Pupillary Behavior in Positive and Negative Emotions

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Abstract— **Emotion recognition process is proven to be an essential tool to increase human-computer reaction, interpret social relations, investigate mental health, and study human behavior. Pupil diameter (PD) has been addressed as the most reliable approach to identify emotions. This is because it is controlled by Automatic Nervous System (ANS) and is easy to detect. The goal of this paper is to identify the difference in PD due to individual's positive and negative emotional states. The paper introduces experimental results obtained using eye-tracking system with 30 participants. Initial results obtained by applying differently paired-sample t-test suggested a significant increase in pupil dilation during negative emotions compared to positive ones. It also shows steeper, higher, more sustained and longer dilation in high arousal negative stimuli.**

Index Terms— **pupil detection, emotion recognition, eye-tracking systems, stimulus, positive and negative emotions.**

I. Introduction

Numerous researches have been conducted in the past 50 years to address the use of pupil diameter change to indicate individual's emotional states. The reason for that is the reliability and accuracy shown by such method. Moreover, measurement of pupil size has important advantages over other physiological signals. It doesn't require attachment of sensors and the technology necessary for accurate measurement is relatively simple to use.

As a result, emotion recognition via pupil diameter is currently a very active research topic and is having increasingly strong interest and great challenges. This is driven by the huge amount of promising usages and applications of emotions recognition in many areas. It began to be more acceptable that emotional reactions can be nominated as central factor in rational human behavior [1]. Surraka et al [2] showed that perceiving other's emotional expressions can significantly affect the non-emotional information interpretation. Emotion recognition is also used in autonomous video-game characters [3], learning process and tutoring systems [4], affective computing, automatic detectors of affective states including fatigue, depression and stress [5], [6], smart surveillance systems, call centers, intelligent automobile systems that help ensuring driver safety, mother-infant interaction system, business fields e.g. customer services [7], [8] and lie detector in courts.

This led to the explicit variety in emotion recognition systems algorithms and approaches e.g.: (1) the visual from facial images and videos, (2) Kinesthetic from autonomic nervous system (ANS) signals and (3) Auditory from speech [9]. Pupil diameter is found to be optimal in measuring human's emotion although differences in luminance between stimuli may have a small influence in uncontrolled environment, an important part of the variation in PD was related to differences in emotional content as in [10].

Pupil diameter is also not affected by different body gestures and less affected by environmental changes. Besides this, it indexes real spontaneous expressions that ensure detection of real emotions. It has short latency of their changes which makes it superior to measures as skin-conductance or heart rate [11], [12], [13] and [14]. Eye movements can provide detailed information of what an individual is considering due to the high ability in considering and discarding various aspects of a task in less than 200ms. Pupil diameter is regulated by the Autonomic Nervous System (ANS) that is consisted of three divisions: the sympathetic, the parasympathetic and the enteric system [15], [11]. The parasympathetic and sympathetic divisions of ANS govern the two sets of muscles in the iris called the sphincter and dilator papillae, which are responsible of pupil diameter. In some studies however, Bradley et al [16] study supported the hypothesis that sympathetic activity increment associated with emotional arousal modulates pupillary changes during affective picture viewing. Previous findings and research showed that pupil dilation may indicate emotion, cognitive load or arousal [17] [18], [11], [16], [19] and [20].

A study conducted by Hess [18] showed bi-directional papillary change with regard to emotions. His study suggested dilation in pupil while viewing pleasant picture and constriction when viewing unpleasant one. However, this claim was challenged when other authors presented opposite result. E.g. Woodmansee in [21] reported dilation of subjects who viewed unpleasant scene. Janisse in [22] found no evidence of pupil constriction to negative stimuli. In fact, constriction of pupil diameter to negative stimuli is yet controversial [23] though some recent studies have suggested more dilation in pupil diameter during positive and negative emotions compared to neutral.

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This paper will introduce the information obtained from an experimental work using eye-tracking system. The information depends solely on the user unconscious and non-cognitive behavior mainly autonomic nervous system activity. This has proven to provide rich details on user valence. The experiment was performed to support the hypothesis that negative and positive emotions can be discriminated through pupil diameter. It focuses on presenting different characteristics of pupil dilation in some positive and negative emotions using developed statistical approach. It describes the database used and the stimulation applied to trigger the emotion of subjects. It also elaborates on PANAS-X model that was used to measure subject emotion.

