MEASURING AWKWARDNESS OF WORKPLACE LAYOUT: DISPERSION OF ATTENTIONAL AND PSYCHOMOTOR RESOURCES WITHIN THE ANESTHESIA WORKSPACE

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In complex tasks such as provision of anesthesia, human operators often carry out simultaneous tasks with conflicting task demands. Workplace design can mitigate the impact of these tasks' conflict with one another, however there are few methodologies for quantifying awkward workplace layout that lead to task conflicts. The current work examines a measure of awkwardness we developed, "dispersion of attentional resources," and further presents a graphical display to represent task conflicts within the anesthesia work domain. These measures and display methods can be generalized to other work domains to guide design.

Workplace layout has long been recognized as a significant contributor to safety and efficiency (Taylor, 1911). A number of methodologies have been developed to evaluate and quantify the appropriateness of workplace layout. One can summarize these methodologies and criteria into five categories. The first is to measure layouts in terms of *reach envelopes* based on anthropometrics (e.g. Konz, 1983; Sanders and McCormick, 1993). A second is to measure optimal layout for *information gathering* tasks or material *transport distances*, based on link analysis of transitions and travels among information sources. A third is to measure the *information integration* tasks and display formats and locations, based on proximity compatibility principles (Wickens and Carswel, 1995). A fourth is to measure *physical overload* based on biomechanics. A fifth is to measure exposure to *repetitive stress* based on task models and biomechanics.

We propose yet another type of criteria to measure the appropriateness of workplace layout for those tasks that require nearly simultaneous attention to different physical locations around the workplace for information sources (mainly visual) and for controls (mainly manual). One source of awkwardness in a workplace layout is the *dispersion of attention*, causing operators to look in one direction while operating on one or more controls in a different direction. The consequences of such awkwardness may not be repetitive stress, or task overload, or specific physical strain. Operators perform trade-offs between the frequency of sampling information and the efforts needed to overcome the awkwardness or inappropriateness in the workplace design. Awkward postures that raise the effort needed to sample information or carry out tasks may be avoided by informed design. There are at least two challenges in the design of a workplace to reduce or remove awkwardness. First, one needs to measure awkwardness due to dispersion of attention around the workplace. Second, one needs to communicate effectively the impact of workplace layout to designers.

Thesis

In this paper, we propose measures to describe the awkwardness of workplace layout. The measures are applied initially to an analysis of data for eye-gaze and hand position in real-life anesthesia cases.

While the anesthesia task has been analyzed (e.g. Weinger et al., 1994), and poor placement of monitoring equipment has been noted (McIntyre, 1982), measures quantifying the *dispersion* of anesthesia care providers' resources around the work area seems conspicuously absent. Visually monitoring the patient is a top priority of care providers (Boquet, Bushman, Davenport, 1980). In addition, they need to manage the patient monitoring equipment and anesthesia machine (Botney and Gaba, 1994). Examining the extent to which they deviate from monitoring the patient may bear a direct relation to the dispersion of attention within the workplace.

Sources of information

We used the process of airway management in anesthesia as a basis in developing this methodology. In a protocol approved by an Institutional Review Board, video was captured along with eye-tracking information, originally for analysis that examined the information gathering of anesthesia care providers (Seagull, Xiao, Mackenzie, Jaberi, and Dutton, 1999). These data were used to assess the allocation of resources within the work environment.

During elective surgical cases, anesthesia care-providers volunteered to wear eye-tracking equipment during airway management. The equipment recorded video from a head-mounted camera, and superimposed a set of crosshairs that designated the care-providers point of gaze (*Figure 1*). A second video camera recorded a lateral view of the care provider and workspace. (See Seagull et al., (1999) for more details of data collection techniques.) Of 16 cases recorded, eight were selected for further analysis on the basis of the quality of the eye-tracking data. From these video records, three types of data were extracted: task-related events, eye-gaze allocation, and right- and left-hand location.

