Interfacing with a speller using EOG glasses

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***Abstract*—Bio-signal based human computer interface (HCI) systems are a good alternative to standard touch based interfaces, offering subjects with motor impairments an alternative means of communication. This work investigates the use of electrooculography (EOG) to interface with a speller application. The use of a wireless EOG glasses currently on the market, known as JINS MEME, comprising only three dry electrodes, is compared to the standard two-pair EOG electrode configuration using wet electrodes. A blink accuracy of 97.63% and a saccade accuracy of 73.38% was obtained using a novel thresholding algorithm on the EOG data collected through the MEME glasses and the results were shown to be comparable to those obtained using wet surface electrodes. A real-time menu driven keyboard is also proposed and tested using the different eye movement recording techniques. In this case an average writing speed of 7.11 letters per minute, with a classification accuracy of 90.59% was obtained using signals recorded from the MEME glasses, showing that this new technology offers an ergonomic system that can easily be used in eye-based assistive applications.**

I. Introduction

Human computer interaction (HCI) allows the possibility of communicating with an external device using bio-signals recorded from the human body rather than the standard approach of using peripheral nerves and muscles. These systems are aimed to assist subjects with motor impairments or any other condition that restricts the use of standard touch based interfaces such as keyboards or touch screens. The type of bio-signal used depends on the subject's condition.

Research shows that there is a lot of work on eye based assistive devices. There are various techniques that can be used to detect eye movements, including videooculography (VOG), infrared oculography (IROG), scleral search coil (SSC) technique and electrooculography (EOG). The use of these techniques depends on their practicality and their respective technical specifications. The SSC technique for example gives the best resolution of 0.0167°-0.0133° but the lens itself has to be replaced every 30-60min and it can lead to blurred vision after use [1]. Video based oculography uses a camera to record the eye movements and can be setup as a head mounted or a remote configuration. This system gives a resolution of about 0.5°, is quite comfortable to use but then it is sensitive to varying light conditions, reflections of eyeglasses and other unwanted eye movements such as squinting while smiling [2]. VOG is also very expensive compared to the other recording modalities. IROG has similar specifications to VOG with the advantage that it allows for some degree of head movement. It however also fails to accurately track the eye movements in changing ambient light [2].

EOG can offer a good alternative solution to these techniques. It records the corneo-retinal potential of the eye which can be considered to behave like an electrical dipole, with the positive pole at the cornea and the negative pole at the retina. The electrical signal is typically recorded through two pairs of surface electrodes placed in periorbital positions around the subject's eyes with respect to a reference electrode. These electrodes capture the change in the electrical potential field caused by the change in dipole orientation, which is used to track the eye movements. EOG has lower spatial point of gaze tracking capabilities than the other eye movement recording techniques but on the other hand it is not sensitive to lighting conditions and the signal processing required to determine the eye movements is much less computationally intensive than the processing required to process video images for example [2].

Using EOG for an eye based assistive device has been attempted very often in the literature [3-5] but the ergonomic factors of such systems are still an issue. This is because wearing the surface electrodes is not aesthetically pleasing, gel is typically required for improved conductivity and this may dry out with long term use, and the setup itself may not be comfortable, particularly if lead wires from the electrodes to the amplifiers constrain the subject's movements [6]. An alternative and more convenient solution is a wireless EOG glasses where the electrodes are mounted on a spectacle frame. JINS Company Limited have recently taken this idea and developed a commercial EOG glasses which they call the JINS MEME [6]. The design of this eyewear consists of only three dry electrodes placed at the bridge of the glasses and at the nose pads. Although there is limited literature [6] on how the EOG captured through this setup compares to standard EOG recordings, the MEME definitely has the advantage of being sleek, easy to wear, requires no electrode gel and offers wireless communication to a computer.

