TITLE: Real-Time Non-Intrusive Assessment of Viewing Distance during Computer Use

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ABSTRACT

Purpose: to develop and test the sensitivity of an ultrasound-based sensor to assess the viewing distance of visual display terminals operators in real time conditions.

Methods: A modified ultrasound sensor was attached to a computer display to assess viewing distance in real time. Sensor functionality was tested on a sample of 20 healthy participants while they conducted four 10-minute randomly presented typical computer tasks (a match-three puzzle game, a video documentary, a task requiring participants to complete a series of sentences and a predefined internet search).

Results: The ultrasound sensor offered good measurement repeatability. Game, text completion and web search tasks were conducted at shorter viewing distances (54.4 cm [CI95% 51.3 to 57.5 cm], 54.5 cm [CI95% 51.1 to 58.0 cm] and 54.5 cm [CI95% 51.4 to 57.7 cm], respectively) than the video task (62.3 cm [CI95% 58.9 to 65.7 cm]). Statistically significant differences were found between the video task and the other three tasks (all $p < 0.05$). Range of viewing distances (from 22 to 27 cm) was similar for all tasks ($F = 0.996$; $p = 0.413$).

Conclusions: Real-time assessment of the viewing distance of computer users with a non-intrusive ultrasonic device disclosed a task-dependent pattern.

KEY WORDS

Computer; Myopia; Ultrasound sensor; Viewing distance; Visual fatigue

Recent decades have witnessed a constant increase in the number of computers at home and at the workplace, with a reported 78.9% of US households owning a computer in 2012[1] and an estimated 2 billion computers worldwide in 2014. Computers and visual display terminals (VDT), ranging from smartphones to desktop computers and TVs, are ubiquitous in developed countries, and serve as a platform for internet access, gaming, communication, entertainment and work.

Hultgren and Knave[2] first documented visual fatigue in computer workers in 1974, and the term Computer Vision Syndrome (CVS) was later introduced to describe a constellation of body, ocular and visual symptoms affecting this population. These manifestations, which are particularly well documented in desktop computer users, may include headache, tired eyes, irritation, dry eyes, blurred vision at near or distance (after prolonged near vision work) and double vision.[3-7] Symptoms are influenced, among other factors, by actual VDT exposure time, type of screen, background luminance, glare sources and distance from the screen.[8-11]

In particular, viewing distance in computer users is the focus of interest of many studies on CVS and ergonomics, even though there is a large discrepancy regarding the actual definition of correct viewing distance, with a range from 30 to 100 cm. Indeed, short viewing distances have been related to an increased visual strain,[8,12] with users reporting fewer symptoms of visual fatigue at 100 cm than at 50 cm when font size is adjusted to provide the same visual angle, and regardless of individual dark-focus point (that is, resting level of accommodation and vergence, which is about 67 cm).[13] In this regard, it is not surprising that the various international standards also recommend different viewing distances.[14] For instance, the EN ISO 9241-5[15] suggests a viewing distance of 60 cm ± 15 cm; the US MIL STD 1472-C[16] states an average distance of 40 cm for continuous viewing and a minimum distance of 25 cm for intermittently viewed displays; finally the DIN 66234[17] proposes a range between 45 and 60 cm, but recommends 50 cm when frequent refixations are necessary between keyboard or source documents and VDT.[18]

In addition, viewing distance has been found to depend on such factors as size and resolution of visual stimuli, type of task[19] and screen/text color combination. Thus, for example, given the recommendation of adopting a 3x acuity reserve,[20] a shorter viewing distance is associated with prolonged viewing of texts in fonts of small size. Similarly, white text on blue background was found to result in a greater viewing distance (60.3 cm) than same size red text on green background (47.4 cm), with observers viewing text at the commonly employed black on white combination at an average distance of 56.9 cm.[12]

It is also relevant to mention that myopia onset and progression, defined as an increase in myopia of more than -0.25 dioptres (D) and up to -1.00 D per year,[21,22] have been related to both viewing distance for near work and the amount of time spent conducting near work tasks. [23-25] In view of the global socio-economic impact of myopia,[26] it may be of interest to accurately monitor viewing distance in order to gain a better understanding of the contribution of distance as a possible risk factor of and to develop strategies to prevent myopia onset and progression.