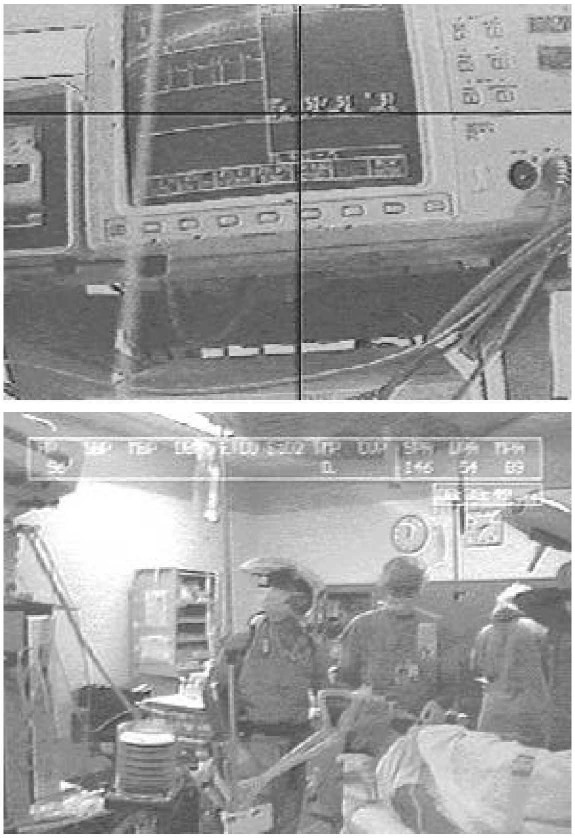

Figure 1. Eye tracking video data showing (top) head-camera view with cross-hairs indicating point of gaze (eye position), and (bottom) synchronized lateral view video showing workplace layout(the care-provider looking at the monitoring equipment).

Video analysis tools
To assist the extraction of data from the eye-tracking video and code the actions of the care provider, a video analysis program was developed and used (*Figure 2*). The program had three primary features. First, it allowed synchronized review of digitized video from multiple cameras (eye-tracking view and lateral-view video). Second, it provided one-button event coding and annotation. This allowed rapid coding of the care-provider's dynamically changing hand position and eye-gaze location. Third, it allowed a reviewer to view any noted event in the video by simply clicking on the listing of the noted event. This facilitated both review and analysis of the cases.

Measures
We extracted the location of the left and right hands of the care provider, and his or her eye-gaze location. Locations were coded into general categories of equipment in the anesthesia work area, such as patient, ventilator controls, re-breather bag, etc., Locations were assigned the corresponding numeric (azimuth angle) value.

Using the data generated from the video analysis, we derived two types of measures. First, the dispersal of "resources." These resources were simply defined as visual gaze, right hand and left hand. The dispersal of these resources was defined as the maximum angle between any two of these three resources. This relatively simple calculation was used as to establish the feasibility of such a measure.

The second measure calculated was the allocation of visual attention to the patient. This was calculated by assigning a measure of angle to each of the eye-gaze locations, with the patient assigned to "zero" degrees, based on the care provider standing at the head of the patient. Other items in the workspace coded as the number of degrees the care provider would need to turn to view the item. Thus, for example, the patient was coded as "zero," and equipment directly to the care-provider's right was coded as 90 degrees.

Figure 2. Interface for video analysis program Jvideo, showing two synchronized video views, task annotations in the lower left, and the one-touch annotation buttons along the right side.

Findings
Focusing visual attention on the patient and limiting the dispersion of attention represent two top priorities for anesthesia care providers, based on the literature (e.g. Boquet, Bushman, Davenport, 1980), and confirmed by our interviews with care providers (not reported here). As such, calculation of the two measures allows assessment of the degree to which the workplace layout allows the care provider to meet these two conflicting priorities (goals) of care provision. Our proposed method of analysis visually represents these two possibly conflicting criteria.

The two measures can be compared on a graph that represents the possible tradeoffs between dispersion of attention and visual focus on the patient. We plot the visual focus on the patient on the Y-axis, with low numbers representing a patient-focused gaze, and high numbers representing gaze diverted from the patient. On the X-axis, we graph the dispersion of attention, with low numbers representing focused resources (eyes and hands working together), and higher numbers representing the separation of eye-gaze and hand position.

