Emotional and cognitive influences in air traffic controller tasks: An investigation using a virtual environment?

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ABSTRACT

Air traffic controllers are required to perform complex tasks which require attention and high precision. This study investigates how the difficulty of such tasks influences emotional states, cognitive workload and task performance. We use quantitative and qualitative measurements, including the recording of pupil dilation and changes in affect using questionnaires. Participants were required to perform a number of air traffic control tasks using the immersive human accessible Virtual Reality space in the "eXperience Induction Machine".

Based on the data collected, we developed and validated a model which integrates personality, workload and affective theories. Our results indicate that the difficulty of an air traffic control task has a direct influence on cognitive workload as well as on the self-reported mood; whereas both mood and workload seem to change independently. In addition, we show that personality, in particular neuroticism, affects both mood and performance of the participants.

1. Introduction

The tasks of air traffic controllers are complex and cognitively demanding. In particular, factors that influence the workload, such as traffic volume or frequency congestion, increase the mental workload and therefore the failure quote of air traffic controllers (Mogford et al., 1995; Brookings et al., 1996; Hilburn, 2007). Despite the fact that air traffic controllers have a greater ability to resolve spatial sense problems as a result of their training and the selection process (Brosch et al., 2013; Seamster et al., 1993), individual differences and individual chosen strategies play a role in their work (Mogford et al., 1995; Brookings et al., 1996). In general, workload is limited by the multiple resources needed to solve a task (Gopher and Donchin, 1986; Wickens, 2008), depends on the difficulty and time pressure of the task (Galy et al., 2012) and affects the performance solving such a task (Wickens, 2002). In particular, in air traffic control tasks the controller has to prioritise different tasks, manage their cognitive resources and evaluate and control their performance continuously (Loft et al., 2007; Majumdar and Ochieng, 2002).

1.1. Influence of individual differences on workload

As described above, Mogford et al. (1995) reported that individual differences influence the workload of an air traffic controller. These individual differences are measured as personality traits (Digman, 1990; Goldberg, 1990a), which influence the controllers' work-related outcome (Dollar et al., 2003), as well as perception of the external situation and internal feelings (Hopkin, 1982; Steel et al., 2008). Goldberg (1990b) published a Five Factor model consisting of the following dimensions: Extraversion, Agreeableness, Conscientiousness, Neuroticism and Openness, and provides, therefore, an integrative descriptive model for personality research (Matthews et al., 2003; John and Srivastava, 1999). Among these dimensions, neuroticism and conscientiousness, seem to be the most important in relation to cognitive processes. In previous studies, neuroticism led to lower performance by reducing the processing capacity of the working memory system (Studer-Luethi et al., 2012), while conscientiousness led to better performance because people with high conscientiousness values define and achieve higher goals (Barrick and Mount, 1991).

1.2. Influence of mood on workload

Additionally, resource intensive tasks like air traffic control tasks (Seamster et al., 1993), with a high mental workload can also be affected negatively by emotions as they influence executive functions (Schmeichel, 2007; Blair et al., 2007). Similarly to mental workload, time pressure also influences emotion and mood by resulting in greater arousal, more negative emotions and less positive emotions (Cœgnet et al., 2013; Van Kleef et al., 2004). Workload theory states that the resources demanded by changes in mood, or affective states, in addition to the resources needed to solve a given task affect the mental workload which may cause lower performance (Navon and Gopher, 1979).

1.3. Influence of individual differences on mood

Personality, however, not only plays an important role in workload theory, but also in emotion theory (Gunthert et al., 1999; Watson and Hubbard, 1996). Therefore, neuroticism and conscientiousness also influence the subjective well-being. Researchers found evidence that neuroticism correlates with negative affect (DeNeve and Cooper, 1998; Ben-Zur, 1999; Gunthert et al., 1999) and conscientiousness with positive affective expectations, low perceived stress, and low negative mood (Besser and Shackelford, 2007; Watson and Hubbard, 1996; Khan et al., 2011).

In order to collect data to train a computational model that is able to calculate and predict the mental workload in an air traffic control task, we conducted this experiment using participants who are not professional air traffic controllers and we asked them to solve a number of air traffic control tasks.

