Web user click intention prediction by using pupil dilation analysis

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***Abstract*—We propose a novel approach for predicting Web user click intention, using pupil dilation data generated by an eye-tracking device as input. Our goal is to determine if this variable is useful to differentiate choice and no-choice states, and if so, to generate a classification model for predicting choice understood as a click. For this, we performed an experiment with 25 healthy subjects in which gaze position and pupil size was recorded while users choose between several elements on a simulated Web site. Our results show that there is a statistical difference between pupil sizes of chosen elements compared with no chosen ones. Furthermore, we generated a click-intention prediction model, based on Artificial Neural Networks, which obtained an 82% accuracy. These results suggest that this variable could be used from a Web Intelligence point of view as a proxy of Web user behaviour, in order to generate an online recommender to improve Web site structure and content.**

Keywords*—*Web user, Choice Prediction, Pupil dilation, Eye-tracking

I. Introduction

Organizations and companies seek to increase their presence over their competitors on the Web, in order to attract and retain customers and increase sales and market position. This goal could be achieved by having interesting and effective Web sites that could guarantee companies capturing users' attention and preferences, and thus be more likely to get higher conversion rates than the competition. However, designing and implementing attractive Web sites require a certain kind of knowledge about the needs of potential customers and the ability to establish personalized services that satisfy those needs, this is a key aspect for companies and organizations in order to stand out among others [1]. Web usage mining is "the process of applying data mining techniques to the discovery of usage patterns from Web data" [2]. This discipline makes use of several techniques for discovering customer experience while browsing a Web site, such as Web log analysis, polls and surveys. These data sources have been complemented with more recent technologies like mouse and eye tracking, to obtain more accurate modelling of user behaviour. In this sense, neurodata-based approaches have acquired certain relevance, due to the fact that biological responses could be useful to explain different human behaviours. In particular, pupil dilation has been related with cognitive load or mental activity [3], and gaze movements and eye fixations have been linked with attention and focus [4], [5], [6].

This study aims to introduce a novel approach for predicting Web user choice using pupil dilation as input. For this, we have stated a hypothesis based on the fact that pupil size varies over time as a response to visual stimuli. Thus, these changes may be an interesting prediction variable that we can capture using eye-tracking devices and analyse from a data-mining point of view. We conducted an experiment where 25 healthy subjects browse a simulated Web site with a given choosing task, while gaze position and pupil size was being recorded.

An important line of research regarding the study of the click intention of Web users was developed by Velasquez et al. Starting by identifying website Keywords, a methodology for determining Keyobjects (a web object or group of web objects that attracts web users' attention and that characterizes the content of a given web page or web site) was derived. However, this methodology had a problem related with the application of a survey for collecting information about users' preferences, thus acquiring subjective results . To overcome this issue, the use of eye-tracking technology was incorporated, in order to measure the time spent on each object in a more precise and objective way [4].

Other studies tend to relate Web user choice with different variables. In 2007, Chandon et al. [7], performed an eye-tracking experiment for analysing object choice situations associated with brands. They concluded that visual attention is relevant in the users' choice process, suggesting that those objects with low choice probability could be enhanced if they were put next to the objects with high choice probability. Reutskaja et al. [8] studied users' behaviour when choosing between objects under conditions of time pressure and overload using eye-tracking techniques. They concluded that objects placed in the centre of the screen have a greater probability to be chosen than objects with similar characteristics placed in other screen zones. This could allow decisions to be influenced by centring the object that is desired to be chosen. Additionally, they concluded that 70% of the chosen objects had *longer* eye fixations. Another study was performed by Krajbich et al. [9], in which they tried to relate the choice process with gaze position. In particular, they developed a choice prediction model based on three main observations: the first and latter fixations are *shorter* than the central ones, yet this does not affect the choice probability of each element; the last seen object has a *higher* choice probability than the rest; and objects with *longer* fixations have more probability of being chosen. Schulte-Mecklenbeck et al. [10] reviewed several process-tracing methods for modelling Judgement and Decision Making (JDM). In particular they revised the principal contributions of using eye movements (eye-tracking data) in this field. They described different studies, highlighting the use of *fixations* as the most important feature of this research tool.