II. Experimental Phase

The experiment was conducted with 30 university students who volunteered to participate in this study. This section explains the subjective and objective data obtained throughout the experiment.

A. Database

The participants of this experiment were Universiti Teknologi PETRONAS (UTP) students with age range between 20-30 years old. Thirty subjects with normal and corrected-to-normal vision participated voluntarily in this experiment of which approximately half were female. Subjects were briefly instructed and informed about the experiment and consent form was signed by each subject.

The system used to run the experiment was Tobii TX300 eye-tracking system. It detects and records data of PD and eye movement such as eye gaze, fixation and saccades. This system allows large head movement while maintaining the accuracy and precision at a sampling rate of 300Hz, which means recording pupil size every 3.3 msec. Subjects were seated comfortably -in luminance-controlled room- with approximately 65 cm from the eye-tracking system. A five-point calibration was executed before starting the experiment to locate participant's pupils. Stimuli were directly delivered through headphones to participant's ear at constant and comfortable level. They were given brief written instructions that were shown also in the system screen prior to the beginning of experiment.

B. Stimulation

To ensure occurrence of desired emotional states, a strong effective stimulation was used to trigger participant's emotions. Generally, stimulations are of three types: visual, audio, and audio-visual. In this experiment, audio stimulations were used. Sounds were selected from International Affective Digitized Sounds (IADS) [24]. The reason for choosing audio stimulations was to help controlling the environment of the experiment and thus eliminate the possible effect of luminance on pupil size. This is besides that audio stimulations are known to be effective in triggering strongly individual's emotional states. Twenty-one stimuli with pleasure (mean=4.2 and std=2.77) and arousal (mean=5.23, std=1.93) were used including negative and positive high and low arousing and neutral stimuli and were delivered through headphones directly to participant's ear at a constant and comfortable level.

Sounds chosen were easy to resolve and communicated quickly affective quality. They were in different arrangement and not one after the other, to ensure different responses based solely on the stimuli type. The subjects were exposed to a trial experiment where three practice sounds were heard prior to the experimental ratings (door bell, buzzer and baby sound). This was to provide the subject with rough estimation on the kind of sounds played and to give them chance to practice rating. Each trial included:

- Preparation sound (3 sec).
- Sound stimulus (6 sec)
- Rating interval (21 sec)

Computer system was utilized to control timing and stimulation and instructions presentation with total experiment time of the approximately 12 min. The presentation started by showing examples of presented sounds.

C. Measurement of emotion

Measuring emotions is the most complicated issue in affective or valence science as suggested by scientific evidence. This is because numbers of facts are affecting one's emotional status such as subjective experience, physiology, background and behavior. Throughout an extensive review, there were findings from dimensional and discrete perspectives to measure emotions. Dimensional perspective concentrates on three dimensions, which are Valence, Arousal and Control or Approach avoidance. On the other hand, discrete perspective focuses more on the particular emotion e.g., sadness, surprise, disgust, etc. [25]. However, there are other points of view that divided emotional measurements into three parts, which seem more supported. They are:

- Non-verbal instrument that measures the expressive component of emotion such as: Facial Action Coding System (FACS) of Ekman.
- Verbal instrument or self-report instrument such as Self-Assessment Manikin (SAM) and Positive and Negative Affect Schedule – Expanded form (PANAS-X) model.
- The product emotion measurement instrument (PrEmo) which is non-verbal self-report instrument [26].

Yet, the relationship between emotion and measurement of this emotion is not well-established [27], thus self-report data might be considered as a supporting measure. In this experiment we applied verbal instrument represented in Positive and Negative Affect Schedule – Expanded form (PANAS-X) model [28].

There are some advantages of using PANAS-X model in this study. It is a simple and easy-to-use model and most participants completed all the played sounds in the specified time, which was 10 minutes. They were given 20 sec rating interval for each 6-second-played-sound. The model has also 11 discrete emotions. Some of them were considered as basic emotions by psychologists. The model also enables wider

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space of rating by having a 5-scale rating ranging from very slightly to extremely felt emotions [29].

