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An operationally-significant number of Griffon aircrew in the Royal Canadian Air Force (RCAF) develop chronic neck pain; however, it is unclear how this chronic pain affects their ability to accomplish their missions. Extant literature on pain and human performance has found that pain can negatively affect tasks constrained by short-term memory and attention switching. We sought to test whether pain has similar effects on personnel piloting helicopters in simulation. Twenty-three RCAF personnel flew a simulated Griffon helicopter through waypoints along a target path. We were particularly interested in the effects of three variables: a) the presence or absence of induced thermal pain, b) the presence or absence of a secondary engine monitoring task requiring sustained attention, and c) the experience level of the pilots. The results suggest that pain can interfere with flight performance, particularly for less experienced pilots engaged in multiple tasks over more extended time durations.

Introduction

An operationally-significant number of Royal Canadian Air Force (RCAF) Griffon flight crew develop chronic neck pain that compromises their ability to fly missions, resulting in pilots benching or grounding themselves (Chafe & Farrell, 2016). Since some pilots continue to fly despite experiencing pain, our aim here was to examine the potential for pain compromising flight performance. Does neck pain negatively affect performance of flight-related tasks such as real-time control and monitoring of systems?

The experience of pain has been shown to negatively affect human performance on a variety of tasks, including tasks requiring controlled executive functioning, attentional switching, and high cognitive load (Berryman, Stanton, Bowering, Tabor, McFarlane, & Moseley, 2013). Chronic pain has been shown to induce deficits in spatial and verbal working memory capacity (Luerding, 2008), attention and working memory (Dick, 2008), immediate recall (Pearce, 1990), and running memory (Veldhuijzen, 2006). Pain can also reduce physiological indicators of information processing such as the amplitude of the auditory P300 in EEG recordings (Alanoglu, Ulas, Ozdag, Odabasi, Cakci & Vural, 2005). Experimentally-induced pain has also been shown to negatively affect cognitive performance, including interference on go-no-go tasks (Babiloni, Brancucci, Arendt-Nielsen, Del Percio, Babiloni, Pascual-Marqui, Sabbatini, Rossini, & Chen, 2004), and deficits in attention control (Eccleston & Crombez, 1999). Moore, Keogh, and Eccleston (2012) showed that the attentional tasks most affected by pain are those that require the processing of multiple cues, and the need for executive control.

It is also possible that pain could positively affect performance. The Yerkes-Dodson Law states that peak task performance is achieved at moderate levels of stress or task demand (Yerkes

& Dodson, 1908). Tasks too low in stress or demand do not fully energize an operator to use all their available cognitive resources for the task. In contrast, tasks too high in demand and stress result in physiological stress responses that impede working memory capacity (Wachtel, 1968) and attentional control (Hockey, 1997). Pain acting as a stressor could therefore increase performance on low-stress/low demand tasks while negatively impacting high stress/demand tasks. Given that pain can lead to deficits in attentional control and that focusing attention is a valid strategy for mitigating pain (Eccleston & Crombez, 1999), we might expect that pain could improve performance when attention is dedicated to a single task.

Taken altogether, the above studies suggest that pain affects cognitive performance as measured by traditional psychological tasks in the laboratory. Our question is whether these effects of pain found in a basic and clinical literature, often using elderly or special populations (e.g., fibro-myalgia patients) and laboratory tasks (e.g., Stroop interference, verbal working memory performance), will generalize to cognitive multi-task performance of RCAF aircrew on flight-related tasks, such as multi-axis control, visual navigation and instrument monitoring. If pain has its greatest cognitive effects on attentional control and task switching while multitasking, then we would expect to find that pain negatively affects multi-task performance. In contrast, we expect pain to have less effect and perhaps even a positive effect on single-task performance, due to enhanced arousal.

Method

Participants

Twenty-three RCAF members served as participants in the experiment. Ages ranged from 21 to 50 having up to 6,000 hours total flight time. All participants provided consent and none withdrew despite being informed that they could withdraw from the study at any time, without consequences. Fifteen participants participated at DRDC Toronto and 8 participated at Canadian Forces Base Gagetown. Post-hoc, 11 participants were classified as experienced helicopter pilots, having more than 1,000 total flight hours, and 12 participants were classified as novice pilots, having less than 1,000 flight hours.