This work aims to analyse the feasibility of using the MEME EOG glasses for an assistive EOG based application and compares this with the EOG signals recorded through a set of wired, gel-based, surface electrodes using the standard electrode configuration. An offline study is carried out to measure the saccade and blink detection accuracy while the subject looks at different horizontal, vertical and diagonal positions on a computer screen. A novel thresholding algorithm is presented and used to distinguish between the different eye movements in an EOG based speller application, which again is tested using both recording techniques. Most spellers found in the literature [3-5] are step-wise controlled, meaning that the user has to perform repetitive eye movements to hover around the screen in discrete steps. This work proposes a menu-driven, EOG based speller which avoids this unnatural control process and allows direct saccadic movements from the centre to a number of fixed locations on screen. Unlike the traditional QWERTY keyboard layouts that have been implemented [5], the proposed speller avoids placing icons across the whole screen, allowing the subject to look at a large section of the screen without generating any control signal, thus avoiding the

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Midas touch problem. This is also further facilitated through cues directing the user to when the necessary eye movements are to be performed.

Section II gives details on the offline study, highlighting the thresholding algorithm implemented to distinguish between different saccadic movements and blinks, and the results obtained when using EOG signals recorded from the MEME glasses and wired surface electrodes. Section III then presents the proposed EOG based speller and the performance obtained by ten subjects when they tested the speller using both EOG recording modalities. Another interesting aspect of this study is that the saccade and blink detection accuracies were compared to the performance obtained using a camera-based eye gaze tracker. The conclusion of this work is presented in Section IV.

II. OFFLINE STUDY

The goal of this study was to process the EOG signals recorded using i) gel based surface electrodes and ii) JINS MEME EOG glasses and compare the blink and saccade detection accuracy. An eye gaze tracker is also used to determine whether the subject was looking at the instructed cue and as another comparative method for saccade detection.

A. Subjects and experimental protocol

10 healthy subjects (8 male and 2 female, all between 21-23 years of age), having normal or corrected-to-normal vision, participated in this study which was approved by the University Research Ethics Committee (UREC) at the University of Malta. Each subject was placed approximately 50cm away from a 26inch LCD monitor, and was instructed to follow a graphical user interface program as shown in Fig. 1, implemented using Psychtoolbox [7].

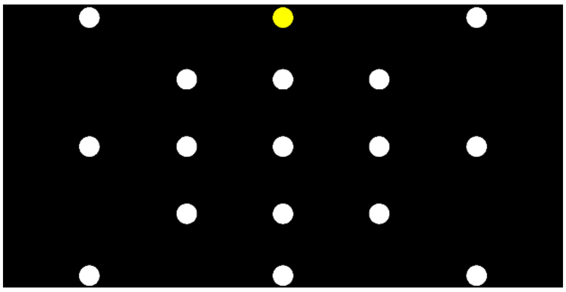

Fig. 1. Experimental protocol

During one recording session, the subject was asked to perform an eye movement from the centre position to the highlighted cue (as shown in Fig. 1) and back. Subjects were shown cues in the vertical and horizontal plane and on 45° diagonals, at two different amplitude levels. Cues placed at one and two units away from the central cue are here referred to as ‘near’ and ‘far’, respectively. The experimental protocol for each 4s trial is as shown in Fig. 2, where initially the user is asked to focus on the central cue (cue 0). A random cue is then highlighted for a duration of 1s instructing the user to direct his point of gaze (POG) accordingly. The central cue is highlighted again instructing the subject to perform a return saccadic movement to the origin. A black screen is then shown allowing the subject to blink once. A recording session involved 16 of

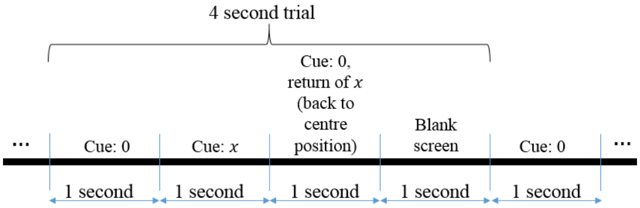

Fig. 2. Graphical user interface program

such trials in which all cues were randomly selected once. A total of five similar sessions were performed with intermittent breaks in between.

