Pol J Aviat Med Bioeng Psychol 2021; 27(2): 5-18
DOI: 10.13174/pjambp.22.04.2024.01

ORIGINAL ARTICLE

HOW DOES MENTAL DISTRACTION INDUCED BY AN ADDITIONAL TASK AFFECT THE SEVERITY OF SIMULATOR SICKNESS SYMPTOMS IN PILOTS: A SPATIAL DISORIENTATION SIMULATOR STUDY

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Source of support: This study was supported by a grant from the Polish National Science Centre (NCN UMO 2013/09/B/HS6/03266).

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Introduction: To improve the effectiveness of spatial disorientation (SD) training in a flight simulator, pilots are recommended to perform an additional task that induces a mental distraction. The presented study explored how the inclusion of an additional task that may enhance the effectiveness of SD training changes the severity of simulator sickness symptoms reported after exposure in the Gyro-IPT simulator.

Methods: We compared the incidence of simulator sickness symptoms in pilots across four setups of flight scenarios (varying according to cognitive load distraction) collected during our previous studies. A total of 77 male military pilots (age 28.3±6.2) with flight experience (810.72 ±969.43 hours) were randomly assigned to one of four groups and then exposed to a 60-min long flight session (12 flight profiles, six involved an SD-conflict) with active control in the Gyro IPT simulator. In addition to the primary flying task, in three flight scenarios, pilots were asked to perform an additional visual (a change detection flicker task [CDFT]), auditory (an auditory N-back task [NBT]), or duration-discrimination task (DDT)). To measure simulator sickness symptoms, the Simulator Sickness Questionnaire (SSQ) was administered pre- and post-simulator exposure.

Results: The severity of simulator sickness symptoms due to visual and motion cues did not significantly change when the pilot performed a non-sickening cognitive task (additional visual or auditory task). The total SSQ score and scores for nausea, oculomotor disturbance, and disorientation in the CDFT and DDT were slightly higher than in the

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control condition (flight without additional task). Despite the observed differences, according to the SSQ scoring criteria, the simulator sickness symptoms reported by the pilots were negligible.

Conclusions: The additional tasks (CDFT, auditory NBT, or DDT) applied to improve the effectiveness of SD training in the Gyro-IPT simulator do not significantly change unwanted effects, such as simulator sickness.

Keywords: simulator sickness, motion sickness, flight simulator, spatial disorientation, expertise, cognitive load

INTRODUCTION

The concern of simulator sickness, a syndrome that is a side effect during and after exposure in a simulator (e.g. flight simulator) and which does not happen in real flight, has been quite deeply studied [3,23,38,56,60,65]. Simulator sickness is still an unsolved problem and affects almost every participant in the simulation [23,41]. It can confound research measurements [32], negatively influence the effectiveness of training [22], and may contribute to the interruption of the task performed in the simulator [10,22]. In the aviation domain, exposure in a flight simulator may also cause temporary flying restrictions [21], mainly due to the strong stimulation of the vestibular system [31,39].

A strategy for mitigating symptoms of simulator sickness

As simulator sickness is a syndrome characterised by symptoms quite similar to those of motion sickness (i.e. malaise, sweating, headache, dizziness, nausea, and vomiting) [26], the names of these sickness will be treated as synonyms in this article. To treat simulator sickness, a special desensitisation program (reduction in simulator/motion sickness susceptibility by repeated or/and prolonged expositions to stimuli) [16,50,53] or anti-motion sickness medicines (e.g. scopolamine) [8,67] are routinely used; however, such a desensitization program may not be effective for every pilot, nor are anti-motion sickness drugs, which are not used among military pilots due to their unwanted side effects (drowsiness, apathy resulting in attention impairment) [51].

In addition to the above-mentioned attempt to prevent simulator sickness, there are several studies where simulator sickness due to motion was reduced by the use of an additional stimulus [6,13,14,45], performing an additional task (cognitive and biofeedback methods) i.e., visuospatial training [54], or by inducing various multisensory conditions [28]. The results of numerous studies have shown that motion sickness can be mitigated by the use of specific distractors. Strayer et al. [57] classified sources of distraction, which were subsequently rearranged [25] as mechanical, physiological, cognitive, and emotional. The psychophysiological model describing how these sources of distraction can modulate the emergence of motion sickness in the context of sensory conflicts is illustrated in Fig. 1. This model was developed based on the physiological model in Benson [2] and Kaufeld et al. [25].

