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Original Article

Relationship between sustained, orientated, divided, and selective attention and simulated aviation performance: Training & pressure effects

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ABSTRACT

The present study examined how different characteristics of visual attention are related to flying ability. Eighty participants completed one of four attentional tests designed to assess sustained attention (SUSTAIN), attentional orienting (ORIENT), divided attention (DIVIDE) or selective attention (SELECT). Median splits were used to create low and high groups. After completing training, participants executed simulated landings under conditions of high anxiety. For the DIVIDE test, there were significant group differences in: (i) landing ability after training and (ii) the effects of anxiety. The high DIVIDE group had lower root mean square (RMS) errors at the end of training and were less affected by anxiety as compared to the low DIVIDE group. For the ORIENT and SELECT tests, there were significant group effects for training but not for anxiety. The high groups for these tests displayed lower RMS errors following training. There were no group differences for the SUSTAIN test. The results suggest that a test of divided attention may be useful for operational assessment of pilots.

1. Introduction

It is well established that effective attentional control is crucial for successful performance in aviation (e.g., Talleur & Wickens, 2003; Gibb, Gray, & Scharff, 2010). For example, amongst other skills, piloting an aircraft relies on the ability to: (i) direct visual attention toward the correct instrument at the correct time, in order to obtain the required information, (ii) maintain focus on crucial information sources in the face of distractions and noise, (iii) effectively divide attentional resources between aircraft control and other tasks (e.g., communication with Air Traffic Control), and (iv) make timely shifts of attention to warnings signals. Given the essential role that attention has in aviation, it has been hypothesized that simple tests of attentional ability may be predictive of pilot training success and performance (O'Donnell, Moise, & Schmidt, 2005) and there has been some evidence to support this claim.

Related to item (i), previous research has established links between visual scanning and flying ability. For example, Bellenkes, Wickens, and Kramer (1997) examined differences in visual scanning between novice and expert pilots. In terms of flight performance, 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. 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. Similar links between individual differences in visual scanning behaviour and flight performance have also been found within experienced pilots (e.g., Tole, Stephens, Harris, & Ephrath, 1982; Ellis & Stark, 1986).

Related to item (ii), tests of selective attention have shown some predictive value in pilot assessment. Using a dichotic listening task as a measure of auditory selective attention, Gopher (1982) reported that flight cadets who recently completed flight training ($n = 229$) had significantly fewer omission, intrusion and switching errors as compared to those which had failed ($n = 1704$). Importantly, there were low correlations between the selective attention test and the other screening tests used (e.g., psychomotor, education, personality). Similarly, using a visual analog of the dichotic

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listening test, Arthur and colleagues found a significant relationship between visual selective attention and performance on Space Fortress, a video game control task (Arthur et al., 1995) .Specifically, high test scorers (determined via a median split on the attention test) had a higher performance score at the end of training in comparison to those which scored low on the test. Although it should be noted that, to our knowledge, this task has not been directly linked with flight performance.

Related to item (iii), individual differences in task switching ability and divided attention have also been shown to be related to flying ability. For example, Tham and Kramer (1994) found that flight instructors made fewer switching errors in a dichotic listening task as compared to student pilots. Furthermore, research has shown strong links between the level of situation awareness (which involves keeping track of multiple elements in a dynamic environment) and flight performance/experience (e.g., Carretta, Perry, & Ree, 1996; O'Hare, 1997). Similar results have also been found in studies of cockpit resource management which involves a flight crew managing multiple concurrent tasks (Colvin, Funk, & Braune, 2005). Finally, within driving safety research involving visual-spatial tracking as in aviation, a substantial amount of research shows that a useful field of view (UFOV) test is predictive of crash involvement, particularly for older drivers (e.g., Ball & Owsley, 1993; Edwards et al., 2005) and can be predictive of hazard detection performance in younger drivers (Wilkins, Gray, Gaska, & Winterbottom, 2013). Although the test is designed as a test of the size of an individual's useful field of view, some researchers have asserted that the test is actually a test of divided attention (Sekuler, Bennett, & Mamelak, 2000). Thus, the literature concerning the utility of UFOV testing may also support the notion of using tests of divided attention to predict pilot performance.

