Analysis of the Effects of Privacy Filter Use on Horizontal Deviations in Posture of VDT Operators

by

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(ABSTRACT)

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The visual display terminal (VDT) is an integral part of the modern office. An issue of concern associated with the use of the VDT is maintaining privacy of on-screen materials. Privacy filters are products designed to restrict the viewing angle to documents displayed on a VDT, so that the on-screen material is not visible to persons other than the VDT operator. Privacy filters restrict the viewing angle either by diffraction or diffusion of the light emitted from the VDT. Constrained posture is a human factors engineering problem that has been associated with VDT use. The purpose of this research was to evaluate whether the use of privacy filters affected: 1) the restriction of postures associated with VDT use, 2) operator performance, and 3) subjective ratings of display issues, posture, and performance.

Nine participants performed three types of tasks: word processing, data entry, and Web browsing. Each task was performed under three filter conditions: no filter, diffraction filter, and diffusion filter. Participants were videotaped during the tasks using a camera mounted above the VDT workstation. The videotape was analyzed and horizontal head deviation was measured at 50 randomly selected points during each task. Horizontal head deviation was measured as the angle between an absolute reference line, which bisects the center of the VDT screen, and a reference point located at the center of the participant's head. Standard deviation of head deviation were evaluated across filter type and task type. Accuracy- and/or time-based measures were used to evaluate performance within each task.

Participants used a seven-point scale to rate the following: readability, image quality, brightness, glare, posture restriction, performance, and discomfort.

The results indicated that the interaction between task and filter type affected the standard deviation of horizontal head deviation (a measure of the average range of horizontal deviation). The standard deviation of horizontal deviation was significantly larger within the Web browsing task under the no filter and diffusion filter conditions as compared to the diffraction filter condition.

Filter type affected subjective ratings of the following: readability, image quality, brightness, posture restriction, and discomfort. The diffraction filter resulted in lower readability, image quality, and brightness ratings than the diffusion and no filter conditions. Participants reported that the ability to change postures was significantly decreased by the use of the diffraction filter as compared to the no filter and diffraction filter conditions. The diffraction filter resulted in an increase in reported discomfort as compared to the no filter condition. The interaction between filter and task type affected subjective ratings of performance. Participants reported a decrease in the rating of perceived performance under the diffraction filter / Web browsing condition as compared to the no filter / word processing, diffusion filter / Web browsing, and diffusion filter / data entry conditions. A decrease in the rating of perceived performance was reported in the diffraction filter / data entry condition as compared to the no filter / word processing and diffusion filter / Web browsing conditions. Neither diffraction nor diffusion filter affected performance within any of the tasks, based on the objective performance measures used in the experiment.

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INTRODUCTION

A key component of the modern office is the computer workstation. However, prolonged work at computer workstations can result in postural fixity, which, in turn, may lead to physiological problems and discomfort for the operator (Sanders and McCormick, 1993). Postural fixity refers to an operator remaining in a fixed posture over a prolonged period of time. Ergonomic design improvements can help to make computer workstations user-friendly. One of the primary points of interest from an ergonomic point of view is the visual display terminal (VDT).

VDTs often have been the subjects of human factors analyses. Areas of interest related to the VDT include VDT position and glare. These areas, if not properly addressed in a workstation, may result in performance problems for the VDT user, as well as increased fatigue and strain. The most common complaints associated with VDT use include eyestrain, headaches, and blurred vision (Sheedy, 1991). Improper positioning of the VDT can result in undue stress on the neck, shoulders and back. It also may contribute to excessive eyestrain (Brophy and Grant, 1986). Glare has been associated with visual discomfort, annoyance, and loss of visual performance and visibility (Pheasant, 1996). Reduction in productivity and an increase in error rates often are attributed to annoying levels of glare (Scalet, 1987).

Glare

Glare on VDT screens is an important problem to consider in the design of computer workstations. Glare is defined as the sensation produced by luminance within the visual field that is sufficiently greater than that to which the eyes can adapt (IES, 1991). Glare can be either *direct* or *indirect*. Direct glare occurs when light enters the field of view directly from a light source. Indirect glare is caused by light reflecting off of the surface of an object. Specular glare, a form of indirect glare, refers to glare that results from light being reflected from the surface of the VDT screen (Kroemer, Kroemer, and Kroemer-

Elbert 1994). Reflections on the screen may interfere with focusing mechanisms due to the eyes focusing alternately on the on-screen material and the reflected image (Boyce, 1997). "Washout" or veiling glare, a form of indirect glare, reduces the contrast of the screen and occurs when high ambient illumination falls onto the display (Kroemer et al, 1994). The degradation of screen contrast can make on-screen material difficult for users to read.

Glare can be controlled through several means, including an anti-reflection filter, changing the position of the screen, using a hood to cover the VDT, and by changing the ambient lighting conditions (Hedge, McCrombie, and Corbett, 1996)

Anti-reflection filters

One method to control for glare is the use of an anti-reflection filter. Anti-reflection filters are designed to reduce the amount of glare at the surface of the VDT screen. Anti-reflection filters often are made of specially-coated glass or plastic plates that are placed over the VDT screen. Anti-reflection filters are available commercially, and most of them can be installed easily on VDTs. Many of the available anti-reflection filters reduce reflections and increase contrast, as well as control static electricity and block some radiation emitted from the VDT screen. These devices are designed to improve screen visibility and help reduce problems such as eyestrain, headaches, and blurred vision.

Another concern with the use of computer workstations is privacy. Many VDTs are not designed to ensure that only the user of the VDT can read the information rendered on the screen. With the proliferation of computers for all types of work, privacy and protection of screen information is an important issue. In an effort to address the issue of screen privacy, some anti-reflection filter manufacturers have introduced "privacy filters." These filters offer the same advantages as traditional anti-reflection filters and offer viewing privacy of the screen material. The filters are designed in such a way as to allow the material on-screen to be viewed only in a certain range of horizontal angles from the center

of the screen (see Figure 1). The design objective of privacy filters is to prevent someone not positioned directly in front of the VDT from reading what is on the screen.

Possible applications for the privacy filters include use in academic and business settings. An academic application example testing centers for computer-based examinations are given, where privacy filters would prevent examinees from copying examination answers of other fellow examinees. A business application example involves protecting sensitive and confidential information rendered on the VDT screen from being viewed by employees working in the office other than the operator of the VDT in question. Other possible areas of application include medical and military settings.
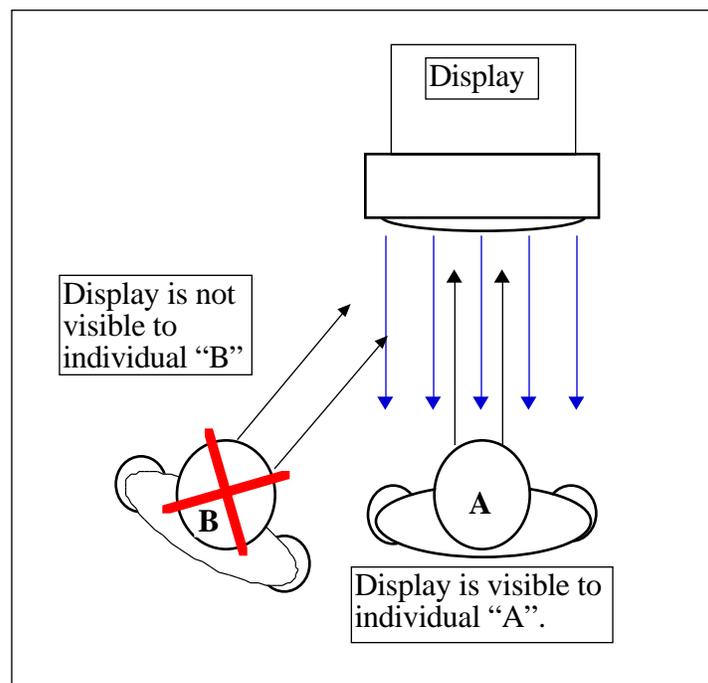
Figure 1. Illustration of restricted viewing angles with a privacy filter (adapted from 3M Optical Systems Application Bulletin).

Currently, there are two principle types of privacy filters: "diffraction" and "diffusion" filters. The "diffraction" filter uses light control film containing microlouvers, which completely block the view of the screen to anyone outside of the allowable range of viewing angles by diffracting the light from the screen. The "diffusion" filter is designed to

blur the image of the screen when viewed outside of the allowable range of viewing angle. The filter diffuses the light emitted from the screen when viewed outside of the viewing angle making the on-screen material illegible.

The design of privacy filters limits the horizontal angle at which the user can view the screen information. Restriction of the horizontal angle between the screen and the eyes of the user limits the allowable horizontal head movement of the VDT user (see Fig. 2) and may result in limiting the postures that a user can assume while viewing the on-screen material.
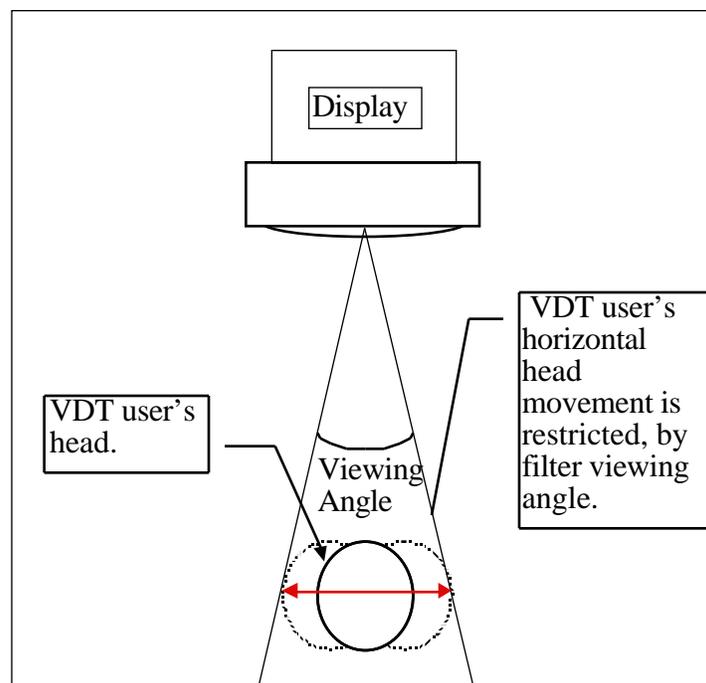
Figure 2. Illustration of the allowable viewing angle of a VDT equipped with a privacy filter.

Little research has been done to study horizontal deviations in posture that occur during typical tasks performed by a VDT user. It has been shown that in certain conditions, such as typing tasks involving the use of a document holder, significant differences in lateral flexion and rotation of the head occur dependent upon the location of the source document (Hamilton, 1996). These findings indicate that the head of a VDT user is not

always positioned directly in front of the screen, depending on the task being performed by the VDT user. However, the nature of lateral deviations that occur during typical tasks performed by a VDT user is not clearly understood.

Constrained Postures

The degree that privacy filters constrain posture of a VDT user is of particular importance. Constraints on posture of VDT user may result in persistent physiological stresses leading to tissue inflammation and degeneration of the affected tissues in the hands, arms, shoulders, and neck (Hünting, Läubli, and Grandjean, 1980), which can lead to an adverse effect on user performance. Changes in posture are recommended to prevent muscular fatigue, to avoid continuous spinal column compression (Grandjean, 1973), and to increase blood circulation (Winkel and Bendix, 1986). Changing posture also can result in the prevention of blood pooling, which can cause swelling and discomfort which may result in a decrease in operator performance (Thompson, Yates, and Franzen, 1986). According to Kroemer (1994), sitting with a static posture is physiologically unnatural for humans. Therefore, VDT users should change postures frequently and should include motions of the head, trunk, arms, and legs (Kroemer et al., 1994).

Objectives and Significance of Research

The objective of this study was to examine the effects of privacy filter use on posture and performance, using operator performance measures, subjective judgments, and quantitative recordings of lateral head position. The quantitative data will measure the amount of horizontal deviation that occurs during typical VDT-related tasks to determine whether or not the use of privacy filters restricts VDT operators from assuming postures that would normally occur at VDT workstations without privacy filters. After identifying possible restrictions in postural ranges, changes in the current design of the filter could be proposed to reduce the human factors problems associated with the products. Ideally, the

identified shortcomings could be improved upon resulting in a product that would increase VDT operator performance, rather than hinder it.

The significance of this research is related to the evaluation of the effects that restrictions in allowable viewing angle have on the natural horizontal range of postures that occur during typical VDT workstation tasks. Through the evaluation of these effects design recommendations could be made with regard to the design of privacy filters as it relates to the restriction of horizontal deviations in posture, assuming that restrictions in the natural range of horizontal deviations results in a decrease in performance.

Summary

The use of computer workstations can result in problems associated with operator performance and comfort. Glare is one factor responsible for some of the common complaints associated with VDT use. One way to control glare is through the use of an anti-reflection filter. A privacy filter also can be used to control glare and to protect on-screen information from unintended viewing. Privacy filters protect on-screen information by limiting the viewing angle of the VDT. In doing so, on-screen information can be viewed only by persons in the allowable viewing angle.

The current design of privacy filters raises an interesting human factors question: Do privacy filters overly-restrain users from assuming postures that would normally be encountered during the workday? If the use of privacy filters constrains the postures of VDT users such that normal working postures can not be assumed, there is potential for physiological-related problems to arise, which may have a negative effect on the performance of the VDT user.

Glare Filter Overview

The available human factors engineering literature concerning anti-reflection filters is limited, focusing mostly on user acceptance of the anti-reflection filters. Hedge, McCrobie, and Corbett (1996) examined user reactions to the use of computer screen anti-reflection filters. Other studies involving anti-reflection filters have focused on the effects of filter usage on the screen image quality. Olacsi, Kempic, and Beaton (1998a) and Kempic, Olacsi, and Beaton (1998) focused on the effects of glare filter usage on readability. Few studies have examined the effects of privacy filters on computer workstation users. Olacsi, Kempic, and Beaton (1998b) also performed a study that focused on the effects of privacy filter usage on image quality.

Olacsi, Kempic, and Beaton (1998a)

The authors of this study examined the effect of privacy filter usage on image quality. The study consisted of a photometric analysis of the optical quality of privacy filters and subjective image quality judgments of VDT equipped with privacy filters. The subjective image quality judgments were made under each of 72 conditions, which represent all combinations of display viewing angle (six levels), ambient illumination (two levels), screen polarity (two levels) and CRT/filter configuration (three levels). Viewing angles of 0, 15, 20, 22.5, 25, and 27.5 degrees horizontal of normal line-of-sight were used. The two levels of ambient illumination were a dark condition and a 500-lux diffuse condition. The two levels of screen polarity included negative (bright text on dark background) and positive (dark text and bright background). The three CRT/filter conditions were no filter, diffraction filter, and diffusion filter. Participants verbally reported a perceived image quality rating using a 9-point anchored scale (1-worst imaginable, 9-best-imaginable).

