Time Course of Simulator Sickness in Asian Military Pilots

Janine En Qi Loi; Magdalene Li Ling Lee; Benjamin Boon Chuan Tan; Brian See

INTRODUCTION: This study sought to determine the incidence, severity, and time-course of simulator sickness (SS) among Asian military pilots following flight simulator training.

METHODS: A survey was conducted on Republic of Singapore Air Force pilots undergoing simulator training. Each subject completed a questionnaire immediately after (0H), and at the 3-h (3H) and 6-h (6H) marks. The questionnaire included the simulator sickness questionnaire (SSQ) and a subjective scale to rate their confidence to fly.

RESULTS: In this study, 258 pilots with a median age of 31.50 yr (range, 21–55 yr) and mean age of 32.61 ± 6.56 yr participated. The prevalence of SS was 48.1% at 0H, 30.8% at 3H, and 16.4% at 6H. Based on a threshold of an SSQ score >10, the prevalence of operationally significant SS was 33.3% at 0H, 13.2% at 3H, and 8.1% at 6H. The most frequent symptoms were fatigue (38.1%), eye strain (29.0%), and "fullness of head" (19.9%). There was no significant difference in mean scores between rotary and fixed wing pilots. Older, more experienced pilots had greater scores at 0H, but this association did not persist. A correlation was found between SSQ score and self-reported confidence.

DISCUSSION: To our knowledge, this study is the first to report the prevalence of operationally significant SS in Asian military pilots over serial time points. Most pilots with SS are able to subjectively judge their fitness to fly. Sensitivity analysis suggests the true prevalence of SS symptoms at 3H and 6H to be closer to 23.8% and 12.0%, respectively.

KEYWORDS: motion sickness, flight simulator, simulator sickness questionnaire, SSQ, flight safety.

Loi JEQ, Lee MLL, Tan BBC, See B. *Time course of simulator sickness in Asian military pilots*. Aerosp Med Hum Perform. 2020; 91(11):892–896.

Simulator sickness (SS) is commonly defined as any form of discomfort resulting from the use of a simulator. It is a form of motion sickness and results from a mismatch between the simulated visual motion and the actual physical stimuli as sensed by the vestibular system.[4] Literature has long described potential operational problems that may result from the aftereffects of SS such as reduced training effectiveness, decreased simulator use, and safety implications.[4,9] In a study of 742 U.S. Army and U.S. Navy pilots on 11 different flight simulators (both fixed and rotary wing), approximately 45% of individuals experienced SS postsimulator training, with 25% of them reporting symptoms that persisted beyond 1 h and 8% having symptoms that lasted for more than 6 h.[2] The highest incidence of SS was found in a U.S. Air Force air-to-air combat simulator, in which 88% of pilots experienced one or more SS symptoms.[7]

Singapore's Air Navigation Regulations' stipulation of a minimum rest period prior to a scheduled flight duty period has the effect of imposing postflight simulator restrictions on flying duties.[1] Similarly, the Republic of Singapore Air Force (RSAF) has adopted a long-standing precautionary approach by placing flying restrictions postsimulator training to mitigate the potential flight safety risk posed by SS. With advancements in flight simulator technology and better synchronization of visual displays and motion, it is plausible that the higher fidelity of newer generation flight simulators may reduce sensory mismatch between visual and proprioceptive cues, with a concomitant decrease in the incidence of SS. Conversely, a more immersive visual environment on nonmotion-based simulators could result in a higher prevalence and severity of SS symptoms. As such, we sought to determine the incidence, severity, and

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This manuscript was received for review in May 2020. It was accepted for publication in August 2020.

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DOI: https://doi.org/10.3357/AMHP.5674.2020

time-course of SS among RSAF pilots undergoing flight simulator training across both motion- and nonmotion-based simulators, as well as elucidate any associations of SS with the pilots' demographic and operational experience characteristics.

METHODS

Subjects

All pilots who underwent simulator training on RSAF flight simulators from May to July 2019 were invited to participate in the study. The study was approved by the Singapore Armed Forces (SAF) Joint Medical Committee (Research) and was exempted from review by the DSO-SAF Institutional Review Board (reference number: 0008/2019).