From the validation and analysis presented in [28], PANAS-X scales were strongly correlated with the commonly applied measures for emotional states. It also indicated that this model scales could be used validly to assess short-term state affect. Through analysis also, three broad subcategories were defined. Fear, Sadness, Guilt and Hostility scales were classified as Basic Negative Emotion. Joviality, self-assurance and Attentiveness were classified as Basic Positive Emotion. Finally Shyness, Fatigue, Surprise and Serenity were grouped as Other Affective States for they do not strongly define either of the aforementioned factors.

Emotions selected in PANAS-X model were managed to be uncorrelated and conforming with the theoretical model supporting the independence of positive and negative affect they normally are [30]. This was made in gray levels color for participants to ease their rating mission. Subjects were instructed that there is no wrong or right answer and asked to rate honestly the sound heard in terms of how it made them feel. For more options, the choice of neutral state was given in case stimuli failed to trigger subject's emotions.

D. Data Analysis

Data obtained from eye-tracking system were pupil diameter for both eyes, fixation, stimulus onset and offset and a validation code that determines the validity of pupil diameter data. The data provided by the eye-tracking system contains values of both right and left pupils. Both pupils had almost the same behavior in all subjects, $p< 0.001$ so the average of these values was taken to ease data processing. Then, to determine a baseline for each participant that is the normal pupil diameter, average of 1sec before stimulus onset was used. Each trial stimulation sound lasted for 6 seconds. Due to the fact that pupil size differs from individual to another based on the iris size, pupil values were then normalized to lie in between [0, 1] to overcome spanning of values in different ranges and to enable proper and accurate signal analysis. After that, a moving-average filter with span of 7 using MATLAB was applied to clean data and remove outliers. Missing data were replaced with linear interpolation and trials with over 50% missing data of blinks or artifacts were eliminated. Pupil dilation was not measured as one value but instead the whole signal characteristics were utilized to enable more accurate differences finding between positive and negative emotions. To assess results obtained repeated measures ANOVA was conducted with subject group (Negative and Positive emotions). Multiple comparisons were applied to find out where the differences are, using Bonferroni test. Two-tailed paired-sample t-test was also applied to confirm differences as well [31].These analyses were performed using SPSS software with p value = 0.05.

III. Result and Discussion

The experiment was performed with the aforementioned preparation and the analysis was divided into two phases:

- Objective data, which included data of pupil diameter.
- Subjective data that included self-report assessment and the analysis associated with it.

Using the self-report data, classification was done to group positive emotions together as well as negative emotions. This was supported by the divisions mentioned earlier in measurement of emotion part given by the self-report model utilized. Twenty-one sounds as specified above were rated using 11 emotions of PANAS-X model plus neutral status. The participants used numbers that ranged from 1 (very slightly) to 5 (extremely) to rate the sounds based on the felt emotions and chose one emotion only (the strongest) each trial. This might be because of the nature of arousal and valence of the stimuli that depended on the ratings provided with IADS data.

In this experiment, we noticed no initial decrease in pupil diameter. This is because luminance of the room was controlled and the stimuli used were sounds that do not affect the amount of light entering the pupil like pictures for example[16].

Figure.1 shows the difference of average normalized dilation for positive and negative emotions that depended on PANAS-X model classification. In negative emotions e.g. a sound that was rated as fear emotion was a scream that had pleasure (mean=2.05, std=1.62) and arousal (mean=8.16, std=2.15), sadness for child abuse sound with pleasure (mean=1.57, std=1.43) and arousal (mean (7.27, std= 1.60). While in positive emotions sound like baby sound with pleasure (mean=7.64, std=2.10) and arousal (mean=6.03, std=1.98) [21] were used.