The results of the subjective image quality analysis, based on an analysis of variance procedure, identify effects of illumination, viewing angle, screen polarity, and CRT/filter configuration as having significant impact on image quality ratings. In addition, the CRT/filter configuration x viewing angle and CRT/filter configuration x illumination interactions were significant. The results of this study show a significant decrease in subjective image quality rating as the screen viewing angle increases for both diffusion and diffraction privacy filters, while the image quality ratings for the no-filter condition are unchanged across the different levels of viewing angle.

The results of this study indicate that changes in viewing angle have a significant effect on the perceived image quality of the VDT. The study also shows that the type of privacy filter used significantly affects the subjective image quality rating. In addition, the interaction of the viewing angle and the type of filter used significantly affects the perceived image quality. It can be concluded from this study that due to the decrease in image quality as the viewing angle increases, for diffusion and diffraction privacy filters, the allowable viewing angle for the VDT operator becomes restricted when a privacy filter of either type is implemented.

Hedge, McCrobie, and Corbett (1996)

The objective of this experiment was to survey VDT users about office lighting and screen glare problems. The study examined the effects of introducing screen anti-reflection filters to the VDT users. VDT users were first surveyed before the anti-reflection filters were made available to them. A second survey was administered about one month after two-thirds of the VDT users received anti-reflection filters. A third survey was conducted about one month after the remaining one-third of the VDT users received anti-reflection filters.

One hundred and ninety-four VDT users volunteered to participate in the study. The study began with a 66-item questionnaire, which was used to collect data on the VDT users

about their computer use, and opinions on environmental lighting, glare, and health. Following the questionnaire, participants were divided randomly into two groups. One group, comprised of approximately two thirds of the participants, received optically coated glass anti-reflection filters, while the remaining one third served as a control group. One month after anti-reflection filters were distributed to the treatment group, a 98-item questionnaire was administered to both the control group and the treatment group. Upon completion of the second questionnaire the control group was provided with anti-reflection filters as well. One month after all participants had received anti-reflection filters, the final survey, a 54-item questionnaire, was distributed. The investigators also measured illuminance, screen luminance, and screen contrast of each participant's VDT, with and without anti-reflection filters.

The results of this study show that the mean illuminance at participants' workstations was 420-lux ± 20.6 lux. Mean screen contrast with anti-reflection filters was 87.4% ± 1%. Mean screen contrast without anti-reflection filters was 88.8% ± 1%. Based on the results of the survey, the decrease in screen contrast due to the addition of anti-reflection filters did not seem to have a negative effect on readability or text clarity. According to the results of the study, 81.3% of the participants claimed the filter made the screen easier to read, while 73.3% claimed text on-screen was clearer with a filter. The study results also indicated a decrease in reports of "bothersome glare" by the participants after anti-reflection filters were implemented. The first questionnaire, administered before any participants had received anti-reflection filters, indicated bothersome glare affected approximately 75% of those who responded to the questionnaire. The final questionnaire, administered after all participants had received filters, indicated approximately 33% of those who responded were affected by bothersome glare. The authors of the study report that this finding suggests the anti-reflection filters were responsible for the decrease in complaints. Overall reactions to the installation of the screen glare filter were "very positive", according to the authors.

The focus of this study is the acceptance of filter usage. The results of the study indicate that a majority of the participants' reactions to the use of anti-reflection filters were positive. Based on the results of this study, it could be concluded that the use of screen anti-reflection filters could enhance VDT users' performances due to the decrease in complaints about bothersome glare. The study involved the use of standard anti-reflection filters not privacy filters; therefore, no indication of the effects of the added "privacy" feature on performance can be found in this study.

Summary of Glare Filter Literature

The current literature suggests that the use of anti-reflection filters can reduce bothersome glare and improve screen readability and clarity, which may result in improved worker performance and comfort. Privacy filters are anti-reflection filters, which retain the glare reduction qualities of standard anti-reflection filters and include an additional privacy feature not found in standard anti-reflection filters. It can be assumed that the findings in the current literature relating to anti-reflection filters also are applicable to privacy filters. The limited amount of literature that focuses on privacy filter usage indicates that image quality is affected by viewing angle when privacy filters are used. The decrease in image quality as viewing angle increases results in a restriction of the allowable viewing angle for the VDT operator. The restriction of the viewing angle will result in a restriction in the amount horizontal deviation of the VDT user that can occur before image quality begins to decrease. The resulting restriction in horizontal deviation may therefore result in constraining the available postures to the VDT user, which presents a human factors problem.

Computer Workstation Posture Overview

The available literature concerning the effects of postures of computer workstation operators indicates that constrained postures may result in increased reports of pain as a

result of VDT usage. This increase in reported pains could lead to a decrease in worker performance. Hünting, Läubli, and Grandjean (1980) studied the effects of constrained postures of workers at computer workstations. The results of this study indicate a higher percentage of incidence of pain that were reported "almost daily" for VDT users when compared to non-VDT users. The authors of the study concluded that VDT-related tasks performed by operators constrained their postures and had resulted in a higher incidence of reported pains. It can be assumed the VDTs used in this study were not equipped with privacy filters. The reduction of viewing angle incurred by the use of privacy filters may result in further constraining the postures of VDT operator, which could have a negative effect on worker performance.

The available literature concerning the posture of VDT users with respect to horizontal deviations is limited. Much of the research in the area of the angular deviations of the head focuses on the effects of display position in relation to viewing angles and vertical head tilt. Studies by De Wall, Van Riel, Aghina, Burdorf, and Snidjers (1992) and Straker, Jones, and Miller (1997) focus on the effect of display positioning on sitting posture. Few experiments have addressed the issue of horizontal deviations in posture. Two studies that examine the issue of horizontal deviations in posture, primarily head posture, are by Collins, Brown, Bowman, and Carkeet (1990) and Hamilton (1996). Collins, Brown, Bowman and Carkeet (1990) examined how a variety of factors affect visual symptoms associated with VDT use, including horizontal head turn. However, the results of this study with respect to the amount of head turn, which occurs in VDT users, were limited and subjective. The study by Hamilton examines the effects of source document position on head position of VDT workers.

Hamilton (1996)

The objective of this experiment was to measure head position across different document positions at a computer workstation. The author investigated the effect of source

document position on the head positions of computer workstation operators. Mechanical load at the C7 vertebra and EMG measurements also were investigated. The experiment task required participants to perform a reading and typing task under each of six conditions. The six treatment conditions were based on the document position. The order of presentation of the conditions was assigned randomly. The six document positions in both linear and angular displacement from the center of the display are listed in Table 1.

Table 1. Document Position

Document Position	y-axis (cm)	x-axis (cm)	z-axis (cm)	Vertical angle (°)	Horizontal angle (°)
Flat Left	31.5	32.5	20.5	45	80
Flat Right	31.5	32.5	20.5	45	80
Stand Left	20.5	32.5	7	35	90
Stand Right	20.5	32.5	7	35	90
Low Center	14.5	0	9	30	0
High Center	0	0	0	0	0

Head position was monitored using two cameras and a split-screen videotape system. One camera produced a saggital plane view, while the second camera produced a frontal plane view. An orthogonal target device was attached to the heads of the participants to serve as an angle reference.

Twenty individuals participated in this experiment (15 females), ranging in age from 21 to 57 years. Participants were seated at a computer workstation and seat height was adjusted to produce an elbow angle >90° with the participants hands on the keyboard. The mean elbow angle in the experiment was 95°. Participants were allowed to make adjustments for comfort as needed. Participants were instructed to begin reading after preliminary measurements were taken. Five samples, one every minute, were taken for the

reading condition. A one-minute rest period was given between the end of the reading period and the beginning of the typing period. Another five samples, one every minute, were taken for the typing condition. The process was repeated for each of the treatment conditions.

The head position results indicated that placement of the document has a direct effect on head position. Head position measures were significantly affected by the placement of the document for both the reading and typing tasks. There was no significant difference in position between the typing and reading conditions. The greatest flexion angle, 16°, in the reading task and the greatest flexion angle, 18°, in the typing task occurred in the "Flat Right" position. The flexion angles for both the "Flat Right" and "Flat Left" positions were found to be significantly greater than the "Low Center" and "High Center" positions. Head rotation for the "Flat Right" and "Flat Left" position was found to be significantly greater than all other conditions, with the exception of the "Stand Right" position.

The primary findings of the study indicate that the location of a source document has a significant effect on head position. This does not directly relate to the restriction in posture that may result when privacy filters are used. However, the results of this study do identify the amount of head movement that occurs when a source document is used, which is relevant to the issue of horizontal deviations of VDT users. The study indicates that, when source documents are used in particular positions, head position does deviate horizontally from the zero-position directly in front of the center of the VDT. The occurrence of this horizontal deviation indicates that restriction of the allowable viewing angle may restrict the typical movements of VDT operators that occur during a task, which involves the use of a source document.

METHODOLOGY

In this experiment, participants were asked to perform typical office tasks that occur at computer workstations. The tasks included a word processing task, a data entry task, and a Web browsing task. Participants completed each task under three different filter conditions: no filter, diffusion filter, and diffraction filter.

Participants

Nine individuals (4 males) between the ages of 21 and 33 participated in the experiment. Participants were volunteers. Eight participants were right-hand dominant. Before beginning the experiment, each participant was screened for 20/20 visual acuity, using an orthorater (Bausch and Lomb, Model: Ortho-Rater).

Equipment

A laboratory computer (Apple Computer, Model: Power Macintosh 7100/80) was used in the experiment. Video data of participants' head position was recorded using a video camera (Diamond Pro, Model: CCD-1000U) mounted at ceiling height above the computer workstation, and a video recorder (Mitsubishi, Model: Diamond Pro S-VHS). Commercial diffraction (3M, Model: PF450XL) and diffusion (Glare Guard, Model: Optima 1800) privacy filters were used.

Participants were seated in front of the computer workstation (see Figure 3) and were allowed to choose a comfortable viewing distance from the computer display. The workstation consisted of the laboratory computer, an adjustable chair, and a table with an attached keyboard tray. Participants also were allowed to adjust their position, chair height, and posture for best initial comfort.

Ambient illumination was fixed at 400 lux (ANSI standard recommends between 200-500 lux) measured vertically at the surface of the VDT.

Figure 3. Computer workstation used in the experiment.

Experimental Design

      A within-subjects 3x3 factorial design was used to organize the data collection. Filter was one independent variable, with three levels: No Filter, Diffraction Privacy Filter, and Diffusion Privacy Filter. The No Filter condition served as a control condition, and it was representative of typical office work environments. The second independent variable was Task Type, with three levels: Word Processing, Data Entry, and Web Browsing. The task types were designed to be representative of typical activities that occur at computer workstations.

Table 2. Independent Variables

Variable	Level 0	Level 1	Level 2
Assigned Task:	Word Processing	Data Entry	Web Browsing
Filter Class:	No Filter	3M PF450XL Privacy Filter (Diffraction)	Glare Guard Privacy Glare Filter (Diffusion)

The primary dependent variable was the horizontal head deviation (measured in degrees of deviation between the operator's head position and the centerline of the VDT). The subjective data and performance measures were collected as secondary dependent variables. Horizontal head deviations indexed how task and filter type affected participants' posture. Subjective data indexed the issues of readability, glare, comfort, and perceived performance. Performance measures indexed how the filter types affected performance across the tasks.

Statistical Analysis

The presentation order of the conditions was counterbalanced using a 9x9 Latin Square. Each participant received a total of nine conditions (3 Filters x 3 Tasks) in the experiment.

Table 3. Treatment Conditions

Task/Filter Level	No Filter	Diffraction Filter	Diffusion Filter
Word Processing	T1	T2	T3
Data Entry	T4	T5	T6
Web Browsing	T7	T8	T9

Table 4. Latin Square

	S1	S2	S3	S4	S5	S6	S7	S8	S9
O1	T1	T2	T3	T4	T5	T6	T7	T8	T9
O2	T2	T3	T4	T5	T6	T7	T8	T9	T1
O3	T9	T1	T2	T3	T4	T5	T6	T7	T8
O4	T3	T4	T5	T6	T7	T8	T9	T1	T2
O5	T8	T9	T1	T2	T3	T4	T5	T6	T7
O6	T4	T5	T6	T7	T8	T9	T1	T2	T3
O7	T7	T8	T9	T1	T2	T3	T4	T5	T6
O8	T5	T6	T7	T8	T9	T1	T2	T3	T4
O9	T6	T7	T8	T9	T1	T2	T3	T4	T5

Several frequency distributions were constructed using the head position data collected. The frequency distributions were constructed for the purpose of creating visual representation of the data collected. Distributions were constructed for each individual participant across each treatment condition. Distributions of the head positions of all participants combined across each distribution were constructed. Distributions also were constructed for the combined head position data for each level of each independent variable. The frequency distributions were constructed to allow for visual comparison of the data across the different levels of the independent variable.

The frequency distributions of head position for each treatment condition for all nine participants were compared to each other using the Kolmogorov-Smirnoff test. The frequency distributions for each treatment condition also were compared to the Gaussian (Normal) distribution using Chi-square tests.

Two separate analyses of variance (ANOVA) were conducted with respect to head deviation. The first ANOVA assessed position of the head; the second ANOVA examined the magnitude of participants' head movements. The first analysis used average head position; the second analysis used standard deviation of head positions.

Task Description

The tasks completed by the participants included a word processing task. Participants were instructed to transfer text from a hard-copy document to the computer using a word processor (Microsoft, Version: Word 98 for Macintosh). A hard-copy text passage to be transferred to the computer was provided to the participants. The text passages were taken from a word processing exercise book. Before beginning the experiment trials, participants were instructed on the use of the software.

A document holder was provided for each participant, the position of which was fixed dependent upon left- or right-hand dominance. There was no time limit on the

completion of the word processing tasks. Participants performed each word processing

task until the task was completed.

THE CAYMAN ISLANDS: A BRITISH DEPENDENCY

Introduction

      The Cayman Islands are one of two British dependencies in the northern part of the Caribbean. The Cayman Islands consist of three islands: Grand Cayman, Little Cayman, and Cayman Brac. The capital is George Town, on Grand Cayman.

      Christopher Columbus sighted the Caymans during his 1503 voyage, naming them "Las Tortugas" because of the large number of turtles he found there. By 1530 the islands were know as the Cymanus, a name that may have derived from confusion between the iguana, which is found on the islands, and the alligator (cayman in Spanish).

Figure 4. Sample of source text for a word processing task (text taken from Zilkowski (1993)).

      The data entry task required participants to input numerical data into a spreadsheet

(Microsoft, Version: Excel 98 for Macintosh). Participants were instructed to transfer data

from a hard-copy document to the computer. A document containing the data to be

transferred was provided to the participants. The hard-copy data was presented in a manner

similar to how it was to be entered into the spreadsheet. Before beginning the experiment

trials, participants were instructed on the use of the software. A document holder was

provided to the participants. The position of the document holder was fixed dependent on

left- or right-hand dominance. There was no time limit on the completion of the data entry

tasks. Participants performed each data entry task until the task was completed.

