INTERNATIONAL JOURNAL ON WORKING CONDITIONS
ISSN 2182-9535

Field study on visual and cognitive stressors in Visual Display Terminal office work

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Abstract: Office Visual Display Terminal (VDT) work is a paradigmatic case of a work system in which the adoption of a new technology introduces new associated risks of different natures: visual, musculoskeletal and cognitive. We carried out a Post Occupancy Evaluation at University of Mendoza administrative offices, and made a diagnosis of visual, cognitive and postural risks associated with VDT office work. Our results showed levels of horizontal illuminance lower than the legally required by our legislation, whose regulations need to be revised and updated. We found that 32% of our participants were outside the acceptable range of mental workload. Also, we explored the hypothetical role of glare sources as environmental distractors, finding a statistically significant linear correlation between vertical illuminance level and Stroop interference. This exploratory study described the behavior of many variables of interest in actual work situations, allowing us to propose a general model of VDT office.

Keywords: Office Ergonomics, Discomfort Glare, Divided Attention, Post Occupancy Evaluation.

Estudo de campo sobre stressores visuais e cognitivos no trabalho de escritório com ecrãs de visualização de dados

Resumo: O Trabalho de escritório com Ecrãs de Visualização de Dados (EVD) é um caso paradigmático de sistema de trabalho onde a adoção de uma nova tecnologia introduz novos riscos associados: visuais, músculo-esqueléticos e cognitivos. Fizemos uma Avaliação Pós-Ocupação (APO) nas áreas administrativas da Universidade de Mendoza, para fazer um diagnóstico dos riscos visuais, cognitivos e posturais associados ao trabalho com EVD. Os nossos resultados mostram uma iluminação média no plano de trabalho inferior à exigida pela legislação vigente, regulamentação que, por outro lado, precisa ser revista e atualizada. 32% dos participantes expressaram um nível inaceitável de carga mental de trabalho. Exploramos o papel hipotético das fontes de iluminação presentes no campo visual dos trabalhadores como distratores ambientais, encontrando uma correlação linear estatisticamente significativa entre o nível de iluminância vertical e a dimensão do efeito Stroop. Este estudo exploratório descreveu o comportamento das nossas variáveis de interesse na presença de fatores de confusão específicos numa situação de trabalho real, propondo um modelo geral de trabalho com EVD a partir do grau de correlação entre as variáveis avaliadas.

Palavras-chave: Atenção Dividida, Ergonomia de Escritório, Ofuscamento inibidor, Estudo Observacional.

Publicação editada pela RICOT (Rede de Investigação sobre Condições de Trabalho)
Instituto de Sociologia da Universidade do Porto

Publication edited by RICOT (Working Conditions Research Network)
Institute of Sociology, University of Porto

http://ricot.com.pt

1. Introduction

From the early 1980s high levels of musculoskeletal and visual problems, as well as concerns regarding psychosocial stress among Visual Display Terminal (VDT) workers had been described in the literature (e.g., Smith et al., 1981; WHO, 1988, Bergquist et al., 1995). More recent publications indicate that musculoskeletal, visual, and psychosocial issues still appear to cause problems for VDT workers (Aarås et al., 2000; Helland et al., 2008; Portello et al., 2012). Thus, VDT work is a paradigmatic case of a work system in which the adoption of a new technology introduces new risks associated with it, as well as their interaction effects (Aarås et al., 1998; Johnston et al., 2010). These risks depend on multiple factors derived from the specific requirements of the task, the job characteristics and the worker.

Visual Risks: The electronic office introduced in the 1980s new concerns about lighting. Office work with VDT has two sources of information: the computer screen and paper. Both have different optical characteristics, and may impose high visual adaptation and accommodation demands. When visual adaptation mechanisms are exceeded glare occurs. A large body of knowledge has been developed to predict discomfort glare (Clear, 2012) caused by natural and artificial light. Glare is caused by an unsuitable luminance distribution, or by high luminance contrasts within the visual field (CIE, 1987). Disability glare is the effect associated with a reduction in visual performance due to the masking effect caused by light scattered in the ocular media which produces a veiling luminance over the field of view, reducing the contrast and hence the visibility of the object (Stiles, 1929; Vos, 2002). Discomfort glare refers to the sensation perceived which is not necessarily tied to a reduction in visual performance. It is the distracting effect of peripheral light sources in the field of view. Glare is a factor that contributes to visual discomfort, along with lighting levels, lighting uniformity, veiling reflections, shadows, and flicker. Around 90% of workers using the computer for more than three hours a day, experience some form of visual impairment (Blehm et al., 2005). Computer Vision Syndrome (CVS) is a set of symptoms associated with the use of computers: eyestrain, eye fatigue, irritation, burning sensation, redness, blurred vision and double vision, among others (Weevers et al., 2005).

Musculoskeletal Risks: Musculoskeletal disorder (MSD) is a set of health problems associated to muscles, tendons, bones, cartilage, ligaments and nerves. It covers all kinds of illnesses, from mild and temporary discomfort to irreversible and disabling injuries. Its occurrence is associated with certain risk factors: excessive mechanical stress, duration of exposure, the frequency of repetition, or postures. It has multi-factorial origins including inadequate furniture design, hard and monotonous working hours, the lack of rest periods and other psychosocial aspects such as work style, perception of time pressure and high workload (del Río Martínez & González Videgaray, 2007). Working with VDT may lead to the maintenance of awkward postures, to static muscular effort or to the execution of repetitive tasks such as typing or using the mouse. Most common MSD are (OHSCO, 2007): back pain, carpal tunnel syndrome, epicondylitis, muscle tension, tension neck syndrome, tendinitis, and tenosynovitis. Symptoms are often similar, regardless of the body part: pain with or without motion, swelling, decreased motion range, stiffness, tingling, and numbness in nerve-related injuries.

Psychosocial Risks: Many VDT work is characterized by high pressure and little decision making by the user, inadequate work organization, repetitive and monotonous activities, and little support from colleagues and supervisors. Prolonged and daily use of computer systems may lead to psychological disorders often grouped under the term technostress, such as techno fatigue, techno anxiety and techno addiction (Salanova et al., 2013). Some of the technostress risk factors are: the perception of high working demands in terms of time and quality; a perceived lack of control over work pacing; little social support from other workers and supervisors; imbalance between workload and remuneration or recognition; perfectionist or obsessive work style of some individuals; lack of rest, among others.