Considering the documented association between viewing distance, visual fatigue, CVS and myopia onset and progression, the current lack of an affordable, non-intrusive means of determining viewing distance in real time is unexpected. In this regard, only two previous attempts at measuring viewing distance in real time were uncovered in our literature review. On the one hand, Eastwood-Sutherland and Gale developed an infra-red system consisting of a video camera and infra-red LED markers attached to the forehead or the back of the head of VDT operators.[19] With this instrument, the authors were able to document changes in viewing distance with a temporal resolution of 7 Hz, noting a link between the type of activity being conducted and distance, with internet browsing resulting in shorter viewing distances than writing a text. On the other hand, Piccoli and co-workers designed an ultrasound emitter (at 40 KHz), coupled with a receiving sensor placed on the operator's forehead[27] with which the authors reported an accuracy of ±0.5 cm and a maximum temporal resolution of 10 Hz when measuring viewing distance on a sample of VDT users.

It may be noted that both approaches require sophisticated equipment and controlled experimental settings (placing a sensor or marker on the forehead of the VDT operator) that prevent their simple implementation in a real life environment such as an office or school. It was therefore the main goal of the present study to develop an automated sensor, based on ultrasound technology, easily attachable to any VDT and adaptable to any working environment, as well as the accompanying software, to measure viewing distance of computer users in real time conditions. To test whether our sensor was able to detect small changes in viewing distance, measurements were conducted on a sample of participants performing four typical computer tasks. As previous investigators have described an influence of the type of task on viewing distance,[19] this research question was also explored.

METHODS

Study Sample

A group of 20 volunteers was recruited to participate in the present study, which took place in the facilities of a high school in the city of Lleida (Spain) between April and May 2014. Participants were selected at random from those attending a word processor workshop in the computer classroom. Inclusion criteria were age between 14 and 25 years (inclusive), spherical component of the refractive error between +5.00 and -5.00 D, ocular astigmatism < -2.00 D and corrected monocular and binocular visual acuity at distance and near equal or better than 0.0 logMAR. Patients presenting any eye disease, dry eye, binocular vision abnormalities, amblyopia or anisometropia > 1.00 D were excluded from the study, as were those showing low cooperation with the study protocol, defined as the inability to comply with the given instructions, mainly to conduct each task during the predetermined 10-minute interval and in silence. Both spectacle and contact lens wearers were included in the study.

All participants provided written informed consent after the nature of the study was explained to them, although details regarding the specific aim of the investigation (distance evaluation) were not revealed until the completion of the study. Parental consent was obtained for those participants who were underage. The study was conducted in accordance with the Declaration of Helsinki tenets of 1975 (as revised in Tokyo in 2004) and received the approval of the Ethics Review Board of the Hospital Universitari Mútua de Terrassa.

Instrumentation: Distance Sensor

The distance sensor was developed specifically for this study by an interdisciplinary team composed by members of the Departments of Automatic Control and Optics and Optometry of the Universitat Politècnica de Catalunya. This device includes hardware and software components. Essentially, the hardware measurement subsystem is a modified ultrasonic range finder (SFR02, Devantech Ltd. [Robot Electronics], Norfolk, England), which is a small distance sensor, typically used in robotic applications, with a range from 0.15 m to 6 m within its detection field (**Figure 1**). It must be noted that detection sensitivity decreases with distance from the sensor, although it remains high within the range of distances that are relevant for the purpose of the present study (see **Figure 1**). This sensor uses two standard communication interfaces (I2C and serial) which are not very common in personal computers. Therefore, an adapter was employed to convert the I2C protocol to USB and to supply power to the device. The two boards with the main sensor and the I2C to USB adapter are small enough to fit into the casing of a standard webcam, as shown in **Figure 2**, which is convenient to mount the whole device on a computer display.

