OPEN

Quantifying the Physiological Stress Response to Simulated Maritime Pilotage Tasks

The Influence of Task Complexity and Pilot Experience

Luana C. Main, PhD, Alexander Wolkow, PhD, and Timothy P. Chambers, PhD

Objective: The aim of this study was to quantify the stress associated with performing maritime pilotage tasks in a high-fidelity simulator. **Methods:** Eight trainee and 13 maritime pilots completed two simulated pilotage tasks of varying complexity. Salivary cortisol samples were collected pre- and post-simulation for both trials. Heart rate was measured continuously throughout the study. **Results:** Significant changes in salivary cortisol ($P = 0.000$, $\eta^2 = 0.139$), average ($P = 0.006$, $\eta^2 = 0.087$), and peak heart rate ($P = 0.013$, $\eta^2 = 0.077$) from pre- to postsimulation were found. Varying task complexity did partially influence stress response; average ($P = 0.016$, $\eta^2 = 0.026$) and peak heart rate ($P = 0.034$, $\eta^2 = 0.020$) were higher in the experimental condition. Trainees also recorded higher average ($P = 0.000$, $\eta^2 = 0.054$) and peak heart rates ($P = 0.027$, $\eta^2 = 0.022$). **Conclusion:** Performing simulated pilotage tasks evoked a measurable stress response in both trainee and expert maritime pilots.

In occupational contexts, it is well-established that human error can be caused by fatigue, stress, and workload.[1] Maritime industry reports estimate that between 50% and 90% of all maritime accidents that result in injury and or death are due to human error.[2,3] Approximately 90% of these human-related accidents occur in confined waters.[4] Central to the safe passage of vessels through these challenging waterways are maritime pilots, who operate at the land–sea interface.[5] Maritime pilots possess extensive knowledge of the restricted and sensitive waterways in which they operate, and are responsible for facilitating the safe navigation of vessels through these challenging areas.[6] However, it has been established that maritime pilotage is a stressful occupation.[5,7] Comparisons with normative populations indicate that maritime pilots are at a greater risk of developing a number of negative health outcomes, including cardiovascular disease and related cardiometabolic risk factors,[8,9] obesity,[10,11] with some achieving as little at 1.5 hours of sleep over a 40-hour shift.[12]

Physiological data also suggest that certain maritime pilotage tasks can elicit an acute stress response (eg, berthing).[7] However, much of this evidence is either dated, or overly reliant upon medical employment records, with little evidence actually quantifying the biological and psychological stress of contemporary maritime pilotage.[5] Given that recent maritime industry reports have forecast unprecedented growth in the number and sizes of vessels in the coming decades,[13,14] the potential for future accidents and incidents may also increase. Therefore, investigating key pilotage tasks in a controlled (ie, simulated) environment to quantify the stressors associated with the role is required.

It is well-known that exposure to threatening or excessively demanding situations can evoke a stress response that is characterized by changes to various biological and psychological systems [eg, hypothalamic-pituitary-adrenal (HPA) axis and cognition, respectively].[15] Acute stressors can be important for the preservation of life, whereas chronic exposure to stress can result in a myriad of mental (eg, depression)[16] and physical health issues (eg, heart disease).[17] Given that chronic stress exposure alters an individual's reactivity to subsequent acute stressors,[18] researchers are turning to controlled laboratory tests (eg, Trier Social Stress Test; TSST)[19] to better understand the acute stress response.[15]

Within the stress literature, there is vast support for examining acute stress responses in controlled laboratory environments.[15,20] Such investigations provide valuable insight into how acute stress reactivity is influenced by chronic psychosocial factors, while reducing or eliminating the influence of confounding factors.[20] However, these laboratory tests do not readily translate into specific contexts, such as high-risk occupational environments. Therefore, alternative tasks that assess context-specific skills in controlled environments similar to the aforementioned laboratory stress tests present as potentially meaningful research pursuits.

The use of simulators to facilitate skill acquisition and procedural training is a well-established practice in many occupations, including training aviation pilots,[21] nurses,[22] and mariners.[23] In these contexts, where stress is known to result in performance decrements,[24] simulator-training enables the monitoring and evaluation of role-specific skills and knowledge in a risk free environment; practicing without risk in alternative conditions that require different courses of action is a key strength.[25] For example, novice operators are known to experience greater stress responses than experts when performing a variety of surgical tasks.[26,27] Given the known risks associated with performing certain tasks in these industries (eg, active military service, surgery), it seems prudent to utilize simulated environments that replicate real-world tasks to quantify occupational stressors. A critical element in simulator research is fidelity. Low-fidelity simulators typically only replicate parts of the entire real-world situation,[28] whereas high-fidelity simulators accurately recreate all aspects of the real-world task and enable individuals to perform real-world skills in real time.[29] Within the maritime industry, high-fidelity simulation training presents as the best opportunity for pilots to gain valuable skills and experience in order to ensure the safe conduct of the vessel without risking other humans and the environment.[30] It remains unknown, however, whether these simulated environments elicit a stress response, similar to laboratory-based stress tasks. High-fidelity simulators should therefore be employed to investigate the impact of performing real-world tasks in simulated environments on the stress response.

