Using Pupillometry and Electromyography to Track Positive and Negative Affect During Flight Simulation

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Abstract. Affect is a key determinant of performance, due to its influence on cognitive processing. Negative emotions such as anxiety are recognized cognitive stressors shown to degrade decision making and situation awareness. Conversely, positive affect can improve problem solving and facilitate recall. This exploratory pilot study used electromyography and pupillometry measures to track pilots' levels of negative and positive affect while training in a flight simulator. Fixation duration and saccade rate were found to correspond reliably to pilot self-reports of anxiety. Additionally, large increases in muscle activation were also recorded when higher anxiety was reported. Decreases in positive affect correlated significantly with saccade rate, fixation duration, and mean saccade velocity. Results are discussed in terms of using psychophysiological measures to provide a continuous, objective measure of pilot affective levels as an additional evaluation method to support assessment of pilot performance in simulation training environments.

Keywords: affect, anxiety, simulation, training, eye tracking, electromyography

Introduction

Airline pilots are usually required to be capable of performing their work in both normal and difficult circumstances. The traditional approach to measuring pilots' performance has been based on technical knowledge and flying proficiency (Mavin & Murray, 2010). While this approach to performance assessment is proposed to be an important reason for the high safety levels seen in commercial aviation (Johnston, Rushby, & Maclean, 2000), recent research has shown that nontechnical skills (NTSs) often play a more significant role in aircraft accidents (Flin, O'Connor, & Crichton, 2009). Shortcomings in NTSs have been found in areas such as decision making, problem solving, and situational awareness (Helmreich & Foushee, 1993; Helmreich, Merritt, & Wilhelm, 1999). These skills require a high level of cognitive processing; however, negative affect which is characterized by emotions such as fear and anxiety has been shown to compromise cognitive processes (Russo, Stetz, & Thomas, 2005). For example, in aviation, numerous accidents have been attributed to the impact of negative affect on NTSs such as decision making (Wiegmann & Shappell, 1997) and also flying proficiency which requires psychomotor coordination and working memory (McClernon, McCauley, O'Connor, & Warm, 2011). Conversely *positive affect* has been shown to improve problem solving, facilitate recall, and enhance decision making through increasing a professional's ability to organize ideas and access alternative cognitive perspectives (Ashby, Isen, & Turken, 1999).

Aircraft pilots have long been taught to practice staying calm (Lehrer, 2009), with the aim of learning to keep a clear mind under high-pressure situations. Simulation training works on the premise that a pilot's confidence in his/her skills can be strengthened through training by learning to achieve success while under the most fraught emotional flying conditions replicated in the simulator. Certainly in early simulator studies comparing novice–expert eye-tracking performance, level of pilot experience was found to impact instrument scanning behavior positively (Bellenkes, Wickens, & Kramer, 1997). In the growing field of cognitive engineering, there is an increasing acknowledgement and appreciation of the important role of emotion in influencing cognitive processing and performance (Gluck & Gunzelmann, 2013), further underlining the important of the simulator training environment beyond technical skill

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acquisition. *Affective* states and the emotions that underlie them are now gaining significant recognition as a critical cognitive stressor (Gluck & Gunzelmann, 2013) which should be considered during training evaluation.

Emotions and Performance

The neuroscience work of Damasio (1995) has convincingly demonstrated the interdependence between emotions and skills previously considered to require only rational thought, such as problem solving and decision making. Emotions prepare individuals to respond to eliciting stimuli by coordinating a system for responses. For example, anger prepares a body to fight, and fear prepares it for flight (Matsumoto & Wilson, 2008). Recognizing this, according to Lazarus's (1966, 1991) transactional model of stress, people are thought to appraise task demands in terms of their own resources to cope. Feelings of confidence in one's ability leads to positive affect which has been shown to facilitate greater cognitive flexibility and creative problem solving (Isen, 2004).

Viewed from this perspective, affect can support or hinder cognitive processing and performance. Affect is conventionally dichotomized as positive or negative with "positive affect being an omnibus variable composed of emotions such as enjoyment, pride, and satisfaction, and negative affect as an omnibus variable composed of emotions such as anxiety, frustration, and sadness" (Daniels et al., 2009, p. 948). Research shows that positive affective experiences facilitate the retrieval of positive self- and task-related information, whereas negative affective experiences facilitate the retrieval of negative self- and task-related information (Daniels et al., 2009; Linnenbrink & Pintrich, 2002). In terms of goal striving, a number of theories suggest when making good progress toward a goal, an individual experiences positive affect, while making poor progress results in negative affect such as stress (Gray, 1990; Seo, Barrett, & Bartunek, 2004). Additionally, the negative affect experienced when making poor progress can have a motivating influence leading some individuals to mobilize more effort (Ballard, 2009).