Experimental Design and Procedure

The experiment was conducted over two consecutive days. On Day One verbal descriptions of the simulator controls were provided, followed by a 5 to 30 minute familiarization flight in the simulator until performance stabilized. Subsequently, instructions described either the *flight control* or *engine monitoring* task (order counterbalanced across participants), followed by one block of three two-minute practice trials, and then repeated for the other task, followed by one block of three two-minute dual-task practice trials performing both tasks concurrently. We then measured pain thresholds and established levels of pain induction.

For Day Two, we analyzed our dual-task paradigm, employing flight control and engine monitoring tasks, using a fixed-effects, factorial experimental design. Table 1 lists the experimental factors. All factors except experience were manipulated within-subjects. Participants completed three blocks of six experimental trials each lasting two minutes. In a given block, trials one and two consisted of either the flight control or engine monitoring task (single task trials); trial order was counterbalanced across blocks and participants. Trial three presented the dual-task where participants completed both tasks concurrently. In a given block, the first three trials and the second three trials were identical, except for presence or absence of pain, which was also counterbalanced across blocks and participants.

Flight Tasks

Table 1.
Factors analyzed of experimental data from Day Two

Factor	Type	# levels	Level Names
EXP	Between-Ss	2	AF_Exp>=1000 AF_Inexp
PAIN	Within-Ss	2	Present Absent
TASK	Within-Ss	2	Single Dual
BLOCK	Within-Ss	3	1 – 3
SEGMENT*	Within-Ss	7	1 – 7

*The SEGMENT effect was only included for flight task data

Stimuli and apparatus. The simulated flight task environment was generated using X-Plane flight simulation software, version 10.51 64-bit (Laminar Research Inc, 1998) with the X-Trident Bell 412 (equivalent to Griffon used by RCAF), a helicopter model add-on available through the X-Plane store. Displays were presented at a frame rate of 60 Hz and performance data were exported from X-Plane at 13 Hz. The primary flight display had a geometric field of view of 90.0° horizontal by 55.5° vertical. At DRDC Toronto, the pilots sat at approximately the design viewpoint of the 4k resolution display producing a viewing angle of 90.0° x 58.2°. At Gagetown, participants viewed the simulated flight environment on a 1280 x 1024 resolution monitor with a viewing angle of 61.9° x 38.6°.

The software package ViEWER (Dyre & Grimes, 2003) controlled the engine monitoring task, which was presented on a 17 cm diagonal LCD screen centered just below the primary flight display. At DRDC Toronto, the secondary task display had a viewing angle of 18.9° x 14.3° with the participant sitting 61 cm from the display, whereas at Gagetown the secondary task display subtended 11.7° x 8.8° of arc with the participant sitting 99 cm from the display. Participant input was sampled at 30 Hz.

Participants viewed the displays while seated at Pro Flight Trainer Puma helicopter controls in a darkened room. The collective, cyclic, and anti-torque pedal controls were similar to their real-world counterparts.

Flight control task. Participants flew the simulated helicopter through a single course defined by a starting helipad (H1), a series of six 91.44 x 91.44 m square gates laid out in a mountain valley, and a final helipad (H2). The target flight path was defined as a line from H1 to the center of each subsequent gate and from the last gate to the center of H2. As each gate was flown through, the subsequent gate appeared. H2 appeared only after the final gate had been flown through. Wind disturbances were not simulated.

Figure 1 . Gates define the target flight path in the primary flight task. Ideally, participants fly from the center of one gate to the center of a subsequent gate.

Engine monitoring task. We simulated the status indicators of two engines based on the MATB-II system monitoring task (Santiago-Espada, Myere, Latorella, & Comstack, 2011, see *Figure 2*). Each engine display appeared as a pair of vertical rectangles representing engine temperature and pressure level. Critical areas were indicated by tick marks near the top and bottom of each rectangle, marked “High” and “Low”, respectively. A red horizontal line indicator within each rectangle moved vertically in a pseudorandom pattern. A “critical condition” occurred when an indicator moved into a critical area. Participants were instructed to squeeze a trigger on the cyclic only when both engines entered a critical condition (a “double critical condition” shown in Figure 2).