From the Deakin University, Institute for Physical Activity and Nutrition (IPAN), Geelong, Victoria, Australia (Dr Main); NHMRC Centre of Research Excellence, School of Psychological Sciences, Monash University, Melbourne, Victoria, Australia (Dr Wolkow); and Australian College of Applied Psychology, School of Psychological Sciences, Melbourne, Victoria, Australia (Dr Chambers).

The authors have not reported any conflicts of interest.

Address correspondence to: Dr. Timothy P. Chambers, PhD, Australian College of Applied Psychology, School of Psychological Sciences, Level 10, 123 Lonsdale Street, Melbourne, 3000 VIC, Australia (tim.chambers@acap.edu.au).

DOI: 10.1097/JOM.0000000000001161

Assessing the effects of a laboratory-based acute stress task is best characterized by monitoring salivary cortisol,[31] with measures of heart rate (HR) variability and assessments of subjective mood effects ensuring accurate interpretation of HPA axis reactivity.[15] The combination of these measures amounts to a noninvasive and continuous assessment of known biomarkers of the stress response.[15] Adopting these procedural considerations will likely facilitate accurate observation of biopsychological responses to an acute stress test, such as witnessed with the TSST. What remains unknown is whether a maritime pilotage simulation task can elicit an acute stress response, as measured by these markers. The present study adopted a multidimensional framework using the outlined procedural considerations to determine whether a simulated maritime pilotage exercise could evoke an acute stress response. The aim of this study was to quantify whether performing simulated maritime pilotage tasks of varying complexity would evoke a physiological stress response. On the basis of the review of available research, it was hypothesized that

(1) Performing maritime tasks in a simulated environment would elicit an acute stress response;
(2) Compared with a simple simulated pilotage task, completing a complex simulated pilotage task would elicit a greater stress response;
(3) Compared with expert pilots, trainee pilots would experience a greater stress response, irrespective of task difficulty.

METHODS

Participants

Eight trainee (36.50 years $\pm$ 9.78; BMI $=$ 24.73 $\pm$ 4.74) and 13 experienced male maritime pilots (56.08 years $\pm$ SD $=$ 7.65; BMI $=$ 27.08 $\pm$ 4.00) participated in the study. Trainee pilots were enrolled in a pilot-training course and had no formal pilotage experience, compared with experienced pilots (22 years $\pm$ 7.97). Snowball sampling techniques were used to recruit participants; a research advert was sent to various industry contacts to recruit pilots. Ethical approval to conduct the study was obtained from the research institutions. Participation was voluntary with no incentive nor reward provided for taking part in the study. All participants were informed that all data collected would remain confidential and individual results would not be disseminated in the maritime industry.

Design

The current study adopted a 2 (experience: trainee vs expert) x 2 (condition: control vs experimental) design to quantify the stress associated with performing simulated pilotage tasks. Each pilot completed two 2-hour testing sessions 1 month apart. Each 2-hour testing session comprised of a 30-minute baseline period, a simulated pilotage task (a maximum of 30 minutes was permitted), and 60-minute recovery period. Due to restrictions in programming the two tasks, all participants completed the control simulation first, and then the experimental simulation.

Materials

NASA Task Load Index (NASA TLX)

The NASA TLX is a six-item self-report measure that assesses workload in the following dimensions: mental demand, physical demand, temporal demand, effort, performance, and frustration.[32] Three of the subscales (mental, physical, and temporal demands) relate to the demand imposed on the subject, whereas the other dimensions focus on the interaction of the subject with the task.[33] Responses are recorded on a 20-point scale (from 0 $=$ no effort to 20 $=$ maximum exertion). The test is reliable, with a Cronbach alpha coefficient more than 0.80 and has high concurrent validity.[34]

Heart Rate

Heart rate was recorded via a Polar RS400 (Polar Electro Oy, Kempele, Finland) wrist-watch as a measure of HR variability and physiological stress response. HR was sampled every 5 seconds across the 2-hour testing period, and later collapsed to 5-minute intervals (Polar Instruments, Polar S 810i). The sampling of HR at 5-second intervals is consistent practice.[35]