Eye-tracking technologies could be used to collect another sort of data such as pupil dilation. This variable is directly related to different cognitive processes, since it is linked with the sympathetic and the parasympathetic systems. Several studies have used this variable in an attempt to describe various sorts of phenomena. For example, Beatty [11] used pupil size to measure mental effort during cognitive tasks; Steinhauer et al. found that an increased task complexity produced larger pupil sizes [12]; Bradley et al. studied its relationship with emotional arousal [13]. We found a specific field of action relative to choice and click-intention prediction where we could target our study, that being the use of pupil dilation through the time domain as a way of characterizing this process. In particular, we proposed a novel approach to click-intention prediction using the pupil size curve as input.

II. Proposed Approach

The main goal of this study is to classify and predict the choice process understood as a click on an object in a Web site, according to physiological-based features. In order to accomplish this goal we proposed a novel eye-tracking-based approach, in which we utilize pupil dilation for predicting click intention on a Web site adaptation. This data can be represented as a stream of data with a time component, and shown as a curve with contractions and dilations depending on the stimulus and the cognitive process implemented. Based on this evidence, our hypothesis is "The changes in pupil size over time correspond to a predictive variable for the Web user's click intention". In this sense, we used the pupil dilation wave as a single feature to characterize choice and no-choice states. This hypothesis was proposed in such a way that would allow us to answer two main research questions: RQ1: Is *Pupil Dilation* a useful variable for characterizing choice and no-choice states for Web users? and RQ2: Is it possible to generate a model for predicting click intention based on this variable?. For predicting the choice process we proposed the use of Artificial Neuronal Networks, Logistic Regression and Support Vector Machine. For the three models we used 70% of the data as the training set, and the remaining 30% was used for testing. Performance is measured with Accuracy and Recall ratios.

III. Data Acquisition

In order to obtain the data, an experiment was performed considering different aspects that allowed us to reproduce the Web user choice-making process, while monitoring and recording pupil dilation and gaze position. This experimental stage took place at the Neurosystems Laboratory of the Faculty of Medicine of the University of Chile.

The experimental group consisted of 25 healthy subjects (11 F, 14 M), students and professionals from different disciplines. The average age of the group was 26.1 years old, with a variance of 2.2 years. All subjects declared having correct vision and neither psychiatric nor neurological illness that could interfere with the experiment. All subjects had to sign an informed consent approved by the *Ethical Committee of the Faculty of Medicine of the University of Chile*. Pupil dilation and ocular positioning for both left and right eyes were recorded with the *SR Research Eye Link 1000* at 1000 Hz sampling rate. Visual stimuli (Web site adaptation) was programmed with the *Experiment Builder* software, and these images were displayed on a $32''$ *LG* screen placed 60 cm from the subject in the experimental room. Subjects had to rest their chin on a support to keep the head steady. The experimental room had no light on during the sessions.

The simulated Web site is composed of three main parts: home page, choice process and ending page. First of all, a home page is displayed showing the instructions of the experiment. Then, a grid containing 9 objects of the same category is shown. All these objects are taken from the *International Affective Picture System (IAPS)* database, corresponding to the *neutral* valence kind. Users have to click on an object to choose it. Once an object was chosen, a pink noise image is displayed for 2 seconds, before starting another decision page. This process is repeated 90 times. The task stated: Using the mouse cursor, choose one object of the grid by clicking on it. Finally a farewell page was displayed, giving thanks for participating in the experiment.

IV. Results and Discussion

Once data was fully acquired, some treatments were performed in order to answer the proposed research questions. First of all, each pupil dilation wave was pre-processed by linearly interpolating blinks, since every time a subject closed their eyes data was lost. Then, saccade offsets were fixed and a low-pass filter of 2 Hz was applied to remove noise. Next, we defined an observation considering the following aspects: i) An observation starts when the subject fixates on an object and ends when he/she fixates on a different one. ii) A minimum fixation threshold of 300 ms was set for an observation. Otherwise it is considered as though the subject did not really pay attention to that object, or only passed through it during a saccade. iii) For the analysis we considered the first 600 ms of each observation. Each observation was then transformed using *Z-score* as a way to standardise and make the comparison between subjects easier. Finally, in order to centre observations, the baseline was removed considering the previous 200 ms of each one, thus the average was calculated for this interval and substracted to the curve.