Also, VDT work often requires great attention and cognitive effort. The introduction of Information and Communication Technologies (ICT) in the office has imposed a constant cognitive processing load on the individual (Wästlund, 2007) under a multi-task paradigm (Hashizume, Kurosu & Kaneko, 2007). Work places with widespread use of technology usually provide complex work environments with network based information and computer-mediated interactions and communication. The amount of information available to ICT users is huge and it constantly flows between people, digital media, and paper (Sellberg & Susi, 2014). In this context, mental workload is a risk factor present in this group of workers. Research in this field has proposed different definitions of mental workload depending on the underlying attentional model (Cain, 2007). We define mental workload as the difference between the capacity of the individual and the demands of the task (Wickens, 1984). Thus, mental load occurs when task demands exceed the capacity of the person.

The interaction between the user and a computer is mainly visual, by means of the VDT. While working with a computer, it is essential that only the relevant information be processed while irrelevant information is either suppressed or ignored while in presence of potential interference from secondary environmental distractors (Cowan, 2010), such as flicker, veiling reflections, or glare. It has been hypothesized that certain desirable outcomes can be increased in likelihood by directing the viewer’s attention to particular elements in the environment. For example, theatrical lighting designs use spotlights to direct audience attention to the important characters on stage. Luminance distributions are the luminous characteristic thought to be most likely to trigger the attention (positive or negative) response (Veitch, 2001).

Our literature review summarized both laboratory and field studies that established models of VDT office work by means of multiple regression analysis, with different predictor and outcome variables. From an office ergonomics perspective, musculoskeletal risks as an independent variable has received much more attention (i.e Faucett & Rempel, 1994; Dainoff, Cohen & Dainoff, 2005) and more recently, the cognitive variables of work (Bridger & Brasher, 2011). Office ergonomics must not only provide design guidance to minimize or eliminate health and safety issues; increasingly, the discipline needs to embrace the interdependencies of the human body as a dynamic biomechanical system through models that seek to combine mechanistic, motivational, perceptual and biological elements of human-at-work systems (Genaidy, Salem, Karwowski, Paez, & Tuncel, 2007). In order to meet such ambitious demands, a broader, systems view for office ergonomics must be adopted (e.g., Malone, Savage-Knepshield & Avery, 2007). Coincidently, our research is framed within this paradigm. Our objective was to sketch a model of interactions among visual, musculoskeletal, cognitive and ergonomic risks in VDT office work. We gathered data about those risks in actual workspaces by means of a Post Occupancy Evaluation (POE) (Federal Facilities Council, 2001). Most of the existing research in this topic was performed in central western countries. However, we found a growing body of literature concerning the effects of the increasing VDT use among office workers in developing countries (i.e. Shahnavaz, 1987; Rocha & Debert-Ribeiro, 2004; Eltayeb, Staal, Hassan, Awad & de Bie, 2008; Das & Ghosh, 2010; Ranasinghe et al., 2011; Rodriguez & Pattini, 2011; Boogar & Mirkouhi, 2013; Loghmani, Golshiri, Zamani, Kheirmand & Jafari, 2013). Our research gathered data from a Latin American context, and there lays its novelty.

2. Materials and Method

An observational study (von Elm et al, 2008) was carried out in the administrative offices of the University of Mendoza. The University of Mendoza is located in the metropolitan area of Mendoza, Argentina (32° 52' S, 68° 51' W, elevation 801 m) in a mid-density built area with abundant trees. Its façade faces approximately to the north. The different academic units (Architecture and Design, Law, Engineering, Medicine, Law) and their corresponding administrative areas are distributed in different buildings which are interconnected around an access courtyard.

We assessed the ergonomic exposures by using multiple methods: direct measurement (via instrumentation), observational (on-site and digital photography), and self-report methods (questionnaires). Table 1 summarizes the variables and methods used during the POE:

Table 1 - Relevant variables for VDT office work.

Variable	Operationalization	Method
Visual	Discomfort Glare	Glare Sensation Vote Evalglare
Cognitive	Divided attention Mental Workload	Stroop task NASA RTLX
Work System	Postural Habits Work equipment Environmental Comfort Psychosocial aspects	Ergolab
Photometric	Lighting levels Luminance Mapping	Grid Horizontal Illuminance Vertical Illuminance VDT HDRI

The design of this study is a between-persons one. For such studies, samples of more than 20 people are recommended, as far as they constitute a relatively homogeneous group in terms of age, training and functions within the organization (SHCP, 1999). All participants in our study worked in non-specialist roles (general administration or management) and had similar backgrounds.

We carried out the POE in a two-step approach:

1. Walkthrough (October 2012): In this stage we selected our case studies by means of a specific checklist. The Case Study Checklist helps to obtain physical and morphological information, data regarding occupancy of the space and to describe the natural and artificial lighting. This checklist also allows describing the activities performed by the worker, the workstation equipment and the user postures.

2. POE: We conducted the first gathering of data on December, 2012, and based on the initial diagnosis we performed a second stage of data collection on September, 2013. We used the following methods:

Glare Sensation Vote: The assessment method chosen for Discomfort Glare was semantic differential scaling using Glare Sensation Vote (GSV). This scale estimates the glare sensation as a function of the time the participant could stand the feeling of discomfort (Hopkinson, 1972). The criteria of this ordinal scale are: Unnoticeable Glare (UG), Just Perceptible (JP), Just Acceptable (JA); Just Uncomfortable (JU); Just Intolerable (JI). A digital form that included a definition for each point, presented the scale on the screen. This scale has been widely used since its introduction (Chauvel, Collins, Dogniaux & Longniore, 1980; Iwata, Kimura, Shukuya & Takano, 1991; Osterhaus & Bailey, 1992; Kim, Han & Kim, 2009). The borderline between comfort and discomfort (BCD) is somewhere between 'just acceptable' and 'just uncomfortable'. We used a self-administered paper form that was given to the participants. For greater accuracy in the answers, each point of the scale was defined in the questionnaire header, to be consulted at any time.