Identification #	Value A	Value B	Value C	Value D	Value E	Value F	Value G
015-459-986	578	45	7894	4556	23	587	798
154-897-635	557	5678	5149	7542	9508	7440	7956
456-985-658	894	789	6786	2169	445	163	6025
438-967-235	4578	327	1284	1704	9229	1410	2713
598-635-789	897	7981	7513	8094	5283	8672	2680
187-962-822	314	159	3719	622	6801	9137	5031
487-889-438	97	7823	8544	3972	9663	4871	4208
789-689-758	789	264	693	7610	5065	5006	6856
424-584-627	1357	687	1622	5552	1008	4142	8784
138-222-571	6878	931	2734	6673	1655	5103	5750
597-488-579	88	4552	5704	2475	717	8625	7026

Figure 5. Sample of source information for a data entry task. (note: identification numbers are arbitrary and not indicative of any actual identification numbers)

The third task type to be completed by the participants was a Web browsing task. Participants were instructed to browse the Internet using an Internet browser (Netscape Navigator 4.5). Participants were instructed on the use of the Web browsing software. All of the information related to this type of task was presented on-screen. There was no time limit on the completion of the Web browsing tasks. Participants performed each Web browsing task until the task was completed.

Assume you want to learn about the near-extinction of crocodiles. Go to the Crocodile Specialist Group homepage to read about the conservation of certain species of the crocodile family. Follow the link labeled "The Story of the Crocodile Specialist Group" at the bottom of the page and read the information presented. Be sure to click on each of the images of the crocodiles included in the story to view a larger image of the pictures.

Figure 6. Sample of a Web browsing task.

Each of the three task types had different characteristics. The word processing and data entry tasks were considerably different than the Web browsing tasks. The information input by the participant in the word processing and data entry tasks was be taken from a source document, which required the participant to look away from the screen in order to read from the document. The Web browsing task involved screen instruction and did not

use a source document. Therefore, all information necessary for the Web browsing task was available on the VDT screen, which eliminated the need for the user to look away from the screen. The Web browsing task also used the mouse as the primary input device, while the word processing and data entry tasks used the keyboard as the primary input device.

The primary difference between the word processing task and the data entry task was related to the nature of the information input into the computer during these tasks. The word processing task primarily involved the input of text information, which required use primarily of the alphabetic keys. The data entry task primarily involved the input of numerical data as opposed to text, which required use primarily of the numeric keys. The intent of these differences was to allow for the evaluation of the effects that different task types had on horizontal movement of the participants.
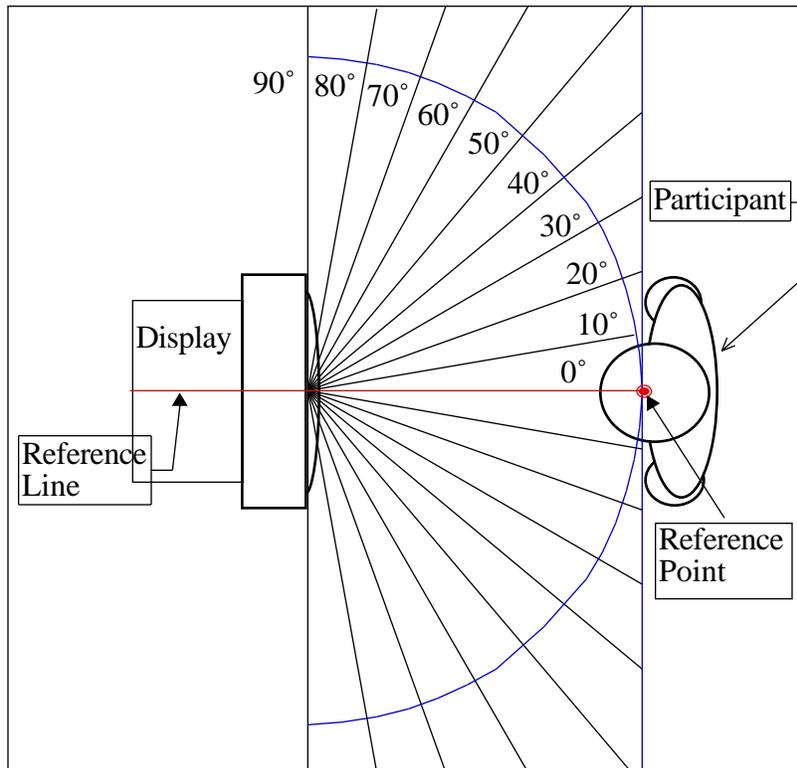
Figure 7. Measurement setup.

Horizontal Deviations

The horizontal deviations were measured as the angle between a reference line bisecting the center of the display and a reference point at the center of the participant's head (see Fig. 6). The video camera was positioned to provide an overhead view of the workstation and the participant. Participants' head positions were videotaped continuously using videotape throughout each task. Measurements of horizontal deviation were taken from the videotape data after the tasks were completed. A total of 50 measurements of each individual in each treatment condition were taken. These measurements were taken at randomly specified points in time during each task.

Each deviation was measured by comparing the position of the reference point on the participant's head with the reference line located at the top center of the display. The videotape was played back on a CRT with a transparent overlay adhered to the screen surface. The overlay displayed lines measured at every half-degree from a reference line which originates from a central point located at the top-center of the monitor. The head position of the participant was measured by comparing the reference point on the participant's head with the angular scale of the overlay.

Performance Measures

Performance of the participants was measured in terms of task completion time and number of errors in the word-processing and data entry tasks. Time to complete each task was measured using videotape analysis. Visual cues were used to identify the start and stop points of each task. Time measures were accurate to 1 second. Participants were instructed to transfer the source material exactly as it was presented on the source document. Therefore, errors were defined to be any character, style, or spacing deviation from the source document. Errors were tallied for each task. The average number of errors was analyzed as an accuracy-based performance measure. The ratio of the number of characters

input divided by time, in minutes, (# of characters/# of minutes) was used a time-based measure.

Performance of the Web browsing tasks was measured using a short quiz after each task. The quiz questions were based on the content of the Web pages browsed. The number of errors on the quizzes was used as the performance measure for the Web browsing task. Since each quiz had five questions, the total range of possible error for the Web Browsing task was zero to five errors.

Table 5. Example of a Web Browsing Quiz

Web Task C	Participant #:____

1. The Great White Shark is responsible for an average of how many attacks on humans each year?
 	
    a. 1
    b. 4
    c. 9
    d. 13	

2. Which is considered the fastest of all sharks?
 	
    a. the great white
    b. the scalloped hammerhead
    c. the mako
    d. the blue shark	

3. According to the web page which of the following pose NO threat to humans?
 	
    a. the lemon shark
    b. the great white
    c. the whale shark
    d. the smooth hammerhead	

4. Which of the following is the most frequent cause of tsunamis?
 	
    a. volcanic eruptions
    b. undersea earthquakes
    c. hurricanes
    d. large changes in atmospheric conditions	

5. Tsunami's can travel up to maximum speeds of how fast?
 	
    a. almost 100 mph
    b. almost 300 mph
    c. almost 500 mph
    d. almost 700 mph	

Subjective Data

       Subjective data also were collected from participants after each treatment condition. Participants completed a brief survey containing seven Likert-type scale questions. The survey addressed issues related to glare, readability, screen quality, postural restrictions, and performance.

Table 6. Survey Questions

1. How would you rate the readability of the on-screen text using this configuration?   **1   2   3   4   5   6   7** **Worst Imaginable   Average   Best Imaginable**
2. How would you rate the overall image quality of this configuration?   **1   2   3   4   5   6   7** **Worst Imaginable   Average   Best Imaginable**
3. How would you rate the brightness of the screen using this configuration?   **1   2   3   4   5   6   7** **Too dark   Just right   Too bright**
4. How would you rate the amount of glare present on the screen surface?   **1   2   3   4   5   6   7** **Bothersome   Noticeable   Non-existent**
5. How would you rate this configuration in relation to the degree to which you were able to change posture or position while working on the task?   **1   2   3   4   5   6   7** **Severely   Restriction   Freedom** **Restricted   of movement   to move was** **Freedom to   was noticeable   not restricted** **Move**
6. How do you feel that the screen type used in this task affected your performance of the task?   **1   2   3   4   5   6   7** **Negative   No Effect   Positive** **Effect   Effect**
7. During the task did you experience any discomfort?   **1   2   3   4   5   6   7** **No   Moderate   Extreme** **Discomfort   Discomfort   Discomfort**

Analysis of Results

        Analysis of Variance (ANOVA) was the primary test for significance used in the experiment. Heterogeneity of covariance, potentially arising from the within-subjects design, was corrected using the Box correction (Box, 1954). Effects with a corrected p-value less than 0.10 were considered significant, because of the low statistical power associated with small sample sizes.

Analysis of Head Position

The Analysis of Variance (ANOVA) summary for average horizontal head deviations is shown in Table 7. The results indicate that Task Type was significant (p=0.080), as was the interaction effect of Task Type and Filter (p=0.022).

Table 7. ANOVA of Average Head Position

Source	df	MS	F	p[1]
Between				
Subjects	8	119.608		
Within				
Task	2	79.709	3.610	0.080*
Task xSubjects	16	22.077		
Filter	2	15.147	1.875	0.192
Filter xSubjects	16	8.077		
Task xFilter	4	14.523	3.853	0.022*
Task xFilter xSubjects	32	3.770		
Total	80			

* indicates a significant result (p < 0.10)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factors: Epsilon-hat (Task) = 0.8508
Epsilon-hat (Filter) = 0.9144
Epsilon-hat (Task x Filter) = 0.7780

The main effect of Task is shown in Figure 8. A Newman-Kuels post-hoc test (see Table 8) reveals that average head position associated with the Web Browsing task is significantly closer to the midpoint of the VDT than the head position associated with the Word Processing task.
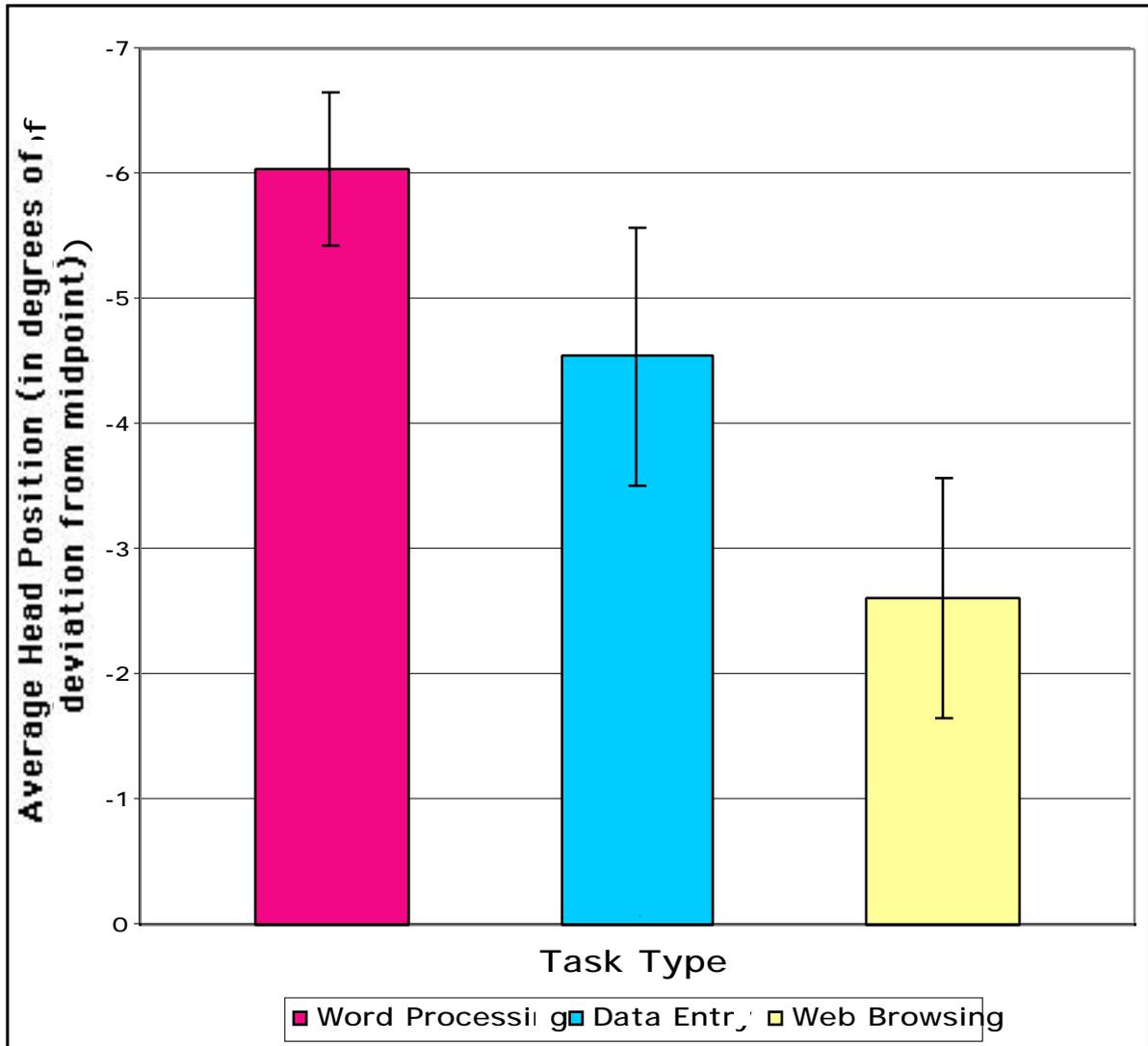
Figure 8. Main effect of Task on average head position. (Error bars indicate +/- 1 standard error of the mean).