Using the collected eye-tracking data we were able to label observations into two groups, *Choice* and *No-Choice*. Then, a grand average was calculated considering all observations for all subjects for each group. Fig. 1 shows these two curves with the respective confidence intervals, where the differences between pupil size for choice and no-choice observations can be seen; choice

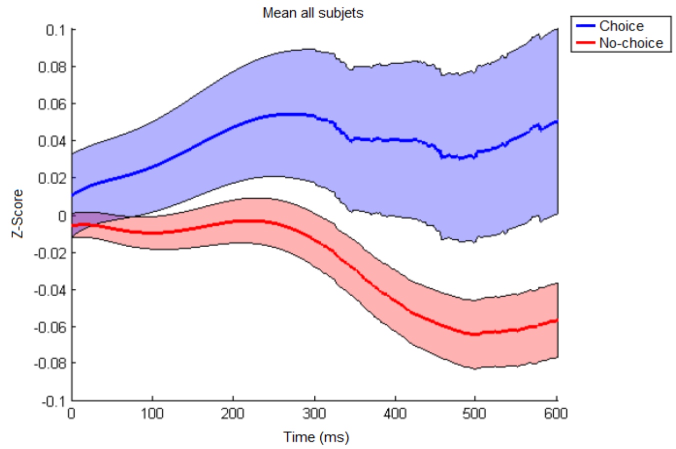

Fig. 1. Choice and No-Choice curves.

(blue) has a *greater* pupil size than no-choice (red).

To statistically validate this difference, we performed a *Lilliefors* normality test, to check if both curves had a normal distribution. With 95% of confidence, the test gave a 0.0970 *p-value*, greater than the critical value of 0.0518, therefore these curves were not normally distributed. Then, to determinate the statistical difference between curves, we performed the *Wilcoxon* Test with 95% confidence, whose result allowed us to reject the null hypothesis that states that both curves have the same mean. Thus, we validated our hypothesis, answering at the same time our Research Question 1.

Then, the prediction model was implemented. Each algorithm was utilized separately, using a $70-30\%$ distribution for training and testing respectively. The main idea was to generate more than one option for prediction and analyse the results. The first algorithm was the Logistic Regression, for this we used the standard logistic function for minimizing the cost function to obtain the beta values of the regression. Next, we applied the SVM algorithm using a Gaussian Radial Basis function kernel with a scaling factor σ 1. Finally, the ANN model was implemented, where the Log-Sigmoid Transfer Function was used as the activation function for each layer, defined as $A = logsig(n)$, where n are the input data. Results can be seen in table I, where ANN obtained the best performance of 82% accuracy.

It is important to say that even though the three models gave high accuracy levels, the recall values are low. This is because cases in which the objective variable is 1 (choice), are strange events within the complete observations set. In these cases the classifier tended to

TABLE I
PERFORMANCE OF THE PREDICTION MODELS

Model	Accuracy	Recall
Logistic Regression	75%	12%
Support Vector Machine	72%	15%
Neural Networks	82%	19%

better predict the objective variable when it is 0 (no-choice), and since these observations ten times outweigh the rare events, the result is an increase in accuracy but at the same time a very low recall. In addition, inter-subject pupil dilation variability is too high to validate the hypothesis individually. Yet, the average among subjects shows that the trend and curves allow choice and not choice to be separated by statistical difference. Based on this, several wave analyses could be performed in order to extend and corroborate these results. Detecting what the most important characteristics of the pupil size wave are could be useful to generate more empirical models to differentiate Web user choice and not choice, for example, obtaining features like maximum dilation and minimum contraction, or velocity and acceleration of the curve.

V. CONCLUSIONS AND FURTHER WORK

In this work, we explored the relationship between pupil dilation and Web user choice understood as a click on a certain object. To collect the data, we conducted an experiment that consisted of recording gaze position and pupil dilation while subjects were shown several choice pages on a simulated Web site. Considering different aspects, we defined an element observation and compared these observations for chosen and not chosen elements. We found that a statistical difference exists between the pupil sizes of these elements. More precisely, chosen objects had greater pupil sizes than not chosen, a fact that allowed us to validate our research hypothesis.

We also proposed a prediction model based on the usage of Artificial Neural Networks. Each observation was labelled with 1 or 0 if it corresponded to chosen and not chosen respectively. Although the model performed well in terms of Accuracy, obtaining 82%, the Recall ratio was low. This means that a quality classification model could not be achieved, because the state we are studying was not well classified. As further work we propose improving prediction performance with the application of techniques such as strange event over-sampling, or changing the costs of the confusion matrix. Second, try to characterize pupil size wave with different features like maximum dilation and contraction and curve acceleration and velocity. Lastly, we propose complementing the eye-tracking analysis with the use of an EEG device to record what is actually happening at the moment that users choose at a more cognitive level.

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