Evalglare: This Radiance (Ward Larson & Shakespeare, 1998) glare prediction tool processes HDRI images to find pixels on the visual scene that might cause glare (Wienold & Christoffersen, 2006). We worked with the task mean luminance as glare threshold criterion; since the foveal vision of the person will be oriented towards the task, it is assumed that his/her vision will be adapted to its luminance. Evalglare looks for pixels that are n times higher than the luminance adaptation and delivers analytical details including Daylight Glare Probability (DGP) (Wienold & Christoffersen, 2006), DGI (Daylight Glare Index), UGR (Unified Glare Rating), VCP (Visual Comfort Probability), CGI (CIE Glare Index). An updated review of these indices can be found in Clear (2012).

Stroop task: Divided attention is the ability to divide attention between two or more tasks, a common situation in office work with VDT, which is a context of distributed cognition (Hollan, Hutchins & Kirsh, 2000). This variable was operationalized through a classic test of experimental psychology: the Stroop task (Stroop, 1935). This test presents stimuli to participants in which the relationship between meaning and color has been manipulated so that it is congruent (the word RED presented in colour *red*) or incongruent (the word BLUE presented in color *green*), resulting in a delay in the color processing of the word, increasing reaction times and promoting errors. This semantic interference is called Stroop effect and its magnitude is an indicator of selective attention by requiring participants to respond selectively to a particular type of information while ignoring other information that competes for the realization of a goal. The robustness of the test has earned its name as the "gold standard" of attentional measures (MacLeod, 1991). This primary task was presented in the VDT through *PsychoPy* open source software. Stimuli (RED, GREEN, BLUE) were presented in the centre of the VDT, in Arial 16-point font colors (red, green and blue). The amount of congruent and incongruent stimuli was balanced and text/color combinations were randomly presented. Our participants were instructed to report the "ink" color in which the stimuli were displayed. The response of the participants was recorded using the computer keyboard.

Raw Task Load Index: Self-report assessments have always been appealing to researchers because no one is able to provide a more accurate judgment about the experienced mental load than the person involved. Self-report scales have high face validity, are easy to apply and have low costs of application (O'Donnell & Eggemeier, 1986). The NASA task load index (TLX) (Hart & Staveland, 1988) is a multidimensional scale that uses six dimensions to assess mental workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. This procedure requires a weighting procedure to combine the six individual scale ratings into a global score. Byers and others (1989) proposed a raw task load index (RTLX) that does not require task paired comparison weights. The RTLX is a simple average of the six TLX scales. Based on the high correlations between the traditional TXL and the raw TLX (r=0.95) we decided to derive the overall workload ratings using the simpler and less time consuming RTLX method.

ErgoLab: We gathered data on the components of the VDT workstations by means of Ergolab questionnaire (Monteoliva, 2009). This tool allows a self-assessment of many ergonomic aspects of the VDT work system in four categories of analysis: postural habits (workstation geometry, postures), environmental comfort (lighting, temperature/ventilation), furniture, and psychosocial aspects (software usability, work organization). It has an acceptable reliability of 0.793 Cronbach's alpha.

Illuminance: We measured the vertical illuminance on the centre of the VDT. Also, the indoor illuminance on the work plane was monitored with a LMT Pocket Lux 2 light meter. Several measuring points at regular distances formed a grid at 0.80 m from the floor. This allowed us to calculate the mean illuminance on the work plane and its uniformity:

$$E_{min} \geq E_{mean}/2 \qquad (1)$$

Where:
E_{min}:Minimum Illuminance
E_{mean} :Mean Illuminance

Luminance Mapping: We generated luminance maps from High Dynamic Range Images (HDRI) (Mann & Picard, 1995; Inanici & Galvin, 2004). A series of Low Dynamic Range Images (LDRI) were taken with a Nikon Coolpix 5400 camera with a Nikon FC-E9 Fish Eye lens mounted on a tripod. Each image was taken from approximate position of the participants' eyes, pointing to the center of the VDT. The LDRIs were processed with *Photosphere* for MAC OS. As every pixel within the HDRI corresponds to photometric values of luminance, this technique replaces point measurements taken with a luminance meter. However, we used a Minolta LS100 luminance meter to obtain control luminances in order to calibrate the scenes.

3. Results and Discussion

As a result of the walkthrough stage, we selected 22 cases in eight different administrative offices of the University of Mendoza (Table 2).

Table 2 - Summary of the selected cases.

Faculty	Locals	Workstations
Architecture and Design	4	10
Medicine	2	7
Law	1	4
Ingeneering	1	1

Grid illuminance: Table 3 shows mean illuminance values for each local. All of them were below the 750 lx required by local legislation. Only one workstation at local 6 reached the lighting level required for reading in paper (500 lx). Also, half of the locals had non-uniform distribution of lighting.

Table 3 - POE. Horizontal Illuminance (Eh) and Vertical Illuminance (Ev) results (lx)

Local	Eh Mean	Eh Min	SD	Eh Uniformity	P1	P2	P3	P4	P5
1	334.9	350	67.02	Yes	Eh 330 Ev 315	-	-	-	-
2	181	84	78.27	No	Eh 212 Ev 93	Eh 179 Ev 108	-	-	-
3	278.5	183	120.90	Yes	Eh 225 Ev 285	-	-	-	-
4	268.7	113	118.60	No	Eh 113 Ev 21	Eh 143 Ev 53	Eh 128 Ev 56	-	-
5	259	158	96.87	No	Eh 370 Ev 140	Eh 182 Ev 84	-	-	-
6	668.4	150	571.76	Yes	Eh 240 Ev 160	Eh 530 Ev 250	Eh 1390 Ev 1440	Eh 140 Ev 120	Eh 160 Ev 130
7	187.3	49	120.03	No	Eh 335 Ev 268	Eh 242 Ev 242	Eh 210 Ev 173	-	-
8	198.2	137	54.41	Yes	Eh 153 Ev 74	Eh 254 Ev 124	Eh 243 Ev 82	Eh 112 Ev 21	Eh 284 Ev 124