Mechanical or electrical source of distraction

A mechanical or electrical source of distraction is used for down-weighting the visual-vestibular conflict (Fig. 1). This distraction can be implemented by adding noise to the vestibular afferences or tactile stimulus [25]. Bos [6] found that sickness due to low-frequency motion can be reduced by adding a high-frequency vibration (inherent non-sickening vibration). The results of other studies [13] showed that the exposure of airflow significantly reduced visually-induced motion sickness, whereas the presence of seat vibration did not have an impact on it. Based on the sensory conflict theory, Kaufeld et al. [25] demonstrated how chewing gum could modulate the occurrence of visually-induced motion sickness. Another way of disturbing the functioning of the vestibular system by physiological modulation of its response is the use of Galvanic Vestibular Stimulation (GVS) [7,15] (described in more detail in the physiological factor subsection).

Attention shift

Although there is also counter-evidence of the positive effect of mental distraction (occurs when ones attention is removed from the processing of certain information [57]) on the reduction of motion sickness [66], recent studies [25,68] still confirm that motion sickness is less common in people who have focused their attention on an additional activity, or when their attention is directed toward external events [6]. This activity or distrac-

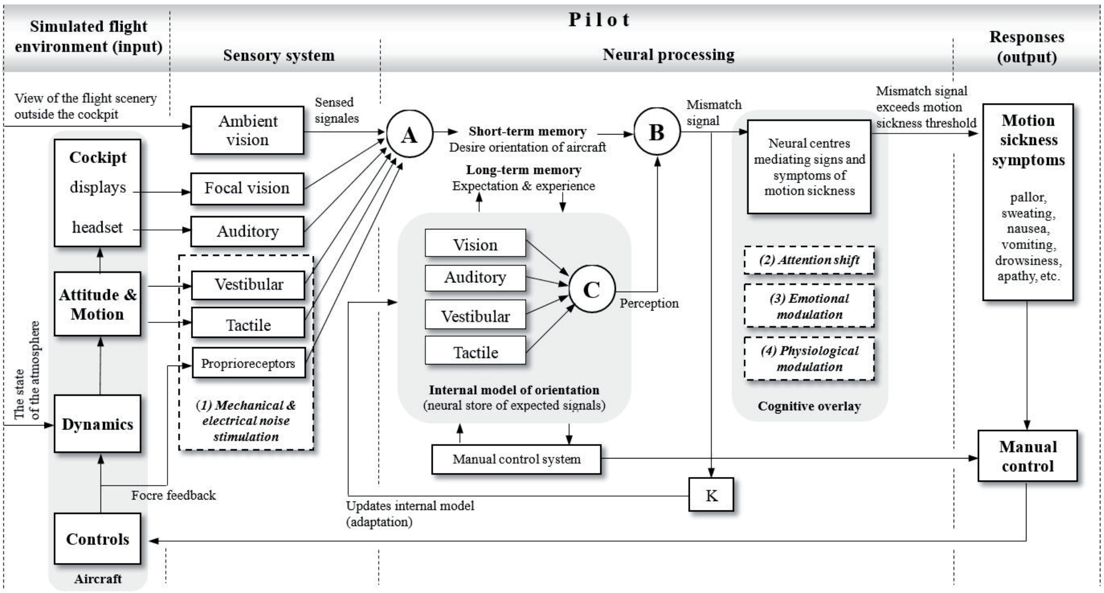

Fig. 1. A schematic representation of the psychophysiological model of the mitigation of motion sickness by the use of specific distractors (mechanical, physiological, cognitive, and emotional).

A, C represent summing block, B represents the comparator of input signals, and K stands for gain. Blocks with a dotted line represent individual sources of distraction: (1) mechanical and electrical noise stimulation, (2) attention shift, (3) emotional modulation, (4) physiological modulation.

tion may be involved in the second task, which diverts attention (attention shift) away from the provocative stimuli [6]. However, not every type of distractor can mitigate the sickness symptoms, e.g. when subjects were asked to concentrate on an imposed motion, their symptoms of the sickness tended to increase [11].

Physiological factor

A physiological factor is mainly based on creating a sensory conflict in order to provoke and activate the adaptation mechanism. Smyth et al. [54] revealed that motion sickness can be reduced through visuospatial training, which involves a person manipulating 3D objects in their imagination. The finding, that males tend to have better visuospatial skills [52] and that they suffer less from motion sickness than females [17], suggests that visuospatial training in the latter group may contribute to reducing the susceptibility of females to this sickness. Another group of researchers [40,59] showed that, under certain conditions, an optokinetic stimulation may also be promising in the treatment of motion sickness.