Finally, related to item (iv), it was recently found that the failure to detect and orient attention to auditory cockpit alarms can occur at a relatively high rate (~40%) even amongst experienced general aviation pilots (Dehais et al., 2014). This effect which the authors called 'inattentional deafness' was also related to flight performance in a simulated go-around task.

While these previous studies provide preliminary support for the potential value of attentional testing in aviation, there are some important limitations. First, the predictive value of these different attentional abilities have not been directly compared. Do they all need to be evaluated in a pilot selection procedure or is there a high inter-correlation between attentional abilities? A second limitation is that most previous studies have been focused on the attention-training relationship and have not evaluated whether attentional tests are predictive of flight performance under operational conditions post-training. This is important because there can be large individual differences in the ability of pilots to perform under conditions such as high pressure (Allsop & Gray, 2014) or high workload (Tole et al., 1982) which cannot be predicted from performance under low anxiety/low workload conditions.

Based on theories of the anxiety-performance relationship, how a pilot handles pressure should be strongly influenced by their individual attentional abilities. For example, attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007) outlines a number of specific attentional changes that may occur as a result of anxiety. 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 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. First, it is predicted that anxiety reduces *inhibitory control*, thereby causing attention to be directed towards pre-potent responses or task-irrelevant stimuli. This effect is amplified when the irrelevant stimuli are threatening, or are perceived to threaten a current goal. Second, it is predicted that anxiety causes a reduction in the ability to *shift attention efficiently* between separate tasks (Eysenck et al., 2007). Since many real world tasks require the ability to shift attention or multi-task, this prediction seems particularly relevant in the current context.

Another point to consider is what extent these different attentional abilities are actually related. For example, are individuals that can selectively focus attention on a target stimulus embedded in distracters also good at re-orienting their attention in response to a critical signal? Although some research has provided evidence that that the ability to divide and focus attention may not be distinct abilities (Lansman, Poltrock, & Hunt, 1983) and that different types of attention (e.g., sustained, switching and divided) can be significantly related to a higher level construct like intelligence (Schweizer, Moosbrugger, & Goldhammer, 2005), overall it has been found that correlations between different attentional abilities and associated individual differences are dependent on the particular task being studied (reviewed in Wickens & McCarley, 2008).

From this brief review, it is clear that more research is needed to identify if and how tests of attentional ability should be used to predict flight training success and operational performance. This conclusion is further supported by the fact that although attention-related tests have been used in some aviation tests batteries, the development of these batteries remains hampered by poor prediction success with correlations between test scores and flight training success ranging between 0.2 and 0.4 (Damos, 2009). The goal of the present study was to expand on research examining the relationship between attentional tests scores and flight performance by addressing the limitations described above.

In the present study, 80 participants were trained to land an aircraft in a flight simulator. Prior to training, each participant completed one of four attentional tests designed to assess sustained attention (SUSTAIN, i.e., the ability to detect rare and unpredictable signals over prolonged periods of time, O'Donnell et al., 2005), attentional orienting (ORIENT, i.e., the ability to shift one's attention to a particular location in space in response to a relevant cue, Posner, 1980), divided attention (DIVIDE, i.e., the ability to split attentional resources between multiple tasks, Ball & Owsley, 1993) or selective attention (SELECT, i.e., the ability to selectively focus on one object while ignoring others, Ball & Owsley, 1993). Following the procedure used by Arthur et al. (1995), a median split was used to create low and high groups for each test. Because, as discussed above, all four attentional characteristics have face validity as predictors of aviation performance it was hypothesized that the landing performance at the end of training would be significantly better for the high groups in all four tests as compared to the low groups.

To address whether these attentional tests have predictive value under conditions different to that of training, participants were asked to land in a high anxiety condition similar to that used in our previous study (Allsop & Gray, 2014). Because anxiety has been shown to influence in particular attentional orienting and inhibitory control control (Allsop & Gray, 2014; Vine et al., 2015), it was hypothesized that the negative effect of anxiety on landing performance would be significantly greater for the low groups on the orienting and selective attention tests as compared to the high groups.