Table 3 also shows vertical illuminance levels at the centre of the VDT, with only one workstation reaching the 750 lx required by Argentinean legislation. An early conclusion could lead to inadequate environmental conditions in relation to lighting levels due to the poor compliance of current legislation. However, the role of ergonomists should not be reduced to a mere verifier of legal regulations. An uncomfortable question arises: Are the specifications given by the local legislation correct? An analysis of the historical development of the Argentinean legal framework shows how lengthy this process was. The Law of health and safety at work was created in 1972 and it was regulated in 1979, while the appearance of the specific protocol for verifying regulatory framework for lighting at work appeared in 2012 (Rodríguez, Pattini & Villarruel, 2013). Considering the technological, social and economic changes that affect work characteristics (i.e. in 1972 computers were in their infancy) along with the scientific and technical advances in the areas of lighting, vision and human factors, there is evidence of a divergence between present legal requirements in Argentina and the current needs of lighting in office environments, in terms of productivity health and safety.

Furthermore, there is no agreement among countries on lighting levels for specific tasks, varying in time and influenced by the technological, political and economic context (Mills & Borg, 1999). For example, while in Spain the minimum value for VDT work should be 750 lx, in the United States values should reach 300 lx, while in Australia 350 lx is required. The European Community is trying to unify that value on 500 lx. Our empirical evidence indicates that the lighting levels measured in this study are the usually ones found in this region, and the 750 lx required by law is perceived by the occupants as too bright. It is necessary to review the criteria for defining the adequate lighting levels in workspaces, although some claim it is impossible (Boyce, 1996). Instead, a new approach was proposed, one that widens attention to the appearance of the space rather than fixating on the lighting of a horizontal working plane (Boyce, 2013). In recent years the prime advocate for this approach has been Cuttle (2010) who argues that, over the last 30 years many visually difficult tasks, e.g. reading a fifth carbon copy, have disappeared and, where they do occur, technology often provides a better way of either doing the task or making it more visible than simply increasing the illuminance. Further, more and more information is being viewed on self-luminous devices such as smart phones and computer screens which higher illuminances make more difficult to see. Cuttle (2013) has already suggested metrics and a design procedure for first lighting the space and then any significant objects in it. Interestingly, this procedure can still lead to an installation producing uniform illumination of a horizontal working plane but now it will be the result of a considered opinion rather than unthinking obedience to a schedule of illuminance recommendations (Boyce, 2013).

Work System: Ergolab results (Table 4) show a lower percentage of compliance for the environmental factors, followed by the characteristics of the furniture characteristics and by the computer equipment. The best scores were achieved in the psychosocial aspects.

Table 4 - ERGOlab scores

	N	% Min	% Max	Mean	SD
Postural Habits	21	42	89	61.53	10.81
Workstation Design	21	41	76	60.53	8.87
Environmental Comfort	21	6	67	41.84	14.47
Psychosocial Aspects	21	38	88	66.26	12.33

Postural habits: Furniture is the main component that positions the worker while using a computer, followed by the characteristics of the computer itself. Computer work is essentially static and it is usually performed in a sitting posture. Indeed, Goossens, Snijders, Roelofs & van Buchem (2003), stated that more people sit all day in an office now than ever before.). Whilst there have been gradual changes in seat design over recent years (Pynt, 2014), the increasing numbers of people exposed to longer periods of sedentary work have shown that the current concept of a work seat is inadequate to reduce the physical consequences of these long periods (Corlett, 2008). Staffel (1884) defined the rules of the modern work chair: a horizontal seat with vertical support where the person is sitting with body and legs at right angles. Ergonomic requirements for office seats still use this approach, despite it imposes unwanted biomechanical demands on people. A review of a catalogue book (Friel & Friel, 2005) shows that every one of the large number of chairs presented as for office use had a substantially horizontal seat. Moreover, during our study we found 66.6% of people with their legs in an angle consistent with Staffel posture. A photographic monitoring of our participants´ postures (figure 1) complemented the analytical information obtained by means of Ergolab.

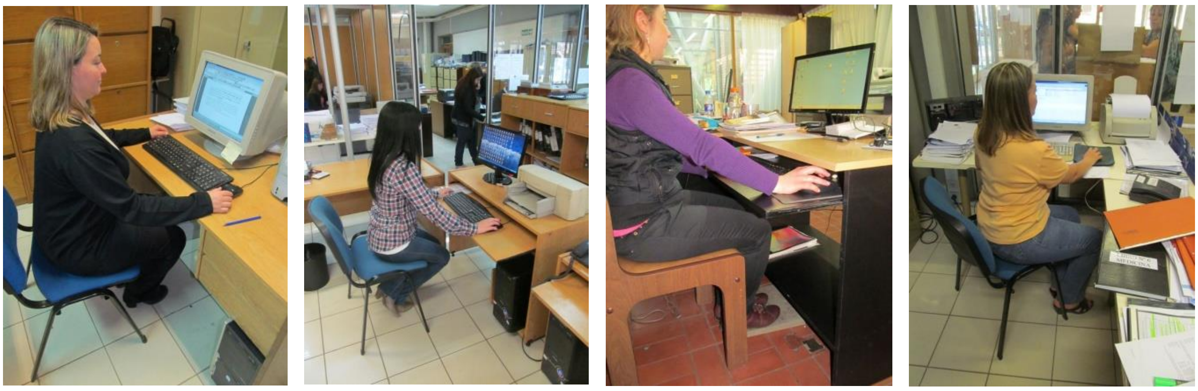


Figure 1- Photographic monitoring of sitting postures

Radiological studies show that the transition from a standing position to a conventional Staffel posture involves a hip flexion of 60° and a flexion of the lumbar spine of 30°, to achieve the 90° angle between the trunk and legs (Keegan, 1953). This effect has been noted in several studies since then (see the survey by Bridger & Bendix (2004)). Studies of pressures (Andersson et al., 1975) evaluated the inter-discs load in different seated positions, showing that the charge on L3-L4 disc represented 140% of body weight in Staffel position. Mandal (1981) proposed a bent forward position of legs that keep the spine´s physiological curvatures, reducing the intra-discal pressure in the lumbar area. It requires a specially designed seat and a table to work in this position. Medical research currently supports the case that a neutral posture maintaining some degree of lumbar lordosis in sitting, as well as movement while in the seated position, is less damaging to spinal postural health than sustained kyphosed postures (Pynt, 2014). However, it should be noted that there is not an optimal posture for all situations of VDT work. Even a biomechanically correct posture (the one that maintains the natural curves of the spine and allows mobility to the body without disturbing the respiratory or circulatory systems nor producing discomfort): no position is good if maintained over time.

