Applied Ergonomics 61 (2017) 79–89

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Workflows and individual differences during visually guided routine tasks in a road traffic management control room

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ARTICLE INFO

Article history:
Received 13 July 2016
Received in revised form
22 December 2016
Accepted 10 January 2017
Available online 24 January 2017

Keywords:
Control room operations
Eye tracking
Information search

ABSTRACT

Road traffic control rooms rely on human operators to monitor and interact with information presented on multiple displays. Past studies have found inconsistent use of available visual information sources in such settings across different domains. In this study, we aimed to broaden the understanding of observer behaviour in control rooms by analysing a case study in road traffic control. We conducted a field study in a live road traffic control room where five operators responded to incidents while wearing a mobile eye tracker. Using qualitative and quantitative approaches, we investigated the operators' workflow using ergonomics methods and quantified visual information sampling. We found that individuals showed differing preferences for viewing modalities and weighting of task components, with a strong coupling between eye and head movement. For the quantitative analysis of the eye tracking data, we propose a number of metrics which may prove useful to compare visual sampling behaviour across domains in future.

1. Introduction

1.1. Control room design: fundamentals and challenges

Ergonomic control room design requires consideration of many factors such as personnel, systems design or equipment layout (Wood, 2004), is subject to standards such as ISO 11064 (part 1–7) or BS EN ISO 6385 and is discussed by substantial literature (Noyes and Bransby, 2001; Ivergard and Hunt, 2008). An important ergonomic design consideration for control rooms is that the available technology has to be aligned with human behaviour, requirements and limitations (Hughes and Kornowa-Weichel, 2004); this helps to maximize the efficiency and effectiveness of operators. Human information processing in control rooms has received scientific interest in domains as varied as air traffic control (Stein, 1992; Endsley and Rodgers, 1996), airplane cockpit design (Steelman et al., 2011), nuclear power plant control (Chang Hoon et al., 2006; Kim et al., 2013) or monitoring of CCTV (Howard et al., 2011; Stainer et al., 2013). Human error as a consequence of insufficient ergonomic workspace design has arguably led to catastrophic accidents such as Three Mile Island, Chernobyl and Bhopal (Meshkati, 1991). The causes for human error are manifold (Kirwan, 1992; Reason, 2000; Dekker, 2014). A possible contributing factor to human error is the incomplete use or false interpretation of visual information; this has for example received substantial interest in medical image analysis (Krupinski, 2010), but also in air traffic control (Stein, 1992) or cockpit design (Hanson, 2004). Furthermore, people might not use available visual resources as expected by designers; an example is the discrepancy between expected and observed behaviour in CCTV control rooms (Smith, 2004) or the selective use of available information sources by air traffic controllers (Stein, 1992; Seok et al., 2006). Analysis of operators' visual workflows and preferences allows understanding of such discrepancies and helps designing towards reliable resource usage.

Most control rooms are built around the presentation of visual information through a multitude of display screens (Hénique et al., 2008; Ivergard and Hunt, 2008; Stanton et al., 2009). In air traffic control, visual information perception has been described as most crucial next to voice communication (Meyer et al., 2013), and this extrapolates to many other control room domains. Activities of operators in control rooms range from making predictions about criminal activity in CCTV footage (Troscianko et al., 2004), to monitoring and control of process control plants (Kim et al., 2013)

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http://dx.doi.org/10.1016/j.apergo.2017.01.006

or evaluating risks for collision in air traffic control (Landry, 2011). In each domain, a core activity of the operator involves interpreting the visual information that is displayed to them in order to infer the state of the system. In order to understand how this information is used, studies from the domain of psychology and ergonomics can apply a methodology called ‘eye tracking’, which allows to measure where operators are looking, what information sources they use and how they combine information.

1.2. Understanding user behaviour and cognitive processes through eye tracking

Humans have to move their eyes to attend to relevant information sources because only central vision provides a high resolution and sharp rendering of a scene (Henderson, 2003; Land, 2006; Borji and Itti, 2014). This is due to the distribution of photoreceptors within the retina and the non-linear representation of this information in the visual cortex (Snowden et al., 2012). Eye tracking allows recording where someone is looking with central vision, which is called the ‘point of gaze’; it has been used as part of study design in thousands, if not tens of thousands, of research papers (Tien et al., 2014) and has long been used to inform user interface design (Jacob and Karn, 2003; Poole and Ball, 2006). For example, scan patterns (the sequence of attended regions of interest) and fixation duration can be used to identify sub-optimal layout of interfaces or the perceived importance of individual user interface elements (Pohl et al., 2009; Burch et al., 2011).

