Influence of Emotional Stimuli on Human Pupillary Behavior

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Abstract. Decision making is influenced by human emotion, being individually or in the context in which it is embedded, which makes the quantification of emotion an important issue. This paper detect and quantify the relationship between positive and negative emotions aroused by emotional images and changes in the pupil diameter of the volunteers measured by an Eye-tracking equipment. The images were presented completely randomly and the objective was to find correlations in the reactions of each individual measuring their biological signals. The samples were collected from 36 volunteers, of whom 29 were valid and the emotional stimuli were selected from the image database of IAPS (International Affective Pictures System). The results showed a statistically significant difference in pupil dilation between emotionally positive and negative images. Therefore, we believe that using the computation framework proposed it would be possible to ensure emotionally driven experiments on decision makers.

Keywords: Pupillary Dilation, Human Emotions, Visual Stimuli

1 Introduction

In the quest to understand the importance of modern computing systems with all their complexity and economic and social applications, it seems relevant to discuss intrinsic aspects of human decisions inherent in people's daily lives and that their existences are neither explicit nor easy to understand. Studies have long sought to relate human emotions to bodily reactions as they can be triggered by diverse contexts such as listening to music, experimenting with food, groping objects and people, possible dangers such as exposure to shock and, among other things, such as to observe emotionally positive or negative images. It is known that when arousing an emotion, there are physiological changes in the individuals and, among them, the diameter of the pupil increases or decreases [4, 5, 23]. These human emotions begin to be formed even before the first year of life of human beings, and studies applied with the help of Functional Magnetic Resonance show that, until the second year of life, there is already evidence of maturation of the areas of the brain responsible for the main characteristics of emotional behavior in adult life, due to the formation of connectivities of specific regions of the brain, especially the amygdala [32, 26, 15].

The objective of this paper is to investigate the emotional impact aroused by positive and negative images, taking as an indicator the pupillary diameter measurement [33, 19]. Although pupillary reactions are not exclusively related to human emotions, they seem to be a very relevant indicator in the analysis of such an event [29, 20].

In a historical retrospective on the motivation behind the tracking of the eye movements, it is known that its onset was motivated by clinical reasons and that, soon afterwards, other applications appeared, mainly for cognitive purpose, besides psychological studies directed to the activities of the day-to-day, since the eyes are moved by cognitive processes. The first report on eye tracking dates from 1879, at this time, by simple observation. Some time later, in 1920, the first lenses implanted in the eyes designed for this purpose [14].

Regarding its use, it is known that ocular tracking technology is increasingly used for the verification of the human visual system in several areas such as ophthalmology, cognitive psychology and neuroscience. These systems allow the measurement of oculomotor responses to multiple factors, such as psychological, emotional, disease, aging and environmental conditions. Two types of eye movements are prominent, fixation and saccadic function, which are essential for these studies of human visual behavior representing their attention. Gaze fixation is defined as the ability to maintain a constant retinal image of a single target of interest, while saccadic behavior describes ocular movements used to produce rapid changes in fixation at different targets within the visual field [22].

Other eye movements such as constriction and pupillary dilation are commonly used to indicate mental workload, because the iris muscles (sphincter and dilator) are innervated by the sympathetic and parasympathetic fibers of the nervous system and involuntarily stimulated or inhibited. by the autonomic nervous system (ANS) [24]. Thus, when an individual is emotionally impacted or making a mental effort, the ANS reactions may be perceived in changes in pupillary diameter and can be associated with the individual's state of arousal [2].

In the 1970s, with the emergence of the microcomputer, smaller and less invasive equipment were developed, allowing a greater movement of the participants during the experiment and allowing the processing of a much larger number of information [14, 1].

In order to do so, we have used here some images directly linked to an emotional factor, which prevent the simulation of fake behavior by the volunteer. This measurement, done by an eye-tracker equipment, allows to quantify the individual human emotions [14]. To make the experiment feasible, we have used the IAPS (International Affective Pictures System) dataset, which consists as one of the largest and most widely used image database to aroused different emotions in individuals [27, 44, 28]. Originally, the IAPS is divided into three categories ('pleasure', 'alert' and 'dominance'), and in this work the emotionally considered positive and negative images of the category called 'pleasure' [23] have been analysed only. Thus, this work sought to directly quantify the emotions perceived by people through a type of biological signals, analogously to other studies that have already sought this quantification, but using, however, other involuntary biological signals essentially related to clinical medical practice, such as heart beat, blood oxygenation, blood pressure among others [7, 38, 40].

2 Materials and methods

In this section it will be presented the set of materials and methods used in the realization of the experiment and is divided into six subsections: Cognitive stimulus; participants; signal acquisition; image luminance control; pupillary signal processing; and heat map calculation.

2.1 Cognitive stimulus

The cognitive stimulus used in this experiment was based on some of the early work on eye tracking in which emotionally positive and negative images were presented to volunteers [16, 17].

