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Quantitative relationship model between workload and time pressure under different flight operation tasks

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ABSTRACT

The goal of this study was to establish a quantitative relationship model between workload and task demand under different tasks, when time pressure was set as the main influential factor to the task demand, with three workload measurement parameters. The workload "redline" was also analyzed and determined with the relationship models between the workload measurement parameters and time pressure. The experiment was designed with three different tasks under different time pressures. Three workload measurement parameters (subjective evaluation workload, accuracy and pupil diameter) and the subjective feeling threshold of time pressure were measured experimentally and then used in a comprehensive analysis for the relationship model. The data analysis result showed significant differences in workload under different time pressures, but workload was not affected by the task type. With a time pressure of 0.8, participants felt a sense of time urgency and the accuracy decreased by approximately 85%. The results demonstrate that the subjective evaluation workload, accuracy and pupil diameter can be used as the measurement parameters for the workload under different time pressures and for different tasks. Thus, for a time pressure of 0.8, an accuracy of 80%–85% was determined as the workload "redline". Linear relationships were found between subjective evaluation workload, and pupil diameter and time pressure, and a quadratic curve relationship was found between accuracy and time pressure. Workload prediction can thus be performed using these relationship models between workload and time pressure.

1. Introduction

Mental workload is often conceptualized as the interaction between the capacity and the operator (Hilburn and Jorna, 2001). The ratio between task demands and capacity therefore determines the level of workload. The workload acting on operators includes time load, mental effort load and psychological stress load (Reid and Nygren, 1988). Capacity is determined by the skills and training of the operator, but may also be influenced by stressors such as fatigue, noise, etc. Task demands are determined by the number of tasks to be performed, the amount of attention needed, and the time available (Hancock and Meshkati, 1988). Cillie (1992) defined the task variables as task criticality, task structure (High versus Low), task novelty, time response, amount of task, task complexity, and task rate. The time available for task demand can lead to conversion of time load and psychological stress load to workload. Engineers typically emphasize operational definitions based on time available to perform a task (Krüger, 2008). It is crucial to assess workload by the time available, which is one of the main factors influencing task demand. Thus, the relationship between time available and workload is an important issue for the workload prediction and assessment.

Time available, as an input variable referring to task demand (Gaillard, 2001), was defined by the task loading index and used in workload assessment with time pressure. The time pressure can be defined as the ratio of time required to complete a task to the time available (Siegel and Wolf, 1969). The time pressure is defined as the ratio of time required for tasks to time available for tasks (Mioch et al., 2010). The ratio of time required to time available (Time Pressure, TP) is widely used in workload prediction and assessment. The time line approach treats the workload as a function of the time

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available to perform a task (Beevis, 1994), and calculates workload with TP, which is used to identify workload encountered in the overall aircraft operations, and then used to develop workload prediction models, such as the Workload Assessment Model (WAM), Time Based Analysis of Significant Coordinated Operations (TASCO) (Roberts and Crites, 1985), the Workload Index (W/INDEX)(North, 1986), etc. The proportion of time required to time available is also taken as an objective indication of workload levels for ATM operators (Cullen, 1999), in which 100% occupation is taken to indicate high workload (and is plotted as a workload value of 5), and 0% occupation is taken to indicate low workload (and is plotted as a workload value of 0).

The time pressure is a critical factor in terms of pilot workload, especially in the flight scenario of emergency operations. The flight operation procedure was designed and fixed after the design of the human-machine interface in the cockpit. The standard normal operating procedure is fixed at each flight phase. In an emergency situation, the number of operation tasks in a unit time increases so that the time pressure becomes the main factor influencing workload. There are various types of flight operation tasks, including visual tasks, such as altimeter monitoring and airspeed indicator monitoring, and operational tasks, such as manipulating the stick (disk), operating the throttle lever, etc. Under these different types of task units, are the relationship between time pressure and workload constant? Understanding the linear relationship between workload and time pressure under different types of tasks can improve the accuracy of workload prediction.

The method of using time pressure (the proportion of time required to time available) to calculate the workload only considers temporal relationships in a fixed period of time without considering task type. However, there are other factors that influence workload, such as task difficulty, but there is no quantitative corresponding relationship between time pressure and workload for more precise workload prediction that considers these additional factors.

