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Flying under pressure: Effects of anxiety on attention and gaze behavior in aviation

Jonathan Allsop, Rob Gray*

School of Sport and Exercise Sciences, University of Birmingham, United Kingdom

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ABSTRACT

Landing an aircraft is a complex task that requires effective attentional control in order to be successful. The present study examined how anxiety may influence gaze behavior during the performance of simulated landings. Participants undertook simulated landings in low visibility conditions which required the use of cockpit instruments in order to obtain guidance information. Landings were performed in either anxiety or control conditions, with anxiety being manipulated using a combination of ego-threatening instructions and monetary incentives. Results showed an increase in percentage dwell time toward the outside world in the anxiety conditions. Visual scanning entropy, which is the predictability of visual scanning behavior, showed an increase in the randomness of scanning behavior when anxious. Furthermore, change in scanning randomness from the pre-test to anxiety conditions positively correlated with both the change in cognitive anxiety and change in performance error. These results support the viewpoint that anxiety can negatively affect attentional control.

1. Introduction

A human operator's emotional state has been linked to performance outcomes in a range of dynamic systems, including aviation (e.g., Causse, Dehais, Péran, Sabatini, & Pastor, 2013; Mortimer, 1995) and driving (e.g., Taylor, Deane, & Podd, 2008; Underwood, Chapman, Wright, & Crundall, 1999). The inherent nature of these tasks means that the consequences for performance errors are high, often for both the operator and other individuals. Given the potential consequences, understanding the underlying changes that occur as a result of emotional fluctuations is of both practical and theoretical importance. Anxiety is an emotion that can be invoked by high-pressure or stressful situations (Staal, 2004). It has been defined as a negative emotional and motivational state that can occur when a current goal is under threat (Eysenck, Derakshan, Santos, & Calvo, 2007), or when physical harm is perceived to be imminent (Stokes & Kite, 1997). Anxiety has been proposed to cause negative changes to attentional and psychomotor skills while performing such dynamic tasks, including aviation (e.g., Stokes & Kite, 1997). The negative changes in attentional control that can occur alongside adverse mental states have been linked to numerous aviation accidents, including "controlled flight into terrain" incidents (Shappell & Wiegmann, 2003). However, relatively few studies have examined the specific influence of anxiety on visual attention during the control of complex, dynamic systems. This study aims to fill this research void by examining the attentional changes that occur when performing an aviation landing task in anxious conditions.

Attentional control theory (Eysenck et al., 2007) has recently outlined a number of specific attentional changes that may occur as a result of anxiety.[1] The central tenets of Attentional Control Theory (ACT) are based upon evidence for the existence of two attentional sub-systems: a goal-directed system and a stimulus-driven system (see Corbetta & Shulman, 2002). The goal-directed system directs attention based upon task knowledge, expectations and current goals. In contrast to this 'top-down' control, the stimulus-driven or 'bottom-up' system is influenced by salient and (currently) unattended sensory events. In an aviation context, the goal-directed system will be influenced by a pilot's mental model, knowledge and phase of flight. The stimulus-driven system could be influenced by other aircraft coming into view, or flashing cockpit instruments. ACT proposes that anxiety disrupts the balance

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* Corresponding author at: School of Sport and Exercise Sciences, University of Birmingham, B15 2TT, UK. Tel.: +44 0121 414 7239; fax: +44 0121 414 4121.
E-mail addresses: jxa620@bham.ac.uk (J. Allsop), r.gray.2@bham.ac.uk (R. Gray).

[1] Attentional control theory was originally developed to explain the effect of trait anxiety on performance and attention. It has however been readily applied to explain changes that occur as a result of state anxiety.

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between these two sub-systems, with the stimulus-driven system taking precedence over the goal-directed system. This overarching imbalance underpins a number of more specific predictions that are made by ACT. Firstly, it is predicted that anxiety reduces *inhibitory control*, thereby causing attention to be directed toward prepotent responses or task-irrelevant stimuli. This effect is amplified when the irrelevant stimuli are threatening, or are perceived to threaten a current goal. Secondly, it is predicted that anxiety causes a reduction in the ability to *shift attention efficiently* between separate tasks. Since many real world tasks require the ability to shift attention or multi-task, this prediction seems particularly relevant in the current context. Thirdly, anxiety causes a reduction in the *ability to update and monitor information in working memory*. The final predictions are derived from processing efficiency theory (PET; Eysenck & Calvo, 1992) which is the predecessor to ACT.