B. Signal acquisition

The overall hardware setup for the recording of eye movements was as shown in Fig. 3. EOG signals were acquired using two different recording techniques; the g.tec G.LADYbird passive surface electrodes feeding the g.USBamp bio-signal amplifier [8], and the JINS MEME EOG glasses [6]. The SMI infrared eye gaze tracker [9] was also used for the reasons outlined previously.

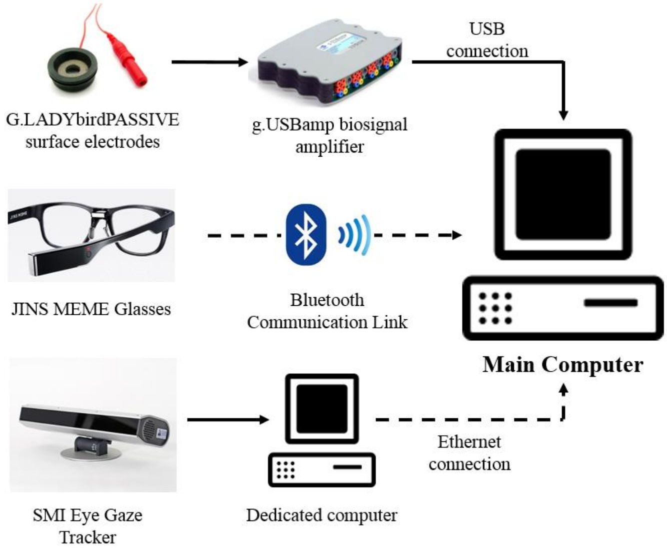

Fig. 3. Hardware setup

Fig. 4(a) depicts the conventional gel-based wired surface electrode configuration, where two pairs of electrodes are aligned vertically and horizontally around the subject’s eye. The potential difference between the vertically and horizontally aligned electrodes is then taken into consideration, yielding what are termed as the vertical and horizontal EOG components, respectively.

For the JINS MEME EOG glasses, three dry electrodes are mounted on the bridge and nose pads as shown in Fig. 4(b). In this case, the vertical V_v and horizontal V_h EOG components are calculated as follows [6]:

$$V_h = V_L - V_R; \quad V_v = V_C - \frac{V_L + V_R}{2} \tag{1}$$

where V_L, V_R and V_C correspond to the potential recorded from the electrodes as labelled in Fig. 4(b).

Fig. 4. (a) Conventional, gel-based electrode configuration, (b) JINS MEME electrode configuration

Fig. 5(a) and (b) show sample vertical and horizontal EOG components recorded from the g.tec surface electrodes and the MEME EOG glasses for various eye movements. Specifically, a number of saccadic movements (and their corresponding returns) are illustrated, namely a far-left (FL), near-left (NL), near-down (ND), near-right-up (NRU), far-up (FU) and far-right-down (FRD) saccadic movements. In addition, the manifestation of blinks (B) in the electrooculograms is depicted as well. It is clearly evident that both electrooculograms possess different signal characteristics. One example is the appearance of blink related artefacts in the horizontal components of the EOG signals recorded using the MEME, which do not occur in the g.tec acquired EOG, assuming perfectly aligned electrodes. This is mainly due to the different electrode configuration, which also results in different voltage amplitudes for the same ocular movements. In addition, as opposed to the g.tec acquired EOG data, the fast voltage decay in the signals in Fig. 5(b) reflects the cut-off frequency of the high pass filter in the MEME glasses as opposed to that of the g.tec equipment where as shown in Fig. 5(a), the signals are still not at zero when the return saccade occurs.