Whether emotion facilitates or interferes with performance may depend on the individual. This notion of "mental toughness" in an individual has been recognized in the field of professional sport for some time. For example, Affective Intelligence is a subscale of a tool developed to measure mental toughness in athletes (Gucciardi & Gordon, 2009). Affective Intelligence recognizes that optimal performance is dependent on an athlete being able to remain in control of their emotions, no matter what obstacles they encounter, and being able to actively bring their emotions into play to facilitate optimal performance (Connaughton, Wadey, Hanton, & Jones, 2008; Gucciardi & Gordon, 2009; Gucciardi & Mallett, 2010).

In the realm of aviation, while the relationship between pilot's personality and job performance has been of interest for some time (Hormann & Maschke, 1996), the measurement of affective states as an additional tool to assess performance has not been previously undertaken. In 2010 Mavin examined individual check captain's personal evaluation criteria by investigating the metrics they used to assess pilots' performance. A check captain is an airline captain who assesses another pilot for promotion to airline captain. Significantly, check captains identified that the first element of the decision-making process was having the confidence to be able to make decisions. A candidate could fail if they were viewed as being too anxious or fearful to take on the responsibility of making a high-level final decision. The recognition of affective state as part of pilot skills assessment is evident in the following quote from a check captain: "I've always believed that flying aeroplanes is nothing more than an exercise in self-confidence" (Mavin, 2010, p. 100). If a pilot's affective state does not support strong cognitive processing, it will inevitably degrade and undermine skills at both a technical and nontechnical level.

Measuring Affect During Simulation Training

Research on affective states, both positive and negative, and their impact on performance are currently constrained by the necessity of relying on self-report measures to assess a trainee's affective state. Both paper-based reports and verbal reports from the trainee on their changing affective levels require the trainee to interrupt their simulation training to some degree. Paper-based self-reports involve stopping the simulation scenario completely. Verbal reports involve the psychological disengagement from the virtual environment to consider and report on anxiety levels. Such techniques not only interrupt the participant's affective-cognitive processes (Ahn, Bailenson, Fox, & Jabon, 2009; Reynolds & Picard, 2005) but also negatively impact the simulation training experience.

In simulation it is the act of becoming immersed to the point of feeling you are actually there, referred to as *presence,* in the replicated world which underlies the success or otherwise of the training experience (Huang & Alessi, 1999). Presence has been widely researched as a key construct facilitating the effectiveness of simulation training (Lombard & Ditton, 1997; Tichon, 2007). It is well established that coherence of a virtual stimulus set promotes learning, and an uninterrupted sense of presence has been identified as a key requirement in achieving this. Thus, any measurement or evaluation devices that require trainees to divert their attention from the simulated experience cause distraction thereby eroding the simulation learning experience. For this reason, capturing behavioral data from participants, such as facial expressions or head movements, may provide a more accurate representation of how and what they feel while avoiding interruption to the training experience.

Feature extraction via pupillometry has garnered significant interest as an objective measurement tool for affect recognition (Liao, Zhang, Zhu, Ji, & Gray, 2006). Stress has been a key variable of interest, with investigations revealing features that are potentially sensitive and robust to measure (Liao et al., 2006). Research has identified a number of parameters relating to the eyes and their movement which are influenced by affective state and specifically state anxiety. Blinks, saccades, and pupil dilation have all been reported as varying systematically with manipulations to stress or measured anxiety levels. For example, Chapman, Oka, Bradshaw, Jacobson, and Donaldson (1999) conditioned subjects to expect an electrical shock to their fingertip, producing raised levels of anxiety and stress. During periods shortly before a shock, subjects showed significant increases in the cycling of pupil size (i.e., variability in pupil size over time). Partla and Surakka (2003) exposed subjects to images designed to produce positive or negative arousal in subjects and reported changes in the maximum, short-term pupil dilatory response which they termed *PSV* (pupil size variation). Some links between eye movement and affective state have also been reported for subjects observing static faces portraying a range of emotional expressions (Susskind et al., 2008). In particular, the authors reported increases in peak saccade velocity in response to fearful expressions. Finally, numerous studies have examined the link between affective states and blink rate. The majority of this work has found that blinking increases as anxiety levels increase (e.g., Harrigan & O'Connell, 1996); however, the opposite result has also been reported (Liao et al., 2006).