2. Virtual reality in scientific research

In recent years, virtual reality (VR) based-solutions have been employed in a wide range of fields, spanning from medical training (Gallagher et al., 2005) to psychological research and rehabilitation (Riva, 2009; Rubio Ballester et al., 2015). The main advantage of using VR in scientific research is the possibility of generating synthetic environments or "virtual worlds", with a high level of ecological-validity while, at the same time, maintaining a high control over interference factors on the dependent variables (Bernardet et al., 2011). VR has been used in the field of air traffic control for quite some time, in particular to develop and validate new interfaces to train professional controllers or to simplify their tasks (Azuma et al., 1996; Singh et al., 2005; Vinot et al., 2014). However, in recent times, the availability of wearable devices capable of measuring human psycho-physiological signals related to cognitive states, including (but not limited to) affect and mental workload, created new and exciting opportunities for scientific research (Betella et al., 2014). This is precisely why in this study we used the eXperience Induction Machine (XIM), an immersive VR room (SPECS Lab, Barcelona, Spain) which includes a pool of sensors and effectors to study human behavior combined with their physiological state (Bernardet et al., 2010). The XIM includes projection screens, a surrounding sonification system, an interactive luminous floor, microphones and wearable sensors capable of measuring electrodermal activity, heart rate and pupil dilation (Wagner et al., 2013; Omedas et al., 2014). Using the XIM, we were able to design and develop a custom-tailored immersive VR scenario recreating the context in which air traffic controllers normally operate, while, at the same time, measuring the behavioral and physiological responses of the participants.

3. The present experiment

The model used in this study is based on the emotional model developed for the "Smart Virtual Worker" (Müller and Truschzinski, 2014), that simulates worker's emotional feelings throughout a typical task in an industrial setting. The model is based on empirical findings
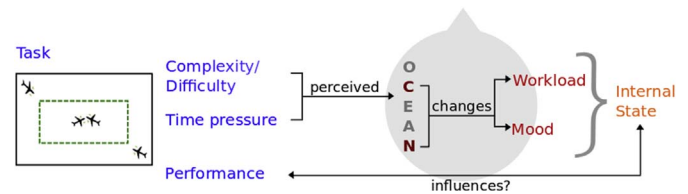

Fig. 1. Based on the emotion model of previous research we added the path for mental workload. We assume tasks with different difficulty and time pressure will cause different internal states in our participants. Each participant has a different personality, which we access using the big five personality traits questionnaire (OCEAN). According to the literature, we assumed that neuroticism and conscientiousness influences how participants will be affected by different task difficulties in respect to workload and mood. Additionally, we assumed that the different evaluation of the situation, expressed as internal states, will affect the performance of the participant solving the air traffic controller task.

that emotions are uniquely generated, based on the interpretation of a stimulus by the individual (Schachter and Singer, 1962; Zillmann, 1971), and validated by experiments, which investigated emotional responses during physically demanding tasks.

In this study, however, we added the possibility of estimating the workload (see Fig. 1). In our experiment, the participants were asked to solve tasks with different levels of difficulty and time pressures. In our model, the internal interpretation of these different levels of task difficulty is influenced by the individual characteristics of each human. Thus, a person with a high level of neuroticism, for instance, will react more emotionally than a person who does not show this personality trait to the same degree. The time pressure will increase the workload as well as the emotional scales. The model builds this correlation with the connections between task difficulty as input and the emotional scales as output. Therefore, if the task difficulty increases, e.g. the time pressure is exacerbated, the emotional scales will increase as well.

Based on the literature, evidence shows that the ability to solve a complex task is influenced by personality, workload, mood and performance. However, the relationship between these factors remains unclear; which is precisely the reason why we conducted this study. The main goal of the experiment is to answer the question of how performance is affected in air traffic control tasks, and if workload and mood affect each other. In this study we used the "eXperience Induction Machine" (XIM) to validate and enhance our emotional model (see Fig. 1).

We developed the following hypotheses:

- H1: Neuroticism and conscientiousness affect mood, workload and performance.
- H2: A higher task difficulty and time pressure affects the subjective mood state negatively.
- H3: The current mood correlates with the workload, in such that an increase in workload results in a more negative mood.

Additionally, we would like to examine if there is an influence of mood or workload on performance.

4. Methods

4.1. Subjects

We collected data from twenty-five volunteers recruited at the campus of University Pompeu Fabra of which 64% were males, and 36% were females (M_{Age}: 28,12; SD = 5,67). 84% had no prior experience in air traffic control (including, but not limited to, video games), while 16% had prior experience.