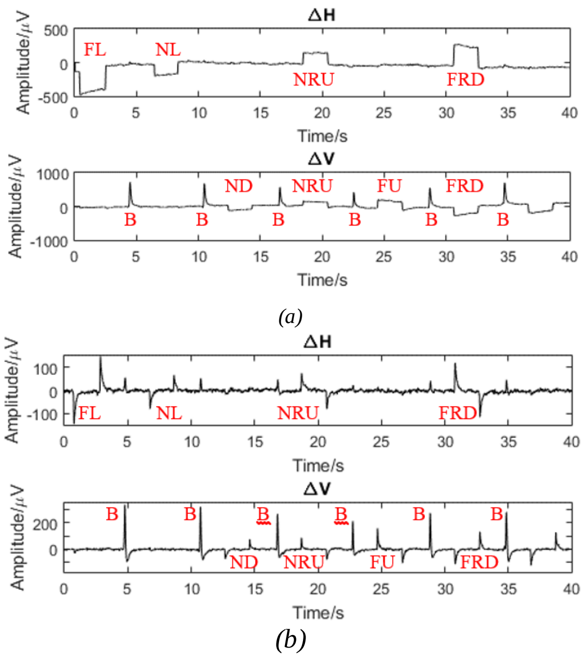

Fig. 5. Sample horizontal and vertical EOG components acquired using (a) g.tec passive surface electrodes and (b) JINS MEME EOG glasses

C. Saccade and blink detection algorithm

As a pre-processing step, the EOG signals captured both with the g.tec surface electrodes and the MEME glasses were passed through a moving average filter to reduce the noise level within the respective EOG data. The derivative of the EOG signals captured through the g.tec surface electrodes was then computed to reduce the saccadic movement to a large, easily detectable peak in the resultant signal. Such a processing step was not necessary for the EOG signals captured by the MEME glasses as they already had these characteristics.

The detection of the different saccadic eye movements was based on a thresholding algorithm. Specifically, five thresholds were required to distinguish between two horizontal positions (near or far), two vertical positions (near or far) and eye blinks. As shown in Fig. 6, thresholds T_{hNF} and T_{vNF} were required to distinguish between near (N) and far (F) saccadic movements in the horizontal (H) and vertical (V) components, respectively, while thresholds T_{h0N} and T_{v0N} were set to distinguish between a fixation (0) and near saccadic movements in the same respective components. The fifth threshold T_{vFB} was needed in the vertical component to discern between far vertical movements and blinks (B).

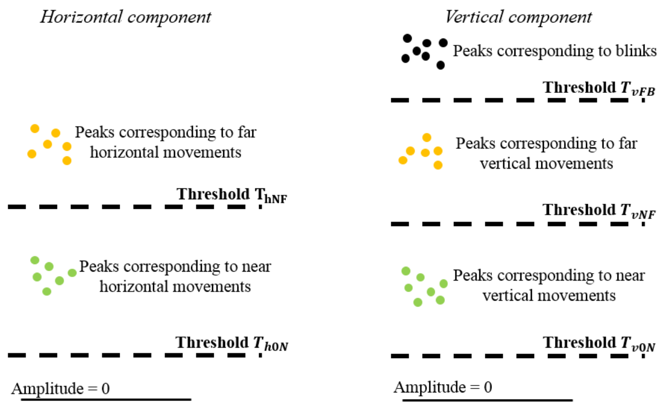

Fig. 6. The five thresholds in the classification algorithm

Classification is performed by comparing the extracted peaks, P_H and P_V, obtained from the horizontal and vertical components, respectively, with the five thresholds. Specifically, values for S_H and S_V, indicating the number of steps moved in the horizontal or vertical directions are computed according to the flowchart in Fig. 7. In this case 0 represents no movement, 1 and 2 represent near and far saccadic movements respectively, and 3 represents blinks. Finally, depending on the values of S_H and S_V, the type of movement performed by the subject is determined. It must be noted that when a blink was detected in the vertical component, any eye movements in the horizontal component were completely ignored. This approach was taken to mitigate the blink artefacts recorded by the MEME glasses in the horizontal EOG component (shown earlier in Fig. 5(b)). Furthermore when an invalid classification was made as no cue was possible at that location, re-classification was carried out giving preference to the horizontal component label. A (2,1) label is thus mapped to a (2,2) label and a (1,2) label is mapped to a (1,1) label.