Several studies have also used surface electromyography (EMG) to evaluate skeletal muscle response to stress and anxiety and have shown a global increase in muscle activation during acute stress exposure (Lundberg et al., 2002; Nilsen et al., 2007, as well as impairments in muscle relaxation ability (Blangsted et al., 2004). Yoshie et al. (2008) examined the relationships among psychological stress, EMG activity, and performance in pianists. EMG activity was reported as a reliable, objective measurement of the underlying target construct, emotion. In response to stress, both agonist and antagonist muscle activity increased resulting in co-contraction and increased joint stiffness. Elevated muscle activity associated with psychological stress also results in increased force outputs and can lead to deterioration in overall signal-to-noise ratio in the motor control system, resulting in further observable, recognizable patterns of motor performance (Yoshie et al., 2008).

The exploratory pilot research reported here investigated whether commercially available eye-monitoring and EMG equipment can reliably measure negative and positive affect via pupillometry and muscle activation data gathered during a flight simulation. As discussed, flight simulators have been used to train pilots in how to remain calm to facilitate optimal performance for many years. Simulation training works on the premise that airline pilots' confidence in their skills can be strengthened through training in difficult situations. For example, working through a highly emotional state into successful goal performance influences how confident a trainee will feel about their own level of skill. This use of simulation to leverage affective state to facilitate performance has not been formally assessed, and therefore this paper introduces a new approach to assessment of trainee performance in simulation.

Method

This study was conducted in January 2011 in a flight training facility located at Aviation High in Hendra, Australia. Eye responses and EMG data were recorded while participants undertook a flight scenario designed to become increasingly difficult throughout the 30-min flight. Before commencing and after completing the training scenario, each participant was required to fill in a questionnaire assessing their affective state.

Participants

Twelve participants were recruited from among currently enrolled undergraduate students of the Griffith University School of Aviation. They were 7 male and 5 female pilots. All had prior flying experience. Previous flight hours ranged from 3 to 173 with a mean of 79.64 hr (SD = 57.99). Prerequisites for participation were normal or corrected-to-normal vision. The pilots were aged from 19 to 31 years of age with a mean age of 26.1 (SD = 3.60) years. Participants volunteered to take part in the study and gave their informed consent.

Apparatus

Simulator

The experiments were conducted in a GeoSim Cockpit style Fixed Wing Synthetic Trainer. The ''outside-the-aircraft'' visual displays consisted of a single scenery screen giving a 120° visual reference. This system consisted of an overhead projector, casting an image on a large 120″ screen using a high-quality LCD laser projector.

An additional ''inside-the-aircraft'' screen displayed the instrumentation. The GeoSim Part Task Training Device (PTT) cockpit layout is representative of general light aircraft cockpits, with a worldwide database. GeoSim currently holds Civil Aviation Safety Authority (CASA) certification on its synthetic trainers. The simulator is capable of replicating a number of aircraft, including single- and dual-engine piston aircraft, and larger turboprop aircraft. The simulator has an enclosed fiberglass shell replicating a small aircraft cockpit. Main controls include dual yoke controls, rudder and throttle quadrant. Other secondary controls and systems are made available, including trim wheel, radios, and a selection of switches for operating lights, beacons, and other associated systems. More sophisticated controls include magneto switch, starter button, and cowl flap controls. The simulator allows for adjustable seating for two pilots. Figure 1 shows the GeoSim simulator.

Figure 1. GeoSim Part Task Training Simulator.

Virtual Scene

Pilot instruments are confined within the main fiber glass shell, and located in front of the pilot. The computer utilized the Flight Simulator X program, which for this study was replicating analogue instruments consistent with a Cessna 172 aircraft. The aircraft was positioned at the Archerfield general aviation airport (a real airport located in Brisbane, Australia), with the flight conducted within 10 nautical miles of the airport. Even though the flights were conducted at various times during the day, the simulated flight replicated daylight hours with no wind or cloud present.

Simulator Setup

The simulator was placed in a large classroom (15 × 15 m). It was positioned approximately 1 m from and facing one wall to allow for the projection of the virtual image onto the large 120″ screen attached to the wall. Floor-to-ceiling black opaque blankets were hung around the back and sides of the simulator. To allow access to the simulator, these blankets were placed approximately 2 m from the simulator. A large fluorescent light was above the simulator, and as the flight simulation was replicating daylight hours, it was left on throughout the study. All cables that were connected to the participant came through the back of the simulator.