Table 8. Newman-Kuels Results of Main Effect of Task on Head Position

	Word Processing (-6.033)	Data Entry (-4.543)	Web Browsing (-2.607)	r	CD$_{N-K}$
Word Processing	-	1.490	3.427*	3	2.825
Data Entry		-	1.937	2	2.323
Web Browsing			-		

*indicates a significant result (p<0.10)

The interaction of Task and Filter is shown in Figure 9. Average head position in each condition was located to the left of the midpoint of the VDT. Average head position did not significantly differ across filters within the word processing condition. The two-factor interaction between Task and Filter follows the same general data trend as the main effect of Task.
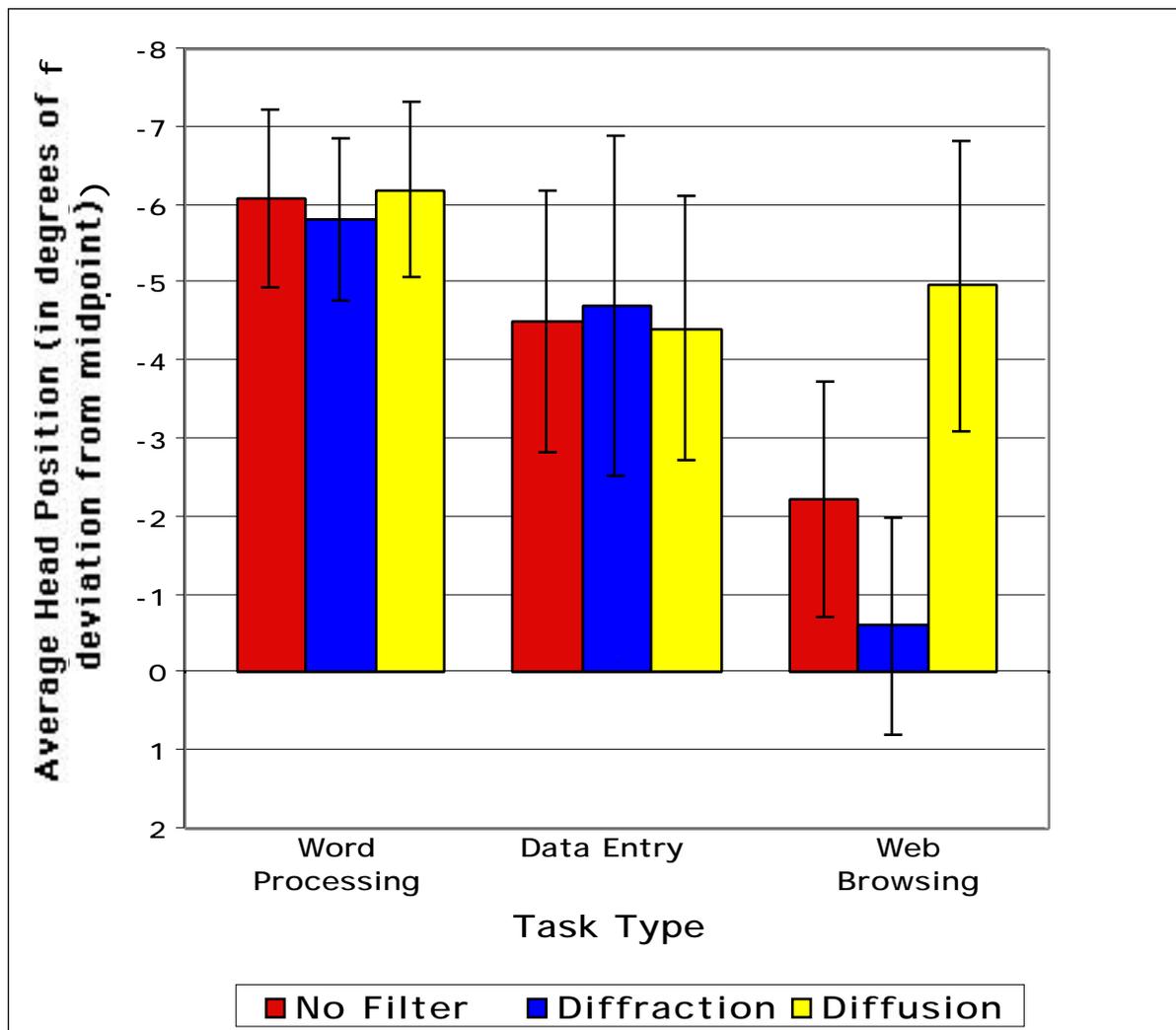
Figure 9. Interaction of Task and Filter Type on head position. (Error bars indicate +/- 1 standard error of the mean).

Results of the Newman-Kuels test are shown in Table 9. The results indicate that head position associated with the Diffraction Filter / Web Browsing condition is significantly closer to the midpoint of the VDT as compared to each condition. The results also indicate that the No Filter / Web Browsing condition yields head positions significantly closer to the midpoint of the VDT as compared to each condition, with the exception of the Diffraction Filter / Web Browsing condition.

Table 9: Newman-Kuels Results of Head Position

	T3 (-6.19)	**T1** (-6.09)	**T2** (**-5.81**)	**T9** (-4.97)	**T5** (-4.71)	**T4** (-4.50)	**T6** (-4.42)	**T7** (-2.24)	**T8** (-0.61)	**r**	**CD**
Diffuse / WP (T3)	-	0.103	0.380	1.226	1.488	1.691	1.773	3.953 *	5.584 *	9	2.757
None / WP (T1)		-	0.277	1.122	1.384	1.588	1.670	3.850 *	5.481 *	8	2.679
Diffract / WP (T2)			-	0.846	1.108	1.311	1.393	3.573 *	5.204 *	7	2.589
Diffuse / WB (T9)				-	0.262	0.466	0.548	2.728 *	4.359 *	6	2.485
Diffract / DE (T5)					-	0.203	0.286	2.466 *	4.097 *	5	2.353
None / DE (T4)						-	0.082	2.262 *	3.893 *	4	2.185
Diffuse / DE (T6)							-	2.180 *	3.811 *	3	1.947
None / WB (T7)								-	1.631 *	2	1.549
Diffract / WB (T8)									-		

* indicates a significant result ($p < 0.10$)

Analysis of Standard Deviation of Head Position

The ANOVA summary for variations in head deviation is shown in Table 10. The results indicate that the main effects of Task Type (p=0.004) and Filter (p=0.057) were significant, as was the interaction of Task and Filter (p=0.008).

Table 10. ANOVA of Standard Deviation of Head Position

Source	df	MS	F	p[1]
Between				
Subjects	8	16.747		
Within				
Task	2	47.570	12.214	0.004*
Task xSubjects	16	3.894		
Filter	2	5.491	4.258	0.057*
Filter xSubjects	16	1.289		
Task xFilter	4	7.142	4.918	0.008*
Task xFilter xSubjects	32	1.452		
Total	80			

* indicates a significant result (p < 0.10)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factors: Epsilon-hat (Task) = 0.8196
                            Epsilon-hat (Filter) = 0.9938
                            Epsilon-hat (Task x Filter) = 0.8146

The main effect of Task is shown in Figure 10. A Newman-Kuels post-hoc test (see Table 11) reveals that the standard deviation of head position associated with the Web Browsing task is significantly larger than the standard deviations associated with the Word Processing and Data Entry tasks.
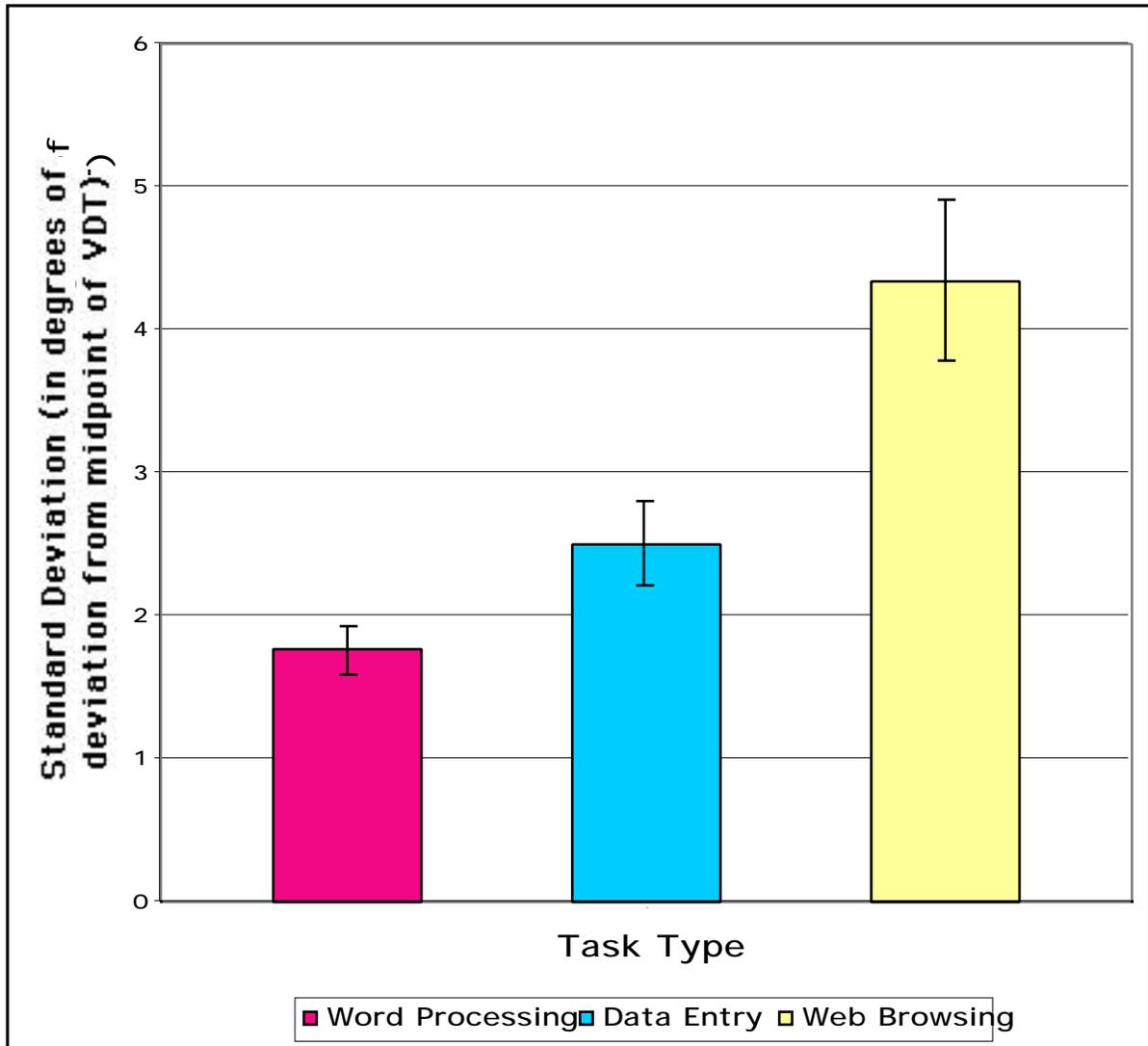
Figure 10. Main effect of Task on standard deviation of head position. (Error bars indicate +/- 1 standard error of the mean).

Table 11. Newman-Kuels Results for Main Effect of Task on Standard Deviation of Head Position.

	Word Processing (1.765)	Data Entry (2.507)	Web Browsing (4.343)	r	CD$_{N-K}$
Word Processing	-	0.742	2.578*	3	1.186
Data Entry		-	1.836*	2	0.937
Web Browsing			-		

*indicates a significant result (p<0.10)

The main effect of Filter is shown in Figure 11. A Newman-Kuels post-hoc test reveals that the No Filter condition yields a standard deviation that is significantly larger than the standard deviation associated with the Diffraction Filter condition.
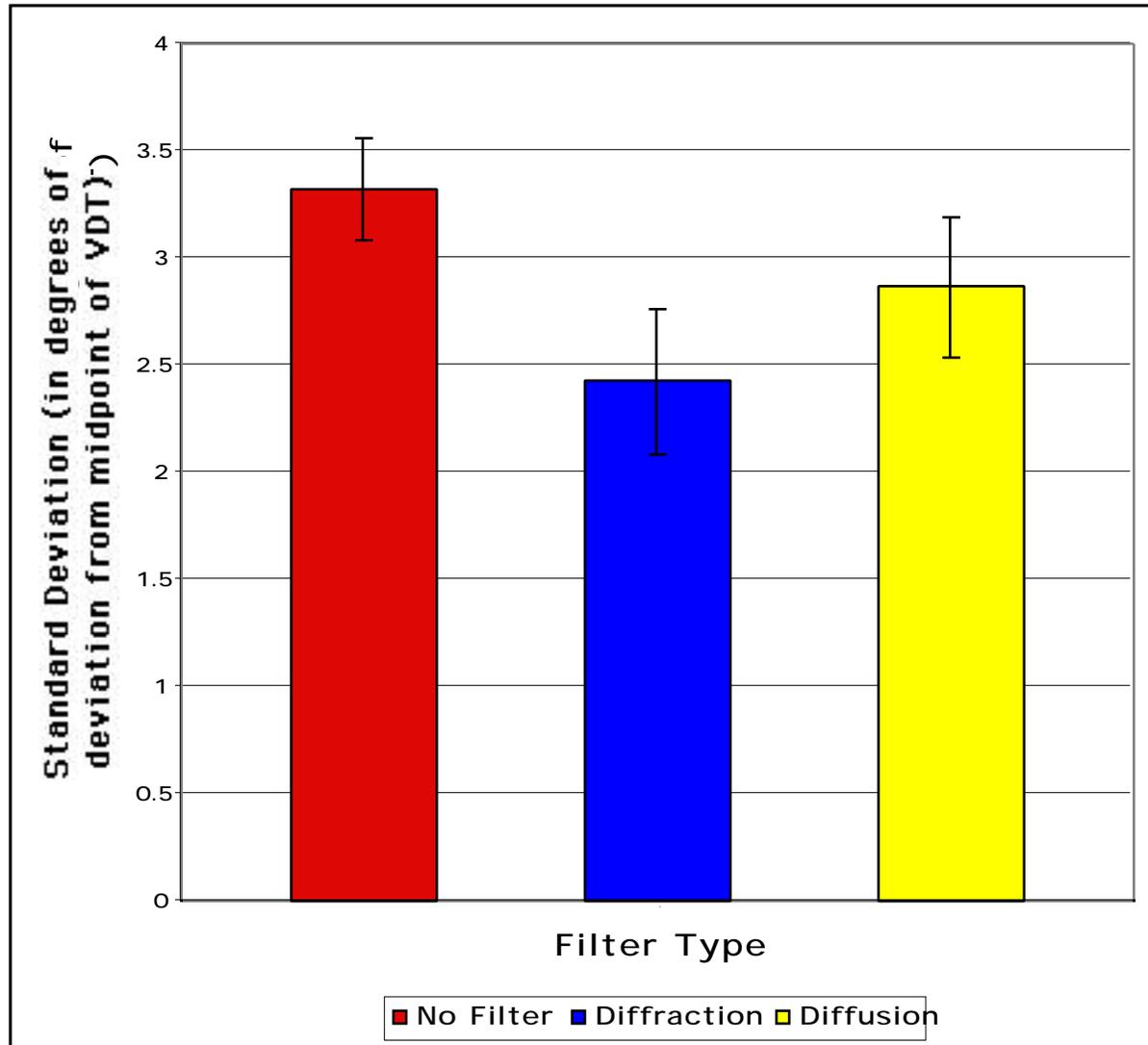
Figure 11. Main effect of filter on standard deviation of head position. (Error bars indicate +/- 1 standard error of the mean).

Table 12. Newman-Kuels Results for Main Effect of Filter on Standard Deviation of Head Position.