Time is yet another factor to consider: at a computer terminal where long periods of sitting are required, in a relatively static position, recovery from pain becomes more than proportionally longer as the exposure time increases. Changing the organization of work to reduce the time spent in a sitting position without disrupting the work process is an attractive proposition. Reducing monotonous positions (e.g., sitting or standing) can curtail static muscle work and its narrow and negative impact on the musculoskeletal system (Alkhajah et al., 2012). Although this section discusses the contribution of the seat to working health, it is only a part of the ergonomics of sitting at work. The desk, work activities and organisation, as well as the environment are all part of the equation. But these can be adjusted. What cannot be altered, once bought, is the seat. Hence it can be a dangerous component of the workplace if it is not selected with knowledge and care.

Workstation Design: The characteristics of the workstation allowed us to understand the results obtained in postural habits. Almost all of the seats we monitored had the basic regulations to adapt to a wide user anthropometry: the position of the backrest (angular and longitudinal), and the seat height. A percentage of 90.5% of the seats had a star-type base with five points of support, but only a small fraction of them (9.5%) had armrests. We detected few accessories: there were 4.8% of workstations with wrist-rests and the same percentage of foot-rests. We found no document-stands during this POE, despite that two information sources coexist in VDT work: the computer screen and paper. Eye movements between VDT, keyboard and manuscript can occur up to 30,000 times per day (Osterhaus, 2005).

We found that the computer equipment was adequate: The VDT allowed regulations in tilt and rotation (81.0% of cases) and most of them were LED/LCD, which are essentially flicker-free. We found no disturbing reflections on the computer screen on 71.4% of cases. Most of keyboards (over 90%) met basic ergonomic guidelines and 66.7% of workers felt that the mouse size was suited to their hands.

Environmental factors: Approximately half of our participants (52.6%) considered the lighting in the workplace as adequate. The mean horizontal illuminance in their workstations was 429 lx. This value is below the 750 lx prescribed by our regulations (Act 19587 regulated by ordinance 351/79, Appendix IV). The horizontal illuminance on the workplace of those who considered the lighting levels as inadequate was 264 lx. We performed a t-test for independent samples to verify the statistical significance of this difference, which was not confirmed (df=13, T=1.163, p=0.266). We detected a lack of control of the lighting environment by workers, for both natural (87.9%) and artificial lighting (63.2%). To be able to control the physical and environmental variables is an important predictor of environmental satisfaction for office workers (Becker, 1986; Leaman & Bordass, 2001; Veitch, Charles, & Newsham, 2004). However, to have control of lighting is not always ranked as the highest priority. The importance given to the control of an environmental variable is related to the degree of dissatisfaction with that variable: the greater dissatisfaction, an increased need for control. It is widely accepted that that lighting and other aspects of the physical environment in general influence work outcomes through the mediation of work attitudes and other psychosocial factors (Newsham et al., 2009). However, office ergonomists must also communicate with workers about the possible benefits of ambient and task lighting and how they might best adjust these for their changing needs (e.g., Akashi & Neches, 2005).

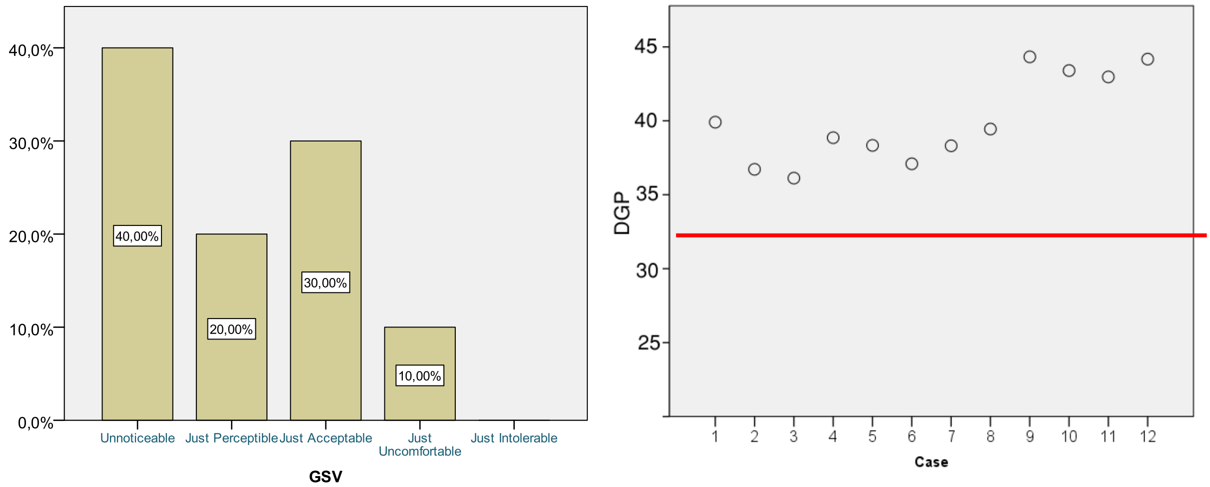
The design of lighting has also experienced a shift from direct guidelines to the importance of the larger context for understanding user-centred design. Research and practice in office lighting have thus changed focus somewhat from an emphasis on prescriptive, static design recommendations to an appreciation for the entire user and organizational context(s) for which lighting is needed.