In this experiment, such images, were organized into a set of 18 stimuli (9 positive and 9 negative), all taken from the IAPS images base. Each image was presented for 6 seconds in a previously defined random sequence, as described in Table 1.

Table 1. Images used as stimulus

Order	Image Code (base IAPS)	Class	Description (summarized)
1	8501	Positive	Lots of money (scattered)
2	2722	Negative	Prisoner behind bars
3	9220	Negative	Sad people next to a tombstone
4	7521	Negative	Empty hospital bed
5	9001	Negative	Cemetery
6	9000	Negative	Cemetery
7	2080	Positive	Two babys
8	2050	Positive	Smiling baby
9	2205	Negative	Old man next to his bedridden
10	2040	Positive	Smiling baby
11	8502	Positive	Pile of money
12	6010	Negative	Prisoner behind bars
13	2058	Positive	Baby holding a finger
14	3220	Negative	Bedridden man
15	1710	Positive	Puppies of dog
16	8503	Positive	Hand holding money
17	7520	Negative	Three empty hospital beds
18	2045	Positive	Smiling baby

All images are of medium emotional impact and have been carefully selected not to expose the volunteer to an unpleasant situation. However, it is still expected to notice significant changes in the pupillary diameter according to the emotion caused by each image presented [25], [3].

2.2 Participants

All volunteers were exposed to the experiment with appropriate consent, by means of the corresponding term signature. Participants are university students at an academic institution, and were approached in a similar proportion between men and women. In all, the signals of 36 volunteers were acquired, but 7 were discarded due to low signal capture (less than 70%), resulting in 14 men 15 women.

2.3 Signal acquisition

For the acquisition of the signal was used an eye tracking equipment, of the Tobii brand, model TX300 with data capture capacity of 300 Hz and display resolution of 1280x1024 pixels. The equipment was positioned in an enclosed room, with artificially controlled lighting within ideal specifications (between 300 and 1000lux) and positioned outside the participant's field of vision [37].

Before starting each signal acquisition, the calibration of the equipment is performed by adjusting the position of the participant within the range of the equipment (as shown in Figure 1) [36].

Fig. 1. Range parameters of the equipment [36].

This step followed the application protocol as described in the items below:

1. Approach of the volunteer;
2. Explanation about the experiment;
3. Fill of specific consent term;
4. Positioning of the volunteer in the Eye-tracking equipment;
5. Calibration of equipment for the volunteer;

6. Start of the experiment with the initial instructions on the screen;
7. First image display for 6 seconds;
8. Display a black screen for 4 seconds;
9. Presentation of the second image for another 6 seconds;
10. Display a black screen for 4 seconds;
11. Process repeated until the 18th image;
12. Ending information and thanks;
13. Viewing the recording of the experiment to the volunteer.

2.4 Image luminance control

Eye tracking equipment was configured with the default brightness and contrast parameters (50% each) and the luminance difference of each image was evaluated by comparing histograms of the images. In this process the images were converted from RGB to grayscale and then a histogram analysis of each image was made. To determine the similarity was made a hypothesis test using analysis of variance ANOVA and Tukey test [12].

Assuming the null hypothesis H_0 that there is a statistically significant difference in luminance of the images, the confidence interval of the comparison between each image was calculated (Figure 2).

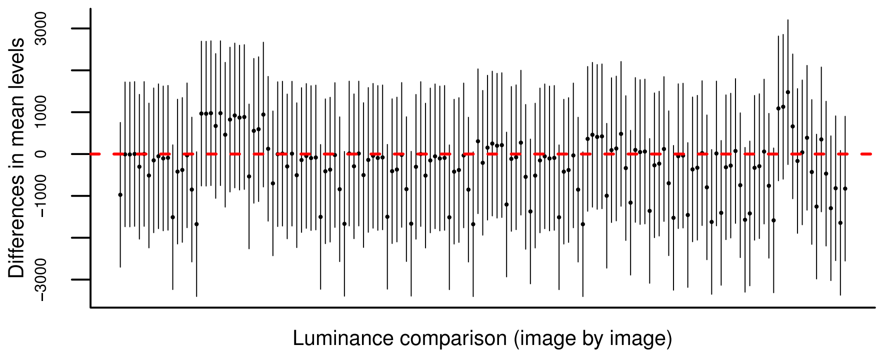

Fig. 2. Analysis of luminance difference by comparing histograms.

In the Tukey test, shown in Figure 2, when the confidence interval crosses the 0 (zero) axis, the null hypothesis H_0 is not rejected. Consequently, as all comparisons cross the 0 (zero) axis, there is no subsidy to say that there is a significant difference between each image. Thus, although some difference in luminance between the images is visually noticeable, it is unlikely that the measured pupillary dilation was caused by the difference in liminance occurred in the transition of each image on the equipment screen.