Salivary Cortisol

Salivary cortisol is a convenient and minimally invasive collection method that provides a valid and reliable measure of the bioactive cortisol in the body.[36] To prevent sample contamination from food debris or fluid intake, participants were not allowed to eat or drink 15 minutes before saliva collection. Salivary samples were collected via a cotton mouth swab (Salivette; Sarstedt, Nümbrecht, Germany) at eight 15-minute intervals during each testing sessions; three were collected during baseline (B30, B15, B0) and five samples were collected during recovery (P0, P15, P30, P45, P60). These collection times were deemed consistent with previous research that noted cortisol peaks approximately 20 to 40 minutes after a stressful task begins, before gradually returning to baseline.[37]

The samples were kept on ice until testing was completed and then centrifuged at 5000 rev/min for 5 minutes, and stored at -80°C. Levels of cortisol were analyzed using an enzyme-linked immunosorbent assay (ELISA; SLV-2930, DRG International, Inc., Hamburg, Germany). The assay was performed according to the manufacturer's directions and read at 450 nm on a luminescence microplate reader (Synergy™ 2 SL; BioTek, Winooski, VT). Analytical sensitivity (lower limit of detection) was 0.14 nmol/L.

Apparatus

Pilots completed two simulated navigation tasks in a high-fidelity maritime bridge simulator.[29] The simulator was equipped with real-world instrumentation that included RADAR, electronic chart display information system (ECDIS), geographical position, and mechanical telemetry, helm, engine controls, and thruster controls.

The Simulated Task

Pilots completed two simulated trials (control and experimental) in a novel port; the sole difference between the trials was the experimental manipulation of simulated weather. Consistent with previous maritime navigational research, a novel port was chosen to minimize variations in the degree of experience participants had with the environment.[38] The control task was conducted under fair weather conditions (eg, minimal wind, current, and tidal flow), whereas the experimental task was performed under severe weather conditions (eg, strong current, tidal flow, localized squall, and high wind speed). All other simulated variables (eg, location and movement of other vessels, berth locating) were constant across the two trials.

Manipulating the severity of the weather was deemed to reflect the real-world variability encountered by pilots, and the decision to do so was supported by evidence that suggested the transportation industry in general performs worse under adverse and severe weather conditions.[39] The selected course taken to complete the task was determined by the pilot (eg, based on their personal experience or preference), and took approximately 25 minutes to complete. Participants were provided with the necessary information (ie, the simulated weather observations, berth arrangements, port traffic, vessel, and navigational details) to devise a passage plan before the task. Participants were also instructed that they would be able to communicate with the local vessel traffic services (VTS),

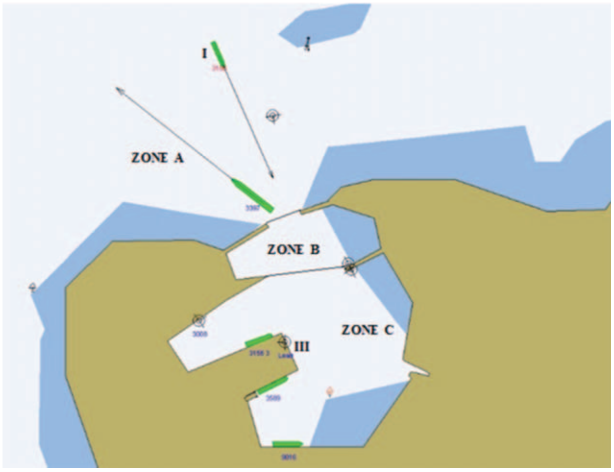

FIGURE 1. Display of simulated maritime pilotage task: The control condition.

and that there were two 40-tonne azimuth stern drive tugboats on standby if needed.

For the control task, the primary objective was to navigate the vessel (see Fig. 1, marker I) into the port and berth it at the designated location (see Fig. 1, marker III). As previously mentioned, participants completed the control task under fair weather conditions. The objective of the experimental task was identical to the control task. However, participants were informed of the variation to the weather, as provided in the pre-simulation information.

Task Performance Measures

To facilitate the analysis of physical and performance-related data, the task was divided into three zones: A, B, and C (see Fig. 1). In zone A, the pilot was required to engage in passage planning. This involves mentally calculating the vessel's course and selecting an appropriate approach to enter the port, taking into account the vessel's heading and speed. It was the pilot's responsibility to calculate the correct course based on the provided information and verbalize these instructions to the helmsman who was responsible for steering the vessel. Navigating through zone B required the pilot to maintain steady course of the vessel, while preparing to berth the vessel (eg, decrease speed). The main goal within zone C was the berthing of the vessel, which required the pilot to align the vessel with the pre-determined berth marker. To assess task performance, time to completion for each zone was calculated in seconds, as well as average vessel speed (in knots).