Materials

The survey questionnaire included fields for demographic and operational variables (age, flying hours, and platform type), as well as the 16-question simulator sickness questionnaire (SSQ) developed by Kennedy et al.[6] For the SSQ questions, subjects were required to rate the severity of each of the 16 symptoms queried on a 0–3 point scale, with 0 being "none" to 3 being "severe." A 17th question was included to assess the subject's confidence, at the point of survey administration, in operating an aircraft on a 6-point Likert scale that ranged from "extremely unconfident" to "extremely confident."

Procedure

Each subject underwent their platform-specific simulator tasks as per usual training procedure, and was requested to complete an online survey questionnaire immediately after the simulator session (0H), as well as at the 3-h (3H) and at the 6-h (6H) marks postcompletion of the simulator session. Structured instructions were provided to all simulator instructors to ensure consistency in the delivery of the instructions during the post-simulator debrief.

Statistical Analysis

The SSQ score of each subject was calculated based on the scoring methodology described by Kennedy et al.[6] and charted to derive an aggregate trend of the incidence, severity, and time-course of SS aftereffects over time. Operationally significant SS was defined as an SSQ score of $>$10 based on the categorization of SS severity proposed in a previous study of self-reported symptoms from over 1600 exposures to 10 U.S. Navy flight simulators.[5]

Secondary analysis by age, flying hours, and aircraft platform type was performed to determine if any of these demographic or operational experience factors were associated with an increased or reduced incidence and persistence of SS postsimulator training. Finally, bivariate (Pearson) analysis was performed to elucidate any correlation between reported subjective confidence in operating an aircraft and the SSQ score. Data were analyzed with descriptive statistics and confirmatory data analysis using SPSS Statistics version 25 (IBM, Armonk, NY, USA).

RESULTS

A total of 258 subjects participated in the study. The median age was 31.50 yr (range, 21–55 yr) and the mean age was 32.61 ± 6.56 yr. All subjects were of Asian ethnicity. There were 109 (42.4%) subjects who flew motion-based simulators [AH-64D: 5 degrees-of-freedom (DOF); AS332: 6 DOF; S-70B: 6 DOF] and 149 (57.6%) who flew nonmotion-based simulators [F-16 Operational Flight Trainer (OFT), F-16 Air Mission Trainer (AMT), F-15SG OFT, F-15SG AMT]. There were 231 (89.5%) subjects who logged their symptoms at 0H and 103 (40.8%) who logged their symptoms at all 3 time points of 0H, 3H, and 6H, and had complete time-course datasets. A total of 27 (10.4%) subjects logged their symptoms retrospectively at 3H and/or 6H.

Based on entries logged at the specific time points, cross-sectional analysis found that 48.1% (of 231 subjects) reported at least 1 SS symptom at 0H. This decreased to 30.8% (of 159 subjects) at 3H and 16.4% (of 134 subjects) at 6H. Of the subjects, 33.3% experienced significant SS at 0H, 13.2% experienced significant SS at 3H, and 8.1% experienced significant SS at 6H (**Fig. 1**). Based on the 103 complete time-course datasets, the mean within-subject reduction in SSQ score from 0H to 3H was 8.4 and from 3H to 6H was 1.6.

To manage the missing data from nonresponse at 3H and 6H, the McNemar test was applied on the subset of subjects who logged their symptoms at all 3 time points (i.e., the 103 subjects with complete time-course datasets) and reported no SS symptoms at 0H ($N = 57$). This found that the proportion of subjects without SS symptoms at 0H was not statistically different from that at 3H ($P = 0.13$) and 6H ($P = 0.25$). As this suggested that subjects with no SS symptoms at 0H were unlikely to subsequently report symptoms at a later time point, sensitivity analysis was performed by extrapolating the data for subjects who reported no symptoms at 0H and did not respond at 3H (47 subjects) to the second time point. This found the adjusted prevalence of SS symptoms at 3H to be 23.8%, with 10.2% being operationally significant SS. The same data treatment was performed for subjects who reported no symptoms at 0H and/or 3H and did not respond at 6H (57 subjects), which revealed the adjusted prevalence of SS symptoms at 6H to be 12.0%, with 5.8% having SS of operational significance (Fig. 1). Similar to