The software processing subsystem of the distance sensor is programmed in Java (Oracle Corporation, Redwood Shores, CA), allowing for its portability among different operating systems. Although the software can work both remotely and on-site, in the first version of the sensor only the on-site functionality was considered. Three main operations are included in the software: sensor set-up, distance acquisition and display and data recording. The set-up process is based on the software provided by the manufacturer and is almost plug-and-play. The automatic calibration of the sensor is executed as soon as the application is started, whereupon, according to the manufacturer, the sensor does not require any further calibration, relying instead on an automatic tuning algorithm working continuously in the background to ensure correct measurements. Distance is measured every 7 seconds by default, although this time interval may be adjusted as necessary, with a maximum temporal resolution of 100 ms. All measurements are stored in a file in which local date is recorded, as well as the local time associated with each measurement. Sensor resolution is 1 cm.

The software may be configured to present a red or green notification at the right lower edge of the screen when observers are beyond or within the recommended viewing distance, respectively. This distance may be adjusted at any value, for example at 40 cm.

Procedure

Notwithstanding the automatic continuous calibration described by the manufacturer, prior to monitoring viewing distance in human participants in the classroom, a preliminary study was conducted to investigate whether the sensor offered repeatable recordings at various controlled testing distances. In this occasion, an object was placed at exactly 20, 40, 60, 80 and 100 cm from the sensor and 10 consecutive measurements were obtained of each distance over the course of approximately one minute. The mean and variance of the readings obtained at each distance were determined. The range of tested distances (20 to 100 cm) was selected as this is the range that may be considered useful for the purpose of monitoring viewing distance of VDT operators.

Participants were recruited following a complete optometric examination in accordance with the inclusion and exclusion criteria. At the beginning of each session, participants were instructed and assisted to sit in front of the computer at a distance of 60 cm and to adjust the height of their chairs and configuration of armrests to ensure comfort and to align the top of the screen at eye level. The inclination angle of the screen was of 100 degrees from the horizontal plane of the computer desk. Computer screens were 20 inch liquid crystal displays (TFT-LCD) set to a resolution of 1280 per 1024 pixels, 32 bit colour configuration and 75 Hz refresh rate. Measurements were simultaneously conducted on three computers adjusted to exactly the same configuration.

Four different typical computer tasks were presented to the participants in a random order. Tasks consisted in a popular match-three puzzle game, a video documentary, a task requiring participants to complete a series of sentences and a predefined internet search. Display luminance was approximately equivalent for all tasks (about 210 cd/m^2, as measured with a light meter [Gossen Mavolux 5032; Gossen Foto- und ichtmesstechnik GmbH, Nürnberg, Germany] with the luminance attachment). When necessary, tasks were completed with the aid of a keyboard and mouse combination. Task duration was set at 10 minutes and distance from the screen was readjusted at 60 cm between tasks. As noted above, for each 10-minute task and participant, distance measurements (in cm units) were recorded every 7 seconds. The average distance for each task and participant was then calculated, as well as the corresponding range of viewing distances, defined by the difference between maximum and minimum viewing distances (in cm units) recorded during that particular 10-minute interval.

Room illuminance was provided by indirect lighting in order to avoid glare sources, and was maintained at about 500 lx. Room temperature and humidity were constantly monitored throughout the experimental sessions and remained approximately constant at about 22°C and between 53 and 58%, respectively. Sessions took place during the mornings of consecutive days. All measurements were conducted while participants used their habitual visual correction.