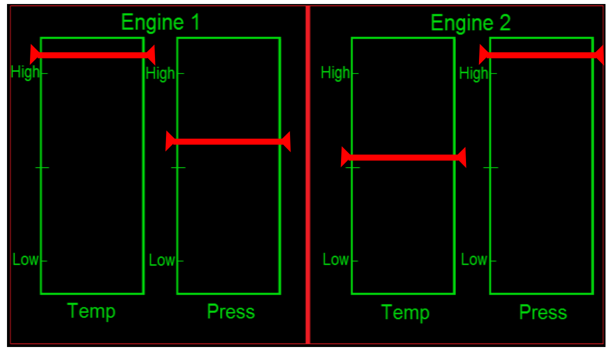

Figure 2. Engine status indicators for the head-down display used for the secondary detection task. The red-marker configuration is consistent with a “double-fault” requiring participant response.

Pain Induction

Stimuli and Apparatus. Thermal stimuli were presented and controlled using two digitally-controlled, thermal nociceptive stimulators (Nocistim units developed by Intellective Consulting & Services, LLC). The Nocistim units are based on the analog design of Morrow and Casey (1981) and are controlled via Nociscale software, which allows a personal computer (PC) connected via USB to control the temperature and exposure duration of two thermodes simultaneously using a variety of psychophysical methods. To present thermal stimuli between 37 and 48˚C, we placed two 12.7 x 12.7 mm square contact thermodes on opposite sides of the participant’s neck approximately 4.5 cm below the hairline on the dorsal surface (nape), held in place using a flexible neck brace.

Procedure for establishing pain thresholds and levels. We measured the pain threshold for each participant using an adaptive staircase procedure with an initial step-size of 2˚C, which decreased by 50% for each reversal of pain judgment (present vs. absent). Trials continued until the participant was satisfied that at least one of the two thermal stimuli was at threshold or the step size was reduced to less than 0.125˚C, whichever came first. A threshold trial consisted of an alternating pair of stimuli, each starting at the cooling baseline of 29˚C with one side ramping up to the set temperature (37-48˚C), and then falling back to the cooling baseline as the other side ramped up to its set temperature, then cooled. The period of a stimulus pair was 10 seconds.

Once the threshold temperatures were established, a second adaptive staircase procedure was used to match a suprathreshold pain stimulus to a marker at 24% of the distance between “no-pain” and "worst pain imaginable"on a visual analog scale (VAS). The 24% value was based on mean VAS pain rating of RCAF aircrew experiencing continuous chronic neck pain based on a recent survey (Fusina, Karakolis, Xiao, Farrell, McGuiness, & Apostoli, 2018). We recorded the set temperature of this stimulus and used it as the induced pain level for all subsequent task trials, where the 10 second anti-phase heating-cooling cycle of the two thermodes was repeated for the full task duration of 2 minutes.

Results

Our results will focus on three classes of measures: a) signal-detection parameters (sensitivity, *A*, and response bias, *β* ; Zhang & Mueller, 2005) and response time for the engine monitoring task; b) flight accuracy measures (lateral and altitude constant, variable, and RMS errors from the prescribed flight path); and c) flight stability measures (e.g., variance in roll, pitch, speed, side-slip). For brevity, we will report only those results from Day Two that are directly relevant to our hypotheses of how pain affects multi-tasking flight performance. Violations of sphericity were corrected using the Greenhouse-Geisser correction where appropriate.