Air quality was affected by inadequate ventilation as referred by 63.2% of our participants. In relation to noise, this factor did not appear to be critical to most of the participants (57.9%). Finally, 57.9% of respondents felt that the temperature in summer was not pleasant. The temperature and humidity were registered by means of a LMT 8000 environmental measurement instrument. The average temperature recorded was 28.2°C (SD=1.411) with an average humidity of 36.4% (SD=3.207). The percentage of people dissatisfied with the thermal environment was consistent with the theoretical predictions, considering the thermo-hygrometric conditions, the metabolic equivalent of the task (1.2 met) and the insulation level (0.6 clo) registered.

Psychosocial Aspects: On the one hand, we evaluated the software usability (Shackel, 1991), which was rated very positively: 90.5% of our participants considered the software interface design as appropriate. Moreover, all of our respondents felt that the computer helped them in their daily activities and that the computers were easy to use. In addition, 90.5% of our sample indicated that the computer programs used by them provide some kind of help and allow them to recover from errors.

On the other hand, we asked about aspects related to work organization and training activities for workers. We found that 76.2% of workers admitted to suffer peaks of mental, visual or postural workload. To overcome such workload, 85.7% of our participants usually take breaks, with freedom to decide when to take them in 81.0% of cases. Some of them (42.9%) make those pauses active and exercise and stretch during their breaks. We found gaps in awareness of office ergonomics (66.6% of our participants) and 61.9% of our participants who had no specific training in work safety and health standards. The value of basic ergonomics information within applied settings often depends on the effectiveness of such training/orientation programs (Levitt & Hedge, 2006).

Discomfort Glare: We gathered GSV and DGP data from 10 workstations. The most frequent response of GSV (Graphic 1, left) was “not perceptible”, in 40% of the cases. Considering that the borderline between comfort and discomfort is somewhere between “just acceptable” and “just disturbing”, only 10% of the participants who participated in this subjective glare assessment felt some level of discomfort caused by a lighting source in their visual field. Based on these results, discomfort glare seems to have a little impact as an environmental stressor in the workstations included in this study.



Graphic 1 - Left: Glare Sensation Vote results. Right: Evalglare DGP results

We complemented glare subjective analysis with objective predictions by means of HDR images and Evalglare software (graphic 1, right). The output of this Radiance-based tool is a set of discomfort glare indices, among them the recently developed DGP. Based on the proposed DGP–GSV correlation (Wienold & Christoffersen, 2006), DGP qualifies a glare source as disturbing when the calculated scores for the scene are above 0.4. The red line marks DGP glare threshold. We analyzed 12 workstations and found that 4 of them were disturbing in terms of glare. Figure 2 presents the luminance mappings of those cases.

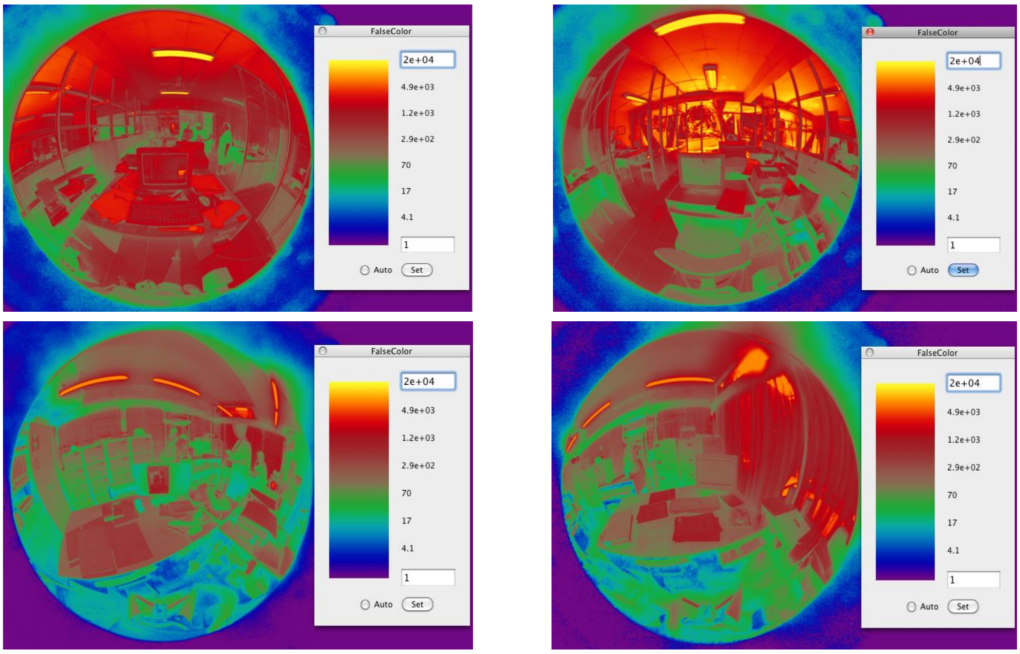
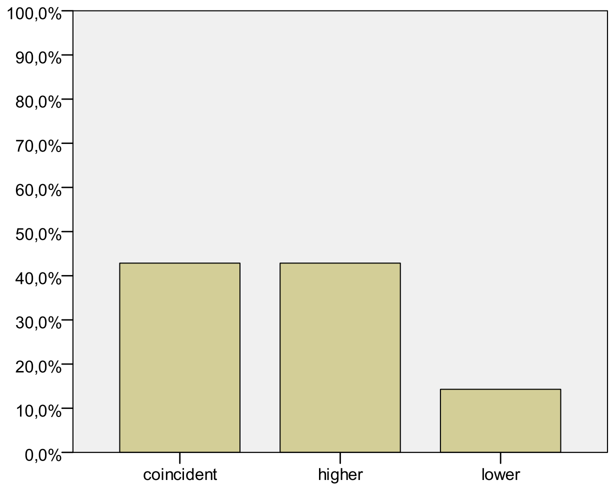


Figure 2 - Luminance mappings of workstations where discomfort glare was predicted.
a. Case 9. b. Case 10. c.Case 11. d.Case 12.

We compared the glare predictive results obtained by objective methods with the subjective response of our participants. Both kinds of data were available in seven of the 22 workstations included in this study (graphic 2). Predictions and sensations were coincident in 42.86% of the cases, but the predicted discomfort glare was higher than the sensation actually reported by our participants in 42.86% of the cases. Finally, 14.29% of our participants referred a higher glare sensation in relation to the theoretical prediction of DGP.