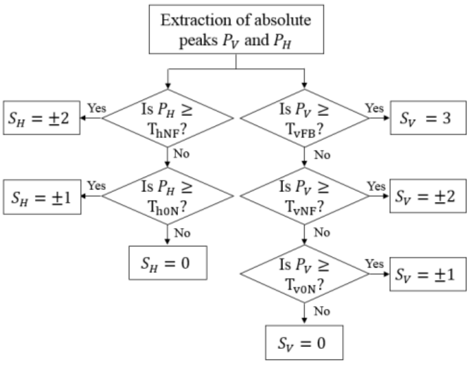

Fig. 7. Classification algorithm flowchart

D. Threshold determination algorithm

To determine the five thresholds needed for the classification algorithm, sample peak EOG values corresponding to the different types of eye movements are collected during a training session. Movements are grouped into five different classes, namely far and near vertical peaks, far and near horizontal peaks, and vertical peaks corresponding to blinks.

The median of each class of peaks is then found and the threshold is placed at some optimal position, depending on the value of k_x, between the two respective class medians as shown in Fig. 8. Specifically, the threshold location setting is governed by:

$$T_x = med_{lower} + k_x(med_{higher} - med_{lower}) \quad (2)$$

where T_x represents any of the five thresholds, med_{lower} and med_{higher} are the median amplitude values of the neighbouring lower and higher classes, respectively, and k_x, which can vary between 0 and 1, gives the exact location of T_x between the two medians. The median was considered as it is immune to any outlier class peaks.

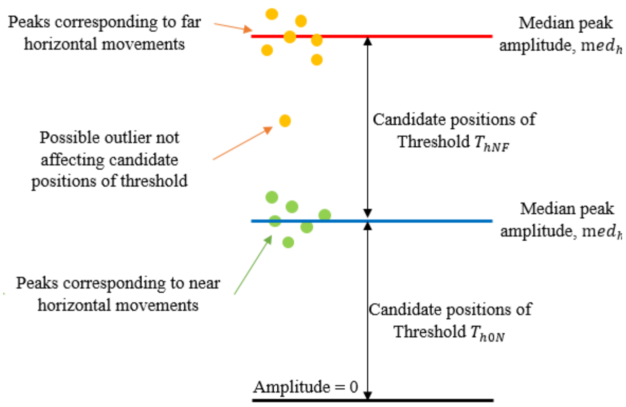

Fig. 8. Candidate threshold locations in the horizontal component

E. Classification of eye-gaze tracking data

The eye gaze tracker used in this work gives (x,y) Cartesian coordinate locations of the detected POG of the subject. During a saccade the (x,y) coordinates traverse from a particular source to a destination with the main activity focused at the saccade destination. Taking the median (x,y) coordinate within a given window and checking on which tile in the Cartesian space, as shown in Fig. 9, this falls, allows the labelling of the saccadic movement performed.

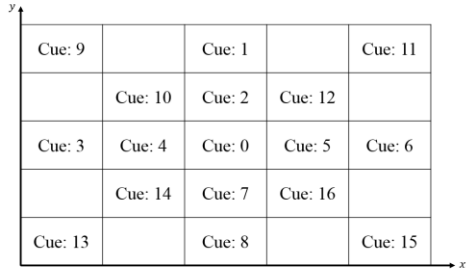

Fig. 9. Tile layout configuration for eye gaze tracker classification

F. Results

The first goal of this analysis was to compare the saccade (SA) and blink (BA) percentage accuracy obtained using EOG data recorded from the g.tec surface electrodes and the MEME EOG glasses. In each case, subject specific thresholds were determined for the classification algorithm. This was done by varying the k_x value for each threshold between 0 and 1, in steps of 0.1, and finding that combination which gave the highest saccade and blink accuracy when using a five-fold cross validation technique. Table 1 shows the results for each of the 10 subjects where it is clear that the EOG data acquired through the g.tec surface electrodes achieved a 5% average higher SA and a 2.88% average lower BA when compared with the results of the MEME glasses. A statistical t-test however showed that these differences are not significant with p = 0.3513 and p = 0.1187, respectively. These results are also comparable to those of the eye gaze tracker where an average 77.75% SA was obtained.