The use of eye-tracking to study operator activity and decision making has been employed in a range of control room domains (Moray and Rotenberg, 1989; Lin et al., 2003; Shepley et al., 2009; Moore and Gugerty, 2010). Eye tracking has also been used with a view to detecting operator fatigue and impairment of visual vigilance (McIntire et al., 2014a,b). Moray and Rotenberg (1989) for example demonstrated that, when dealing with incidents, operators tend to increase the frequency of fixations on the failed system component, rather than increasing the duration of fixations, and that information processing becomes restricted to one information source at the expense of attending to subsequent or parallel incidents. This suggests that operators might not optimally use available resources (Smith, 2004). Analysis of operators’ workflows and preferences could aid the understanding of such discrepancies. To date, reports of visual scanning behaviour (the act of moving the point of gaze across a scene) across a wide range of domains is lacking and hence conclusions are often drawn on a case-by-case basis.

Gaze shifts can be executed by eye movement alone or accompanied by head movement (Wollaston, 1824; Bizzi et al., 1972; Morasso et al., 1977; Zangemeister and Stark, 1982; Guitton and Volle, 1987; Goossens and Opstal, 1997; Oommen and Stahl, 2005). Gaze shifts larger than $45°-50°$ visual angle have to be executed by head movement simply because the eyes do not rotate further within the head (Proudlock and Gottlob, 2007; Freedman, 2008). Gaze shifts larger than $75°-90°$ additionally need rotation of the upper body due to the functional limits of head/neck rotation (Proudlock and Gottlob, 2007). For example, in a study of visual search in a mail room, 80% of search time was spent moving head and body rather than only the eyes (Foulsham et al., 2014). Recent work has highlighted that aligning eyes and head, rather than diverting gaze laterally, results in better performance during visual search tasks (Nakashima and Shioiri, 2014). Hence, aligning eye and head orientation is likely beneficial for cognitive information processing. The interaction between eye-, head and arm movements has previously been investigated in air traffic control (Boyer, 1995) and so it would be interesting to determine the relationship between eye- and head-movement in other control room environments. For this paper, the control room environment under consideration concerns road traffic management.

1.3. Road traffic control rooms: purpose and goals

Road traffic management involves the monitoring of traffic, responding to incidents and influencing road user behaviour. Given that incidents can contribute to some 25% of the overall congestion levels on major roads (UK Highways Agency, 2009), it is important that any incident is resolved as quickly as possible. Regional Control Centres, such as the ‘Direction Interdépartementale des Routes Centre-Est’ (DIR-CE) in Grenoble, France, are the central focus of communications regarding major roads. They monitor traffic flow (through CCTV, through verbal reports or through sensor data from the roads or vehicles) and control the Variable Message Signs on these roads. In broad terms, the goals of such a centre can be summarized as follows (Folds et al., 1993): i.) maximise the available capacity of the roadway system; ii.) minimise the impact of incidents (accidents, debris, etc.); iii.) contribute to demand regulation; iv.) assist in the provision of emergency services; and v.) maintain public confidence in the control centre operations and information provision.

1.4. Aims and scope of this study

The present study is a case study, constrained by the availability of staff and environmental factors. Aim of the study was to i) present insight into operator behaviour in a road traffic control room, both from the perspective of qualitative work analysis and quantitative visual sampling analysis, and ii) present a number of eye tracking metrics which we deem useful to compare visual sampling behaviour across domains in future. We use a Hierarchical Task Analysis (HTA) and eye tracking to study information sampling behaviour and workflow in a road traffic management control room. Visual scanning via eye- and head movement forms the sensory foundation for decision making and actions in control rooms and would benefit from further exploration, especially in context of user interface- and control room design. The present study provides a rare reference dataset on visual scanning behaviour in a fully operational road traffic management facility.

2. Study setting

2.1. Control room layout

Data for this study were collected at the road traffic management facility at DIR Centre Est, Grenoble, France. The control room under investigation for this study consisted of multiple displays (Fig. 1). In front of the operator, at arm's length, is an arced arrangement of five monitors, containing the following information sources and components:

- D1 (“Display 1”) - generic display with access to internet and software packages.
- D2 (“Display 2”) - user interface (UI) for incident logs. The workflow of operators is systematically guided by this UI, which contains for example dropdown menus and text entry fields to document incident details.
- D3 (“Display 3”) - interactive schematic map of the road traffic network.
- D4 (“Display 4”) - live CCTV feed, which the operator can select from a number of available feeds. The selected camera can be controlled by the operator through zooming, panning and rotating.
- D5 (“Display 5”) contains an auxiliary schematic interface