Graphic 2 - Comparison between glare predictions and the participants actual glare sensations

We calculated two statistical measures of the performance of DGP: Sensitivity and Specificity. Sensitivity (also called the true positive rate), measures the proportion of actual positives which are correctly identified as such (i.e. the percentage participants disturbed by glare who are correctly identified as having the condition, defined by their actual glare sensation). Specificity (or true negative rate) measures the proportion of negatives which are correctly identified as such. A perfect predictor would be described as 100% sensitive and 100% specific. Our results showed that DGP sensitivity was 50% and its specificity was 60%, indicating that in the context of this study, DGP had a moderate sensitivity and performed better when ruling out discomfort glare.

This mismatch between actual sensations and predictions is consistent with previous studies (Iwata et al., 1991; Rodriguez & Pattini, 2012) and highlights the need to consider other factors than the existing ones in current discomfort glare models, for instance the visual content of windows, cultural aspects, or habituation to the luminous climate (Kittler, Miroslav & Darula, 2012), in order to achieve a systemic approach to the problem of discomfort glare.

Divided attention: Our Stroop task results are consistent with previous studies (MacLeod, 1991; van Maanen, van Rijn & Borst, 2009), showing longer reaction times when stimuli were incongruent (mean=1.006, SD=0.304), in relation to congruent stimuli (mean=0.939, DS=0.322). There is empirical evidence from two studies that lighting can influence attention (Hopkinson & Longmore, 1959; LaGiusa & Perney, 1973), so we explored the relationship between discomfort glare and divided attention. Raynham, Osterhaus & Davies (2007) proposed a study in which observers were presented with a relatively easy task in terms of size and contrast, carried out in a 'neutral environment' and then in the presence of discomfort glare. They proposed the change in the time taken to perform the task as a metric in assessing the significance of the glare stimulus as an attentional distractor. Comparing the magnitude of the Stroop effect between workers who reported discomfort glare (n=4, mean=0.975, SD=0.337) and those who did not reported discomfort glare (n=18, mean=0.972, SD=0.312), we found a slightly higher semantic interference in the former group. This increased interference, would be indicative of greater demands of divided attention. In order to verify the statistical significance of this result we performed a T-test for independent samples, that could not confirm the existence of statistically significant differences in reaction times between glare disturbed participants and not glare disturbed ones (t=-0.017, df=20, p=0.987). Regarding Stroop task error rates, we found no statistically significant differences between groups, both presenting a 2% error rate. In this study we found a visual environment that produced moderate levels of glare, which were overestimated by glare prediction equations. It is possible that in presence of higher visual discomfort, differences in reaction times between glare disturbed and not glare disturbed people would be statistically significant.

Mental workload: There are few studies in which validated techniques have been applied, such as NASA-TLX in real work settings (Dalmau, 2007). Our case study allowed us to gathered data in actual workplaces from 16 participants by means of the RTLX method (Table 5). Each source of workload has a score of 0 to 100. The higher the number is, the greater its contribution to overall workload, except for performance that is scored differently in relation to the other RTLX scales: a low score means good performance and has a positive effect, lowering the global score. Mental demands (64.40) and temporal demands

(59.70) were the main sources of workload, along with the worker´s effort (64.35) to achieve a self-perceived good performance (24.05) while feeling moderate levels of frustration (36.85). Physical demands were rated with a score of 31.25. Our results are consistent with the literature: Computerised jobs are more sedentary, require more cognitive processing and mental attention, and require less physical expenditure of energy (Mocci, Serra & Corrias, 2001; Wästlund, 2007).

Table 5 - RTLX mental workload

Source	min	max	Mean	Sd
Mental Demands	35	85	64.40	15.6
Physical Demands	10	100	31.25	23.2
Temporal Demands	30	100	59.70	19.3
Effort	30	100	64.35	20.1
Performance	5	60	24.05	18.0
Frustration	10	85	36.85	26.6
Overall Workload	**35**	**79.17**	**46.77**	**11.1**

Table 5 also shows the overall workload score. The accepted range in RTLX scale is 50±10 as proposed by Calkin (2007). Participants below that range work in an under load situation while those above it are in an overload situation. The overall mean score obtained in this sample was 46.77 indicating that workers were mostly within the proper range of mental workload. Another criteria based on a psychometric study of the TLX method in Spanish workers (n=398) (Díaz Ramiro, Rubio Valdehita, Martín García & Luceño Moreno, 2010), defined a global TLX score of 61.66 as the 50th percentile. Our 46.77 global score is situated below the 20th percentile. The study performed by Diaz Ramiro et al. (2010) assessed the workload of seven different professional groups (administrative workers, councilors, security personnel, teachers, journalists, sanitary personnel and maintenance workers). The TLX scores of the administrative workers was 55.29 (SD=15.99), which is higher than our sample´s overall score. Also, an online survey (n=352) defined VDT user profiles based on their e-skills and assessed their mental workload (Rodriguez & Pattini, 2011). The mean TLX score of the general user profile (in which administrative workers are included) was 62.3 (SD=10.64). Our results show lower scores, with the advantage of having complementary data that allows understanding the context in which the scores were obtained. In relation to the standardized subscale scores proposed by Díaz Ramiro et al. (2010), our results of mental demands were below the 30th percentile, while physical demands and temporal demands were near the 40th percentile. Finally, effort, performance and frustration scores were below the 50th percentile.

Correlation between variables: The general model of man-machine system describes the information flow and the control relationships that occur between a user performing specific tasks with an artefact in a given context. In this research we evaluated several components of the human – computer system in an office context, each one measured with a specific methodology. We analyzed our data using either Pearson's or Spearmann´s (in the cases of ordinal data) correlation coefficients between the elements of that system. Correlation between variables does not imply causation, it simply indicates association. Based on Walpole, Myers & Myers (1999) we considered as moderate a correlation higher than 0.4 and as high correlation coefficients above 0.7. Table 6 shows the statistically significant correlations.