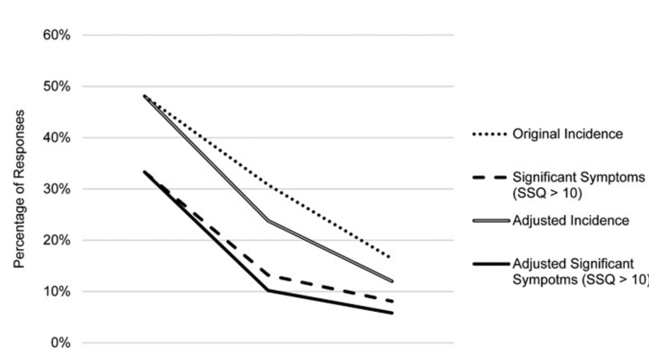

Fig. 1. SS symptomology at 0H, 3H, and 6H.

the pattern of symptom decay among the complete time-course datasets, a greater proportionate reduction in subjects with operationally significant SS symptoms was observed from 0H to 3H (23.1% reduction), compared to from 3H to 6H (4.4% reduction).

Across the three time points, fatigue (38.1%), eye strain (29.0%), and "fullness of head" (19.9%) were the most frequently reported SS symptoms. Overall, subjects reported significantly more ocular [mean = 9.44; $t(523) = 9.55$, $P = 0.00$] and disorientation [mean = 8.72; $t(523) = 5.26$, $P = 0.00$] symptoms than nausea (mean = 5.07) symptoms (see **Fig. 2A**).

Stratified analysis by simulator type found no significant difference in the incidence of SS at 0H between subjects who flew on motion-based simulators and those who flew on nonmotion-based simulators [$\chi^2(1, N = 231) = 3.44$, $P = 0.06$]. The difference between the mean SSQ score at 0H for subjects who underwent motion-based simulators (mean = 13.84) and for those who flew nonmotion-based simulators (mean = 12.17) was also statistically insignificant [$t(230) = -0.43$, $P = 0.67$]. Moreover, the pattern of symptomology in both motion- and nonmotion-based simulators at 0H was similar to the overall trend, in that subjects in both conditions reported more ocular and disorientation symptoms than nausea symptoms (**Fig. 2B**).

Secondary analysis showed a very strong positive correlation between flying hours and age [$r(522) = 0.80$, $P = 0.00$] and a weak positive correlation between flying hours and SSQ at 0H [$r(229) = 0.23$, $P = 0.03$] (**Fig. 3A**). While the older and more experienced subjects generally reported greater SSQ scores at 0H, this association with age and experience disappeared at 3H [$r(157) = -0.10$, $P = 0.42$] and 6H [$r(132) = 0.00$, $P = 0.99$].

A clear negative correlation [$r(522) = -0.67$, $P = 0.00$] between SSQ score and self-reported confidence of operating an aircraft safely was found based on the best-fit line drawn on a scatter-plot of the two variables (**Fig. 3B**). Subjects ($N = 7$) who rated themselves as extremely unconfident tended to report greater intensity of disorientation-related symptoms (mean = 131.25) compared to nausea [mean = 51.79; $t(6) = 3.29$, $P = 0.02$] or ocular [mean = 85.55; $t(6) = 1.71$, $P = 0.14$] symptoms (**Fig. 4**).

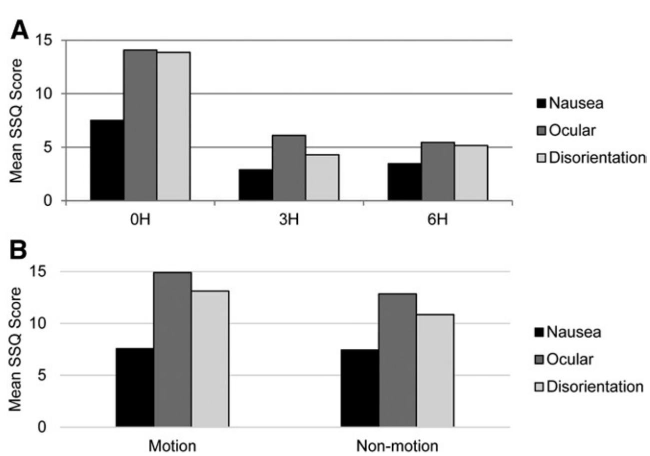

Fig. 2. A.) SS symptomology by symptom clusters at 0H, 3H, and 6H. B.) SS symptomology by simulator type at 0H.