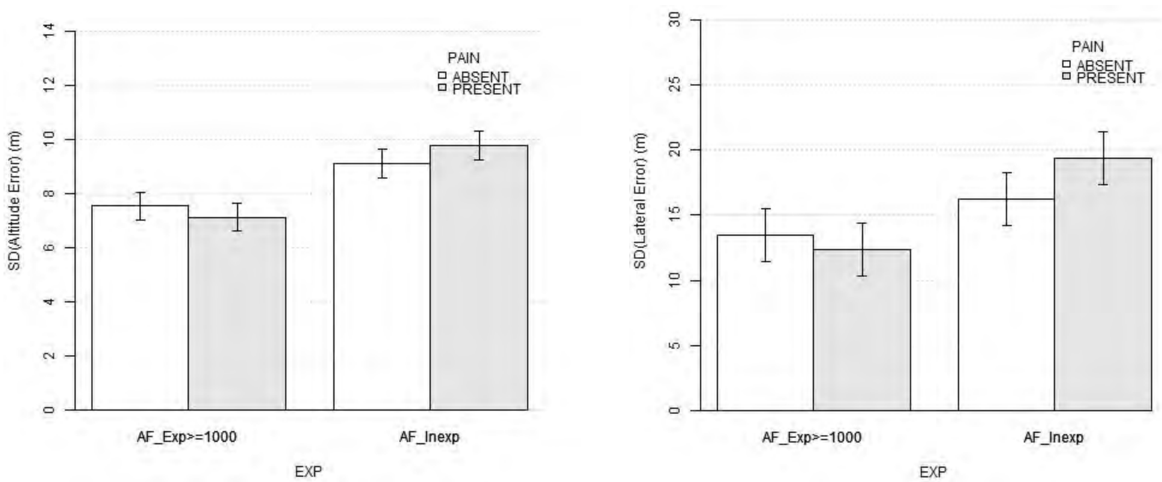

Figure 3. Standard Deviation of Altitude and Lateral Course Errors (m) plotted by the PAIN and EXPERIENCE factors. Error bars represent 95% within-subjects confidence intervals of the means.

We used several mixed-factor fixed effects ANOVAs with the factors listed in Table 1 to assess how pain affected our performance measures on Day Two. Engine-monitoring performance showed significant dual-task decrements on response time (Dual-task RT = 904 ms, Single-task RT = 635 ms, 95% CI = 9 ms; $F[1, 21] = 64.8$, $p < .01$, $\eta_P = .76$) and sensitivity (Dual-task A = .88, Single-task A = .93, 95% CI =.02; $F[1, 21] = 9.16$, $p < .01$, $\eta_P = .81$). Response bias was also affected by task (Dual-task $\beta = 2.24$, Single-task $\beta = 1.73$, 95% CI =.14; $F[1, 21] = 26.5$, $p < .01$, $\eta_P = .56$). However, there was no effects or interactions involving PAIN or EXPERIENCE (p > .05). PAIN did however significantly affect flight task performance. We found PAIN x EXPERIENCE interactions for the standard devations of both lateral error and altitude error ($F[1, 21] = 4.66$, $p < .05$, $\eta_P = .18$ and $F[1, 21] = 4.49$, $p < .05$, $\eta_P = .18$, respectively; see *Figure 3*). For inexperienced participants, pain degraded performance, but for experienced participants, pain improved performance. Identical patterns of interaction were found for other flight-stability measures, including the standard deviations of pitch, roll, ground speed, and vertical velocity ($p < .05$). Finally, there was a four-way interaction of PAIN x EXPERIENCE x TASK x BLOCK for the standard deviation of altitude error ($F[2, 42] = 3.92$, $p < .05$, $\eta_P = .16$). Performance on the dual-task produced greater variability in error in later blocks for inexperienced pilots in pain, while the variability of error decreased across blocks for all other conditions.

Discussion

The engine monitoring task showed typical dual-task decrements and performance was unaffected by pain. In contrast, flight-task performance did not show dual-task decrements and was influenced by pain, although differently for experienced and inexperienced pilots. These results suggest that our pilots treated the monitoring task as secondary. This is perhaps unsurprising given that pilots are trained to prioritize flight control over instrument monitoring or navigating. The lack of pain effects on the engine-monitoring task may be due to the fact that the engine monitoring task demanded little or no working memory resources.

Pain had opposite effects for experienced and inexperienced pilots. The stability of flight control and flight path errors increased during pain trials for inexperienced pilots, but decreased for experienced pilots. It appears that pain increases flight control error for inexperienced pilots with less-developed automaticity for flight control, perhaps due to working memory interference.

In contrast, pain enhances flight-control for experienced pilots with more-developed automaticity, perhaps due to increasing arousal (the Yerkes-Dodson law).

To conclude, our results suggest that flight-task performance and training decrements may be likely to occur with pilots experiencing chronic pain during the first few hundred hours of flight training, but these decrements become less likely with more flight experience.

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