	Diffraction (2.423)	Diffusion (2.866)	No Filter (3.325)	r	CD_{N-K}
Diffraction	-	0.443	0.902*	2	0.683
Diffusion		-	0.459	3	0.540
No Filter			-		

*indicates a significant result (p<0.10)

The interaction of Task and Filter is shown in Figure 12. Results of the Newman-Kuels test are shown in Table 13. The results indicate that within the Word Processing and Data Entry conditions, Filter did not have a significant effect on standard deviation. However, within the Web browsing condition, Filter did have a significant effect. The two-factor interaction does not change the general data trend for the significant main effect of Task.
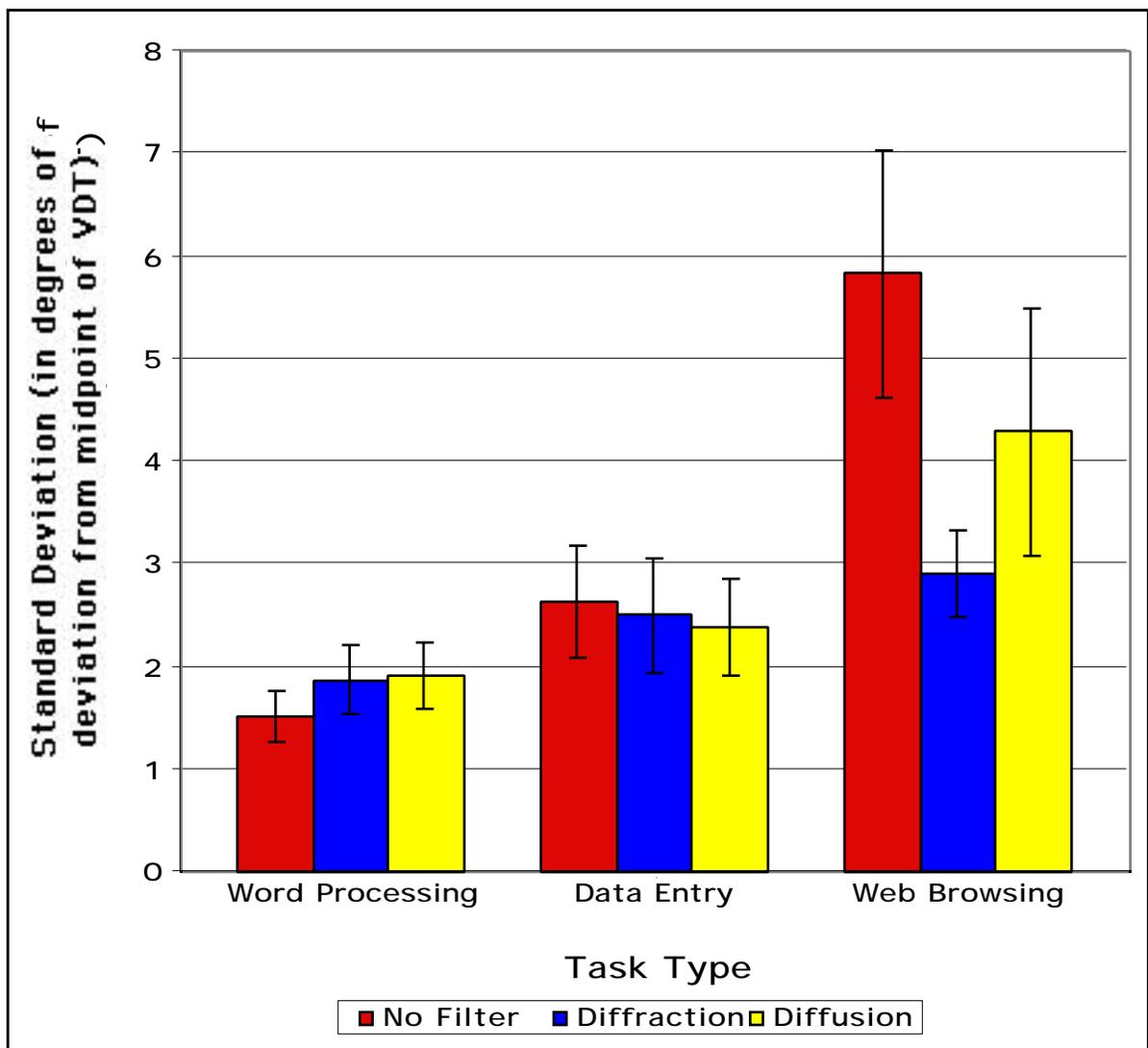
Figure 12. Interaction of Task and Filter Type on standard deviation of head position. (Error bars indicate +/- 1 standard error of the mean).

Table 13. Newman-Kuels Results of Head Deviation

	T1 (-6.19)	T2 (-6.09)	T3 (-5.81)	T6 (-4.97)	T5 (-4.71)	T4 (-4.50)	T8 (-4.42)	T9 (-2.24)	T7 (-0.61)	r	CD
None / WP (T1)	-	0.348	0.396	0.875	0.982	1.113	1.390	2.776 *	4.312 *	9	1.711
Diffract / WP (T2)		-	0.048	0.528	0.634	0.765	1.043	2.428 *	3.964 *	8	1.663
Diffuse / WP (T3)			-	0.480	0.586	0.717	0.995	2.381 *	3.917 *	7	1.607
Diffuse / DE (T6)				-	0.106	0.238	0.515	1.901 *	3.437 *	6	1.542
Diffract / DE (T5)					-	0.131	0.409	1.795 *	3.331 *	5	1.461
None / DE (T4)						-	0.277	1.663 *	3.199 *	4	1.356
Diffract / WB (T8)							-	1.386 *	2.922 *	3	1.208
Diffuse / WB (T9)								-	1.536 *	2	0.962
None / WB (T7)									-		

* indicates a significant result (p < 0.10)

Frequency Distributions

The frequency distributions provide visual representations of the head positions of the participants during each treatment condition. The frequency distributions supplement the statistical analyses and facilitate the understanding of the postural changes observed in the experiment. The frequency distributions can be found in Appendix B.

Chi-square tests were performed on the frequency distributions of each treatment condition. The Chi-square tests revealed that the frequency distribution of observed head positions significantly differed from a Gaussian (Normal) distribution.

Pair-wise comparisons among the frequency distribution of each treatment condition were performed with the Kolmogorov-Smirnoff test. A total of 36 pair-wise comparisons were made. Results of the Kolmogorov-Smirnoff Tests are shown in Table 14. The results indicate that the head positions associated with the T1 condition (no filter / word processing), T2 condition (diffraction filter / word processing), and T3 condition (diffusion filter / word processing) follow the same distribution. The distributions of each of the remaining conditions were significantly different from each other.

The deviation of the frequency distributions from the Gaussian distribution is a concern when performing statistical analysis. The ANOVA is a parametric test, which assumes that data follows a normal distribution. However, when a large number of observations ($N>30$) are made, ANOVA is a valid analysis, regardless of whether the data follows the Gaussian distribution. The Central Limit Theorem also states that the sampling distributions of the means of large random samples with finite variances will be approximately be distributed according to the Gaussian distribution regardless of the form of population. The analyses performed in this experiment evaluated the mean values associated with the non-Gaussian data. Therefore, by the Central Limit Theorem the mean values analyzed should will approximately follow the Gaussian distribution, and should not violate the underlying assumptions of the ANOVA.

Table 14: Results of Kolmogorov-Smirnoff Tests

Comparison:	Dm,n	Decision (0.05 level)
T1 v T2	0.060	Fail to Reject
T1 v T3	0.058	Fail to Reject
T1 v T4	0.191	Reject
T1 v T5	0.229	Reject
T1 v T6	0.198	Reject
T1 v T7	0.382	Reject
T1 v T8	0.509	Reject
T1 v T9	0.187	Reject
T2 v T3	0.076	Fail to Reject
T2 v T4	0.182	Reject
T2 v T5	0.236	Reject
T2 v T6	0.193	Reject
T2 v T7	0.356	Reject
T2 v T8	0.473	Reject
T2 v T9	0.189	Reject
T3 v T4	0.220	Reject
T3 v T5	0.244	Reject
T3 v T6	0.207	Reject
T3 v T7	0.349	Reject
T3 v T8	0.502	Reject
T3 v T9	0.207	Reject
T4 v T5	0.164	Reject
T4 v T6	0.104	Reject
T4 v T7	0.202	Reject
T4 v T8	0.369	Reject
T4 v T9	0.156	Reject
T5 v T6	0.093	Reject
T5 v T7	0.278	Reject
T5 v T8	0.427	Reject
T5 v T9	0.129	Reject
T6 v T7	0.213	Reject
T6 v T8	0.378	Reject
T6 v T9	0.158	Reject
T7 v T8	0.187	Reject
T7 v T9	0.240	Reject
T8 v T9	0.407	Reject

Critical Value for Dm,n = 0.091 (=0.05)

Subjective Data Analysis

   Subjective data was recorded following the completion of each treatment throughout the experiment. Participants were asked to respond to seven questions that addressed issues of readability, image quality, glare, posture, comfort, and performance. The same seven questions were used across each treatment condition. Participants' responses were based on seven-point Likert-type ratings. The responses to each question were evaluated using an ANOVA.

   In addition to the ANOVA, Kruskal-Wallis tests were performed to evaluate the effects of Filter and Task on the readability ratings. This test was performed due to the possibility that participants may have viewed the rating scales as ordinal scales as opposed to interval scales. All Kruskal-Wallis test results were adjusted for ties.

Question #1

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1. How would you rate the readability of the on-screen text using this configuration?

1   2   3   4   5   6   7
Worst Imaginable   Average   Best Imaginable

Figure 13. Survey Question #1.

The ANOVA summary for Question #1 is shown in Table 15. The effect of Filter on the average rating for Question 1 was significant. Figure 14 shows the average ratings across the levels of Filter, and Table 16 shows the results of a Newman-Kuels post-hoc test on the average ratings. These results indicate that the perceived readability ratings associated with the no filter and diffusion filter conditions are significantly higher than the rating associated with the diffraction filter.

Table 15. ANOVA for Question #1

Source	df	MS	F	p[1]
Between				
Subjects	8	2.167		
Within				
Task	2	0.778	0.602	0.454
Task x subjects	16	1.292		
Filter	2	5.778	4.622	0.053*
Filter x Subjects	16	1.250		
Task x Filter	4	1.222	1.872	0.183
Task x Filter x Subjects	32	0.653		
Total	80			

* indicates a significant result ($p < 0.10$)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factors: Epsilon-hat (Task) = 0.748
                                            Epsilon-hat (Filter) = 0.794
                                            Epsilon-hat (Task x Filter) = 0.593

Table 16. Newman-Kuels Results of Question #1

	Diffraction (3.519)	Diffusion (4.185)	No Filter (4.407)	r	CD_{N-K}
Diffraction	-	0.67*	0.89*	2	0.67
Diffusion		-	0.22	3	0.53
No Filter			-		
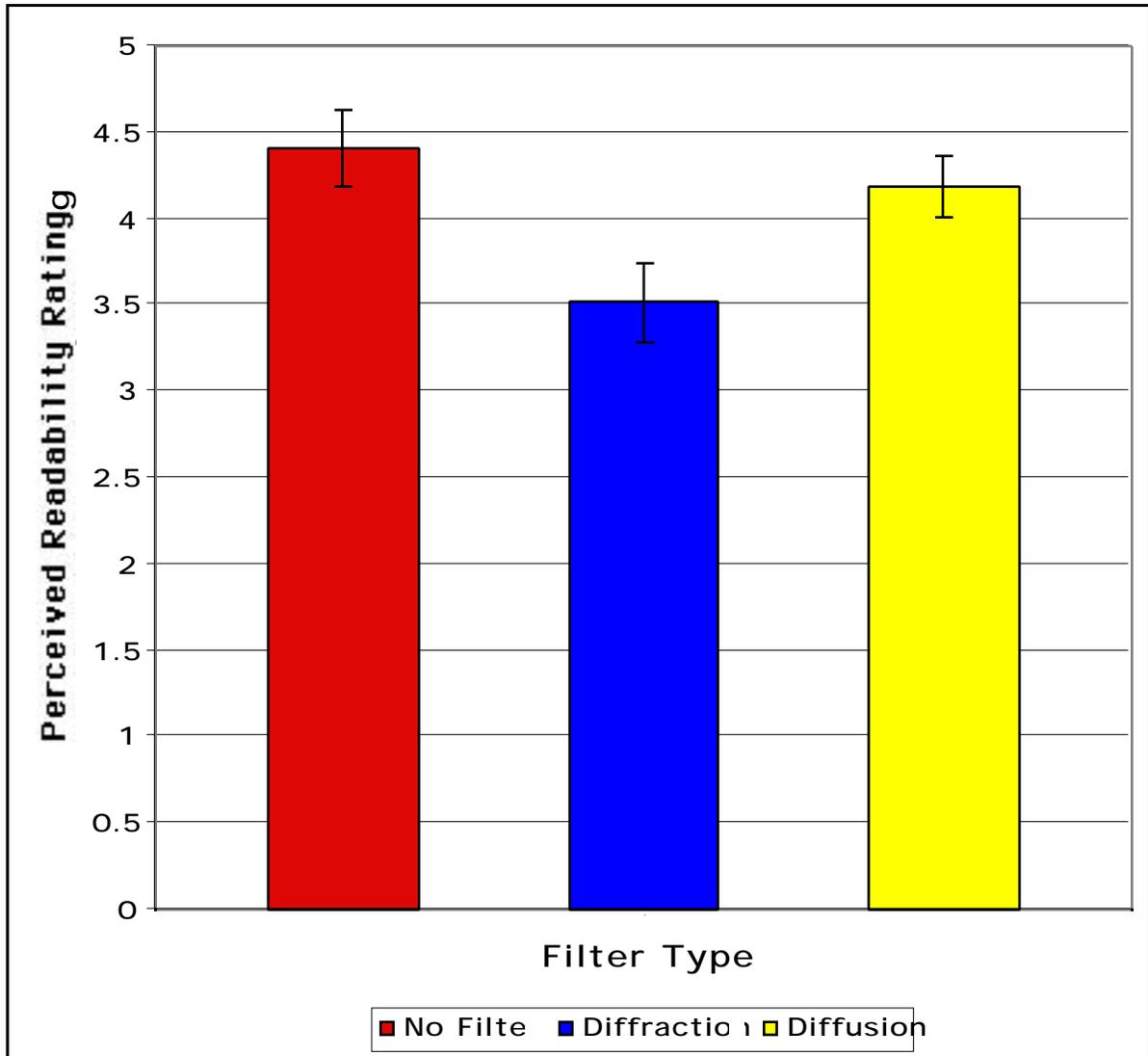
Figure 14. Main Effect of Filter on perceived readability ratings.

A non-parametric Kruskal-Wallis test supports the significant effect of Filter [H(2)=7.96, p=0.019] on the average ratings for Question #1.

Question #2

> 2. How would you rate the overall image quality of this configuration?
>
> **1   2   3   4   5   6   7**
> **Worst Imaginable   Average   Best Imaginable**

Figure 15. Survey Question #2.

The ANOVA summary for Question #2 is shown in Table 17. The effect of Filter on the average rating for Question #2 was significant (p=0.024). The average ratings across the levels of Filter are shown in Figure 16. Table 18 shows the results of a Newman-Kuels post-hoc test. These results indicate that the No Filter and Diffusion Filter conditions yielded significantly higher perceived image quality ratings than the Diffraction Filter condition.