To reduce the visual-vestibular conflict responsible for causing motion sickness, a galvanic vestibular stimulation is also used [12,20,49,63,64]. In this method, galvanic signals from electrodes placed close to the mastoid vestibular afferents are modified. It was demonstrated that this physiological modulation of the vestibular system activity in synchronicity with visual stimulation in a flight simulator may reduce the incidence and severity of sickness symptoms [7].

Emotional modulation

Other studies have found that music distracted the participants from their cyber sickness (visually-induced motion sickness), reducing its severity by listening to their favourite [45] or pleasant [30] music. In addition to the music, pleasant odours and airflow may reduce visually-induced motion sickness [13,29,46]. Kaufeld et al. [25] also showed that emotional modulation by pleasant distractors may explain the genesis of visually-induced motion sickness. This is likely to be due to the fact that pleasant stimuli evoke a pleasant emotional state, which diverts the subjects' attention from nausea-inducing stimuli to the more pleasant stimuli.

In addition to the above-mentioned sources of distraction (mechanical, physiological, cognitive, and emotional), according to the model (Fig. 1), the comparator (B) generates a mismatch signal not only when one sensory input conflicts with another, but also when the congruent sensory input does not match the expected sensory input based on previous experience [2,42,43,47,48].

An incidence of simulator sickness in a spatial disorientation simulator

A spatial disorientation (SD) simulator is used in ground-based flight training for military pilots to demonstrate the phenomena of the loss of spatial orientation that may occur in flight [9]. In such a simulator, pilots also learn how to counteract the effects of sensory mismatch during flight. This sensory conflict, which is mainly due to the incongruence of visual and motion cues [24,44], may induce simulator sickness. On the other hand, the strength of this sensory conflict largely determines whether an illusion-related SD can be induced in such a simulator, and how SD training can be effective.

To effectively trigger SD events, NATO's SD Working Group recommends multi-task and high-workload flight simulations with scenarios such as cockpit distraction [5]. This type of approach has been applied in our previous studies [1,19,58], in which pilots experienced additional cognitive load (induced by visual or sound stimuli) when flying an aircraft in the Gyro-IPT SD simulator. Given that our previous studies did not identify a possible effect of additional stimuli on the severity of simulator sickness symptoms (we only tested the influence of exposition in the simulator on simulator sickness incidence to ensure that participants did not feel sick during and after the experiment), whether the additional tasks performed by the pilots could contribute to reducing or increasing the severity of sickness symptoms is of interest. We compared these effects to the incidence of simulator sickness symptoms in pilots across four setups of flight scenarios (varying according to an additional cognitive task) collected during our previous studies [1,19,58]. Each of the additional tasks involved the engagement of a higher level of processing (reaction with a choice), and therefore, their possible impact on motion sickness should be considered in terms of the source of mental distraction - shifting attention (induced by a visual or auditory stimulus).

The aim of the study

The study explored whether including an additional task that can increase pilots' susceptibility to SD and may improve the effectiveness of SD training changes the severity of simulator sickness symptoms reported after exposure in the Gyro-IPT simulator. It should be noted that we did not intend to investigate how applied distractions (additional cognitive task) are a potential countermeasure to simulator sickness, as other researchers have done [28]. In our study, we incorporated distraction built into an additional task as a method of increasing SD susceptibility and the effectiveness of SD training only.

To address the above-mentioned research issue, we compared the results of our previous studies [19,58], including flight scenarios with additional visual or auditory task-induced cognitive load, with the study having the same flight scenarios [1], in which the pilot did not perform an additional task (control study). The additional cognitive load was imposed by one of three tasks. The first task was a change detection flicker task (CDFT) [19] based on a measurement of a subject's response to visual stimuli. The second task was an auditory N-back task (NBT) involving sound stimuli (the sequential letter memory task), and the third concerns a duration-discrimination task (DDT) in which the subjects had to respond to the sound stimuli (tones) [58]. In these experiments, we used multi-task and high-workload flight simulation with a cockpit distraction (induced by CDFT, NBT, or DDT) while flying in a degraded visual environment. In the aviation domain, these tasks mainly refer to visual and auditory activity. The impact of simulator-induced cues (visual and motion) and the additional cognitive task on simulator sickness incidence was measured by the Simulator Sickness Questionnaire (SSQ) [4].

We did this research as part of other studies [1,19,58] that investigated the overall effects of SD events on flight performance and instrument scanning [1], an attentive blank stare [19], and the cognitive performance [58] in military pilots while they were piloting a flight simulator.