Simulator Procedure

Attaching the measuring equipment to participants took between 10 and 20 min, which included a 5-min test of the equipment. Only one participant had to be asked to return on another day, due to wearing eyeglasses. Eyeglasses created difficulties with the eye-tracking software, and the participant returned the following day wearing contact lenses, which did not pose any problems.

Once all measuring equipment had been safely attached, a 30-min simulated flight was conducted. Participants were then required to take over the controls and conduct the following maneuvers:

Stage 1. Engine start, taxi, and manual takeoff.
Stage 2. Level off at 1,000 feet.
Stage 3. Thirty-degree level turns, in both directions.
Stage 4. Climbing and descending turns at 30 degrees, at 80 knots, at 500 feet/min (for the level of their flight experience, all participants found this maneuver extremely difficult to complete).
Stage 5. Landing on the runway they departed from.

During Stage 1, the instructor, who sat in the right-hand seat, provided clear guidance to participants (sitting in the left-hand seat) on how to operate the simulator. Participants were given an overview of the instrument panel, including primary and secondary instruments that would be required for the exercise. Primary instruments were attitude (artificial horizon), altitude, airspeed, and heading indicator, displayed in a standard T setup. Vertical speed, which is to the lower right of the T, was also shown. Students were guided through the engine start procedure and assisted in the initial taxi. Once airborne (the last part of Stage 1), participant were directed to look "outside" the simulator and use the virtual scene shown on the 120-in. screen.

The simulator was designed not to replicate the real aircraft, by having aircraft pitch control overly sensitive, requiring smaller than normal yoke inputs. Roll control with the yoke was normal. As such, all participants encountered initial difficulty during the takeoff, with most noting the sensitivity of the pitch control. However, the instructor provided positive guidance and in some cases, assisted in the initial climb sequence. Stage 1 was aimed at relaxing and familiarizing the participant as best possible.

As the simulator approached 1,000 feet during the climb, participants were requested to level off at 1,000 feet. On reaching 1,000 feet, the instructor withdrew all support until the beginning of Stage 5, when limited support was given for the landing.

As the simulator was designed not to replicate the real aircraft – by having overly sensitive pitch – participant had difficulty initiating and maintaining level flight. Once participants had maintained 1,000 feet for a short period (around 2–3 s), participants where immediately requested to conduct 30-degree level turns, in both directions (Stage 3). Some students did not initially comply with the turn instructions, as they were having some difficulty maintaining level flight at 1,000 feet. In these cases, after approximately 10 s, the instructor repeated the instruction. For the Stage 3 maneuver, the participant's focus was primarily on attitude and altitude instruments, and to a lesser degree, the vertical speed indicator. Participants maintained bank angle and altitude using only yoke control.

For Stage 4, participants where then required to conduct climbing and descending turns at 30 degrees, at 80 knots, at 500 feet/min. For this maneuver, participants had to visually monitor four instruments: attitude, altitude (for leveling off), vertical speed, and airspeed. During the turns, participants were also required to finish the maneuver on a particular heading, requiring use of the heading indicator. Unlike

Stage 3 turns, the participants not only used yoke control for bank and pitch, but also required throttle movements for speed. Given the setup of the simulator, the complexity of this maneuver cannot be understated. On all occasions, participants commented on the extreme difficulty they were having flying the simulator accurately in Stage 4. The instructor remained passive even while comments were directed at him.

For the purposes of the research, Stage 2 was defined as the easy phase (Phase 1) of the simulation, and Stage 4 was defined as the hard phase (Phase 2) of the simulation. Physiological measures were taken throughout the simulation but analyzed at Stages 2 and 4 at which points easy and hard phases could be compared for differences in physiological responses.

Diagnostic Features Derived From the Eye

Eye movement and pupil size data were recorded using an SR Research EyeLink II head-mounted tracker, performing binocular 500-Hz sampling. Data collected by the eye tracker includes relative pupil size, eye position, and movement velocity. Feature measures derived from the eye-tracking data included saccade rate, saccade duration, pupil size, pupil size variation, saccade amplitude, peak saccade velocity, saccade velocity, and blink rate.

The eye tracker requires an initial calibration procedure for each participant. This involves first fitting the head-mounted cameras, just below the line of sight under each eye. The subject is then asked to fixate a series of control points enabling the eye-tracker software to calculate how to extrapolate from eye movement and position to gaze direction for each subject.

Electromyography

EMG data were recorded at 1,000 Hz using surface electrodes feeding into a National Instruments analogue recorder controlled by a LabView program running on a central PC (Control PC). Eight synchronous analogue recording channels were available.