Procedure

Ethical approval to conduct the study was obtained from the researchers' educational institutions. Participants arrived at the simulation center at a self-nominated time. Upon arrival, participants read the information sheet and asked any questions about the study, after which point they attached the HR monitor. Participants then completed the paper-based questionnaires and familiarized themselves with the task information during the baseline phase. Participants then completed the first simulated task, followed by the 60-minute recovery phase during which pilots could complete any seated task of their choice (eg, paper work, reading). Following this 60-minute recovery period, the HR monitor was removed and pilots were debriefed. Pilots then returned 1 month later to complete the experimental simulated maritime task (severe weather condition). The same procedure described for the control task was applied when conducting the experimental task.

Analysis

All data were entered into a single SPSS V.22 spreadsheet for analysis (IBM, SPSS, New York). Nonparametric analyses were conducted on all performance and questionnaire data [Friedman two-way analysis of variance (ANOVA) by Ranks]. Before performing all analyses, the data were screened for any violations of assumptions of normality. Preliminary data screening revealed that the average HR data were non-normally distributed. Hence, a log transformation was performed on the variable before running further analyses.

RESULTS

Before establishing whether changes in task complexity or expertise influenced the stress response, an analysis of the control condition physiological data was performed. A repeated-measures ANOVA was performed to determine whether cortisol levels changed following the completion of the simulated task, with results indicating that cortisol levels changed between baseline and recovery periods for all participants [$F(7, 249) = 5.026$, $P = 0.000$, $\eta^2 = 0.139$]. A similar result was found for average HR [$F(7, 249) = 2.957$, $P = 0.006$, $\eta^2 = 0.087$], and peak HR [$F(7, 249) = 2.602$, $P = 0.013$, $\eta^2 = 0.077$] for all participants. Put simply, the cortisol and HR data suggested that performing simulated pilotage tasks evoked an acute stress response, irrespective of task complexity and experience.

To test whether varying task complexity affected the stress response, a series of repeated-measures ANOVAs were performed on the cortisol and HR data. The first analysis revealed no difference in cortisol between the control (M = 12.537, SD = 6.715) and experimental (M = 11.770, SD = 7.968) simulated conditions [$F(1, 249) = 0.284$, $P = 0.595$, $\eta^2 = 0.001$]. However, significant results were found between the control (M = 3.734, SD = 0.134) and experimental (M = 3.808, SD = 0.260) conditions for average HR [$F(1, 249) = 5.910$, $P = 0.016$, $\eta^2 = 0.026$]. Similar findings were also evident between the control (M = 3.867, SD = 0.135) and experimental (M = 3.934, SD = 0.252) conditions for peak HR [$F(1, 249) = 4.530$, $P = 0.034$, $\eta^2 = 0.020$]. In other words, there were no differences between the two conditions for cortisol, but differences were evident for average and peak HR, with HRs higher in the experimental condition.

To determine whether expertise influenced the acute stress response, another series of repeated-measures ANOVAs were performed on the cortisol and HR data. Similar to the previous results, there was no difference in cortisol between expert (M = 12.387, SD = 6.660) and trainee (M = 11.824, SD = 8.346) pilots [$F(1, 249) = 0.132$, $P = 0.717$, $\eta^2 = 0.001$]. Again, there was a difference between the expert (M = 3.801, SD = 0.224) and trainee (M = 3.714, SD = 0.159) pilots for average HR, [$F(1, 249) = 12.562$, $P = 0.000$, $\eta^2 = 0.054$], with novices recording elevated average HRs compared with experts. Likewise, there was a difference in peak HR between the expert (M = 3.919, SD = 0.223) and trainee (M = 3.865, SD = 0.153) pilots [$F(1, 249) = 4.978$, $P = 0.027$, $\eta^2 = 0.022$], meaning that trainee pilots experienced greater HR variability in both conditions.

A final series of analyses were performed to determine whether there was an interaction effect of condition and experience on the stress response, with results indicating that there were no interaction effects between condition (ie, control and experimental) and experience (ie, trainee and expert pilot) for cortisol [$F(1, 249) = 2.183$, $P = 0.141$, $\eta^2 = 0.010$]. Similar findings were yielded for average HR [$F(1, 249) = 2.836$, $P = 0.094$, $\eta^2 = 0.013$] and peak HR [$F(1, 249) = 2.961$, $P = 0.087$, $\eta^2 = 0.013$]. In other words, cortisol response, and average and peak HR did not vary between experts and trainees across the control and experimental conditions.