Since the procedure to find the subject specific thresholds is computationally intensive, use of average k_x value settings (AS) across subjects was investigated as well. Fig. 10 shows the saccade and blink percentage accuracies obtained in this case and compares them with the average results obtained using subject specific (SS) thresholds. The results show that for all recording techniques, there is only a marginal degradation of

TABLE 1. SACCADE ACCURACY (SA) AND BLINK ACCURACY (BA) PERCENTAGES FOR SIGNALS GATHERED USING G.TEC SURFACE ELECTRODES, JINS MEME EOG GLASSES AND THE SMI EYE GAZE TRACKER

Device	***g.tec wet surface electrodes***		***JINS MEME EOG glasses***		***Eye gaze tracker***
Subject	***SA(%)***	***BA(%)***	***SA(%)***	***BA(%)***	***SA(%)***
S1	95.00	100.00	78.13	100.00	68.75
S2	79.38	100.00	62.50	97.50	97.50
S3	76.89	97.50	76.88	100.00	93.75
S4	90.63	81.25	86.88	93.75	93.75
S5	93.13	100.00	63.75	100.00	93.75
S6	55.63	95.00	83.75	95.00	66.88
S7	66.88	96.25	76.25	98.75	75.63
S8	85.63	93.75	70.00	95.00	74.38
S9	63.75	83.75	61.25	96.25	38.75
S10	76.88	100.00	74.38	100.00	74.38
Average	**78.38**	**94.75**	**73.38**	**97.63**	**77.75**

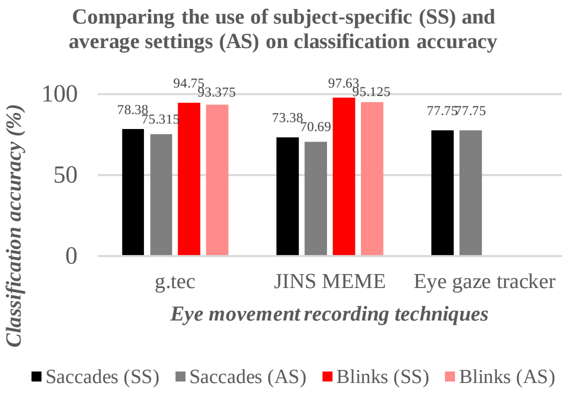

Fig. 10. Classification accuracy

detection performance, specifically 3.06% and 2.69% average degradation of saccadic detection performance, and 1.37% and 2.50% of blink detection performance, for g.tec and JINS MEME, respectively. This represents the trade-off that needs to be paid for a more generic classification algorithm.

III. Online Study

The online study built upon the results of the offline study and was aimed at testing the JINS MEME glasses as opposed to the g.tec surface electrodes to control a real time speller application using EOG. A novel speller design was implemented where the letter selections are again based on near or far, horizontal, vertical or diagonal movements, thus moving away from the standard, unnatural, discrete-step speller interfaces found in the literature [3, 5]. The speller interface and the performance of the 10 subjects who tested the application are given in the following sections.

A. EOG based speller interface

The basic interface of the menu-driven EOG based speller is shown in Fig. 11. The main menu clusters letters, numbers or punctuation symbols in groups of four which are positioned across the screen such that i) more icons are placed along the horizontal to cater for the landscape screen display and increase the chance of correct detection, ii) it allows the subject to freely hover the centre of the screen without issuing a command, hence addressing the Midas touch problem, and iii) have less icons on each menu, thus increasing the classification accuracy. The speller consists also of several sub-menus where letters and control options are arranged in a cross format as shown in Fig. 11(b) and (e), whereas numbers (Fig. 11(c)) and punctuations (Fig. 11(d)) are arranged in the same format as the main menu.

