Daylighting and Cognition: Experimental Studies on Working Memory and Attention in Clerical and Educational Contexts.

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Introduction

This paper introduces our interdisciplinary research on the influence daylight in human cognition, specifically in working memory and attention in two cognitive demanding contexts where we spend several hours during our lifespan: office and school environments.

Theoretical Framework

Humans are able to face novel situations and to adapt to changing conditions in a flexible way thanks to a set of cognitive skills called *executive functions* such as the *memory* and *attention.* The close relationship between these constructs arises in *working memory (WM).*

Attention involves directed and selective perception, interest in a particular source of stimulation, or concentration on a task (Van Zomeren & Brower, 1994). Its capacity is gradually developed from infancy to adulthood, but its activity is not only confined to regulate information inputs, it is also involved in processing the same information (Cooley & Morris, 1990). There is evidence of a third neuro-physiological system, the *attentional system* with the same status that the motor (efferent) and sensory (afferent) systems (Posner & Petersen, 1990). Theoretical and clinical interest in these attentional processes is based in its importance in learning development processes.

The concept of short-term memory in the last 30 years has expanded from a passive limited store to a more complex and active tripartite system that handles and processes information, known as Working Memory (Baddeley and Hitch, 1974). It is defined as a system that temporarily maintains and manipulates information, involved in cognitive processes such as language comprehension, reading and reasoning.

Study I: Clerical contexts

The introduction of Information and Communication Technologies (ICT) in offices added a constant cognitive processing load that might be beyond human capabilities. Working memory plays a crucial role in ITC work, retaining the incoming information, changing and renewing the contents of information accordingly to the operation and the processing. Previous studies investigated WM variations in ICT work (Shieh et al., 2005). The effect of indoor lighting on cognitive performance via mood was studied by Knez (1995) and Vanderwalle et al. (2007) found non-visual effects on working memory and arousal from different monochromatic light exposures.

However, the role of glare sources as attention distractors, and their impact on cognitive performance is lacking in the literature so far. The hypothesis behind this investigation is that glaring lighting conditions might be related to non-visual effects affecting ICT operators´ cognitive efficiency and effectiveness.

Methods

Glare caused by natural lighting is usually studied in dark chambers lit with devices emulating a window and we used the same strategy to test our hypothesis. The experiment took place inside the experimental light laboratory at CCT CONICET–Mendoza, Argentina. We measured cognitive efficiency and effectiveness on 25 volunteers (mean age 30.16 years old; SD 3.95), with normal or corrected vision and without any medical treatment.

Cognitive efficiency was assessed by means of RTLX (Byers and others, 1989), a multidimensional scale that uses six dimensions to assess mental workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. Cognitive effectiveness was measured as Working Memory Span with the Reading Span Task (RST) [Daneman & Carpenter, 1980], a complex performance measure that correlates with a wide range of high order cognitive tasks present in ICT work [Conway and others, 2007]. We developed a digital version of RST. The subjects were required to read aloud at their own pace sentences presented on screen and to remember the last word of each sentence for later recall. Increasingly larger groups of sentences were presented until the subject failed to recall all three groups of a given size. To include processing besides storage, the subjects also had to indicate whether any word of the sentence had a spelling error or not.

We created a large area (1 m x 1.5 m) non – uniform luminance glare source with 54 incandescent lamps and a diffusing screen. A three factors at two levels full factorial experiment was designed. The factors were: (i) Luminance contrast between the task and the source. In clear sky conditions, with sun presence in the visual field, the luminance can reach values of 10^5 cd/m^2 near the solar disc. We considered unnecessary to replicate those levels because glare sensation depends on the luminance the visual system is adapted to; therefore it is a relative concept. (ii) Apparent size of the source in steradians: The lower level was 10^{-2} sr and the higher level was 6.6 x 10^{-2} sr to avoid a raise of adaptation luminance by the source. (iii) How the task was done: In the prosaccadic condition the participants had to shift their vision between the source and the computer screen, a visually demanding scenario in terms of visual adaptation. In the antisaccade condition, the subjects had to fixate in the computer screen, ignoring the glare source.

To characterize lighting conditions on each treatment we built luminance maps from HDR images and calculated Daylight Glare Index (DGI) with *Evalglare* (Wienold and Christoffersen, 2006). We assessed the participants´ subjective sensation of glare with GSV scale (Hopkinson, 1972).

Results and Discussion

We performed a factorial ANOVA and found higher scores of GSV in the prosaccadic scenarios (p-value 0,001). Glare sensation was directly proportional to source size (p-value<0,0001) but the largest effect was caused by luminance: higher glare sensation votes were associated with higher luminance contrasts (p-value<0,0001). Interaction effects between source size and luminance were also found (p-value<0,0001).