In addition to analyzing individual stress response, task performance data were also analyzed. Total time spent in each zone was calculated for all pilots on both trials. Shapiro Wilk nonparametric tests were performed to compare the control and experimental tasks. Results revealed that, compared with the control task, all pilots spent more time navigating the vessel in zones B ($Z = 2.551$, $P = 0.011$) and C ($Z = 3.059$, $P = 0.002$) in the experimental task. Corresponding results were found for vessel speed, where all pilots navigated at slower speeds in zones B ($Z = 1.961$, $P = 0.050$) and C ($Z = 1.961$, $P = 0.050$) in the experimental task. Combined, these results indicate that all pilots opted to perform the complex simulated pilotage task at slower speeds, which resulted in increasing the amount of time they spent in zones B and C.

Perceived task difficulty was measured using the NASA TLX. Results revealed that, compared with the control task, pilots reported that the experimental task evoked greater temporal demand ($Z = 2.251$, $P = 0.024$), and greater effort ($Z = 2.306$, $P = 0.021$). There were no significant differences between simulated tasks for mental and physical demand, or for performance and frustration. In sum, these results suggest that pilots felt more time-pressured in the complex simulated pilotage task, which also required more effort to complete.

DISCUSSION

The current study attempted to quantify whether performing simulated maritime pilotage tasks of varying complexity would elicit a stress response. As hypothesized, completing a simulated maritime pilotage task evoked an acute stress response, as demonstrated by increases in cortisol and HR. These physiological changes occurred irrespective of the task difficulty for all participants. Partial support was found for the independent influence of task complexity on an acute stress response; greater elevations in HR, but not cortisol, were recorded in the experimental condition. Similarly, partial support for the influence of expertise on acute stress response was observed; trainee pilots experienced greater elevations in HR, yet there was no difference in cortisol between the two groups. Furthermore, the self-reported perception of time pressure and effort indicated that severe weather condition was more challenging for all pilots. In sum, the study highlighted that undertaking maritime pilotage operations in a simulated environment evoked a stress response.

The physiological results in the present study demonstrated that both cortisol and HR significantly changed as a consequence of performing a simulated pilotage exercise. Irrespective of task complexity, all participants in the current study experienced substantial elevations in cortisol and HR, known indicators of the stress response,[36] after completing the simulated tasks. On the basis of these findings, it was apparent that performing maritime pilotage tasks in a high-fidelity simulator led to the activation of the physiological stress pathways. These reported elevations in cortisol and HR are consistent with those from other occupational contexts. For example, considerable evidence within the medical profession demonstrates that trainees experience both psychological[40] and physiological stress[41] when performing core occupational tasks (eg, resuscitation) in simulated environments. Specifically, trainee surgeons have reported experiencing increased physical and psychological stress following simulated laparoscopic surgery procedures.[41] The findings from the present investigation are also consistent with previous literature that demonstrated the presence of two or more stressors leads to increased stress.[19,42] In the case of the present study, participants were required to attend to multiple simulated stressors (eg, port vessel traffic, changing weather conditions) that resulted in a physiological stress response.

It was anticipated that the activation of the stress response would vary between the two conditions; that a greater stress response would occur following the experimental condition. Partial support for this prediction was obtained; only variations in HR were recorded, as there was no difference in cortisol between the two conditions. In order to manipulate task complexity, the researchers chose to vary a real-world factor (ie, weather), rather than create an unrealistic yet complex simulated task. Typically, it is easier to detect differences in simulated performance and subsequent stress response if one investigates extreme situations.[38] Doing so, however, runs the risk of minimizing the generalizability of findings. Accordingly, varying the weather across both tasks was anticipated as a naturally occurring event that pilots would experience in the real world. It is plausible that the tasks were similarly difficult for participants; perhaps the pilotage task itself was suitably challenging that variations in the weather offered minimal fluctuations in the associated stress of completing the simulated exercises. In order to see stress response activation that is more visible, greater distinction between the two tasks is perhaps required (eg, a simulated emergency procedure such as an engine failure). Variations within the team environment may also facilitate differences in the stress response. For example, variations in simulated surgical training environments led to more elevated stress responses of trainee surgeons; specifically, the presence of an experienced observer during the task resulted in more pronounced stress behaviors and elevations in HRs.[41] In other words, variations to the social milieu and not the task may lead to greater acute stress response activation.