Interfacing with the EOG based speller followed the sequence of events shown in Fig. 12. The first 2s were allocated to search for the required icon. A red centre cue was then presented for 0.7s to ask the subject to initiate the required saccadic movement from the centre of the screen, similar to what was done in the offline study. Movement was to be carried out within 0.5s as soon as the red cue turned green. The EOG data recorded during this 0.5s interval was then classified as explained earlier in Section IIC and feedback was given to the subject by highlighting the classified icon in green as shown in Fig. 13(a). If the classification is correct, the user validates this

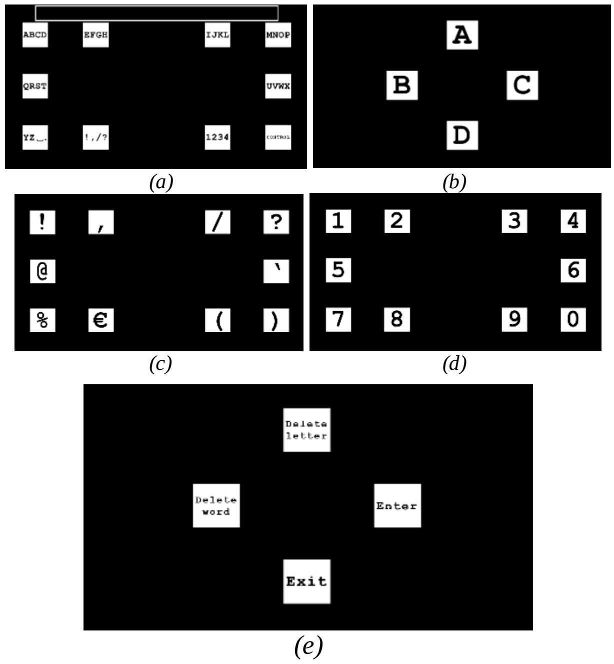

Fig. 11. (a) Main menu, (b) Letter sub-menu (c) Punctuation menu, (d) Numbers menu, and (e) Control menu

choice by performing a fixation for a duration of 0.5s. Else, the user can cancel the choice and restart the process by performing a random ocular activity (saccade or blink).

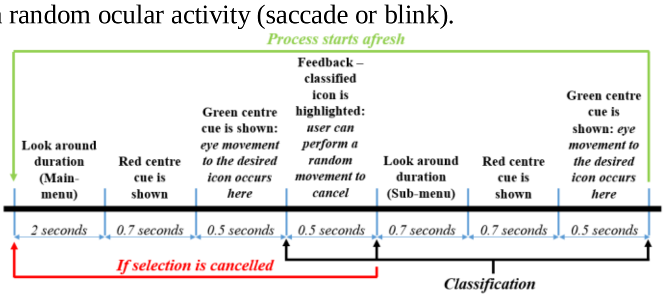

Fig. 12. Timing scheme for the EOG based speller

Successful classification and validation leads to the corresponding sub-menu where again the user is given time to search the required icon. In the sub-menus comprising of only four icons, a searching duration of 0.7s was allocated and no feedback was given since in this case the final choice will be outputted in the writing bar as shown in Fig. 13(b). For numbers and punctuation sub-menus, since they have the same layout as the main menu, the same procedure of choosing and validating from the main menu was adopted.

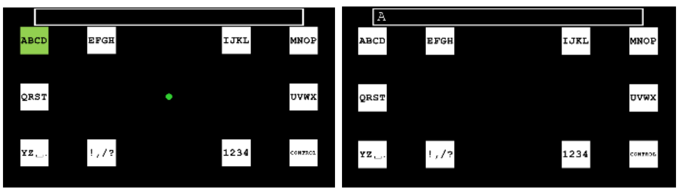

Fig. 13. (a) Validation, and (b) outputting the user's selection in the writing bar at the top of the main menu

One other consideration taken by the system is the case when the subject is at the main menu (or in the numbers and punctuation sub-menus) but has not identified the required icon within the 2s allocated interval. To avoid entering into unnecessary sub-menus, the subject was asked to keep focused at the central green cue to restart the process and be allocated another 2s icon searching interval.