The factorial ANOVA showed no significant effects (p-value>0,05) of the experimental factors on cognitive efficiency: The RTLX method failed to predict variations in cognitive efficiency caused by the glare source. Our results showed that cognitive effectiveness was statistically significant lower (p-value<0,05) in those treatments where the volunteers had to shift their sight between the glare source and the task. The source acted as a powerful environmental distractor by reducing WM capacity of the subjects. This result links WM span with the attention management capabilities of the individuals (Jarrold and Towse, 2006). Finally, two effects were not statistically significant but showed a trend: Luminance (p-value 0,103) and the interaction between task and luminance (p-value 0,127).

Study II: Educational contexts

Daylight is one of the classroom´s most critical environmental factors (Phillips, 1997) and has been strongly associated with performance and health of school children (Wei, 2003). The relevance of the visual environment in the classroom, is given by its influence on a student's ability to perceive visual stimuli and to affect his mental attitude, and hence his performance, learning, attitudes and value judgments (Heschong Mahone Group, 1999). For instance, children with attentional dysfunction have different performance in classrooms with different light sources (Antrop, Roeyers & De Baecke, 2005).

In our context, one of the most significant risk factors for school failure is the attentional dysfunction in childhood; issues that affect academic performance and social development. Considering this, the assessment of attentional skills in children with valid, reliable and suitable methods for our school population is relevant to achieve a precise diagnosis and to plan adequate intervention programs (Ison and Anta, 2006). In this context we present an interdisciplinary study, part of a new research line relating lighting and attention that began with pilot studies conducted by Dr. Ison and Dr. Pattini (2009), and continued in greater depth as part of a doctoral thesis in progress (Monteoliva, 2010). Our main objective is to find a correlation between daylight and attentional skills in educational environments. The following field experiment was conducted during morning shift in November 2011 (pre-summer) to test our hypothesis that "classrooms with daylight source might improve attentional efficiency". The experiment took place at Republic of Chile primary school in Mendoza, Argentina.

Methods

The sample size was 24 third grade primary students (14 men and 10 women) aged between 8 and 10 years old (mean 8.78), half of them from division A and half of them from B division. Due to the high rate of absenteeism in marginal institutions like this one, the initial sample was oversized (n= 36) anticipating participant loses during the study. We worked with two independent groups (divisions A and B) to randomize the conditions of the independent variable (avoiding potential bias caused by learning and adaptation effects), and to develop the experiment in the habitual contexts of the participants. Attentional skills were assessed with was the Differences Perception Test "FACES" (Thurstone, 1941) and its evaluation parameter was "attentional efficiency." This test has 60 main feature graphic elements, each consisting of three schematic drawings of faces (mouth, eyes, eyebrows and hair rendered with basic strokes), two of which are equal. The goal is to determine the different face and cross it off. The test is applicable from 6 to 7 years old. In its original version the score was represented by a raw score of the total number of hits. For the attentional efficacy parameter, we evaluated the accuracy a child could discriminate stimuli within a set of similar looking stimuli by means of errors of omission and commission. This parameter allows assessment of individual performance on tasks that combine sustained and selective attentional skills, which is the *dependent variable* of the study.

The *independent variable* was the type of primary lighting source. We selected two classrooms of the institution with the same morphological characteristics (8.1 m x 6.5 m x 3.8 m), each one lit by a different light source: (a) Natural and (b) Artificial. For condition (a) the study was based on predictive dynamic daylighting in these spaces, orientation North-South, with windows in both orientation; 5600°K. Condition (b) had six twin-tube lighting fixtures T8 36W –Sylvania-, neutral light, 4300°K, heighted at 2.5 m above the work-plane. The total and partial blockage of daylight allowed view and reference from outside. Both conditions had the same light uniformity and lighting levels between 100-300 lux of horizontal illuminance on the work-plane without sun patches or glare sources.

Result and Discussion

Our results, unlike those obtained in previous pilot studies (Ison and Pattini, 2009) showed no statistically significant relationship $t\ (44) = 0.655$, $p > 0.05$ (0.516) between attentional efficiency and the light source type. However, new evidence emerged from this experiment, and further studies are in development in order to find an expression that would relate the attentional effectiveness with a time factor. This way we would get more accurate results, letting us know not only the subject's production (effectiveness), but his ability to produce (efficiency) too. This metric would be more "sensitive" to the environmental conditions and to their influences on attentional skills.

Conclusions

The studies presented are framed within "the third stage" of lighting profession (Cuttle, 2011), dealing with the effects of lighting on basic psychological mechanisms, such as memory and attention. We addressed our investigation questions from a systemic perspective, analyzing the complex relationship between the subject, the task and the environment in terms of efficiency and effectiveness, as components of the overall performance of the task. The first steps were taken here. However, this perspective must be framed in a new paradigm: "healthy lighting", based not only on the photometric parameters of "good lighting", but on the effects of these on the subjects as well. These studies, like others currently under development by different laboratories, bring new proposals of methodological tools to evaluate lighting and its impact on cognitive aspects, such as memory working and attention, in order to provide light conditioning patterns that promote health and performance of the subject.

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