A key finding from the present study was partial support for the influence of expertise on acute stress response; trainee pilots recorded higher average and peak HRs than experts. While perhaps not surprising, a possible explanation for this finding is that experts are likely to have acquired strategies to deal with various occupational demands during their extensive piloting careers. Within the aviation industry, similar findings have emerged from longitudinal analysis of pilots, which revealed that expertise was related to better simulated flight performance[43] and better in-flight decision making.[44] Accordingly, when experienced pilots are required to perform simulated maritime pilotage tasks of varying complexity, it is plausible that they are quicker to adapt to the task due to years of exposure to real-world stressful stimuli.

The differences in physiological responses between expert and trainee maritime pilots to the simulated exercises are consistent with findings in other occupational contexts. For instance, experienced physicians found it less difficult to deal with affective interruptions compared with trainees due to their enhanced ability to master the cognitive demands associated with surgical duties.[41] Experienced surgeons experienced a reduced stress response when performing a variety of procedures, compared with novices.[45] Support for differences in physiological stress response between experts and novices are also evident in the military. Expert marksmen recorded lower HRs and greater HR decelerations than novices, when simulating the execution of deadly force, indicating that experts experienced a reduced fight–flight response.[46] These findings highlight that the differences between expert and trainee pilots reported in the present study are consistent with those documented in related fields; experts seem to experience a reduced stress response when performing typical duties compared with trainees.

Performance data from the present study confirmed that executing the more complex task resulted in slower pilotage times, and the perception of greater temporal demand and frustration. Collectively, these findings suggest that all participants found the experimental task more challenging to perform, albeit not enough to elicit differences in physiological stress markers. That the present study found no difference between experts and trainee pilots for task performance is contrary to previous research. For example, experienced aviation pilots performed better that less experienced pilots on decision-making tasks.[44] Despite not demonstrating differences in task performance measures between trainee and expert pilots, the physiological data suggested that expert pilots were less stressed during the more complex simulated task.

Limitations

In attempting to explain the contrary findings, a number of explanations emerged from the study. First, it is conceivable that despite allowing 30 minutes to establish a true baseline, participants may have experienced an anticipatory response to the study such that HR and cortisol may have been slightly elevated before starting the baseline period. Second, operational constraints precluded the randomization of task type to the participants as previously stated. Accordingly, all participants completed the two tasks in the same order, which may have resulted in a practice effect. In executing the second (ie, experimental) task, experienced pilots may have relied upon their extensive knowledge of pilotage procedures, including completing the first simulated pilotage task, to better control the navigation of the vessel in the severe weather.

Third, despite utilizing a high-fidelity simulator that accurately modeled real-world ship handling, the actual pilotage tasks lacked real-world consequences. For example, a ship that runs aground in real life will have potentially catastrophic environmental and organizational consequences. In contrast, a simulated grounding may only result in the associated visual and verbal feedback (ie, image and sound), in addition to potentially acute psychosocial consequences (eg, embarrassment). Accordingly, the lack of real-world consequences may have affected task motivation, which was not measured in the current study. That the present study did not capture participants' level of commitment to performing the task may be a confounding factor that influenced the findings.

Despite the growing body of evidence related to simulator-based research, there still appears some contention in the literature regarding the artificiality of these environments. The present study utilized a high-fidelity simulator that was explicitly designed to replicate the real world. A recent investigation of driving in real and simulated environments reported considerable similarity in the structure of individual task workload responses for simulated and real-world driving.[47] Encouragingly, findings from the same study indicated that there was no significant difference for stress response between driving in a simulated environment, and driving in one's own vehicle.[47]

Implications of the Current Research

The simulated pilotage tasks described in the present investigation may be interpreted as acute stressors that evoked a momentary stress response in participants. Accordingly, findings from the present study provide a preliminary insight into the impact of simulated pilotage tasks on the stress response. While these findings represent a valuable contribution to the existing knowledge, an investigation of the impact of repeated acute stress exposure on pilot health and wellbeing is required. Specifically, given that pilots are responsible for navigating a multitude of vessels in a variety of environmental conditions, it remains unknown whether accumulated acutely stressful experiences have a negative impact on individual health and wellbeing. Perhaps a first step to better understanding these relationships would be to investigate repeated stress exposure within a simulated environment. Given that the current findings suggested that high-fidelity simulated environments evoked a stress response, exploring repeated exposure to simulated occupational tasks may be insightful.