The activity of the following muscles were of interest and were recorded:

1. Jaw clenching (masseter).
2. Shoulder tension muscles (upper trapezius).
3. Wrist flexing (flexor carpi radialis).
4. Calf tension (lateral gastrocnemius).
5. Thigh tension (vastus lateralis).

It was our intention to also record eyebrow movement (corrugator supercilii), but it proved too difficult to attach electrodes effectively without interfering with the eye-tracker head harness. The entire experimental layout with all monitoring equipment is presented in Figure 2 below.

Survey

The Multiple Affect Adjective Checklist (MAACL-R) was used to assess general emotional state throughout the simulation. This measure has been used extensively to investigate the impact of stress on psychological functioning (Hunsley, 1990), particularly in simulator training evaluations. For example, in studies of acute stress, the US Army Research Laboratory (ARL) found that temporary stress effects such as anxiety, depression, and hostility are revealed by the MAACL-R (Redden, Sheehy, & Bjorkman, 2004). Numerous studies have established both the reliability and validity of the MAACL-R with adults (Girden, 2001). The checklist consists of 132 adjectives that comprise five primary subscales (anxiety, depression, hostility, positive affect, and sensation seeking) and can be completed in approximately 5 min. The drawback of the scale is that it more easily achieves independence between positive and negative affect than between two dimensions of negative affect. While limitations of self-report scales do exist, the goal of using the MAACL-R items during our preliminary testing was to provide a participant-informed check on whether pupillometry and EMG data did reliably correspond to the levels of anxiety participants experienced at the easy and hard phases of the simulation. This verification is an important first step required to move beyond self-report surveys and scales to the use of an objective measure based on physiologically-derived measures of positive and negative affect.

Results

Of the eight measures taken relating to the eye (e.g., eye movement, pupil size, and blink rate), most produced a mixed response across subjects. However, two measures – saccade rate and pupil dilation – did reveal a consistent pattern with a clear link to the reported levels of anxiety. Participants who reported opposite trends in anxiety across the 30 min of testing and, in particular, across the two crucial test phases corresponding to easy and hard flying, revealed opposite trends in eye movement velocity in degrees per second over the 20-s intervals recorded in Stages 2 and 4 of training. Participants who reported higher levels of anxiety on the MAACL-R after completing the hard phase (Stage 4), produced larger numbers of saccades during the more demanding second phase of the simulation. In contrast, a participant who reported no elevation in anxiety revealed saccade rates that remained constant across the two phases of flying.

Similarly an examination of relative pupil area recorded over a 60-s period during the same two test phases reveals that pupil size increased for participants who reported elevated levels of anxiety under the hard flying conditions. In contrast, pupil size was seen to decrease in participants who reported no increase in anxiety levels moving from the easy to hard flying conditions.

To demonstrate the difference in the two measures measures between anxious and nonanxious participants, a summary of the data collected from two participants is presented in Figure 3. Of the two participants, Participant I reported increasing anxiety and Participant G did not. As shown in the left panel, for participant G there was no