2.5 Pupillary signal processing

The signal acquisition step resulted in a data matrix (gross) of dimension 29x32400, in which 29 is the number of individuals participating in the experiment and 32400 is the number of samples collected during the stimulus display (18 images x 6 seconds of display x 300 Hz acquisition = 32400). These data, coming from pupil measurement, need to be treated and corrected, since it is common to have loss of signal momentarily by involuntary actions of the individual, like winks or blinking [30]. Therefore, the data went through a pre-processing stage composed of: removal of isolated samples; reconstruction of signal loss intervals; and noise removal. The effects of this step can be seen in Figure 3.

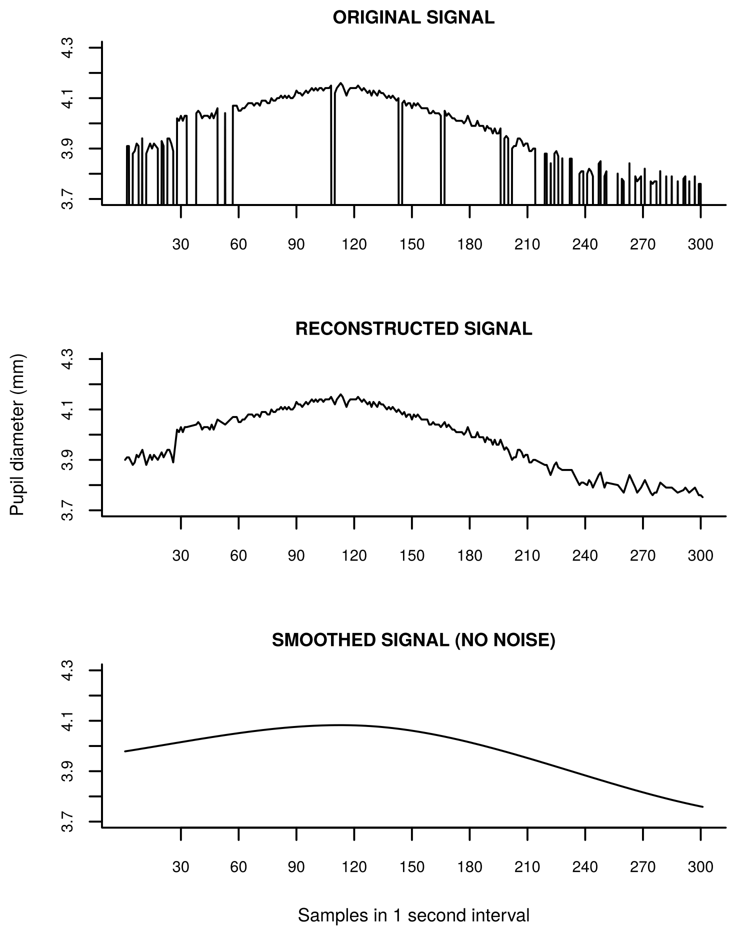

Fig. 3. Steps of the pre-processing of the signal.

In the isolated samples removal stage, a cut-factor filter based on the standard deviation of neighboring samples was used. This filter is necessary because when there is signal loss is common for some samples to follow the actual measurement decay until zero [30], as shown in Figure 4.

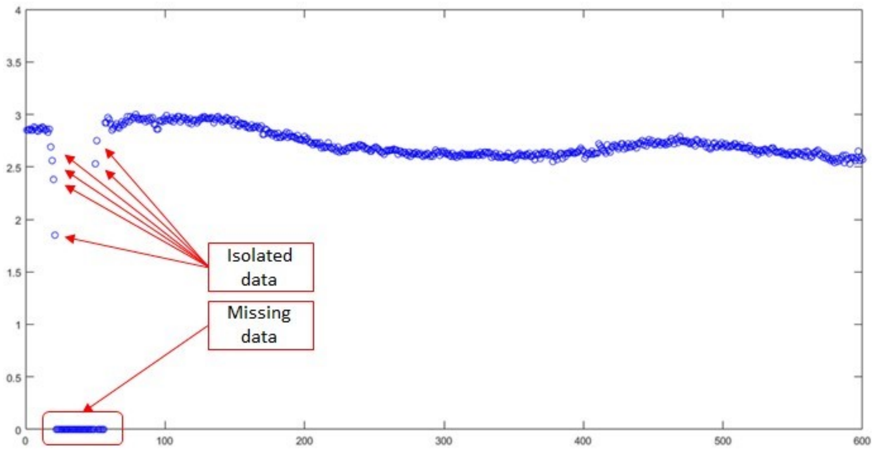

Fig. 4. Example of signal loss with isolated samples caused by equipment recording inertia.

Without the removal of the isolated samples, the reconstruction of the signal loss would be impaired, since in this step a linear interpolation is made to fill the data loss intervals.