CONCLUSION

Maritime pilots must learn to handle a myriad of vessels under a variety of environmental conditions in restricted and often sensitive waterways, all of which seemingly make the occupational role extremely stressful. The present investigation attempted to quantify the stress associated with performing these pilotage maneuvers in a simulated environment. Results revealed that the simulated tasks elicited a stress response in both trainee and experienced pilots. Yet, contrary to predictions, task difficulty and expertise did not independently impact upon the stress response. Task difficulty did however influence simulator performance, whereby all participants were slower to complete the severe weather task. This study makes a unique contribution to the existing research, as it is the first to quantify the stress associated with performing maritime pilotage tasks in a simulated environment. The findings serve as a platform for future investigations to examine the real-world impact of the maritime pilotage role; quantifying the stress associated with repeated piloting performance may reveal new insights into maritime incidents and accidents that occur in confined environments.

ACKNOWLEDGMENT

The authors wish to thank the Navitas Professional Institute Pty Ltd. for funding the research project and the Fremantle Maritime Simulation Centre for providing the venue and technical support to conduct the research.

REFERENCES

1. Reason J. Understanding adverse events: human factors. *Qual Health Care*. 1995;4:80–89.
2. Hancock PA, Desmond PA. *Stress, Workload, and Fatigue*. London: Lawrence Erlbaum Associates; 2001.
3. Raby M, Lee JD. Fatigue and workload in the maritime industry. In: Hancock PA, Desmond PA, editors. *Stress, Workload, and Fatigue: Human Factors in Transportation*. London: Lawrence Erlbaum Associates; 2001. p. 566–578.
4. Cockroft AN. Collisions at sea. *Saf Sea Int*. 1984;17–19.
5. Main LC, Chambers TP. Factors affecting maritime pilots' health and well-being: a systematic review. *Int Marit Health*. 2015;66:220–232.
6. Darbra RM, Crawford JFE, Haley CW, Morrison RJ. Safety culture and hazard risk perception of Australian and New Zealand maritime pilots. *Marine Policy*. 2007;31:736–745.
7. Cook T, Shipley P. Human factors studies of the working hours of UK ship's pilots 1: a field study of fatigue. *App Erg*. 1980;11:85–92.
8. Saarni H, Niemi L, Pentti J, Hartiala J, Kuusela A. Cardiac status and cardiovascular risk factors among Finnish sea pilots. *Int J Occup Med Env Health*. 1996;9:53–58.
9. Zorn EW, Harrington JM, Goethe H. Ischemic heart disease and work stress in West German sea pilots. *J Occup Med*. 1977;19:762–765.
10. Meere K, Van Damme J, Sprundel MV. Occupational injuries in Flemish pilots in Belgium: a questionnaire survey. *Int Marit Health*. 2005;56:67–77.
11. Scovill SM, Roberts TK, McCarty DJ. Health characteristics of inland waterway merchant marine captains and pilots. *Occup Med*. 2012;62: 638–641.
12. Ferguson SA, Lamond N, Kandelaaris K, Jay SM, Dawson D. The impact of short, irregular sleep opportunities at sea on the alertness of marine pilots working extended hours. *Chronobiol Int*. 2008;25:399–411.
13. Bureau of Infrastructure, Transport, Regional Economics. *Australian Maritime Activity to 2029-30*. Canberra: Commonwealth of Australia; 2010.
14. Fang I, Cheng F, Incecik A, Carnie P. *Global Marine Trends 2030*. London: Lloyd's Register, QinetiQ and University of Strathclyde; 2013.
15. Allen AP, Kennedy PJ, Cryan JF, Dinan TG, Clarke G. Biological and psychological markers of stress in humans: focus on the Trier Social Stress Test. *Neurosci Biobehav Rev*. 2014;38:94–124.
16. de Carvalho Tofoli SM, Von Werne Baes C, Martins CMS, Juruena M. Early life stress, HPA axis, and depression. *Psy Neuro*. 2011;4:229–234.
17. Maddock C, Pariante CM. How does stress affect you? An overview of stress, immunity, depression and disease. *Epidemiol Psychiatr Soc*. 2001;10: 153–162.
18. Chatkoff DK, Maier KJ, Klein C. Nonlinear associations between chronic stress and cardiovascular reactivity and recovery. *Int J Psychophysiol*. 2010;77:150–156.
19. Kirschbaum C, Pirke KM, Hellhammer DH. The "Trier Social Stress Test": a tool for investigating psychobiological stress responses in a laboratory setting. *Neuropsychobiology*. 1993;28:76–81.
20. Chida Y, Hamer M. Chronic psychosocial factors and acute physiological responses to laboratory-induced stress in healthy populations: a quantitative review of 30 years of investigations. *Psychol Bull*. 2008;134:829–885.
21. Hays RT, Jacobs JW, Prince C, Salas E. Requirements for future research in flight simulation training: guidance based on a meta-analytic review. *Int J Aviat Psychol*. 1992;2:143–158.

