main arteries carrying blood to the brain. The subjective ‘feeling’ of the pain will be concluded by the subject’s direct report.

a. Participants

4 subjects, ages 21-56, right hand dominant. All of the subjects volunteered.

They were randomly assigned to the experimental groups, half to the manipulation group, and half to the control group.

b. Instruments

- Web camera, monitoring the subject’s face, and the two main arteries to the brain (around the right ear).
- Algorithm code, or by using the application on the web for the Eulerian magnification\(^1\), under the following conditions;

  (1) The temporal bandpass filter will set to 0.5-3Hz.

  Because we are trying to magnify a pulse, the frequencies that we will use are at the range of those that fit for a healthy subject’s heart beats per minute.

  For color amplification of blood flow, as recommended by Hao-Yu et al. (2012), the choice will be for narrower bandpass than for motion magnification, because it produces results with less noise.

  (2) The amplification factor will be set as \(\alpha=15\).

  (3) Both magnifications are tested, separately.

  (4) The other parameters as default.

\(^1\) http://videoscope.qrclab.com/vidproc.html
➤ Mindfulness guidance for relaxation\(^2\), as the experimental manipulation.
➤ A poking pen. The experimenter will use it to moderately prick the subject.
➤ Direct report pain scale (appendix 1).

**c. Experimental course**

At first we will assess the level of blood flow of the subject at resting state. Afterwards, the painful stimulus will occur as the experimenter will moderately prick the subject. The subject then will be asked to report the intensity of the pain that the pricking cause, using the scale to estimate the level of perceived pain.

Manipulation: The next step is 15 minutes of constructed meditation (i.e. mindfulness practice). In contrast, the control group will be asked to drink a glass of water and will wait 15 minutes.

Then the final step is to once again execute the pain stimulus (i.e. the pricking) and to monitor the blood flow reaction and the subjective direct report.

Each subject will be monitored as mentioned during the whole time of the experiment. We will refer to 4 critical points of measurement-

1. Baseline measurements, the subject’s resting state.
2. Given a first pain stimulus.
   - Between stages 2 and 3, the subjects in the experimental group will experience mindfulness manipulation.
3. Second baseline after the break/manipulation.

\(^2\) http://69.89.31.146/~thushear/talks/guided%20meditation/Yonathan%20Dominitz/Yd07%20meditation%2015min.435.mp3
4. Given a second pain stimulus.

III. Initial results

By using the Eulerian magnification algorithm, the movement of the arteries is clearer. As speculated, it seems to be clear different in the vibration between the points of time before/after painful stimulus (between both baseline-pain measurements).

However, as opposed to what was speculated, there seem to be little or no difference between the response before and after the manipulation, although there has been a change between the subjective estimation (first stimulus- 3, second stimulus- 1), but due to the small number of participants the correlation is meaningless.

Moreover, for the color analysis due to the illumination used in the experiment (fluorescent-type) we came across a noise problem (light source flicker), that prevented us from assessing the changes in the color of the subject's face.

IV. Discussion

In order to treat pain and pain-related suffering, it is important to understand the brain activity during the experience, or the essence of perception of pain sensation, of the subjects.

Presently, there are a variety of methods that correlate with the physiological measures of brain activity. Some of them are invasive and others are non-invasive but incur high cost (e.g., neuro-imaging). For choosing a method one must try to balance between spatial and temporal resolution and to match them to the research goals. This research offers
an alternative, holistic, non-invasive approach to assess the subjective feeling of pain.

In this research there were no clear results. But, as a feasibility study, the main goal was to determine if it is possible to infer pain perception from the level of brain activity (blood flow). The evaluation of the blood flow to the brain was deduced from a video signal by using a computational vision tools to amplify and reveal very small motions and slight changes of color.

Concerning the magnification of the movement of the arteries feature, we have seen change in the vibration of the arteries according to the experimental state (before/after the painful stimulus), and the results showed orientation toward such discrimination. However, we have not seen a change of this feature before and after the experimental manipulation, therefore it is possible that there are other explanations that can cause the change before/after painful stimulus. For example, the brain activity can be increased by the cognitive interpretation of the poking pen, or emotional interpretation as a surprise from the action.

Further studies could attempt to use this movement-analysis in a more complex way, as differing between the anterior/posterior streams of blood toward the brain. For instance, for increasing blood flow in the anterior stream (that circulates the frontal parts of the cortex), one may assume there was a cognitive process that was affected by the painful stimulus or task, as opposed to increasing blood flow in the posterior stream that can represent a lower level of process or the intervention of an emotional process.

During the analysis of the color changes we encountered a problem of assessing the color of the subject's faces. Apparently this problem comes from the light conditions of the room. Therefore, there is a need to take the video shots using plain old light bulb lighting, rather than using not
one of the new kinds of energy saving gadgets (their light intensity flickers).

For the full study, modifications of the video magnification software should be done. First, develop code that can yield, in addition to the magnification video, the values of the magnification. That way the analysis will be more effective and accurate as capable of plot the points of maximum and minimum in the velocity of changes of brightness (for the vibration) and of the brightness itself (for the color).

There is solid evidence that increased rCBF indicates higher level of activity of the brain (synaptic activity), which can reflect on inhibitory or activating processes (Peyron, Laurent, & Garcia-Laerrea, 2000). Yet, there is still the problem of interpretation of changes in blood flow as indicators to activation of brain activity, and furthermore, the interpretation of the level of the brain activity as indications of perception of pain.

Hence, there is a need for a further research to be conducted with significant more subjects. This will enable to find correlations between the amount of blood flow and the subject’s perception of the pain sensation, and will connect between the next two pieces, level of brain activity and subjective perception of pain sensation.

V. **Conclusions**

The main goal of this feasibility study was to determine if it is possible to infer pain perception from measuring color changes or artery vibration using a computational vision tools. This is an indirect measurement as the hypothesis is that pain sensation causes increased brain activity which in turn requires increased blood flow to the brain. It was proposed that the evaluation of the blood flow to the brain be measured from a video signal by using a computational vision tools to amplify and reveal very small
motions and slight changes of color. In other words, to try and find the existence of an initial link between usually unseen changes in blood flow toward the brain and the activity of the system as a result of perception of pain sensation.

We've found hints that such a connection between slight changes of face color and artery motions with pain perception may be possible but the results are clearly not decisive. Therefore, follow up studies in this direction should further explore this approach. If such connection be found, the Eulerian magnification algorithm may be employed in low cost instruments to research processes of the brain, by the level of blood flow to the brain.
Appendix 1: Direct report pain scale

For each stimulus, please circle the most adequate volume of pain you felt;

1 - no pain at all  
6 - strong pain

Stimulus 1:

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<tr>
<td>1    2    3    4    5    6</td>
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0- Please circle if you haven’t felt the stimulus.

Stimulus 2:

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<td>1    2    3    4    5    6</td>
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0- Please circle if you haven’t felt the stimulus.
Bibliography