After reconstruction of the signal is necessary to smooth it to reduce noise and preserve the identity of the signal, because in addition to the distortions caused by linear interpolation, it is common to percept small jumps in the measurement of pupillary diameter. In the noise removal phase the data were smoothed through the *smooth.spline* function of the *stats* library in the R language, which fits a cubic smoothing spline to the supplied data, but optionally you can also use the software *filtfilt* function *Matlab* which uses zero phase filtering to reduce noise and preserve signal identity [30]. A sample of the result obtained in this process can be seen in Figure 3

2.6 Heat map calculation

The calculation and generation of the relative visual attention map, or simply heatmap, are made based on the location and duration of the fixation, according to Figure 5. The places that the user fixed the look are defined (left side of Figure 5) and their weighting, considering the fixing time in each pixel (right side of Figure 5) in seconds. Then more or less intense colors are attributed proportional to this weighting as can be seen in Figure 6 (left side). The distribution of values around the fixation points is defined by the use of a Gaussian curve, as shown in Figure 6 (right side). Within this distribution, the pixels with the highest observation number are red and, as the incidence decreases, the color gradually changes until it reaches the green as can be seen in the Figure 6. The human eye captures information not only from the fixation point but also from the 50 pixels around this point [10].

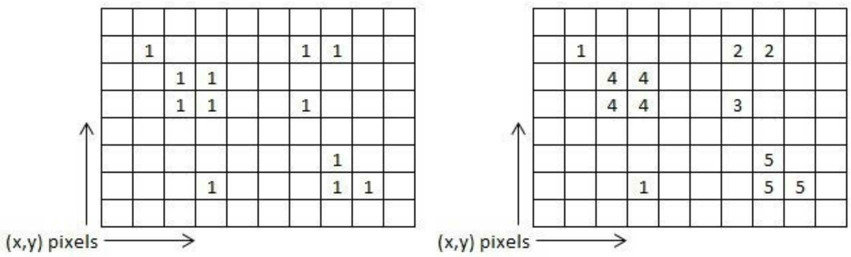

Fig. 5. Exemple of heatmap generation matrices.

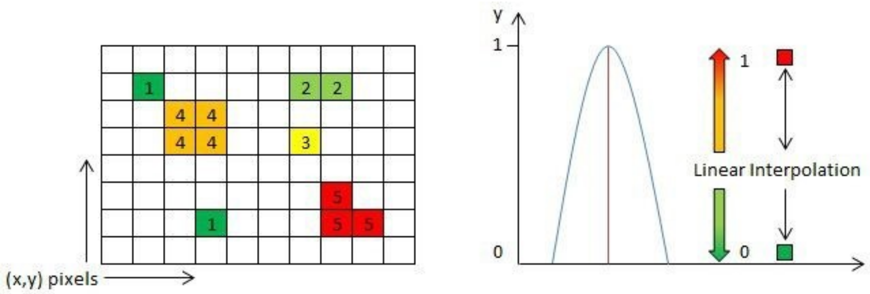

Fig. 6. Attribution of color gradients proportional to the calculated weights (left side) and Gaussian curve of fixation intensity (right side).

2.7 Estatistical analysis

Due to the large volume of data involved in this experiment, there is no way to infer the hypotheses of interest without a statistical method, such as, the analysis of variance (ANOVA) method used to compare the luminance of the images in subsection 2.4. As the objective of this work is to detect the impact caused by different stimuli, to make the statistical analyzes we used the T-Student hypothesis test, which is a trivial and recurrent method to detect the difference between a data set [35].

The main measure extracted from the hypothesis test is p-value, which indicates the probability that the result comparing the data sets occurred by chance. The P values are from 0% to 100% represented in decimal form (0-1) is a measure commonly used to infer statistical significance is 0.05 (5%), that is, the the null hypothesis H_0 that the data is similar is rejected only if when the p-value obtained is less than 5% [35].

3 Results

The results will be presented in two subsections: Pupillary measurement, which shows the observed differences between the positive and negative images; and Heat map of the areas of interest, which presents the points of highest incidence of ocular fixation in each image.

3.1 Pupil mensureament

As can be seen in Figure 7, there is a clear difference between the positive and negative visual stimuli presented to the volunteers, with the negative stimuli showed a greater impact on the alteration of the pupillary diameter during the 6 seconds of the presentation of each image, showing that the pupil reacted differently to them.