Table 6 - Paired correlation coefficients between VDT work variables

Variable 1	Variable 2	Correlation	p-value
Divided Attention	VDT Illuminance	0.396	0.025
VDT Illuminance	Horizontal Illuminance	0.410	0.020
Performance	Mental Demands	-0.614	0.011
Performance	Temporal Demands	-0.533	0.033
Performance	Effort	-0.611	0.012
Effort	Temporal Demands	0.498	0.05
Effort	Physical Demands	0.788	<0.01
Temporal Demands	Physical Demands	0.505	0.046
Physical Demands	Discomfort Glare	0.781	0.038
Workstation Design	Environmental Comfort	0.490	0.024

We found a statistically significant low to moderate correlation between Stroop effect and the vertical illuminance measured at the centre of the screen: higher VDT illuminance was associated to higher Stroop interference. This performance variation points to a distracting effect of the illuminance levels of the screen. However, we have no evidence that attention was the mechanism involved in the observed decrease of performance. Previous research has addressed the possible effect of the lighting environment on attention. Hopkinson & Longmore (1959) observed a tendency to turn towards the light, which the defined as human phototropism. They reported that attention on a vertical visual task was best when the task was locally lit, than when it was lit from general illumination alone. According to Veitch (2001), this early study missed important details about the methods and data, and lacked appropriate statistical tests. One extension of the attention hypothesis is the notion that task lighting can focus attention on desk work, thereby improving task performance. This hypothesis has been tested for paper-based clerical work (e.g. McKennan & Parry, 1984; Slater, Perry & Carter, 1993). Our results provided data for VDT clerical work.

We found several correlations between RTLX subscales: Performance showed a negative correlation with mental demands, temporal demands and effort. This is consistent with a strain – stress model of human performance that equate workload with the magnitude of the demands imposed on the operator, physical, mental, and emotional responses to those demands or the operator's ability to meet those demands. Effort showed a positive correlation with physical demands and temporal demands while temporal demands also showed a positive correlation with physical demands. These correlations between RTLX subscales is usually found in the literature and, according to Hart (2006), it simply illustrates the fact they are all measuring some aspect of the same underlying entity. It is assumed that the NASA Task Load Index (NASA-TLX) consists of six subscales that represent somewhat independent clusters of variables and that some combination of these dimensions are likely to represent the "workload" experienced by most people performing most tasks. However, a psychometric analysis of NASA-Task Load revealed a factorial structure formed by two components (Díaz Ramiro et al., 2010). The first of the two components was formed by all of the NASA-TLX dimensions except frustration. The second was formed only by frustration dimension. Coincidentally, we found no statistically significant correlations between frustration and the other workload dimensions.

Discomfort glare (GSV) showed a high correlation with physical demands measured by means of RTLX. This visual variable did not show significant correlations with any of the measured photometric variables included in this study (horizontal desk illuminance and VDT illuminance). Luminance, which we measured by means of HDRI technique, is the main photometric variable affecting discomfort glare. We calculated DGP from the luminance maps and found no correlation between DGP (that includes our luminance readings) and GSV. The differences we observed between the predicted discomfort glare outcomes and the actual sensations of our participants caused this lack of correlation. Mocci et al. (2001) studied the contribution of several variables to visual symptoms (asthenopia) reported by users of VDT workstations and obtained a similar result. They found that lighting conditions were not correlated with eye discomfort, but that asthenopia was significantly and positively correlated with the presence of discomfort relative to noise and smoke instead. However, the same study showed that physical workload was the only factor not significantly correlated with asthenopia, which was a result not expected by the authors. Eye discomfort is a concept broader than discomfort glare, but our literature research was unable to find studies concerning the relationship between the physical component of work and discomfort glare.

Workstation design (desk, chair, and computer characteristics and their layout) had a statistically significant moderate correlation with the environmental comfort (lighting, noise, thermal environment, air quality). It is generally accepted that workstation design, as well as the environmental factors are related to musculoskeletal, visual and general physical symptoms (Lu & Aghazadeh, 1996; Brand, 2008) in a direct or an indirect way (Isen & Baron, 1991).

The statistically significant correlations we found are based on a limited observational study with a small sample. This initial model based on correlations will allow the selection of the best variables to include in further multiple regression analysis with a larger sample, model the relative contribution of these factors to the visual, musculoskeletal and cognitive symptoms reported by the users of office workers in the context of a developing country.

4. Conclusions

Office VDT work is a paradigmatic case of a work system in which the adoption of a new technology introduces new associated risks of different nature: visual, musculoskeletal and cognitive. The constant evolution of VDT work mainly caused by the introduction of new technology in terms of hardware and user interfaces, as well as new communication paradigms makes this research topic always timely. Most of the existing research in VDT office work has been conducted in central countries. Our research, which gathered data from a Latin American country, is part of a growing body of literature concerning the effects of the increasing VDT use among office workers in developing countries.

In this context, we carried out a POE at the administrative offices of the University of Mendoza (Argentina), performing a diagnosis of visual, cognitive and postural risks associated with VDT office work. We framed our research in a broad, systemic view for office ergonomics to embrace the interdependencies of the human body as a dynamic biomechanical system through models that seek to combine mechanistic, motivational, perceptual and biological elements of human-at-work systems.

Observational studies provide valuable information from the worker´s perspective allowing the researcher to detect the type and magnitude of detrimental demands and efforts. However, observational studies have a lack of control of variables by the researcher, and each study of this kind tends to be unique, making it difficult to reproduce the results that therefore lack of generalizability. The value of exploratory studies such as the present one is that they make it possible to describe the behaviour of the variables of interest in context, a very difficult situation to achieve in laboratory studies, thus ensuring that ergonomics research and recommendations will reflect the evolving, organic realities that influence people within contemporary organizations.

Our study shifted in focus from merely promoting safety to demonstrating value to the entire organization for human factors/ergonomics designs and interventions. Certainly health and safety will never diminish in importance, but they have begun to be integrated into a larger systems perspective. This change comes from an increased interest in using ergonomics design principles to improve the quality of work life in addition to employee productivity.

Acknoledgments

The researchers thank to Andino, Marcos; Moreno, Lucía; Fioquetta, Emilia for their collaboration in the data gathering during this research.

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