Table 17. ANOVA Table for Question #2

Source	df	MS	F	p[1]
Between				
Subjects	8	2.111		
Within				
Task	2	0.259	0.195	0.667
Task x Subjects	16	1.329		
Filter	2	10.037	6.142	0.024*
Filter x Subjects	16	1.565		
Task x Filter	4	1.019	2.304	0.124
Task x Filter x Subjects	32	0.442		
Total	80			

* indicates a significant result ($p < 0.10$)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factors: Epsilon-hat (Task) = 0.793
                               Epsilon-hat (Filter) = 0.895
                               Epsilon-hat (Task x Filter) = 0.711

Table 18. Newman-Kuels Results of Question #2

	Diffraction (3.407)	No Filter (4.444)	Diffusion (4.482)	r	CD$_{N-K}$
Diffraction	-	1.04*	1.07*	2	0.67
No Filter		-	0.04	3	0.53
Diffusion			-		

***indicates a significant result (p < 0.10)**
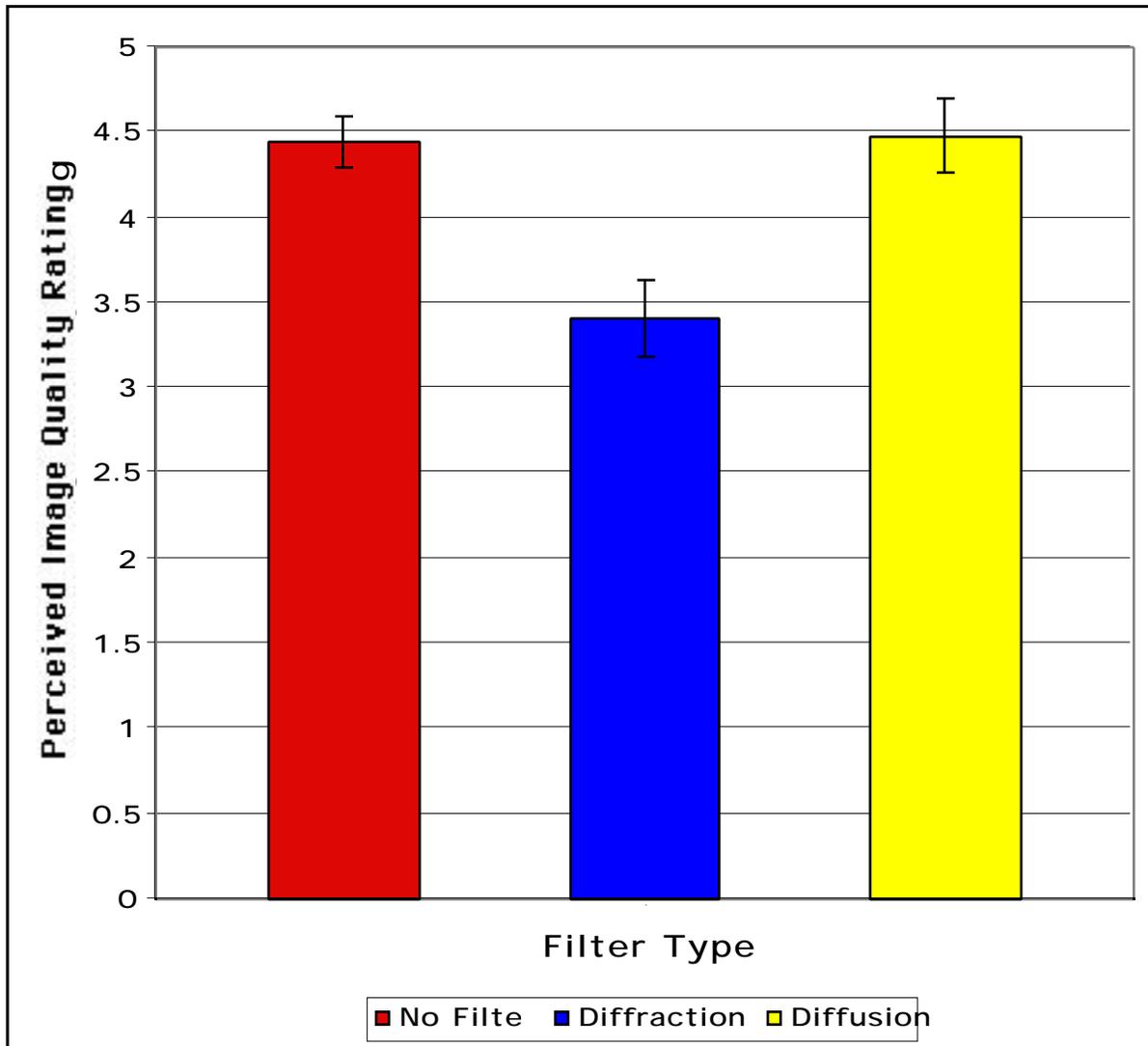
Figure 16. Main effect of Filter on perceived image quality ratings.

A non-parametric Kruskal-Wallis test supports the significant effect of Filter [H(2)=14.70, p=0.001] on the average ratings for Question #2.

---

3. How would you rate the brightness of the screen using this configuration?

    1   2   3   4   5   6   7
  Too dark   **Just right**   **Too bright**
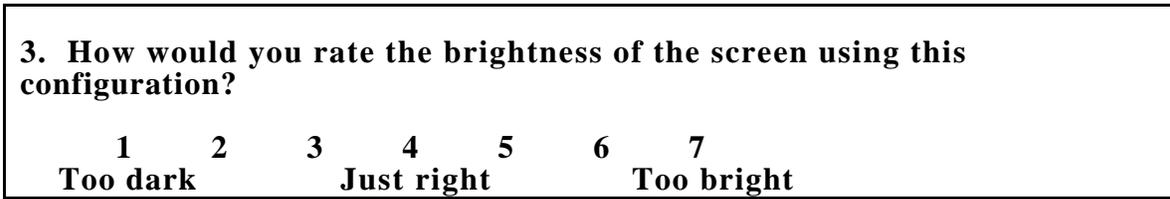
Figure 17. Survey Question #3.

The ANOVA summary for Question #3 is shown in Table 19. The effect of Filter on the average rating for Question #3 was significant (p=0.001). The average ratings across the levels of Filter are shown in Figure 18. Table 20 shows the results of a Newman-Kuels post-hoc test. These results indicate that the perceived brightness associated with the No Filter condition is significantly closer to the ideal "Just Right" rating of "4" as compared to the diffraction and diffusion conditions. The rating associated with the Diffusion Filter is significantly closer to the ideal rating as compared to the Diffraction Filter condition.

Table 19. ANOVA for Question #3

Source	df	MS	F	p[1]
Between				
Subjects	8	1.611		
Within				
Task	2	1.370	1.113	0.308
Task x Subjects	16	1.232		
Filter	2	18.370	20.454	0.001*
Filter x Subjects	16	0.898		
Task x Filter	4	0.407	0.727	0.544
Task x Filter xSubjects	32	0.560		
Total	80			

* indicates a significant result (p < 0.10)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factors: Epsilon-hat (Task) = 0.947
                                    Epsilon-hat (Filter) = 0.944
                                    Epsilon-hat (Task x Filter) = 0.894

Table 20. Newman-Kuels Results of Question #3

	Diffraction (2.556)	Diffusion (3.593)	No Filter (4.185)	r	CD_{N-K}
Diffraction	-	1.04*	1.63*	2	0.57
Diffusion		-	0.59*	3	0.45
No Filter			-		

*indicates a significant result (p < 0.10)
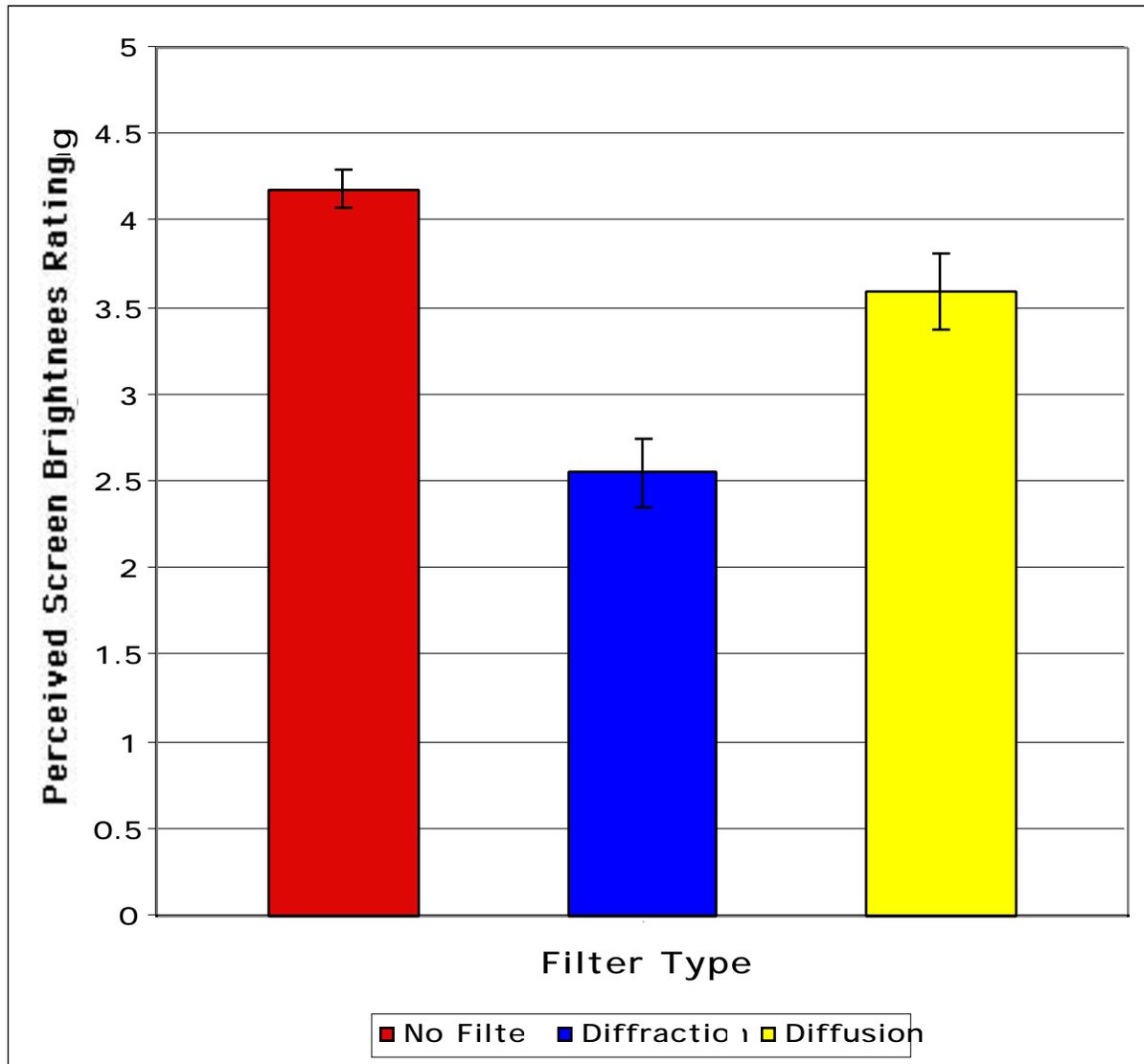
Figure 18. Main effect of Filter on perceived screen brightness rating.

A non-parametric Kruskal-Wallis test supports the significant effect of Filter [$H(2)=30.66$, $p=0.001$] on the average ratings for Question #3.

Question #4

4. How would you rate the amount of glare present on the screen surface?
1   2   3   4   5   6   7   **Bothersome   Noticeable   Non-existent**

Figure 19. Survey question #4.

The ANOVA summary for Question #4 is shown in Table 21. The results indicate that no effects were significant. Non-parametric Kruskal-Wallis tests also yielded no significant effects.

Table 21. ANOVA for Question #4

Source	df	MS	F	p[1]
Between				
Subjects	8	4.161		
Within				
Task	2	0.161	0.094	0.764
Task x Subjects	16	1.716		
Filter	2	1.383	0.344	0.566
Filter x Subjects	16	4.022		
Task x Filter	4	0.938	1.134	0.352
Task x Filter x Subjects	32	0.827		
Total	80			

* indicates a significant result (p < 0.10)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factors: Epsilon-hat (Task) = 0.948
                             Epsilon-hat (Filter) = 0.939
                             Epsilon-hat (Task x Filter) = 0.890

```
5. How would you rate this configuration in relation to the degree to which you were able
to change posture or position while working on the task?

    1      2      3      4      5      6      7
Severely              Restriction           Freedom
restricted free       of movement          to move was
-dom to move          was noticeable       not restricted
```

Figure 20. Survey question #5.

The ANOVA summary for Question #5 is shown in Table 22. The effect of Filter on the average rating for Question #5 was significant (p=0.037). The average ratings across the levels of Filter are shown in Figure 21. Table 23 shows the results of a Newman-Kuels post-hoc test. These results indicate that the ratings associated with the No Filter and Diffusion Filter conditions are significantly higher than the rating associated with the Diffraction Filter condition.

Table 22. ANOVA for Question #5

Source	df	MS	F	p[1]
Between				
Subjects	8	7.735		
Within				
Task	2	0.346	0.555	0.468
Task x Subjects	16	0.624		
Filter	2	11.309	5.420	0.037*
Filter x Subjects	16	2.086		
Task x Filter	4	0.698	1.249	0.312
Task x Filter x Subjects	32	0.559		
Total	80			

* indicates a significant result (p < 0.10)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factors: Epsilon-hat (Task) = 0.956
Epsilon-hat (Filter) = 0.856
Epsilon-hat (Task x Filter) = 0.818

Table 23. Newman-Kuels Results of Question #5

|	Diffraction (5.185)	Diffusion (6.074)	No Filter (6.444)	r	CD$_{N-K}$
Diffraction	-	0.89*	1.26*	2	0.87
Diffusion		-	0.37	3	0.69
No Filter			-		