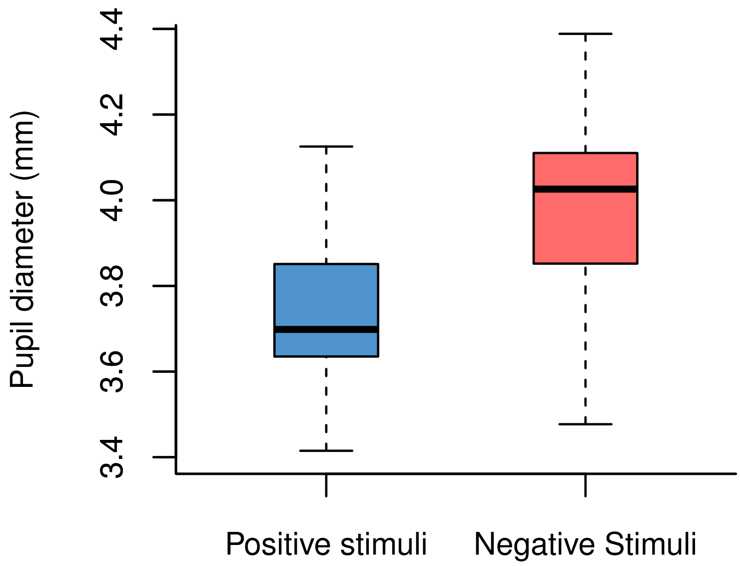

Fig. 7. Mean pupillary diameter change for all positive and negative stimuli (images) of all volunteers.

A preliminary analysis of the results showed that there were interferences in the pupillary signal coming from the own experimental process, such as the sensitive alteration of the luminosity that occurs with the transition of images or as the dispersion of the volunteer after sweeping the image with the eyes. In this way, it was convenient, as a good practice, to remove the first and last seconds of the signal, segmenting only the interval that indicates the cognitive processing, as shown in Figure 8.

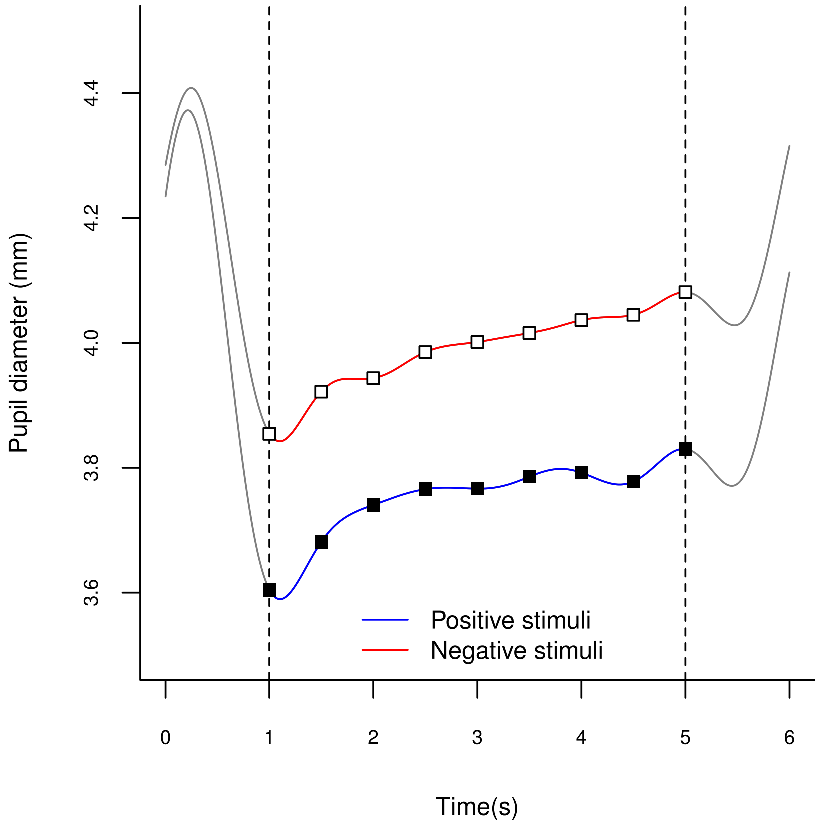

Fig. 8. Extraction of the signal of interest relative to the mean signal of each stimulus group.

After extracting the signal of interest the statistical report was taken by means of the test *T Student* [35], which showed that there is significant statistical difference between the classes, with p-value = 2.2e-16. Additionally, the standard deviation obtained in each positive and negative curve was, respectively, 0.06035923 and 0.06481293

The difference between the classes can still be evidenced visually in Figure 9, which shows the sequence of presentation of the stimuli (positive and negative) and the respective measure of pupillary diameter in each of them. This same figure shows a boxplot with the relation between the 18 emotional images presented to the volunteers and the dilation of the pupil diameter for each of them, and the negative images (in red color) are mostly above the positive images (in blue color), indicating that they caused greater dilation of the pupils of the volunteers, suggesting that the negative images cause greater emotional impact in the individuals.