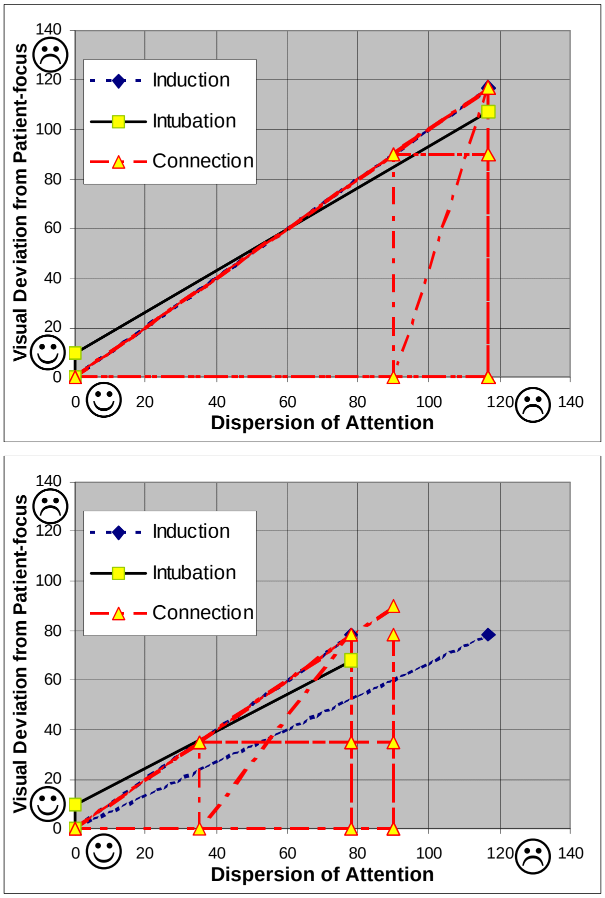

Figure 3. Visual deviation from patient (Y-axis) and dispersion of attention (X-axis) for the observed layout (A, top) and the two proposed improved layout schemes (B, bottom). The proposed improved layout graph shows a shift in downward and to the left.

The combination of these axes provides a graphical representation of the degree to which these two priorities of care provision are met. Each point on the graph represents a particular position of the care provider's eyes and hands at a given point in time, and the lines represent trajectory maps of a series of positions or postures within the task. (There are fewer unique points on the graph than there are points of data, since some combinations of eye-gaze and hand-position are repeated several times within the task.) Points near the origin ([0,0]) represent eyes and hands all focused on the patient. Points in the upper right represent non-patient-orientation and resource dispersion. For example, eye-gaze and hands focused on the anesthesia machine would result in low (good) levels of dispersion of resources, but high (poor) levels of attention to the patient, placing a point in the upper left portion of the graph.

Performance data from the airway management task derived from the video analysis was used to plot this graphical representation of task performance (*Figure* 3A).
The graph shows a small concentration of points near the origin [0,0], reflecting the anesthetist's focusing eyes and hands on or close to the patient. It also shows a second cluster of points in proximity to the coordinates [110,110], reflecting the anesthetist's looking away from the patient, and a large dispersion of attention between hands and eyes. The dispersion could indicate looking at monitoring equipment while having hands on the patient, or reaching to the equipment while keeping a hand on the patient. Because of the dispersion of equipment around the workplace, the care provider is required to spread his or her resources across a wide area to accomplish the task at hand.

The data from the video analysis was also applied to a proposed improved workplace layout (*Figure* 3B). Since the data were coded for functional location (e.g. the patient, the re-breather bag, etc.) and not absolute Cartesian location, the (angular) values for the proposed workplace layout could be substituted for the original locations, and the values for the visual focus and attentional dispersion could be recalculated based on the same activities and actions. In comparison to *Figure* 3A, in *Figure* 3B there are notable changes. The points on the graph have been shifted downward and to the left, reflecting a reduction in the maximum dispersion of attention and the maximum deviation from the patient focus. This demonstrates that for the same series of activities, the redesign of the workspace would have reduced both the dispersion of attention and the visual deviation from the patient.

In addition to these graph-based analyses, review of the video records provided opportunity to observe awkward work postures adopted by care providers to cope with their environment. Still pictures (*Figure 4*), as well as short video clips were extracted from the raw data, and could be used to demonstrate graphically and clearly the effects of poor workplace layout on task-related postures and dispersion of attention. The pictures in *Figure 4* show the postures used to adjust the ventilator (specifically, the APL switch) (4A), checking the ventilator settings (4B), and checking patient vital signs (4C).