ACT has subsumed the major predictions made by PET. Specifically, PET proposes that anxiety reduces the processing and storage capabilities of the working memory system. However, a key component of PET is that this reduction can be partially or fully offset by an increase in on-task effort. PET therefore predicts that anxiety is more detrimental to processing efficiency (i.e., the ratio between performance outcome and effort) than performance outcomes. A number of studies have provided support for the effort/outcome predictions made by PET, in both simple (e.g., Ikeda, Iwanaga, & Seiwa, 1996), and more complex perceptual-motor tasks, such as driving (e.g., Murray & Janelle, 2003; Wilson, Smith, Chattington, Ford, & Marple-Horvat, 2006). The associated predictions made by ACT (i.e., decrements in inhibition, attentional shifting and working memory capacity) have been examined in relatively simple laboratory tasks (e.g., Coombes, Higgins, Gamble, Cauraugh, & Janelle, 2009; Derakshan, Ansari, Shoker, Hansard, & Eysenck, 2009; Derakshan, Smyth, & Eysenck, 2009). For example, support for the deleterious influence of anxiety on inhibitory functions has been found in an anti-saccade task (Derakshan, Ansari, Shoker, et al., 2009; Derakshan, Smyth, & Eysenck, 2009). Briefly, this task requires a fixation upon a central location while peripheral stimuli are unexpectedly presented to either the left or right side in a random manner. When the stimulus appears, participants are required to quickly direct their gaze to the opposite side of the screen. In order to achieve this, precise top-down control is needed in order to inhibit a reflexive saccade toward the stimulus. Derakshan, Ansari, Shoker, et al. (2009) found that the reaction time for saccades in the correct direction was slower for participants high in trait anxiety in comparison to their low anxiety counterparts, providing evidence for less efficient goal-directed control. It is acknowledged that such simple tasks allow a localized and process-pure approach to examining specific predictions (see Derakshan & Eysenck, 2009), however the overarching predictions have also been shown to be applicable to more complex real-world tasks (e.g., Causer, Holmes, Smith, & Williams, 2011; Wilson, Vine, & Wood, 2009).

The goal of the present study was to expand previous PET and ACT research into the context of aviation. Aviation is a particularly relevant domain to explore attentional changes for two main reasons. Firstly, the effective orientating of visual attention is essential for adequate performance (Talleur & Wickens, 2003). Secondly, a precise mental model is needed in order to effectively master the complex inter-related flight dynamics (Wickens, 1999, 2002). Specifically, fixed wing aircraft have three primary flight axes–pitch, roll and yaw, which are inter-related with three positional variables: altitude, lateral deviation from flight path and position along a flight path (Wickens, 2002). Their inter-related nature means that pilots must monitor multiple variables when making any input to the primary flight axes. For example, initiating a roll will cause a decrease in pitch, as a consequence of the change in direction of the lift vector. Secondly, when direct perception of the environment is unavailable (in low visibility conditions, termed instrument meteorological conditions) flying is a radically different and more challenging task (Gibb, Gray, & Scharff, 2010; Schvaneveldt, Beringer, Lamonica, Tucker, & Nance, 2000). In these conditions, pilots must derive the values of the aforementioned flight variables from discrete, spatially separated cockpit instruments. The pilot's mental model of the system (see Kieras & Bovair, 1984, or Rouse & Morris, 1986, for a discussion of the development of mental models) drives the visual scanning of these instruments in order to direct visual attention toward the correct instrument at the correct time, in order to obtain the required information (Bellenkes, Wickens, & Kramer, 1997; Brown, Vitenese, Wetzel, & Anderson, 2002). As mentioned previously, such control will require the goal-directed (top-down) system to take precedence over the stimulus-driven (bottom-up) system. It is proposed that that the sequencing of visual attention will be negatively affected if the stimulus-driven system is not subservient to the top-down control of the mental model. While previous aviation research has not explored the attentional changes that occur as a result of increased anxiety, a considerable number of studies from this body of research have investigated visual scanning and attentional control.

Bellenkes et al. (1997) examined differences in visual scanning between novice and expert pilots. The average instrument flight experience was 1 h and 80 h, for novice and experts, respectively. A desktop flight simulator task was employed that required participants to complete a number of flight maneuvers while wearing a head-mounted eye tracker. Results revealed that lateral axis control was similar for novice and expert pilots, whereas novices were less able to accurately control vertical and longitudinal flight parameters. The analysis of eye movement data revealed a number of interesting results. Specifically, novices tended to exhibit longer dwell durations on each instrument, whereas experts visited instruments more frequently. Tentative evidence for a more refined mental model in expert pilots was also found. In maneuvers where both a heading (roll) and altitude (pitch) change was required, experts exhibited more dwells to the vertical velocity indicator. This suggests that experts are more aware of the cross-coupling between roll and pitch. They therefore attempted to make early corrections to rectify the loss of lift brought about by initiating a roll. The authors also found that the sequencing of dwells was more homogenous for novices than experts; this finding will be expanded upon later. A large number of studies have examined the effect of increased workload, in the form of secondary tasks, on visual scanning and attentional control (e.g., Hameluck, 1990; Itoh, Hayashi, Tsukui, & Saito, 1990; Tole, Stephens, Harris, & Ephrath, 1982; Wickens, Hellenberg, & Xu, 2002).

Tole et al. (1982) asked pilots of varying skill level (specific demographic information was not provided) to perform a straight and level instrument flight task while performing an auditory secondary task. A particularly interesting finding in relation to the current study was that increases in workload (achieved by decreasing the inter-stimulus interval of a secondary task) were linked with increases in scanning randomness for some pilots. This suggests that the sequencing of fixations may be a viable way of assessing top-down attentional control in aviation. This is further supported by Ellis and Stark (1986), who investigated the sequencing of visual fixations in expert pilots. The pilots were asked to make judgments on the outcome of air-traffic encounters, which were viewed on a cockpit display of traffic information. The primary purpose of the study was to investigate whether the sequencing of visual fixations is statistically dependent. This was achieved by constructing a first-order Markov matrix for each pilot. Put simply, these provide the probabilities of transitioning to an area of interest (AOI) based on the AOI previously viewed. These probabilities were compared with models that were based on an alternative assumption, that the