*indicates a significant result (p < 0.10)
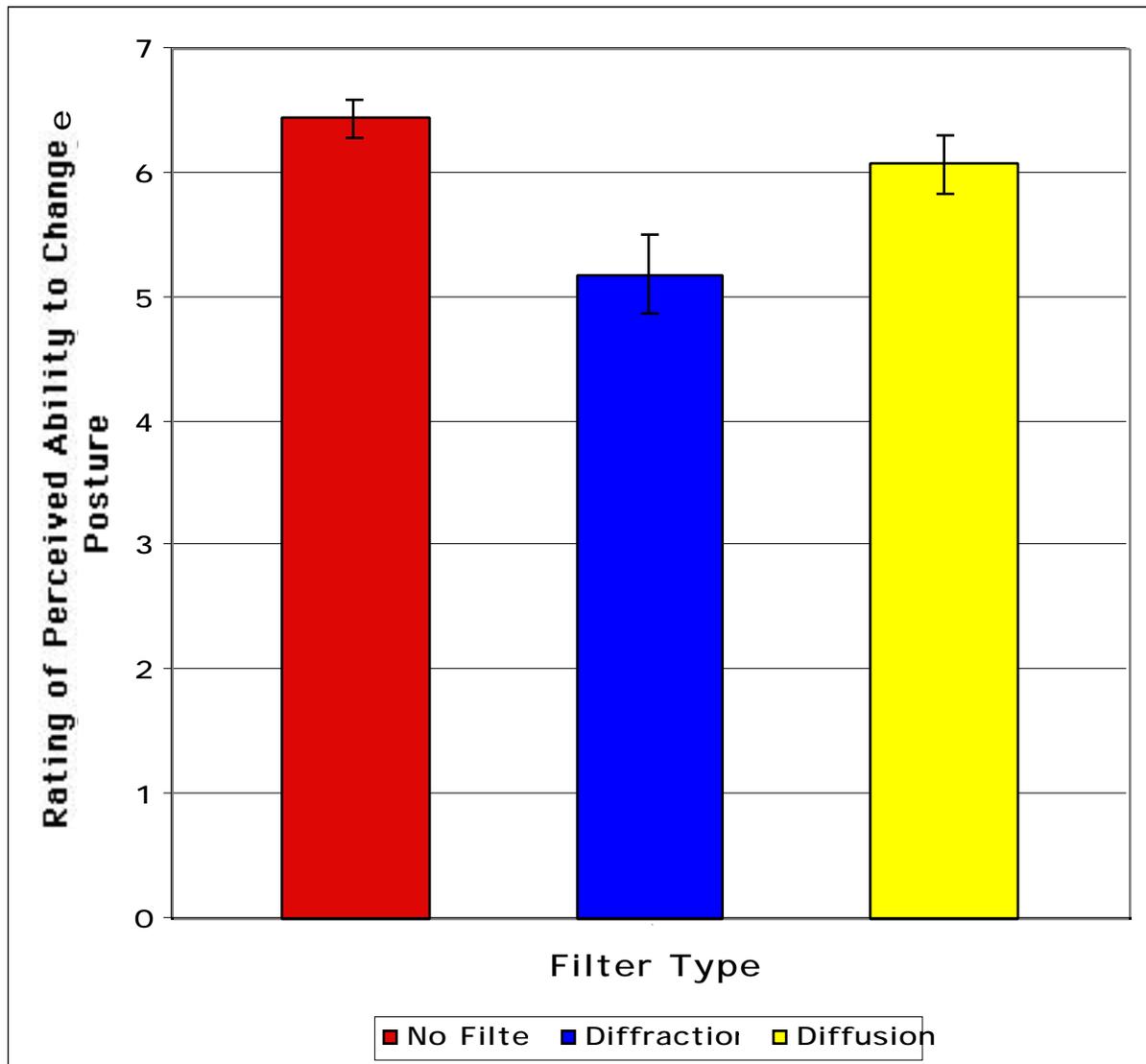
Figure 21: Main effect of Filter on perceived ability to change posture or position.

A non-parametric Kruskal-Wallis test supports the significant effect of Filter [H(2)=10.79, p=0.005] on the average ratings for Question #5.

6. How do you feel that the screen type used in this task affected your performance of the task?

| **1**	**2**	**3**	**4**	**5**	**6**	**7**
Negative			**No Effect**			**Positive**
Effect						**Effect**
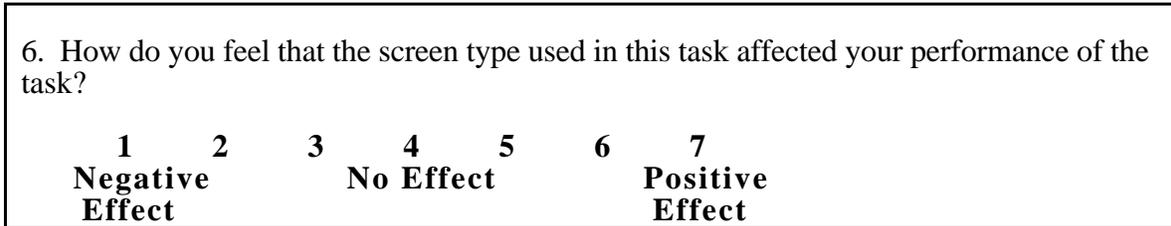
Figure 22. Survey question #6.

The ANOVA summary for Question #6 is shown in Table 24. The effect of the interaction between Task and Filter on the average rating for Question #6 was significant. Figure 23 shows the average ratings across the levels of Task and Filter. Results of a Newman-Kuels post-hoc test are shown in Table 25. These results indicate that, within the Data Entry and Web Browsing tasks, the Diffraction Filter condition yielded significantly lower ratings of perceived performance as compared to other Filter / Task conditions.

Table 24. ANOVA for Question #6

Source	df	MS	F	p[1]
Between				
Subjects	8	1.012		
Within				
Task	2	0.642	1.149	0.307
Task x Subjects	16	0.559		
Filter	2	4.457	1.878	0.196
Filter x Subjects	16	2.374		
Task x Filter	4	1.475	2.641	0.099*
Task x Filter x Subjects	32	0.559		
Total	80			

* indicates a significant result ($p < 0.10$)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factors: Epsilon-hat (Task) = 0.730
                            Epsilon-hat (Filter) = 0.798
                            Epsilon-hat (Task x Filter) = 0.583

A non-parametric one-way Kruskal-Wallis test indicates the effect of Filter on the average ratings for Question #6 was significant [H(2)=7.29, p=0.027]. These results indicate a similar data trend in the ratings associated with the Diffraction Filter when compared to the parametric analysis. However, the Kruskal-Wallis test does not take into consideration the two-way interaction of Task and Filter.

Table 25. Newman-Kuels Results of Question #6.

|	T8 (3.22)	T5 (3.56)	T4 (**3.89**)	T7 (3.89)	T2 (3.89)	T3 (4.00)	T6 (4.44)	T9 (4.56)	T1 (4.67)	r	CD
Diffract / WB (T8)	-	0.33	0.67	0.67	0.67	0.78	1.22*	1.33*	1.44*	9	1.06
Diffract / DE (T5)		-	0.33	0.33	0.33	0.44	0.89	1.00*	1.11*	8	1.03
None / DE (T4)			-	0.00	0.00	0.11	0.56	0.67	0.78	7	1.00
None / WB (T7)				-	0.00	0.11	0.56	0.67	0.78	6	0.96
Diffract / WP (T2)					-	0.11	0.56	0.67	0.78	5	0.91
Diffuse / WP (T3)						-	0.44	0.56	0.67	4	0.84
Diffuse / DE (T6)							-	0.11	0.22	3	0.75
Diffuse / WB (T9)								-	0.11	2	0.60
None / WP (T1)									-		

* indicates a significant result (p < 0.10)
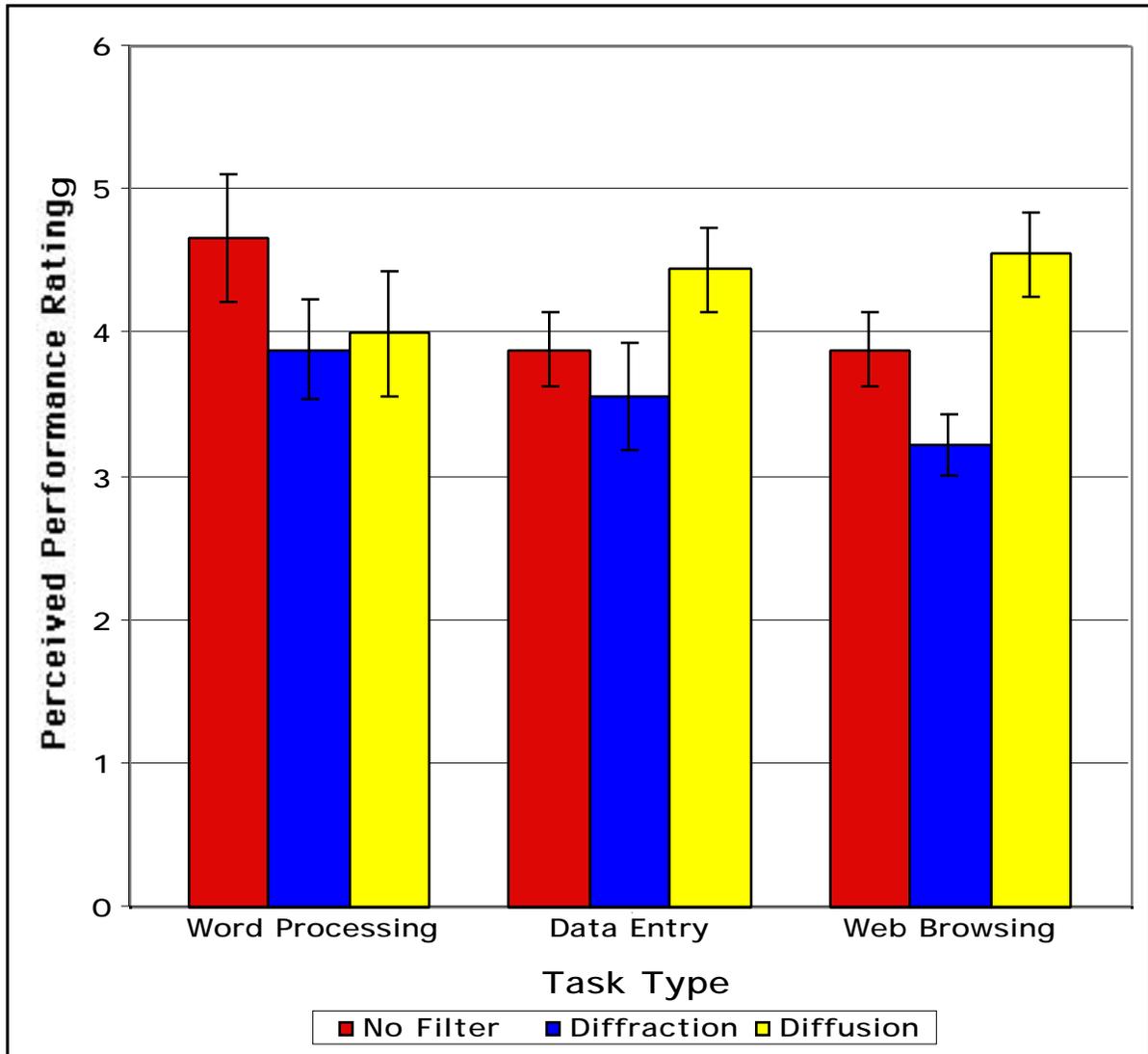
Figure 23. Interaction of Task Type and Filter on perceived performance ratngs.(Error bars indicate +/- 1 standard error of the mean).

Question #7

7. During the task did you experience any discomfort?

1	**2**	**3**	**4**	**5**	**6**	**7**
No			**Moderate**			**Extreme**
Discomfort			**Discomfort**			**Discomfort**

Figure 24. Survey question #7.

The ANOVA summary for Question #7 is shown in Table 26. The effect of Filter on the average rating for Question #7 was significant (p=0.065). Average ratings across Filter are shown in Figure 25. Results of a Newman-Kuels post-hoc test are shown in Table 27. These results indicate that the discomfort rating associated with the Diffraction Condition is significantly higher than the rating associated with the No Filter condition.

Table 26: ANOVA for Question #7

Source	**df**	**MS**	**F**	**p[1]**
Between				
Subjects	8	18.250		
Within				
Task	2	4.926	2.614	0.127
Task x Subjects	16	1.884		
Filter	2	4.111	4.000	0.065*
Filter x Subjects	16	1.028		
Task x Filter	4	0.148	0.229	0.876
Task x Filter x Subjects	32	0.648		
Total	80			

* indicates a significant result (p < 0.10)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factors: Epsilon-hat (Task) = 0.978
                             Epsilon-hat (Filter) = 0.913
                             Epsilon-hat (Task x Filter) = 0.893

Table 27. Newman-Kuels Results of Question #7

	No Filter (2.04)	Diffusion (2.48)	Diffraction (2.81)	r	CD$_{N-K}$
No Filter	-	0.44	0.78*	2	0.61
Diffusion		-	0.33	3	0.48
Diffraction			-		

*indicates a significant result (p < 0.10)
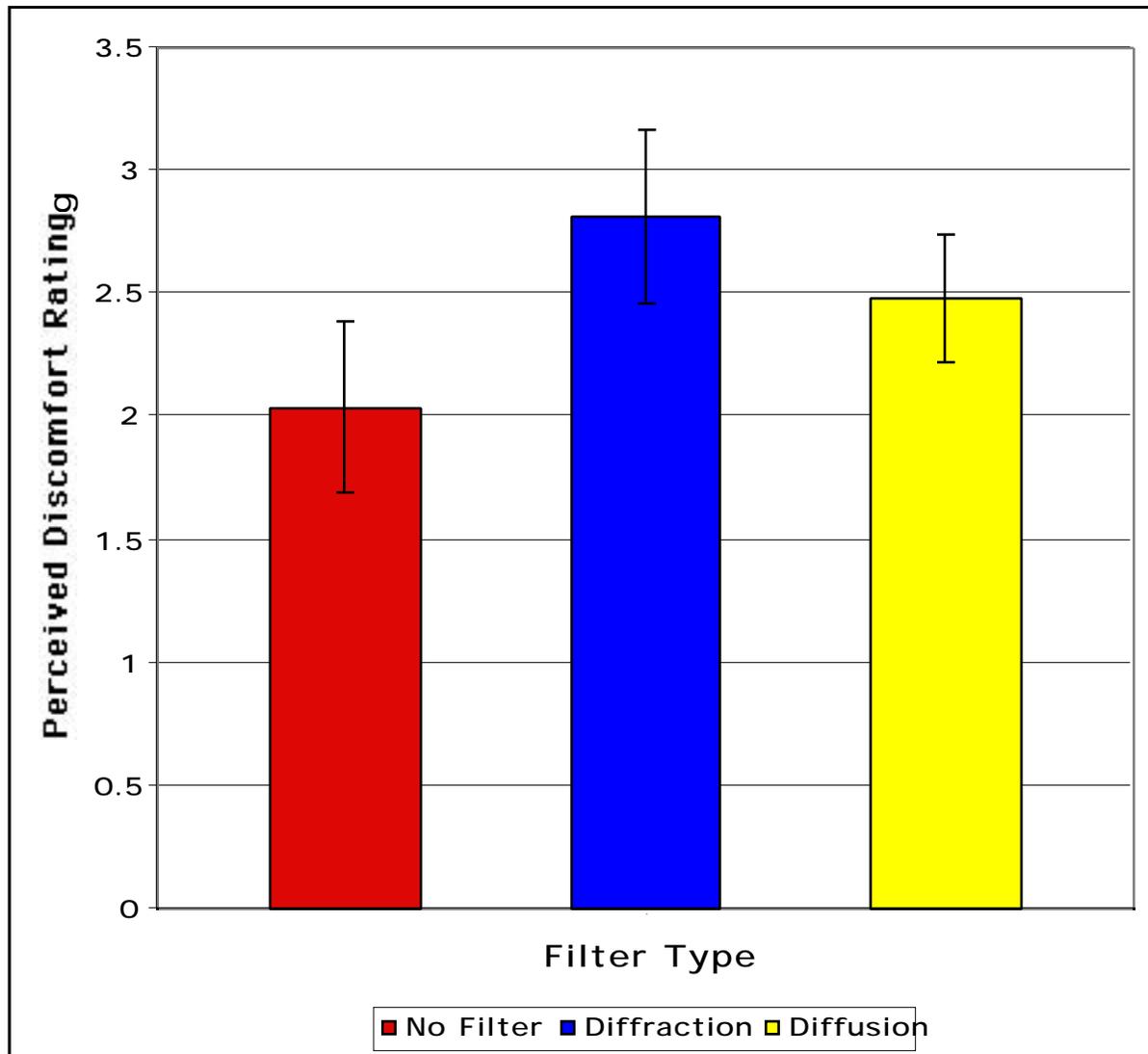
Figure 25. Main effect of Filter on perceived discomfort ratings. (Error bars indicate +/- 1 standard error of the mean).