Discussion

The paper presents an example analysis of archival data from airway management and the ways in which it can be reanalyzed to answer specific questions of task performance. The methodology for examining multiple, possibly conflicting task criteria demonstrated in this paper could be applied to nearly any setting or set of measures. As practitioners of workplace and task analysis, we are often confronted with tradeoffs, such as speed-accuracy tradeoffs, or cost-safety tradeoffs. The graphing methodology presented here allows nearly any two simultaneously existing measures to be examined. Similar to a "performance operating characteristic" (POC) (Navon & Gopher, 1980) or the Speed Accuracy Operating Characteristic (SAOC) (Pew, 1969), it helps to visualize the interaction between task goals. The graphs presented represent the continuous complement or competition between two goals inherent in the single task. Using eye-gaze and hand-position data, we derived a preliminary measure to represent dispersion of resources within the anesthesia workspace. This measure was combined with a measure

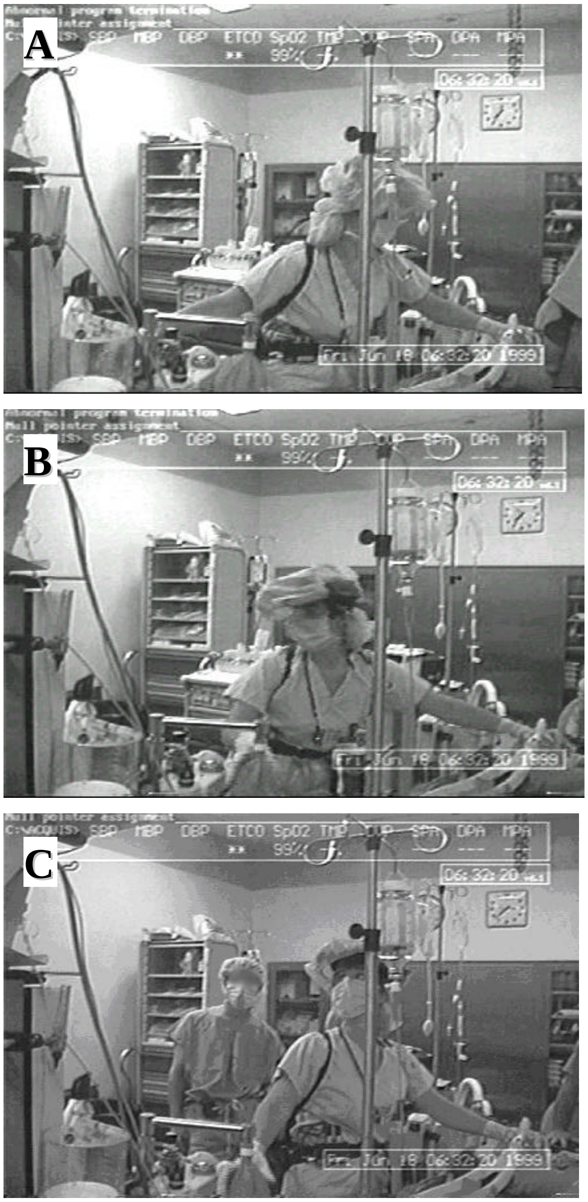

Figure 4. Example still pictures from anesthesiology task showing (A) awkward reaching posture and (B, C) awkward visual monitoring and dispersion of attention during the airway management task.

showing the degree to which care-provider priorities for task completion (attention to the patient) are fulfilled.

The methods described in this paper create opportunities for human factors principles to impact the design process, and provides an additional tool for communicating with designers and decision makers regarding ergonomic considerations. Data from real performance of a task can provide valuable credibility to analysis. While the particular calculations are relatively crude in this initially proposed measure, the principle used in deriving the measure could be developed more fully, and applied easily through more sophisticated techniques. The developed measure is a first attempt to capture an important aspect of workplace design. Further refinement in different task domains is needed.

Acknowledgements
This research was supported in part by a grant from the National Patient Safety Foundation, and Datex-Ohmeda, now a division of GE Healthcare. The authors would also like to acknowledge the help and support of Dr. Richard Dutton and the people of the R Adams Cowley Shock Trauma Center.

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