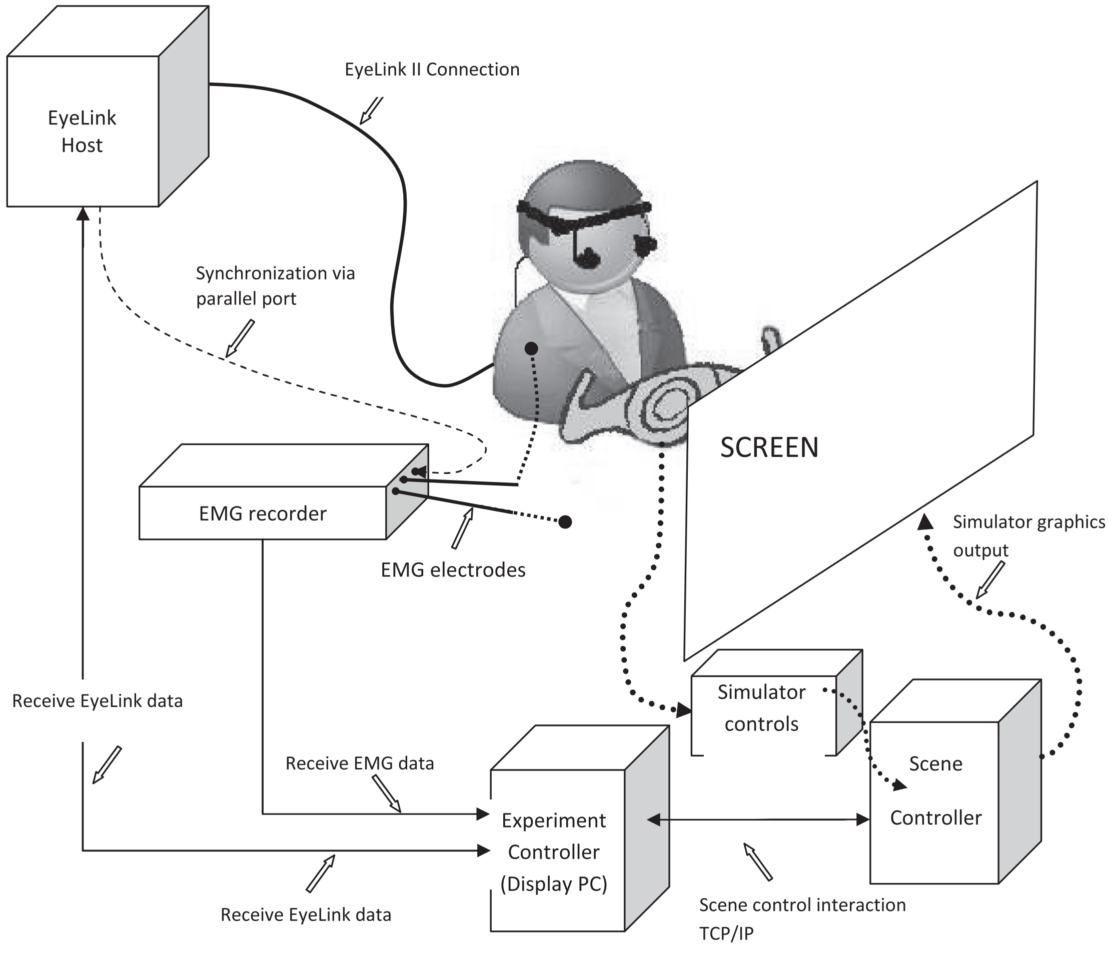

Figure 2. Experimental layout. EMG = electromyography.

detectable change in saccade rate, whereas for Participant I there was a substantial increase of approximately 30%. Similarly, as shown in the right panel of Figure 3, relative pupil size generally increased during the 'harder' phase of flying for Participant I, whereas for Participant G, pupil size actually decreased. The summary changes in pupil size for Stages 2 and 4 of testing are given in Figure 3 (right-hand chart).

In contrast to earlier literature, no consistent link emerged between eye movement peak velocities or blink rates, and self-reported state anxiety. However, as with earlier reports, there was evidence of a positive correlation between pupil size and anxiety. Our work also revealed a tentative link between saccade rate and anxiety. Thus, while strong conclusions are prohibited by our relatively small sample size, our results suggest that with a larger sample, a set of objective physiological measures will prove to be conclusive indicators of state anxiety.

While the amplitude of the EMG signal is a reflection of the degree of muscle activation, it can also vary depending on a number of biophysical factors including electrode placement, impedance, and muscle size. As a result, we compared the relative changes in EMG as a function of task difficulty for each individual rather than across individuals. To examine how muscle contraction corresponded to increased levels of anxiety, a direct comparison of the change in activation between two participants who reported low versus high anxiety is provided in Figure 4. Participant I reported much higher levels of anxiety when they were required to perform simulator tasks in the 'hard' phase of flying (Phase 2). The relative increase in muscle activation, reported as root mean squared (RMS) EMG, from the 'easy' to 'hard' phases is much greater for this participant (77% increase) than for participant G (13% increase). Participant G reported much lower levels of anxiety when required to perform the 'hard' phase and correspondingly their muscle activation was much less. It was important to find that the physiological measures of anxiety reliably tracked both high levels of anxiety as well as reduced levels of anxiety.