1.1. Task demand, performance and workload

The earliest relation model between task demand and performance has been described by Meister (Meister, 1976). Meister defined three regions: performance remains unchanged with the increase in task demand, performance decreases with the increase in task demand, performance remains at this minimum level with further increase in demand. Other studies (Meijman & O'Hanlon, 1984) described the relationship among task demand, performance and workload with a reverse “U” model, including the underload and overload regions. There are six regions in the relation model among workload, performance and task demand (De Waard, 1996). The relationship among task demand, performance and workload was detailed in these models. However, there is no quantitative analysis on their relationship because the task demands are determined by task difficulty and time pressure. A quantitative relationship model between workload and task demand can be established when the task demand mainly comes from one factor, task difficulty or time pressure.

1.2. Workload measurement

There are numerous methods to measure workload, such as subjective measurement, physiological measurement (pupil dilation, heart rate, respiratory, sinus, arrhythmia, etc.) (Berka et al., 2007; Glenn et al., 1994; Vigo et al., 2012; Miriam Reiner and Gelfeld, 2013; Faure et al., 2016; Mansikka et al., 2016), primary task performance (accuracy, reaction time, etc.) and secondary task performance (Brookhuis and De Waard, 2010; Mazur et al., 2013; Reiner and Gelfeld, 2013). Under different methods, there are many parameters that can be used to indicate workload. To qualify the relationship of workload and time pressure, the parameters used to indicate the workload should also be defined with qualification. Among all the parameters, performance accuracy is the most direct indicator of the workload (Mazur et al., 2013; Krüger, 2008). Subjective measurement is the most widely used method in measuring workload (Fairclough et al., 2005; Prichard et al., 2011; Stuiver et al., 2012; Fallahi et al., 2016; García-Mas et al., 2016). Meanwhile, the correlation of pupil size in physiological measurement with mental workload has long been supported (Juris and Velden, 1977). Pupil size is the most promising single measure of mental workload because it does not disrupt a user's ongoing activities, and provides real-time information about the user's mental workload (Kahneman, 1973). Startle eyeblink was attenuated during both tasks, and the attenuation was greater during the multiple-task condition than during the single-task condition (Neumann, 2010). Although the difference in pupil size between different emergency operation procedures (EOPs) was not significant, there was a tendency for pupil size in the high complexity EOP to be larger than that in the low complexity EOP (Gao et al., 2013). When participants drove a simulator and performed the n-back task, the initial results show their pupil size (PS) measurements have the expected trends, but significant differences between n-back levels found in the PS data suggest that PS may be more sensitive to differences in workload (Gable et al., 2015).

It is well known from a variety of studies that an observer's pupils dilate with increasing cognitive workload being imposed (Klingner et al., 2008). All of the parameters are not indicated to individually influence workload, but rather combining physiological information with subjective and performance information leads to a more pronounced insight into workload. We chose the workload measurement parameters of subjective evaluation, accuracy and pupil diameter to represent workload for the comprehensive analysis on the relationship model between task demand and workload.

When using pupil diameter as the measurement indicator to workload, the factors influencing pupil diameter require consideration. Winn et al. (1994) reported that pupil size decreased linearly as a function of age at all illuminance levels. Pupil diameter changes under different tasks (Batmaz and Ozturk, 2008). Pupil dilation is known to quickly respond to changes in the brightness in the visual field and a person's cognitive workload while performing a visual task (Pomplun and Sunkara, 2003). Pupil diameter as a workload measure should be introduced and discussed in light of some recent research demonstrating, for instance, an effect of blink duration but not pupil size with workload (Gao et al., 2013). Also Schulz et al. (2013) showed that pupil diameter increases were associated with a shift of visual attention from monitoring towards manual tasks. Gao et al. (2007) reported that pupil diameter was affected by stress. Thus, pupil diameter can be affected by various factors, such as task, brightness, stress, etc.

1.3. Workload “redline”

Estimates of workload can determine whether specified functions and tasks allocated to human operators are feasible in terms of time and capability requirements (Krüger, 2008). Therefore, it is important to determine the workload “redline”. The value of the workload is called “redline”. Workload “redline” is always presented as another parameter, for instance, performance has been used as the presentation of workload “redline” (Colle et al., 1988).

Therefore, it may be more useful to place a workload redline at the transition from the optimal performance region to the task-