Data analysis

Statistical analysis of the data was performed with the SPSS software 19.0 (IBM Corp., NY, US) for Windows. All data were examined for normality using the Kolmogorov-Smirnov test, which revealed normal distributions for all variables. Therefore, descriptive statistics present results regarding distance and range as the averages of all participants for each task and the corresponding standard deviation (SD). An analysis of variance test (ANOVA) was subsequently employed to explore the statistical significance of the differences between the four tasks in average viewing distances and average range of distances and, when statistical significance was found, a *post-hoc* Bonferroni test was used for pair-wise analyses of the differences between tasks in these parameters. Possible associations between the average viewing distances of the different tasks were investigated with a Pearson's test of correlation. A p-value of 0.05 or less was considered to denote statistical significance throughout the study.

RESULTS

Study sample demographics

Twenty young subjects participated in the study (11 were female), with an age of 17.07 ± 3.14 years (mean ± SD). Ten participants had myopia, 6 hyperopia and 4 were emmetropes, with an average spherical refractive error of the study sample of -1.23 D (± 0.72 D).

Sensor operability

Sensor repeatability at the controlled distances of 20 cm, 40 cm, 60 cm, 80 cm and 100 cm was good. Maximum and minimum variance values of 0.16 cm at 100 cm and of 0.09 cm at 20 cm, respectively, were obtained. The average of the 10 measurements was centered at the corresponding distance under evaluation.

Viewing distance in different tasks

Viewing distance values for each task are summarized in **Table 1**. Results are presented as average distance (**Figure 3**) and range of viewing distances (difference between maximum and minimum viewing distance) (**Figure 4**) for each task. It may be observed that, although all participants started their tasks at a set distance of 60 cm, viewing distance changed during the 10-minute period. Thus, whereas during the game, text completion and web search tasks a slightly shorter viewing distance was measured (54.4 cm [CI95% 51.3 to 57.5 cm], 54.5 cm [CI95% 51.1 to 58.0 cm] and 54.5 cm [CI95% 51.4 to 57.7 cm], respectively), participants settled at an average of 62.3 cm [CI95% 58.9 to 65.7 cm] when tasked with watching a video. When submitted to an ANOVA analysis, a statistically significant difference was found between average distance values as a whole ($F = 5.447$; $p = 0.002$). Further pair-wise exploration of this difference with a Bonferroni test revealed statistically significant differences between the video task and the other three tasks (p values of 0.008, 0.009 and 0.010 for the game, text completion and web search tasks, respectively).

Range of viewing distances was similar for all tasks ($F = 0.996$; $p = 0.413$), with values from 22 to 27 cm. Therefore, even if mean viewing distance was close to the initial set value of 60 cm, within each 10 minute evaluation interval participants did not remain stationary at the initial distance, placing themselves alternately at shorter and longer distances while conducting their particular tasks. For instance, distance measurements for one specific participant while performing the video and text completion tasks are plotted in **Figure 5**. The horizontal line at 40 cm denotes a minimum recommended viewing distance. It may be observed that this participant had a preferred viewing distance for each task: about 54 cm for the video task and about 40 cm while conducting the text completion task. However, during the 10-minute duration of the task the participant kept changing to shorter or longer distances from the display, sometimes going under the threshold of 40 cm. From this information it is possible to measure the range of distances that a given participant uses during the development of each task. It is also noticeable from **Figure 5** that approximately the first ten measures are more irregular than the other set of measurements. This pattern was common for all tasks and participants, suggesting that during the first minute of each task the participant is deciding on the most comfortable viewing distance.

Finally, upon examining possible associations between the variables under study with the Pearson correlation test, a moderate to strong statistically significant positive correlation was found between the average viewing distances of many of the tasks (**Table 2**), that is, in general, participants opting to complete one task at a shorter viewing distance also preferred shorter distances for the other tasks.