Although reports of state anxiety were generally aligned with the changes in eye movement behavior described above, the correlations cannot be reported as statistically significant, due to the small sample size. However, in contrast, positive affect, also collected via the MAACL-R,

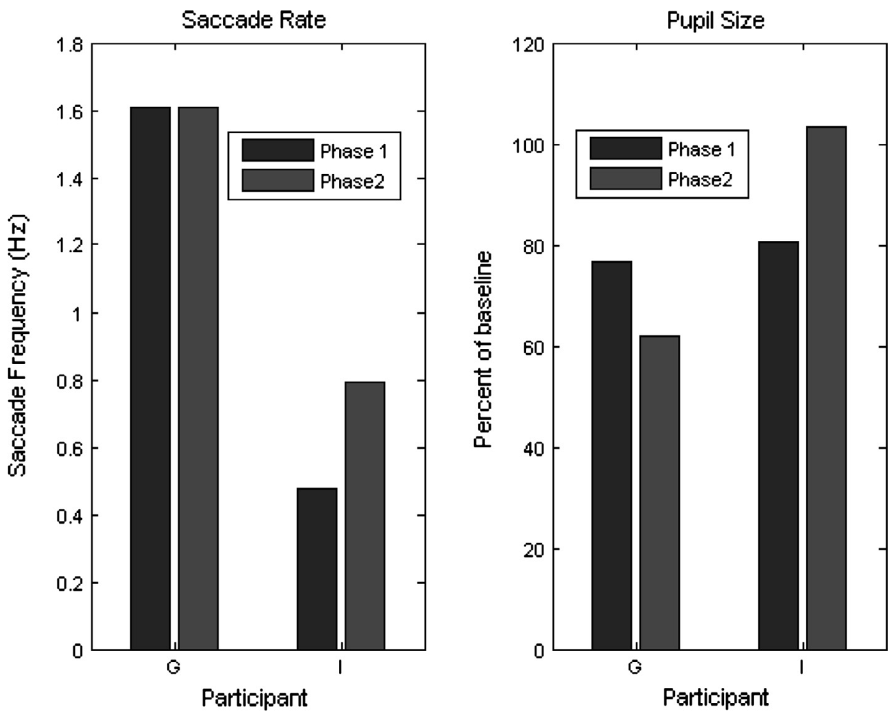

Figure 3. Percentage change in saccade rate and relative pupil size. Participant G = nonanxious participant; participant I = anxious participant.

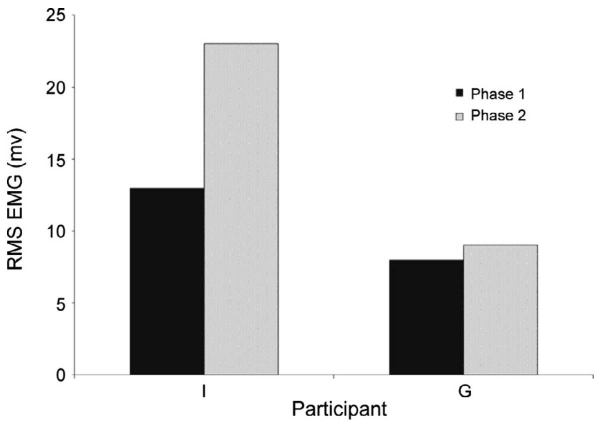

Figure 4. Relative increase in muscle activation. RMS EMG = electromyography.

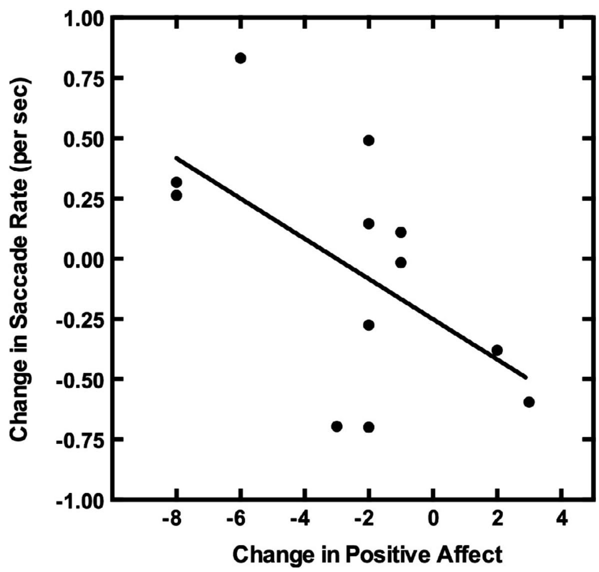

Figure 5. Scatterplot comparing changes in saccade rate and positive affect between Phase 1 (easy) and Phase 2 (hard) of the experiment. Line represents best linear fit to data points.

revealed much stronger and more consistent tendencies across the group of subjects.

The correlational analysis for change in saccades generated per second across all participants between the two flying conditions, and the change in self-reported positive affect are shown in Figure 5. The correlation was negative and statistically significant, $r = .58$, $p < .05$, implying that pilots who reported a decrease in positive affect, which typically occurs as stress and anxiety increases, tended to produce more saccades per second.