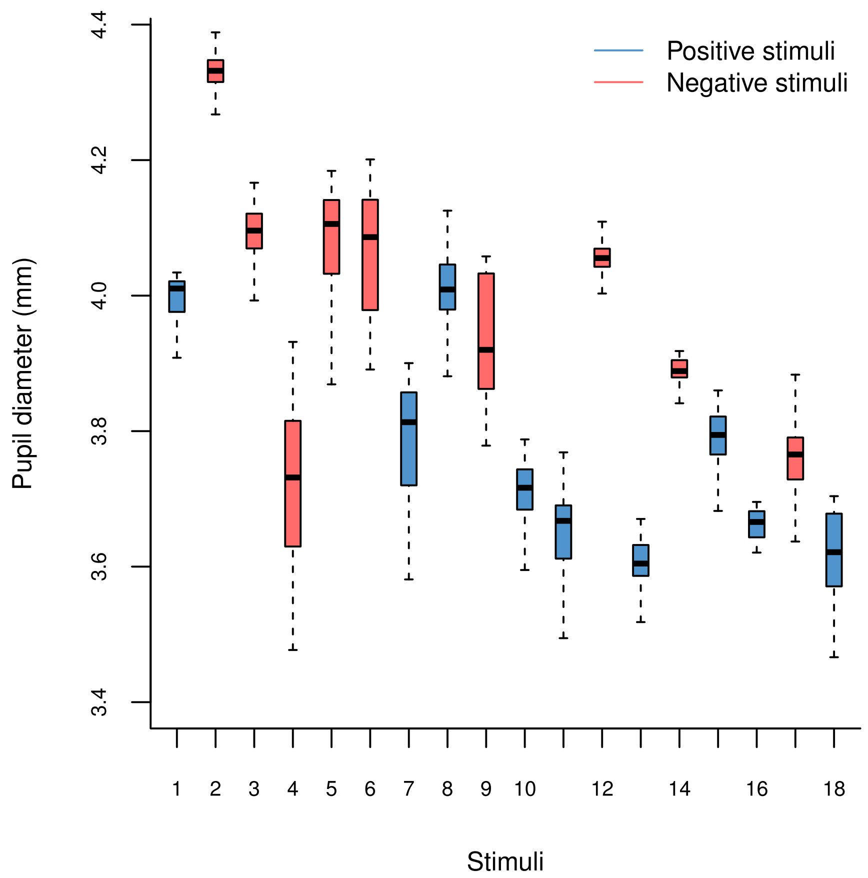

Fig. 9. Distribution of the pupillary diameter measurements of all volunteers per image.

3.2 Heat map of areas of interest

In this section it will be presented the heat maps obtained in each image, but due to the restrictions set by the Center for Emotion and Attention Study, the IAPS images used in this work can not be published. For this reason, the original images were digitally blurred, reducing their resolution by 99% so that the image's identity was preserved and still allowed some examples to be drawn to the readers of this work. The displayed image codes are from the respective entity catalog.

Figure 10 shows two images that contain money and it is perceived that the volunteers focused their attentions on the hand that is holding the banknotes (right) and the image of the person printed on the ballot (left). With this it turns out that the attention of people is drawn by human figures or parts of their body to the detriment of the other attributes in any scene.

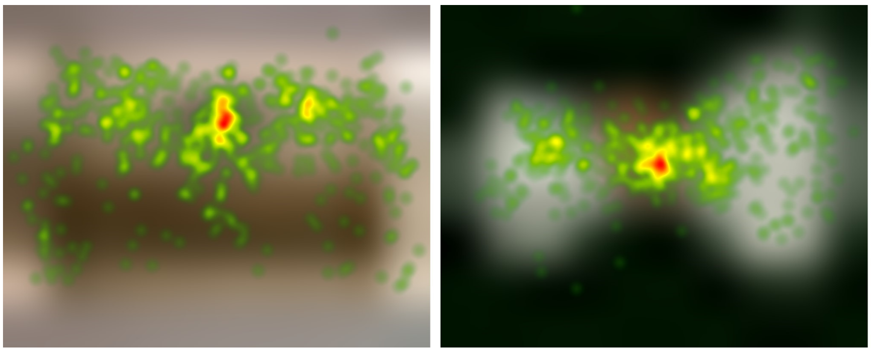

Fig. 10. Images IAPS-8502 (left) and IAPS-8503 (right).

Figure 11 shows, on the left side, a hospital room with an old lady in the bed and a gentleman, supposedly her husband, sitting beside her. Once again the attention of the volunteers was directed to the people who are on the scene, more specifically to the faces in focusing the region of the eyes and nose. On the right side was an image of a hospital corridor with several stretchers without anyone. In this scene the volunteers scanned the various parts of it, focusing on the center point of the image which confirms that people prioritize attention to people.

Figure 12 shows (on the left side) three puppies side by side and two babies on the right side. It is interesting to note that the attention of the volunteers turned to the same region both for the images with the animals as for the image with the human beings.

Figure 13 shows images of cemeteries and once again the focus of attention has been on the faces in case there are humans (left image) and much more dispersed when there are no people (right image).