DISCUSSION

The main objective of the present study was to develop an affordable (price of each sensor is about 10$), non-intrusive method to evaluate viewing distance of VDT users and to test it on a sample of participants undertaking four typical computer tasks. Previous efforts at assessing viewing distance in real time in computer users rely on either infrared[19] or ultrasound complex systems,[27] requiring part of the equipment, or at least some markers, to be placed on the forehead of the participants. Therefore, it is believed that these approaches lack operability in that they involve non-trivial installation and configuration, and may interfere with the task being conducted by the participants. The present approach is almost plug-and-play, and no expertise is needed to upload the software to the local computer and to keep the sensor running silently in the background while it monitors viewing distance. In fact, the software also contemplates a remote mode of operation with which a central server computer may govern several sensors installed at different local computers without the need for any further local software configuration. In this regards, it may be easily implemented in a working or academic environment, as well as at home on a personal computer.

It may be noted that in its current configuration the instrument lacks the temporal and spatial resolution of previous devices, with measurements conducted every 7 seconds and a maximum distance resolution of 1 cm. However, within these limitations, the sensor was found to provide repeatable and accurate measurements when a series of consecutive recordings were conducted at controlled prefixed distances of 20, 40, 60, 80 and 100 cm.

When testing our sensor on a sample of VDT users undertaking different tasks, the equipment revealed the influence of the type of task on viewing distance. In effect, interactive tasks (text completion, web searching and game) were associated with shorter viewing distances than the non-interactive video watching task. However, in disagreement with previous research,[19] in which no details on the study sample are provided, no statistically significant difference was found between the text completion and the web browsing tasks. It may be noted that previous research has documented a relationship between the type of task being conducted by computer operators and aspects such as eyeblink[28] rate and visual stress or fatigue.[29] These authors attributed their findings on the actual cognitive demands associated with each task, with more difficult tasks resulting in a reduction in eyeblink rate[28] and an increase in visual fatigue.[29] Although the present research investigated similar tasks to those described by these authors, further research is required to determine whether viewing distance is regulated by task difficulty or by other undisclosed factors.

The present findings served to underline that viewing distance may be considered an intrinsic attribute of each individual. In effect, even if viewing distance was found to depend on the type of task, participants were consistent throughout the four different tasks when opting for either short or long viewing distances. Besides, even though all participants conducted all tasks with their habitual correction, and any subjects with binocular vision abnormalities were excluded from the study, it may be speculated whether small differences in such binocular vision function parameters as amplitude and flexibility of accommodation may account for differences in preferred viewing distance. Likewise, given the reported relationship between viewing distance at near and myopia onset and progression, it may be interesting to investigate whether myopes prefer shorter viewing distances than hyperopes and whether this preference is a cause or a consequence of their refractive error. The small study sample and exploratory nature of the present research did not allow conclusions to be drawn in this regard, opening avenues for further research.

This first version of the software included a crude feedback mechanism consisting of a small red or green circle appearing on the lower right-hand side of the screen (right side of **Figure 5**). This notification, which could be set at any distance or deactivated, advised computer users of their correct or incorrect viewing habits. Further research shall be devoted to design new, more effective feedback strategies, such as switching off the display or progressively reducing its luminance.

In conclusion, the present findings revealed a task dependence on viewing distance in computer users. The implications of our results on such relevant issues as myopia onset and progression or visual fatigue require further research. The design and implementation of non-intrusive real-time distance monitoring mechanisms could be the first step towards developing effective feedback strategies to advice computer and other VDT users to maintain correct viewing habits both at home and at during work.

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FIGURES

Figure 1. Beam pattern of the transducer used on the ultrasonic sensor. Receiving sensitivity is -65dB at 40KHz according to technical specifications of manufacturer. Sensitivity reduction at various distances is shown in dB.