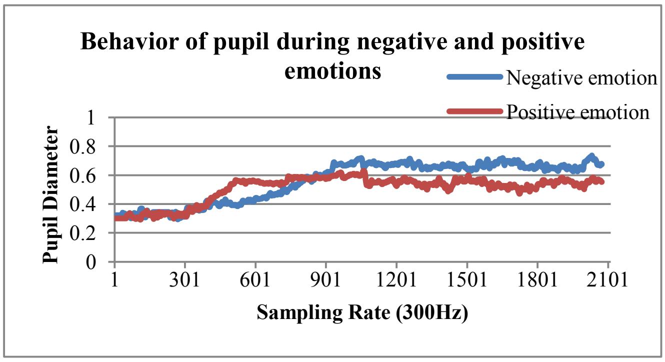

Fig. 1. Pupillary behavior during positive and negative emotions

From Fig.1, one can notice the slower, higher and more sustained dilation of negative trend compared to positive one. Dilation in both cases started almost 1.25sec after stimulus onset and reached the peak almost in 3.2sec after stimulus onset. Highest point in dilation of negative emotions reached 0.7(normalized value) while in positive ones it was 0.61(normalized value).

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Two-tailed paired-sample t-test was applied to check the difference in means between the two groups. In recent studies, average of pupil dilation subtracted from pupil baseline or normal pupil diameter is used to indicate significant difference between positive and negative signals as in [11] and[16]. The baseline for this experiment was computed for each participant by taking the average of pupil diameter 1 second before stimulus onset for each trial. The maximum pupil dilation was determined by averaging each participant's trials. This is because pupil diameter behavior is prone to spontaneous fluctuations. Thus, pupil dilation was calculated by subtracting maximum dilation from baseline diameter for each participant. The result using t-test showed no significant difference with df(29) and p-value =0.228 . However, our hypothesis is proposing different way to indicate differences between positive and negative emotions. It is suggesting a significant change at the end of both signals. Based on this, data were segmented in second's basis to present differences at the end of each second. An average of 300 samples per second (300Hz sampling rate) was calculated for each participant positive and negative trials. Then t-test was applied using MATLAB and the result is shown in table.1 below.

Table.1. T-test result between positive and negative signals.

second	df	h	p
1st sec	29	0	.738
2nd sec	29	1	.04
3rd sec	29	0	.102
4th sec	29	0	.241
5th sec	29	1	.001
6th sec	29	1	.000

From Table.1, it is founded that initial dilation (2nd second) besides sustainability of dilation (5th snf 6th second) are considered differences between positive and negative emotions. This is indicated by the significant value of P that is less than 0.05 besides the h value that is equal to 1 that indicates a rejection of the null hypothesis.

Repeated measures ANOVA was applied to check and confirm the significance of difference as well. Since data violated sphericity assumption, Greenhouse_Geosser test was used. The difference was significant in 2nd, 5th and 6th second and thus confirmed the result of t-test. However, the mean differences of Bonferroni correction test was 0.286 that shows pupil diameter during negative stimuli was higher and significantly differs in mean compared to pupil diameter during positive stimuli.

Numerous researchers tried studying the difference in papillary change between emotions in general. Though, few researches addressed directly positive and negative emotions differences, it is predicted that strong negative and positive emotions show higher dilation than normal or neutral ones[16], [11]. This was supported by the objective and subjective data used in this experiment.

Moreover, one may argue that increase in pupil diameter might be affected by the intensity of the sounds and that loud sounds will cause large dilation. It has been addressed in previous studies as in [32] and its shown that loud sounds cause a slight and negligible increase in pupil diameter of about 0.04mm. In our study, dilation of pupil diameter reached 2mm in negative emotions compared to normal pupil diameter.

There are recent researches that showed difference between positive and negative emotions [33], [34]. These researches were performed on infants and were examining the effect of peer's emotion on infants' emotional states. In addition, some of the stimuli sounds used in this experiment were non-linguistic emotional vocalizations. This was e.g. in a baby sound (positive) and scream (negative). In both cases however, participants showed increase in pupil diameter with regard to the sound which indicates clearly that non-linguistic forms and expressions are complementary to facial expressions and other verbal communications forms when it comes to emotions. This paper is supporting the use of pupil size variation as an index for individual's emotional states and is presenting and evidence for differences between negative and positive emotions effect on individuals' pupil diameter.

IV. Conclusion

This paper presented the difference between negative and positive emotions. It examined experimental phase and explained thoroughly on stimuli, dataset, type of emotion measurement used and results obtained. The paper also discussed experimental result and supported the hypothesis that pupil is a good index of individuals' emotional states and that it dilates with emotional states regardless of whether it is positive or negative emotions. Results showed that there is significant difference between negative and positive emotions in terms of sustainability, duration and dilation diameter.

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