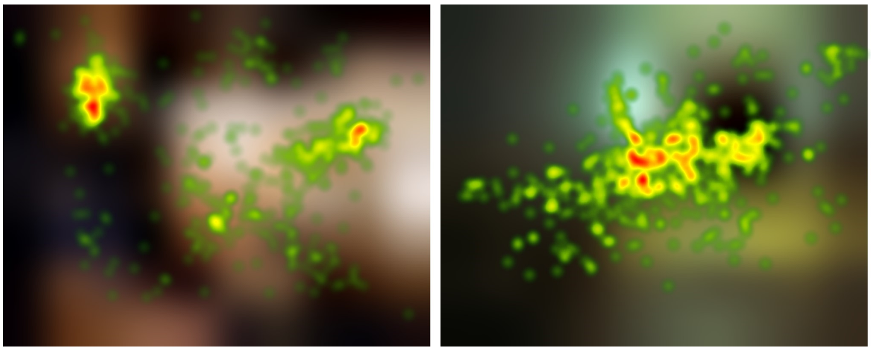

Fig. 11. Images IAPS-2205 (left) and IAPS-7520 (right).

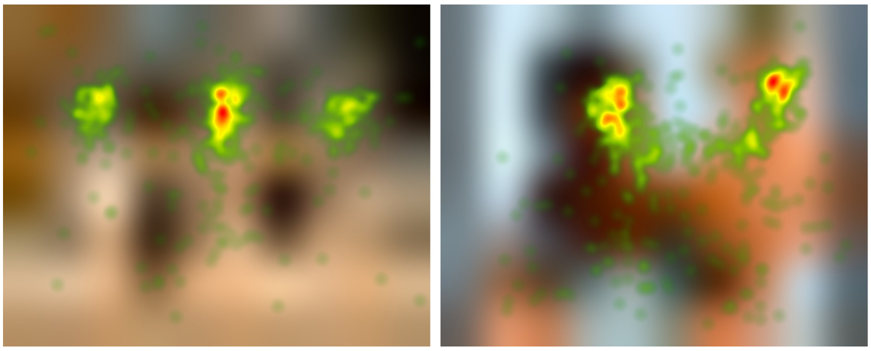

Fig. 12. Images IAPS-1710 (left) and IAPS-2080 (right).

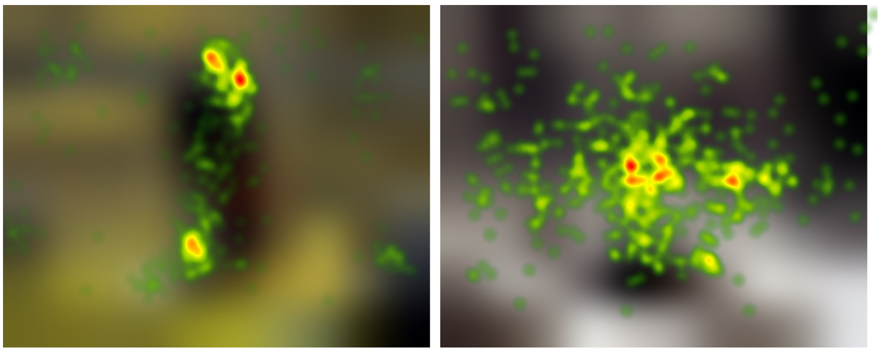

Fig. 13. Images IAPS-9220 (left) and IAPS-9001 (right).

Figure 14, just as the figures previously presented once again show, in an image of two babies, that people instinctively seek the region of their eyes, nose and mouth to focus their gaze.

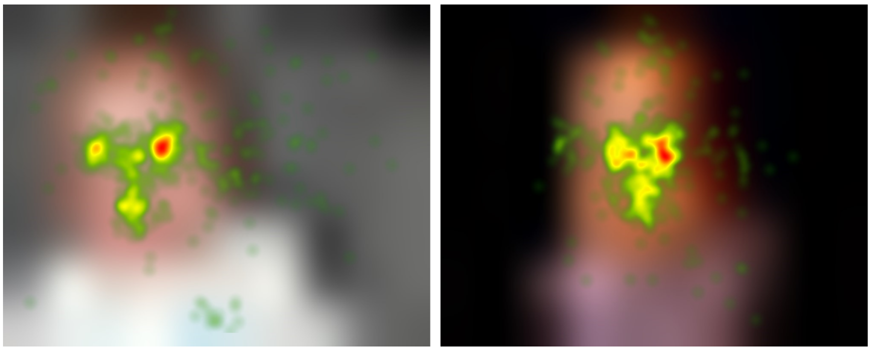

Fig. 14. Images IAPS-2045 (left) and IAPS-2050 (right).

Figure 15 (left side) shows a baby on his lap holding an adult's finger (probably his guardian). In this case the visual interest was once again turned to the baby's face and to his hand holding the adult's finger.

Still Figure 15 (right side) another image is shown from a prisoner behind the bars but without appearing his face. In this case the attention was turned to his hanging hands and to the keyhole of the prison cell where the prisoner is.