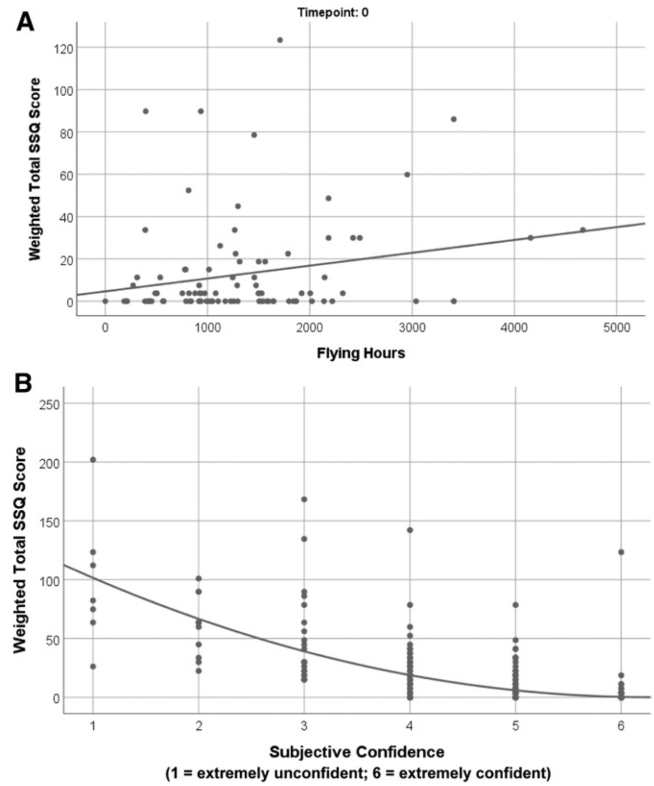

Fig. 3. A.) Scatter-plot distribution of SSQ scores by flying hours at 0H ($r = 0.22$). B.) Scatter-plot distribution of total SSQ score by self-reported confidence ($r = -0.67$).

DISCUSSION

The aim of this study was to determine the incidence, severity, and time course of simulator sickness in RSAF pilots and its potential association with demographic and operational variables. The overall incidence of SS among respondent pilots at 0H of 48.1% largely mirrors the 45% previously reported by Baltzley et al.[2] Notwithstanding, this quantification of the severity of SS symptoms using the SSQ score in this study has allowed us to additionally determine the prevalence of operationally significant SS at serial time points postsimulator exposure. These were found to be 33.3% at 0H, 13.2% at 3H, and 8.1% at 6H based on the lower SSQ threshold of 10 for operationally significant SS proposed by Kennedy et al.[5]

Previous studies have found that more experienced pilots reported increased incidence and severity of SS symptoms than

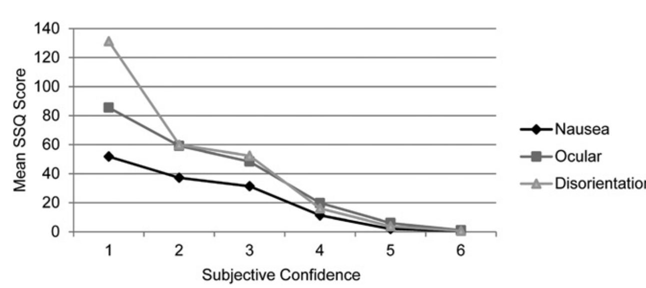

Fig. 4. SS symptomology by subjective confidence in operating an aircraft.

student pilots,[3,12] with another reporting that a greater proportion of experienced aviators (more than 1500 flying hours, 27%) had SS symptoms compared to their less experienced counterparts (18%).[10] This is supported by the theory that the higher incidence and severity of SS in experienced pilots was due to their experiences leading them to have a greater expectation of physical movement with a particular maneuver. Our study similarly found that more experienced pilots had higher SSQ scores compared to less experienced pilots.