22. Cant R, Cooper SJ. Simulation-based learning in nurse education: systematic review. *J Adv Nurs*. 2009;66:3–15.

23. Chambers TP, Main LC. Symptoms of fatigue and coping strategies in maritime pilotage. *Int Marit Health*. 2015;66:43–48.

24. Arora S, Sevdalis N, Nestel D, Woloshynowych M, Darzi A, Kneebone R. The impact of stress on surgical performance: a systematic review of the literature. *Surgery*. 2010;147:318–330.

25. Carron P-N, Trueb L, Yersin B. High-fidelity simulation in the nonmedical domain: practices and potential transferable competencies for the medical field. *Adv Med Educ Pract*. 2011;2:149–155.

26. Berguer R, Smith WD, Chung YH. Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery. *Surg Endosc*. 2001;15:1204–1207.

27. Bohm B, Rotting N, Schwenk W, Grebe S, Mansmann U. A prospective randomized trial on heart rate variability of the surgical team during laparoscopic and conventional sigmoid resection. *Arch Surg*. 2001;136: 305–310.

28. Hockey GRJ, Healey A, Crawshaw M, Wastel DG, Sauer J. Cognitive demands of collision avoidance in simulated ship control. *Hum Fact*. 2003;45:252–262.

29. Chambers TP, Main R. The use of high-fidelity simulators for training maritime pilots. *J Ocean Tech*. 2016;11:117–131.

30. Baldauf M, Schröder-Hinrichs JU, Benedict K, Tuschling G. Simulation-based team training for maritime safety and security. *J Mar Res*. 2012;9: 3–10.

31. Foley P, Kirschbaum C. Human hypothalamus–pituitary–adrenal axis responses to acute psychosocial stress in laboratory settings. *Neurosci Biobehav Rev*. 2010;35:91–96.

32. Hart SG, Staveland LE. Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In: Hancock PA, Meshkati N, editors. *Human Mental Workload*. New York: Elsevier; 1998. p. 139–183.

33. Cao A, Chintamani KK, Pandya AK, Ellis RD. NASA TLX: software for assessing subjective mental workload. *Behav Res Meth*. 2009;41:113–117.

34. Rubio S, Díaz E, Martín J, Puente JM. Evaluation of subjective mental workload: a comparison of SWAT, NASA-TLX, and workload profile methods. *App Psychol Int Rev*. 2004;53:61–86.

35. Reinhardt T, Schmahl C, Wüst S, Bohus M. Salivary cortisol, heart rate, electrodermal activity and subjective stress responses to the Mannheim Multicomponent Stress Test (MMST). *Psych Res*. 2012;198:106–111.

36. Kirschbaum C, Hellhammer DH. Salivary cortisol in psychoneuroendocrine research: recent developments and applications. *Psychoneuroendology*. 1994;19:313–333.

37. Dickerson SS, Kemeny ME. Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research. *Psy Bull*. 2004;130:355–391.

38. Nilsson R, Gärling T, Lützhöft M. An experimental simulation study of advanced decision support system for ship navigation. *Trans Res Part F*. 2008;12:188–197.

39. Koetse MJ, Rietveld P. Adaptation to climate change in the transport sector. *Trans Rev*. 2012;32:267–286.

40. Hunziker S, Laschinger L, Portmann-Schwarz S, Semmer NK, Tschan F, Marsch S. Perceived stress and team performance during a simulated resuscitation. *Int Care Med*. 2011;37:1473–1479.

41. Andreatta PB, Hillard M, Krain LP. The impact of stress factors in simulation-based laparoscopic training. *Surgery*. 2010;147:631–639.

42. Van Gemmert AWA, Van Galen GP. Stress, neuromotor noise and human performance: a theoretical perspective. *J Exp Psychol Hum Percept Perform*. 1997;23:1299–1313.

43. Taylor JL, Kennedy Q, Noda A, Yesavage JA. Pilot age and expertise predict flight simulator performance: a 3-year longitudinal study. *Neurology*. 2007;68:648–654.

44. Schriver AT, Morrow DG, Wickens CD, Talleur DA. Expertise differences in attentional strategies related to pilot decision making. *Hum Fact*. 2008;50:864–878.

45. Arora S, Aggarwal R, Moran A, et al. Mental practice: effective stress management training for novice surgeons. *J Am Coll Surg*. 2010;212: 225–233.

46. Johnson RR, Stone BT, Miranda CM, et al. Identifying psychophysiological indices of expert vs. novice performance in deadly force judgment and decision making. *Front Human Neuro*. 2014;8:1–13.

47. Milleville-Pennel I, Charron C. Driving for real or on a fixed-base simulator: is it so different? An explorative study. *Presence*. 2015;24:74–91.