The correlational analysis for change in the mean fixation duration in seconds across all participants between the two flying conditions, and the change in self-reported positive affect is shown in Figure 6. Again the correlation was positive and statistically significant, $r = .62$, $p < .05$, implying that as positive affect fell, so too did the duration of the pilots' fixations.

The correlational analysis for change in mean saccade velocity across all participants between the two flying conditions, and the change in self-reported positive affect is displayed in Figure 7 and reveals the same relationship. The correlation was positive and statistically significant, $r = .64$, $p < .05$, implying that as pilots reported decreases in positive affect, their mean saccade velocity fell.

Correlation between positive affect and EMG was not examined, as increases in muscular contraction would be expected to correlate only with increasing negative affect (e.g. stress, anxiety). Neutral and positive affect states tend to exhibit no steady state EMG activity and therefore would be insensitive to changes in positive affect as the EMG would already be at zero. In that sense EMG is not an ideal measure of positive affect as it exhibits a 'floor' effect. Indeed, in our study there was no consistent EMG activity with which to perform correlation analysis with positive affect.

Discussion

Our initial examination of pupillometry measures during flight simulation revealed that fixation duration and saccade rate corresponded reliably to pilot self-reports of increasing anxiety, while pupil size and saccade amplitude did not. This was echoed by, self-reports of significant decreases in feelings of positive emotion, which also correlated significantly with saccade rate, fixation duration, and mean saccade velocity. Control theory suggests that poor performance is associated with negative affective states which should motivate a pilot to exert more effort to improve their performance (Carver & Scheier, 1998). Conversely, pilots will experience positive affective states when confident in their performance (Ballard, 2009). Thus the measure of decreasing positive affect is potentially just as important as increasing negative affect (in this study, anxiety) in both facilitating and measuring pilot performance during simulation training. In the current study, measures of flight performance were not recorded; however, in future work a correlational analysis among changes in affect, level of experience, and simulator performance data may provide an interesting starting point for ascertaining the impact of expertise on confidence during flight and its role in performance.

Regarding pilot levels of confidence, then a decreasing level of positive affect may be a key indicator that confidence levels are faltering. Decreasing levels of positive affect have not yet been examined with regard to their relationship with performance of technical skills in aviation, as far as we are aware. However, the existing research that indicates that positive affect facilitates problem solving and promotes flexible, responsive approaches to situations (Isen, 2004) would indicate that affect should be further investigated as a factor in flying that is likely to be influencing nontechnical cognitive-processing skills. However, one of the issues that continues to be brought up within the aviation industry is the difficulty in assessing NTSs (Sidney, Hummerdal, & Smith, 2010) and performance overall (Mavin, Roth, & Dekker, 2012). With the integral role that NTSs play in the flight deck of an aircraft, there are increasing discussions on how best to evaluate them. It could be that the continuous monitoring of affective state, synchronized to technical skill metrics recorded by the simulator, will provide a possible solution to this ongoing problem. This pilot work lays the foundations for the development of such a continuous objective measure of affective state.

Modern aircraft have two pilots working closely together, managing both human and machine resources in a way that requires a combination of both technical skills and nontechnical proficiency. Having both pilots more acutely aware of any degradation in the other pilot's affective state, may lead to better countermeasures by the other pilot if required. A continuous measure of affective state that could be inserted into training simulations to provide an in-aircraft warning system if either pilot's affective state degraded to a predetermined *alert* value could be developed. The preliminary work reported here lays the foundations for the development of such a continuous objective measure which may be utilized to both facilitate better knowledge of the importance of affective state and provide initial skills training in awareness of changes to a fellow pilot's affective state.

Affective levels could also be used to compare real-world training and simulator training, as an evaluation of whether the simulated world is real enough to achieve desired learning outcomes. If either positive or negative affective levels are significantly different in the simulator from the real world, then the simulator may not be adequately replicating the real-world experience – that is, the emotional response to required training tasks is not as significant in the simulator.

Based on the relatively small sample size of this study, it is of course too early to conclude whether the range of eye movement and eye response measures identified coupled with EMG measures will prove to be reliable indicators of affective state. To establish this, the task for future studies will be to test for correlations between the eye movement variables and a range of other negative and positive affective states. However, objective physiological real-time affective state monitoring of pilots undertaking simulated difficult flying conditions may help to answer such questions as whether there is an optimal degree of affective arousal, positive or negative, after which technical or NTSs degrade. Such insights will assist the development of a model to guide use of pupillometry and EMG monitoring to support more extensive evaluation of simulation training.

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