Based on this framework, a subject can make a selection in 5.6s (equivalent to 10.71 letters/minute). It is important to point out that the 0.5s eye movement interval was set after analysing the subjects' average reaction time, and the other time intervals were based on finding a compromise between typing speed and the practicality of using the application. These intervals can however be changed to the user's choice, depending on his/her familiarization with the application. It is expected that the overall selection time can be reduced with user experience.

B. Results

The same ten subjects used in the offline study assessed the performance of this real-time EOG based speller, using the g.tec surface electrodes, the JINS MEME glasses, and also the eye gaze tracker. Table 2 outlines the average time in letters per minute (lpm), denoted by the writing speed (WS), obtained by each subject when asked to write 'WATER', 'GOOD MORNING' and 'DAY 0', using any of the eye movement capturing techniques. When the keyboard was operated using either of the EOG modalities, the eye gaze tracker was also used in parallel to be able to discern between subject-related errors and algorithm misclassifications. Specifically, this was done by verifying whether the user was focusing his POG on the expected cue prior to penalising the system in terms of accuracy.

TABLE 2. WRITING SPEED (WS) AND CLASSIFICATION ACCURACY (CA) OF THE REAL-TIME EOG BASED SPELLER

Device	***g.tec wet surface electrodes***		***JINS MEME EOG glasses***		***Eye gaze tracker***
Subject	***WS (lpm)***	***CA (%)***	***WS (lpm)***	***CA (%)***	***WS (lpm)***
S1	8.62	96.03	7.52	93.38	8.15
S2	5.63	81.65	7.21	94.55	8.71
S3	8.16	95.83	6.42	87.00	8.73
S4	6.76	87.91	8.73	98.48	7.24
S5	5.52	89.08	7.30	94.78	5.84
S6	5.39	79.52	8.11	98.55	8.25
S7	4.79	74.90	7.04	77.72	6.98
S8	7.05	83.82	6.12	93.44	6.06
S9	5.05	63.96	6.07	79.39	6.19
S10	7.40	91.35	6.53	88.59	7.54
Average	***6.44***	***84.41***	***7.11***	***90.59***	***7.37***

As observed in Table 2, the classification accuracy (CA) is high for both the g.tec surface electrodes and the MEME glasses with the latter obtaining an average of 6.18% higher accuracy. The writing speed using EOG signals was found to be higher for the MEME glasses, and is comparable to that obtained using an eye gaze tracker. Analysis showed that the average writing speed is relatively lower than the theoretical value of 10.71lpm as the subjects did not have enough time to familiarise themselves with the speller interface. In fact, similar tests performed on a different subject who had more experience with this interface resulted in a writing speed of 9.45lpm and 8.81lpm using g.tec equipment and MEME glasses, respectively. The corresponding classification accuracy was of 100% and 98.81%. Furthermore, a writing speed of 9.10lpm was achieved when the keyboard was interfaced using the eye gaze tracker.

IV. CONCLUSION

This work has investigated the use of the wireless JINS MEME EOG glasses, comprised of three dry electrodes placed on the bridge and nose pads of a standard pair of glasses, for an eye based assistive application. When comparing the blink and saccade accuracies obtained for the EOG signals captured through the MEME glasses and a set of wired, gel based set of electrodes using the conventional EOG electrode setup, comparable results were obtained. An offline study involving 10 participants showed that a saccadic accuracy of 73.38% and a blink accuracy of 97.63% was achieved, using the proposed thresholding classification algorithm. A novel, real-time EOG based speller was also presented and average results over 10 subjects showed that a writing speed of 7.11lpm was achieved, with 90.59% accuracy, using the MEME glasses. This compared well with the writing speed obtained using a camera based eye gaze tracker. This performance is expected to improve as the subjects become familiar with the speller.

V. ACKNOWLEDGEMENT

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