A One-way non-parametric Kruskal-Wallis tests indicates that Filter was not significant. The discrepancy between the parametric and non-parametric results can be attributed to the lower-power associate with the non-parametric test.

Analysis of Variance of Performance Measures

ANOVA procedures were used to examine the effects of filter type on operator performance. The analyses were done within-task, since the measures could not be meaningfully compared across tasks.

Word Processing Tasks

Table 28. Performance Measure Values for Word Processing Tasks

	No Filter	Diffraction	Diffusion
Avg. # of Characters/ Avg. Minutes	144.44	139.19	145.65
Avg. # of Errors	20.44	24.11	23

Two measures were used to characterize operator performance in the Word Processing condition: ratio of characters input per minute (time-based) and the number of errors (accuracy-based).

The ANOVA summary for the ratio of characters per minute in the Word Processing condition is shown in Table 29. The results indicate that Filter was not significant.

Table 29. ANOVA of Characters per Minute (Word Processing Performance Measure)

Source	df	MS	F	p[1]
Between				
Subjects	8	2931.85		
Within				
Filter	2	108.67	0.67	0.43
Filter xSubjects	16	161.25		
Total	26			

* indicates a significant result ($p < 0.10$)

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factor: Epsilon-hat (Filter) = 0.892

The ANOVA summary for the number of errors in the Word Processing condition is shown in Table 30. The results indicate that Filter was not significant.

Table 30. ANOVA of Errors (Word Processing Performance Measure)

Source	df	MS	F	p[1]
Between				
Subjects	8	9704.74		
Within				
Filter	2	63.63	1.51	0.24
Filter xSubjects	16	336.37		
Total	26			

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factor: Epsilon-hat (Filter) = 0.998

Data Entry Tasks

Table 31. Performance Measure Values for Data Entry Tasks

	No Filter	Diffraction	Diffusion
Avg. # of Characters/ Avg. Minutes	64.22	61.31	56.73
Avg. # of Errors	1.55	1.55	1.89

Two measures were used to characterize operator performance in the Data Entry condition: ratio of characters input per minute (time-based) and the number of errors (accuracy-based).

The ANOVA summary for the ratio of characters per minute in the data entry task is shown in Table 32. The results indicate that Filter was not significant.

Table 32. ANOVA of Characters per Minute (Data Entry Performance Measure)

Source	df	MS	F	p[1]
Between				
Subjects	8	473.26		
Within				
Filter	2	120.64	2.12	0.18
Filter xSubjects	16	56.84		
Total	26			

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factor: Epsilon-hat (Filter) = 0.651

The ANOVA summary for the number of errors in the data entry task is shown in Table 33. The results indicate that filter type was not significant.

Table 33. ANOVA of Errors (Data Entry Performance Measure)

Source	df	MS	F	p[1]
Between				
Subjects	8	3.08		
Within				
Filter	2	0.33	0.15	0.70
Filter xSubjects	16	34.66		
Total	26			

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factor: Epsilon-hat (Filter) = 0.694

Table 34: Performance Measure for Web Browsing Tasks

	No Filter	Diffraction	Diffusion
Avg. # of Errors	0.78	0.78	1.78

A five-question quiz was used to evaluate performance for the Web Browsing tasks. Each quiz addressed issues that were discussed in the readings involved in each Web Browsing task. The measure used to rate performance was the number of errors on each quiz.

The ANOVA summary for the number of errors in the Web Browsing condition is shown in Table 35. The results indicate that Filter was not significant.

Table 35. ANOVA of Errors (Web Browsing Performance Measure)

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p[1]</u>
<u>Between</u>				
Subjects	8	1.33		
<u>Within</u>				
Filter	2	2.11	2.58	0.13
Filter xSubjects	16	0.82		
<u>Total</u>	26			

[1]The Box correction was used to correct p-values for heterogeneity of covariance.

Box correction factor: Epsilon-hat (Filter) = 0.979

Analysis of Head Position

       The purpose of performing an analysis of variance on the average head position was to examine whether changes in the independent variables had a significant effect on the average position of the heads of the participants during the tasks performed in the experiment. The importance of this was finding was that it would establish a reference for average head position of VDT operators that could be used for further research.

       The focus of this experiment was to determine whether the use of privacy filters have an effect on the posture of VDT operators, and specifically, whether the design of privacy filters would restrict operators from assuming neutral or normal work postures. Past experiments have shown that constrained postures result in decreased performance (Hünting, Läubli, and Grandjean, 1980). The posture of VDT operators is indexed by head position. The analysis of average head position indicated an interaction between Filter and Task Type.

       The effects of privacy filters on the average observed head position followed different trends across tasks. For the Word Processing and Data Entry tasks, the Diffraction and Diffusion Filter conditions did not affect the observed average head position as compared to the No Filter condition. However, for the Web Browsing condition, the filter types produced significant differences in head position. The Diffraction Filter condition produced an average head position significantly closer to the center position than the Diffusion Filter condition. The finding that average head position was affected by the use of privacy filters under certain task conditions suggests further research is warranted.

       The Web browsing task resulted in average head positions closer to the midpoint of the VDT under the no filter and diffraction filter conditions, as compared to the word processing and data entry tasks. However, the head positions associated with the Diffusion Filter / Web Browsing condition did not significantly differ from the head positions associated with the Word Processing and Data Entry tasks.

The use and placement of the document holder is a factor that may explain the greater left-sided deviation under the Word Processing and Data Entry tasks. The document was placed to the left of the VDT, which may have introduced a bias of head positions toward the left-hand side of the VDT. The participants viewed a document, in the word processing and data entry tasks, which was located to the left of the VDT. The Web browsing task did not require the participants to look at any information presented off the screen, which may explain why the left-sided deviation was significantly lower in the No Filter / Web Browsing and Diffraction Filter / Web Browsing conditions.

Also, it should be noted that the mouse placement in this experiment may have biased the results. The mouse was placed on the same vertical level as the based of the VDT. The placement of the mouse in this experiment could be a contributing factor in the head position data, based on the fact that the user would have to reach to operate the mouse. Under all conditions the mouse was placed to the right of the VDT. The right-hand placement of the mouse could be a contributing factor to the clusters of observations located to the right of the majority of observations seen in the frequency distributions (see Appendix B).

The analysis of the standard deviation of head position provided interesting information on the effects of privacy filters on workstation postures. The results of this analysis showed that privacy filters reduce the range of head positions of participants, in the Web Browsing task. Within the Word Processing and Data Entry tasks, privacy filters did not affect the range of head positions.

One explanation for these effects involves the constraints on posture caused by the tasks themselves. The Word Processing and Data Entry tasks required participants to read information from an off-screen source. It is possible that any effects that the privacy filters may have on head position would be decreased or nullified in these tasks, due to the fact that the participants were not looking at the VDT screen during a majority of time these tasks were being performed. Another consideration that should be taken into account is

keyboard use. The Word Processing and Data Entry tasks involved extensive keyboard use, while the Web Browsing conditions were entirely mouse-driven. Differences in placement of the keyboard and the mouse may affect the posture of the participants. Differences in hand and arm motions across the two input devices may also affect workstation posture.

The most important information, which resulted from the ANOVA of the standard deviations was the effect of Filter in the Web Browsing condition. Under the Web Browsing condition, it is clear that the use of both diffraction and diffusion type privacy filters resulted in a decrease in the degree to which head positions changed and the range of observed head positions as compared to the control condition, in which no filter was used. Moreover, use of the diffraction filter resulted in a significantly lower standard deviation of head position as compared to the diffusion filter. The general range of head positions observed in the No Filter and Diffusion Filter conditions was approximately +/- 25˚ from the line bisecting the midpoint of the VDT. The range observed in the Diffraction Filter condition was approximately +/-15˚ (See Appendix B).

It is apparent from the results of the analysis of standard deviation of head position that the use of privacy filters limits the range natural of horizontal head deviations under the conditions of the Web Browsing task. If a normal range of head positions is to be allowed for Web browsing tasks, privacy filters should be designed with a viewing cone specification of approximately +/- 25˚.

The Web Browsing task was a mouse-driven reading intensive task that required the operator's attention to be focused primarily on the VDT screen. The design implications of these results could be applied to other similar task in which the information displayed on the VDT screen is the primary focus of the user. Some examples of similar tasks may include air-traffic control positions, computerized-switchboard operators, CAD/CAM operators, and graphic design applications.

Subjective Data Analysis

The analysis of survey questions identified significant differences across the filter types. In most cases, the participants reported a negative or undesirable effect associated with the use of the privacy filters. The Diffraction Filter condition was judged negatively in terms of readability, image quality, screen brightness, discomfort, performance and its constraint on postures. Screen brightness was the only subjective dimension issue that was affected by the Diffusion Filter condition.

It is noted that the use of the privacy filters had no significant effect on perceived screen glare as reported by the participants. This point is of interest due to the fact that both privacy filters are designed with the function of reducing screen glare to increase performance. Based on the subjective data collected neither privacy filter offers a perceived improvement upon the standard no-filter VDT. However, the actual "privacy" effect of the privacy filters was not addressed by the subjective survey questions. The "privacy" feature of the filters could have a desirable effect in terms of issues that were not addressed in the subjective data analysis.

Analysis of Performance Measures

The results of the analysis of the performance measures used in the experiment indicated that there were no significant changes in performance across any of the different treatment conditions. The results of the analysis indicated that the use of privacy filters have no effect on performance, assuming that the performance measures used are valid. A problem with measuring performance of the tasks in the experiment and using the results as a predictor for real-world applications is that the tasks performed in the experiment were short tasks. The duration of the tasks in the experiment is not necessarily representative of the duration of similar tasks that may be performed in a real-world setting. The constraints in posture observed in the Web browsing tasks under the diffraction and diffusion

conditions might affect performance significantly if similar tasks were performed over a longer duration of time.

Design Implications

The results indicate that under specific task conditions the use of privacy filters significantly decreases the range of natural horizontal head deviation. The decrease in range of allowable postures should be taken into account in the design of privacy filters. Previous research tends to indicate that restrictions in the ability to change posture can lead to decreases in performance and worker health. While the objective performance measures did not indicate any significant change in performance, it should be noted that the symptoms associated with restricted postures are often cumulative effects, which may appear after prolonged exposure to the postural restrictions. The tasks involved in this experiment only exposed the VDT operators to any such restrictions for 20 to 30 minutes. It can not be concluded whether prolonged exposure would result in a decrease in performance, based on this experiment. The subjective data does indicate that participants perceive negative effects, associated with the privacy filters (the diffraction filter, in particular). It is unclear as to how the actual privacy feature is perceived by the participants in this experiment, because the participants were not asked to rate any aspect of the privacy feature. Further research is needed on the issues addressed in this experiment before a final conclusion can be reached.

Future Research Implications

It is clear from the results of this experiment that the use of privacy filters does have a significant effect on the range of postures assumed by VDT operators, at least under certain task conditions. Based on the findings of this experiment, it is possible that further study of this topic could provide greater insight on the effects of privacy filter usage and the effects of constrained postures at VDT workstations. The design of this may be improved

in the future, such as by increasing task length. A future experiment, which involved collecting data over a longer range of time, could possibly identify any long-term effects on performance that may be caused by the use of privacy filters.

Another recommendation for future research would be to increase the number of levels of task type. The addition of at least one more screen-based task would allow better comparisons between tasks that involved the use of source documents and tasks that were entirely screen-based. Tasks should also be set up in order to control for keyboard use versus mouse use. Having control tasks for input devices would be useful in investigating whether particular input devices cause an interaction effect with privacy filter use.

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APPENDIX A:

PARTICIPANT"S TASK INSTRUCTIONS

INSTRUCTIONS FOR WORD PROCESSING TASKS

1.   You will be provided with a series of hard copy text passages.

2.   Your assigned task is to transfer the text to the word processing application by inputting the text using the keyboard. The word processing application will be open and ready for you to begin inputting the text information when the task begins. Proper font and point size will be pre-selected prior to the start of the task.

3.   You should input the text exactly as it appears on the hard copy document, maintaining capitalization, formatting, punctuation, and alignment.

4.   The only toolbar buttons you will need for these tasks are the text formatting buttons (bold, italics, and underline), the alignment buttons (left, center, and right), and the spacing buttons (single, and double). These buttons are located at the top of the screen and can be activated/deactivated by clicking on the respective button using the mouse. **Do not** use the mouse to click any other buttons or menus.

5.   The hard copy text passages should be placed in the document holder provided and should remain there while the information is being transferred to the word processing application. Do not move the document holder from its original position.

6.   The task will be performed until it has been completed. This task is considered complete when the assigned text passage has been completely transferred to the word processing application. Do not attempt to save the file. When you have inputted the last text character, the task is complete.

7.   Upon completion of the task verbally notify the experimenter.

INSTRUCTIONS FOR DATA-ENTRY TASKS

1.   You will be provided with a hard copy document comprised of numerical data.

2.   Your assigned task is to transfer the data to the spreadsheet application by manually inputting the data using the keyboard. The spreadsheet application will be open and ready for you to begin inputting the data when the task begins. All cells will be properly formatted for the given task prior to the start of the task. The proper font and point size will also be pre-selected. Alternating columns will be underlined. The spreadsheet is formatted to do this automatically. You will not have to manually underline any text.

3.   You should enter the data exactly as it appears on the hard copy document.

4.   You will not need to use any of the toolbars in the spreadsheet application to complete this task. **Do not** use the mouse to click on any buttons or menus.

5.   The hard copy document should be placed in the document holder provided and should remain there while the information is being transferred to the word processing application. Do not move the document holder from its original position.

6.   The task will be performed until it has been completed. This task is considered complete when the assigned data has been completely transferred to the spreadsheet application. Do not attempt to save the file. When you have inputted the last number of the last cell, the task is complete.

7.   Upon completion of the task verbally notify the experimenter.

The following instructions were presented on-screen before each Web browsing task:

Below are instructions for the web tasks you are to complete. Links will be provided to each site that is to be visited for a particular task. Links will be denoted by blue text. Simply click on the link to go to the web page specified by the link. Once you have completed a task you will return to this page to receive instructions on the next task. To return to this page, locate the "GO" menu at the top of the screen. Pull down the menu, by holding down the mouse button. While continuing to hold down the mouse button, highlight "Task X" and release the mouse button. You should then return to this page. If at any point you are for any reason unable to complete a task, simply proceed to the next task.

APPENDIX B:

FREQUENCY DISTRIBUTIONS