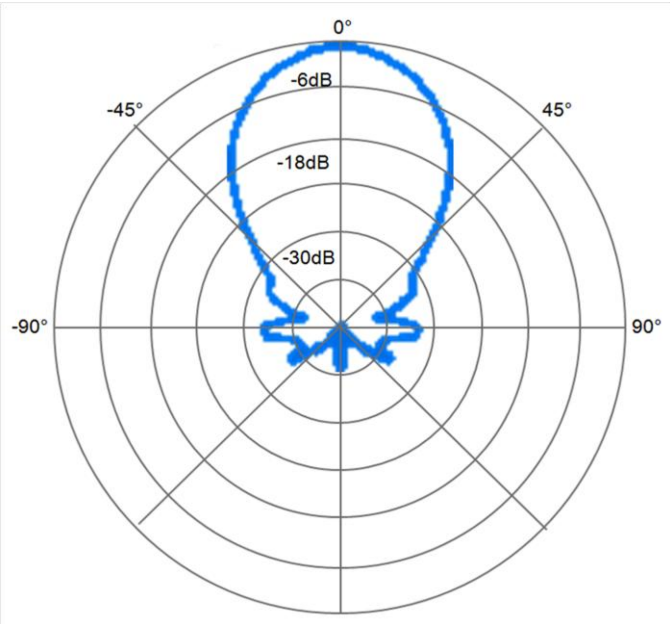


Figure 2. Sensor and USB adapter fitted inside a webcam case.

Figure 3. Average viewing distance (in mm) for each task (±2SD error bars are shown). The horizontal line at 60 cm denotes initial viewing distance for all tasks.

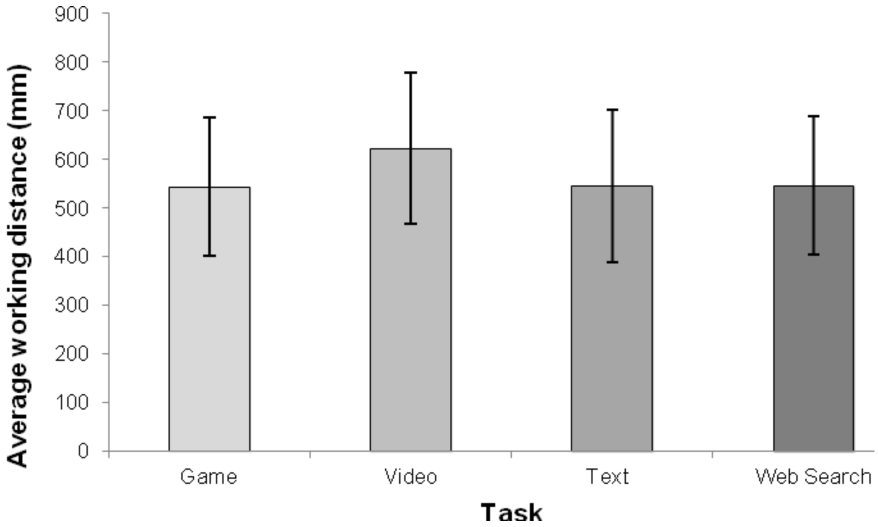


Figure 4. Average range of distances (in mm) for each task (±2SD error bars are shown).