A particular strength of this study is the availability of 103 complete time-course datasets for all 3 time points, which allowed us to investigate the within-individual change in SSQ scores with time. Of note, there was a rapid reduction in mean SSQ score of 8.4 in the initial 3 h, from 0H to 3H. The absolute decrease in mean SSQ score subsequently tapered down to 1.6 in the next 3 h, from 3H to 6H. This empirical finding is in keeping with the findings of a previous study of 742 exposures, which similarly found that 75% of those who reported aftereffects said their symptoms disappeared within 1 h.[2]

Although a minority of subjects still reported SS symptoms after 3–6 h, our finding that those with higher SSQ scores generally reported being less confident of operating an aircraft safely suggests that most pilots will be able to judge their fitness to fly based on their subjective physiological cues. This provides a level of assurance that the individuals with persistent SS symptoms would be self-aware of their condition and acts as a safeguard in circumstances where there are no specified postsimulator exposure flying restrictions. As a corollary, the clear negative correlation between SSQ score and self-reported confidence of operating an aircraft safely also suggests that the SSQ score provides a useful indication of an individual's overall subjective sensation of SS severity.

Consistent with previous research on the effects of motion in flight simulators,[11] we did not find a significant difference in the incidence of SS symptoms between pilots who underwent motion- vis-à-vis nonmotion-based simulator training. There was also no significant difference in the distribution of symptomology between the two simulator types. We postulate that the difference in sensory conflict between the motion- and nonmotion-based simulators was not large enough to affect the experience of simulator sickness.

The most common SS category reported in the literature was nausea (51%), followed by disorientation (28%) and ocular symptoms (2%).[2] In contrast, our study population reported more ocular and disorientation symptoms, rather than nausea-related symptoms. We attribute this to a form of 'healthy worker effect,'[8] with the typical RSAF pilot less predisposed to encountering nausea-related symptoms from flight simulator exposure as those with a greater propensity for developing nausea would have been screened out at an early stage of their pilot training.

This study had a number of limitations. First, in order to encourage a high response rate, other measures that may influence susceptibility to SS (e.g., motion sickness history, amount of sleep the night before, duration of training session) were omitted so as to streamline the survey questionnaire. As such, we were unable to determine if fatigue (the most commonly reported SS symptom) was an outcome of SS or sleep loss and/or training duration. Additionally, as the study was broadcasted as an investigation into SS symptoms postsimulator training, we suspect there was a voluntary attrition of responses by pilots who felt that they had nothing to report at the 3H and 6H time points. It is therefore likely that the true prevalence of SS symptoms at 3H and 6H were lower than the crude prevalence derived from the responses of pilots who completed the questionnaire at these time points, and closer to the adjusted prevalence of 23.8% and 12.0%, respectively, based on sensitivity analysis.

As far as we are aware, this study is the first to chart the prevalence of operationally significant (i.e., SSQ $>$10) SS in Asian pilots over serial time points, viz. 33.3% at 0H, 13.2% at 3H, and 8.1% at 6H. Parallel to the decline in the aggregate incidence of operationally significant SS, the complete time-course datasets from the 103 subjects revealed a rapid reduction in mean SSQ score within the first 3 h postsimulator exposure. For the few individuals with persistent symptoms, our study supports the position that most pilots with operationally significant SS will be able to judge their fitness to fly based on their subjective physiological cues.

ACKNOWLEDGMENTS

Approval granted by the RSAF Medical Service for the authors to conduct this study is gratefully acknowledged. The opinions expressed in this paper are that of the authors, and may not reflect the official policy or position of the RSAF Medical Service, the RSAF, the Singapore Armed Forces, or the Ministry of Defence, Singapore.

Financial Disclosure Statement: The authors have no competing interests to declare.

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