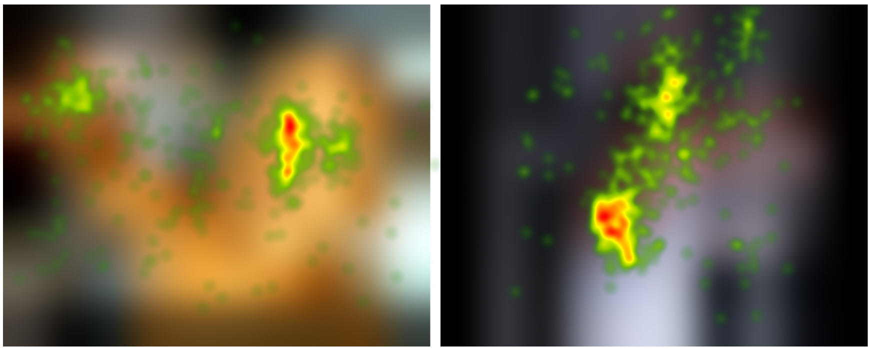

Fig. 15. Images IAPS-2058 (left) and IAPS-2722 (right).

Figure 16 (left side) also shows a prisoner behind the bars, but this time his face appears in the scene, and the visual attention of the volunteers turned largely to his face. The interesting thing is that on the right side shows a hospital room with an empty bed, and the volunteers searched for a patient on the bed.

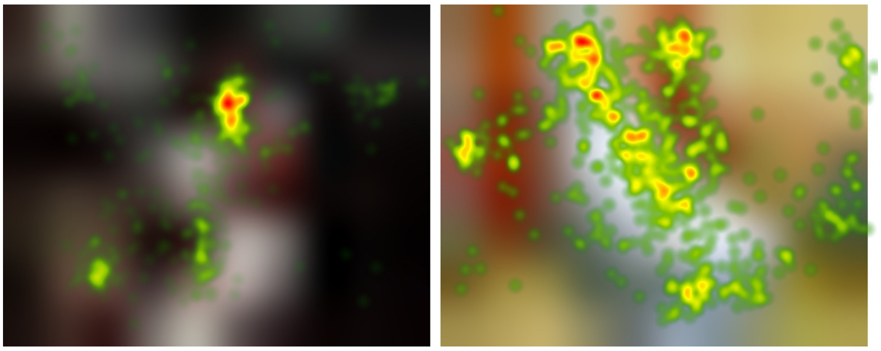

Fig. 16. Images IAPS-6010 (left) and IAPS-7521 (right).

4 Discussion

Although the human decision-making process goes back to our prehistory, economic decision-making studies are much more recent, as are personal economic decisions that are even more current and are in a field of study that began to be studied from the finding of Kahneman and Tversky in the 1970s, where it was realized that people are not completely rational in their decision-making, what today is known as the non-rationality in economic decisions [21] [31] [39].

Several other studies have already been performed to identify pupil alterations of volunteers in positive and negative contexts and all have identified significant differences between them [13, 41, 8, 34]. However, the contribution of this work is to show that the characteristic emotional stimuli, exclusively linked to the pleasure dimension, provided by the reference IAPS, can also influence the pupil behavior of volunteers with statistically significant differences.

Human attention can be defined as the ability to respond to stimuli that are more significant to the detriment of others, the nervous system being responsible for the selectivity of stimuli captured by the sensory organs, directing those that are behaviorally relevant to each individual, directing attention to them, unlike how computers react [6, 11]. In this context, this paper also shows that in photographic images people tend to search for humans faster than other objects in the scene. In addition, the time spent is much longer to observe people than other attributes of the image even though they occupy a considerably smaller part of the image, and there is a competition with other attributes that should draw more attention[43] [42].

Therefore, it is fair to say that we tend to be more sensitive to images that contain humans, with special attraction to faces (and within the faces, the eyes) [9] [18], than other types of images, and consequently such information should be considered to ensure emotionally driven visual experiments on decision makers.

5 Conclusion

One way to identify non-rationality in human decisions is to report biological signals emitted by decision makers in an involuntary way, and this work performed this biological sign measurement by pupil dilation. This work contributes to identify how to quantify human emotions through the analysis of pupillary variation, which may help a better understanding of human aspects in information systems. The main benefit is that it makes it possible to objectively assess whether a person has been impacted by an external visual stimulus before making a financial decision, for example. Such an experiment also makes it possible to quantify the emotions felt by human beings.

The subsequent works of this study will carry out new experiments with a larger number of volunteers and apply this methodology of visual stimuli to, after the presentation of emotional images, investigate the consequent and subsequent behaviors in these volunteers for economic making decisions.

Future works:

1. Neutral stimulus analysis;
2. Decision making evaluation;
3. Quantitative heat map interpretation.

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