A STUDY OF THE INFORMATION CAPACITY OF HUMAN EYE MOVEMENT FOR AUGMENTATIVE COMMUNICATION

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Abstract

Eye tracking technology offers a potentially revolutionary approach to aiding people with disability by permitting them full use of personal computers. Unfortunately, existing eye tracking applications do not adapt to a user's particular needs and thus exclude many who could thus gain from the technology. The first step toward correcting this problem is the characterization of the individual's ocular control, considering both eye movements and fixations. This paper proposes a preliminary experiment, aimed at this goal, to measure fixational stability and accuracy, as well as movement speed. We present the subject with a sequence of points, recording the point-of-regard during fixation and the movement time in between points. We can analyze the dependence of fixation on position and the dependence of movement on distance and direction. By changing various experimental parameters, we can also investigate the effects of visual feedback, calibration scheme, color, and time on both fixation and movements.

Background

To provide the best opportunities for vocational rehabilitation, an eye tracking package must consider the various idiosyncrasies of the individual's eye gaze. For instance, should the person have difficulty fixating in the bottom left corner of the screen, buttons in that region should be larger or should perform functions rarely needed. Or, if the person fixates poorly but can shift gaze quickly, the interface should employ motion-sensitive activation schemes, as opposed to the usual dwell-time schemes. As motivated by Rosen (4), we must develop an assessment procedure in order to take full advantage of eye tracking's potential as an augmentative communication device. By taking the client's strengths and weaknesses into account, eye tracking technology can make maximum use of his/her capabilities.

Unfortunately, the eye tracking applications that do exist in the rehabilitation literature usually use a *fixed* format. For instance, Hutchinson (3) described ERICA, the Eye-gaze-Response Interface Computer Aid developed at the University of Virginia. The authors used a pupil-corneal reflection eye-tracker, interfaced with a personal computer, using the standard fixation-activated interface. The user interface divided the display into a 3x3 matrix, so that when the user fixated within one area of the grid for approximately two to three seconds, a tone sounded and a mark appeared in the region. The small number of target areas allows users with poor fixational accuracy to still use the system. On the other hand, users with accurate fixations still had to make many selections to indicate just one letter. Even experienced users had to spend 60 minutes entering one page of text.

Foulds (2) innovated the Etran eye movement encoding technique used in computer software developed at Tufts Rehabilitation Engineering Center. The Etran, originally implemented on a clear plastic board, coded 64 characters and important words into sequences of two successive motions (either left, right, up, down, or along the diagonals). Because of its movement-dependent scheme, Etran avoided any potential fixational difficulties. The authors predicted that such a computerized system, using an entire keyboard with a syllabary of 500 or more selections, could yield rates of 60 words per minute. This rate is based upon the assumption of errorless selections at maximum speed. Many of the potential users we studied have difficulty in initiating accurate eye movements, which would imply a lower rate due to errors.

Cleveland (1) discussed potential applications of the better known LC Technologies Eyegaze Eye-tracking system. The paper is mainly a summary of the system and projections about its application but does not provide much detail about the quality of the performance of the system. Several of the problems we found with the LC system include the fact that most of the activation areas (icons) on the display were unnecessarily small. For instance, the communication board only uses half of the available screen, requiring unreasonably precise fixation. In fact, a client with any amount of head movement, leading to small instabilities in fixation, would have little success activating the small icons. Unfortunately, the system does not allow modifications to the size of the keys, nor to the layout of any interface.

The first step in developing an eye-tracking package responsive to the individual's unique capabilities is to characterize the information transfer ability of her/his eye. To do so requires a standard evaluation procedure that will produce an *eye movement and fixation profile* of the individual user. The user will run through a short series of tests, aimed at characterizing his/her fixations and eye movements. With the information contained in the client's eye movement profile, we could design customized interfaces.

Experimental Design

Hardware

Currently, we are using the RK-520PC Auto calibration System of ISCAN, Inc. (Cambridge, MA), running on an IBM-compatible 386 personal computer. An infrared camera, coupled with a light source and infrared filter and run by the ISCAN RK-464 Camera Control Unit, produces the eye images used by the RK-520PC to calculate the center points of the pupil and corneal reflection. The calibration process, during which the user looks at selected (either five or nine) fixed points, results in a mapping between the pupil and corneal reflection locations and the intended point of regard (POR). The user views a 20-inch color monitor of an Apple Macintosh Quadra 950, which receives the POR data through a NB-DIO-96 digital interface board from National Instruments (Austin, TX).

Procedure

To produce this eye movement and fixation profile, we must analyze the user's fixational capabilities, in terms of accuracy, stability, and positional dependence. To do so, we present the user with a target, a small colored dot on the monitor, and define a circular tolerance region around it. The subject has acquired the target when he/she maintains POR within the tolerance region for a certain amount of time, which we define as the minimum fixation period. Then, the system records a fixed number of POR samples. Upon completion of the recording, the target moves to a new location on the screen and the process repeats itself.

We must also analyze the user's eye movement capabilities. The fixation study's experiment allows a suitable framework for understanding movements as well. Once the data collection on one location concludes and the target moves to its new location, we can measure the time for the user's POR to cover the distance in between. We exclude the latency time for the eye to begin its motion by starting the clock when the POR exits the tolerance region about the old target location. We stop the clock on entry to the new tolerance region. If the user's POR should exit the new tolerance region before the minimum fixation period elapses, the clock will continue to run. Therefore, we keep timing through overshoots and any other instabilities before the subject attains the target.

It is important that we decouple the eye-tracking system from perceived eye movements. We expect some displacement between the POR data and the target point, even after the user has attained stable fixation. We must measure this displacement and determine its positional dependence.

To make the data amenable to analysis, we constrain the fixation points to a rectangular grid and construct the sequence of points to guarantee that each point-point transition appears a minimum number of times. This guarantees, in turn, that each point also appears a minimum number of times.

Analysis

After the subject has run through the entire sequence, the application writes the results to disk for future analysis. When viewing the results, the application processes the data, calculating the mean point-of-regard and average distance from the mean for each point, as well as the average movement time for each transition. We can measure fixational accuracy by calculating the bias (the distance between the target and the mean POR for that point). It can also present the data graphically, plotting all the collected data points, as well as the mean point-of-regard and a circle representing the average deviation from the mean.

Parameters

From this data we can analyze the effects of various parameters on fixational and movement capabilities. For instance, by moving the fixation points across the screen, we can analyze the dependence of bias on position and the dependence of movement times on direction and distance. In addition, we can run the experiment with various levels of visual feedback. During the calibration and practice portions of the experiment, the ISCAN output appears as a small inverted rectangle on the Mac window. During data collection, we can turn the cursor off to study the effect of its visibility. The tolerance region's visibility is also optional, to allow analysis of its effect.

We can also investigate various factors at the eye-tracking end of the system. For instance, we will measure the differences between the five- and nine-point calibration techniques. In addition, the tolerance region, grid of test points, and the dimensions and colors of the prompt and POR cursor are all modifiable, permitting analysis of the importance of these parameters.

By varying the time parameters, we can investigate the eye's stability and accuracy. By increasing the number of samples taken per test point, the subject will fixate for longer periods of time, leading to information on fixational stability. We can also vary the number of repetitions and analyze fatigue effects on fixation and movement times.

Results

Results obtained from 10 to 20 subjects will be presented. We will utilize the above protocol, varying the parameters such as visual feedback and calibration scheme to investigate their impact on fixational accuracy and movement time.

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