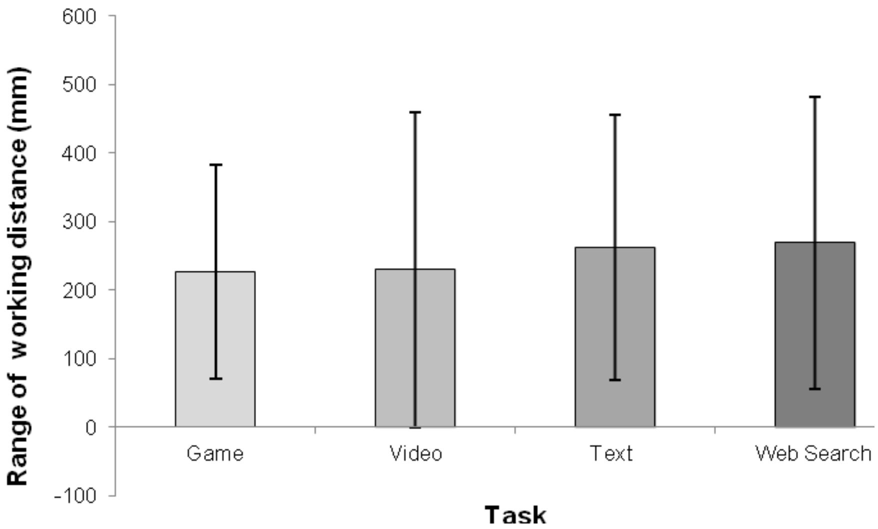
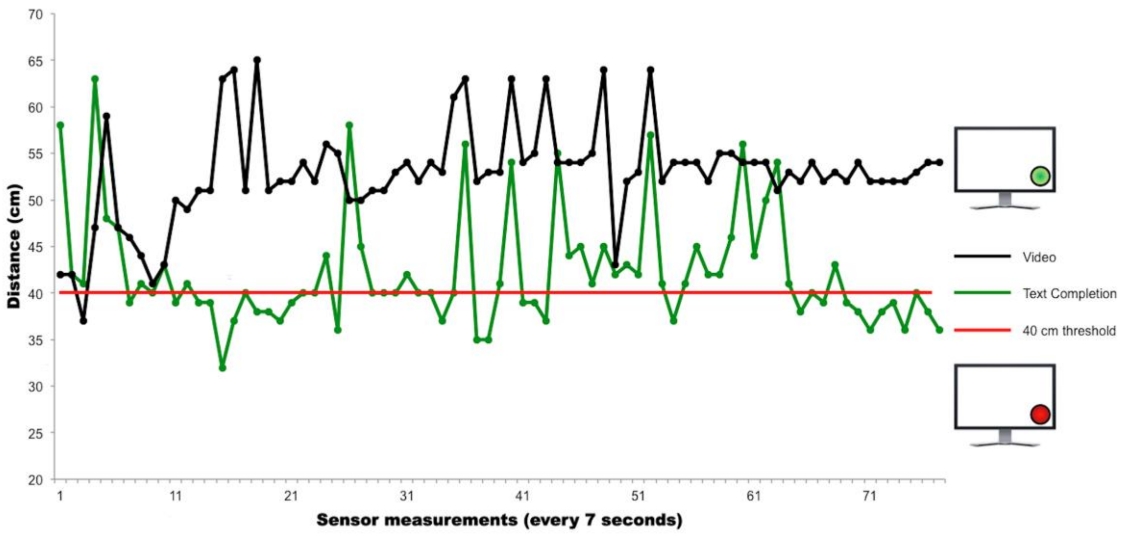


Figure 5. Consecutive sensor measurements within a 10 minute interval. Two tasks are drawn (watching a video and completing a text). A 40 cm reference threshold is shown. The software may be configured to present a red or green on-screen notification as a feedback mechanism when observers are beyond or within the recommended viewing distance, respectively.



TABLES

Table 1. Average distance and range of observation distances (difference between maximum and minimum observation distance) for each task (game, video, text completion, web search). Data is presented as mean and standard deviation (±SD). The longest average working distance corresponded to the video task, with small, not significant differences between the other three tasks. The range of observation distances over the 10-minute interval was similarly large for all tasks.

TASK	Observation Distance (cm)	Range of Observation Distances (cm)
Game	54.4 ± 7.1	22.6 ± 7.8
Video	62.3 ± 7.8	22.9 ± 11.5
Text Completion	54.5 ± 7.8	26.2 ± 9.7
Web Search	54.5 ± 7.1	26.9 ± 10.7

Table 2. Correlations between mean observation distances for the different tasks. Pearson coefficient of correlation, r, and statistical significance, p (between brackets), are presented. The highest correlation was found between the web search and text completion tasks, whereas average working distances for video and game were not correlated. Overall these findings suggest that each subject consistently selects shorter or longer working distances to conduct most tasks.

TASK	Game	Video	Text Completion	Web Search
Game	-	0.327 (0.159)	0.597 (0.005)	0.473 (0.035)
Video		-	0.629 (0.003)	0.624 (0.003)
Text Completion			-	0.740 (<0.001)