METHODS

The study design

The between-group study design consisted of four experiments (which we have previously conducted [1,19,58]) in which a different group of participants performed flying tasks in an SD simulator. Experiment 1 [1] was set in the presented study as a control (baseline) test that consisted of carrying out manoeuvres with the maintenance of flight parameters according to the flying instructions given in defined, standard flight scenarios. The rest of the experiments aimed to explore how the severity of simulator sickness symptoms changes when the participant next to the flying task (Exp. 1) simultaneously performed an additional cognitive task that induces mental distraction.

In these experiments, the same flight scenarios were used as in Exp. 1 and additionally included one of the following cognitive tasks: a CDFT in

Tab. 1. Characteristics of the study group/sample.

Experiment No.	**Participants (pilots)**			
	Number	**Age** (M ±SD years)	**Flight experience** (M ±SD total flight hours)	**Source of data** (reference)
1	20	31.6 ±8.2	1300.2 ±1167.4	[1]
2	21	23.2 ±1.2	116.8 ±60.9	[19]
3	16	26.3 ±8.8	855.1 ±1817.2	[58]
4	20	32.3 ±6.6	970.7 ±832.1	[58]
Total	77	28.3 ±6.2	810.7 ±969.4	

Note: Values represent mean (M) and standard deviation (SD).

which the participants had to response to visual stimulus changes from behind the cockpit (Exp. 2 [19]), an NBT involving sound stimuli (the sequential letter memory task) (Exp. 3 [58]), or a DDT in which the participants had to respond to the sound stimuli (tones) (Exp. 4 [58]). According to the NATO's SD Working Group [5], multi-task and high-workload flight simulations with scenarios such as cockpit distraction (like those designed in the Exp. 2–4) are recommended for effectively-triggering SD events.

Participants

Overall, the 77 volunteers were recruited in our previous studies [1,19,58] to perform flight-simulator experiments. The inclusion criteria was healthy, active-flying male pilot (fixed-wing aircraft) between the age of 20 to 55 years, normal or corrected-to-normal vision, and no history of neurological disorders, especially any negative clinical history of vestibular symptoms e.g., dizziness and vertigo. Characteristics of the study sample (age and flight experience) in each of the four experiments is presented in Table 1. All pilots were male with no experience of exposure to simulator-induced SD. They were Polish military aviators actively flying fixed-wing military aircrafts (M-28M, CASA C-295M, TS-11, MiG-29, Su-22, F-16, M-346 Master, and PZL-130).

The protocol study was approved by the Ethical Committee of the Institute of Psychology at the John Paul II Catholic University of Lublin, Poland, and an informed consent form was completed by each participant prior to the experiment.

Stimuli and apparatus

Flight simulator

The Gyro-IPT simulator (Environmental Tectonics Corporation, Inc., Southampton, US) was used to generate flight scenarios and to trigger SD events. This simulator generates illusions that are usually the result of a sensory conflict (usually visual-vestibular), which is the main factor responsible for inducing motion sickness (known as air sickness in an actual flight). The simulator is equipped with 3-degrees of freedom (roll ±30°, pitch ±15°, and yaw 360°), with a one-channel, non-collimated out-the-window (OTW) visual display (with ~40° horizontally by ~28° vertically total field-of-view). More technical details about this simulator was given in the paper [34].

Stimuli

As described in our previous studies [1,19,58], the set visual, vestibular, and auditory cues were included in 12 flight scenarios. The flight profiles were comprised of the following manoeuvres in a fixed-wing aircraft with six visual and vestibular-origin illusions: a day-time false-horizon illusion (caused by a sloping cloud deck) included in the straight and level flight (S&LF) profile, a constant shape illusion (caused by an up-sloping runway) implemented in a circle-to-land procedure (C-T-LP) at night-time, a constant size illusion (caused by a narrower-than-usual runway) included in a straight-in approach (S-IA) profile at night-time, a somatogyral illusion (caused by erroneous perception of the strength and direction of actual rotation – the false sensation or lack of rotational motion) induced in a straight and level flight after left turn (S&LFALT) at daytime, a Coriolis illusion (created by cross-coupled stimulation of semi-circular canals when there is a change of head during rotational motion) induced in a right banked turn (RBT) at daytime, and a Leans illusion (caused by the limited sensitivity of vestibular organs) induced in a straight and level flight after right turn (S&LFART) at night-time.

Each flight profile was presented in two conditions, the disorientation condition (conflict flight), in which visual or vestibular disorientation cues were present, and the control condition (non-conflict flight), in which these specific disorientation cues were absent. The remaining parts of the flight profiles were kept the same for the control and disorientation conditions. All the participants flew the same profiles (a total of 12 flight profiles).

Detailed descriptions of the applied flight profiles, including the specifications of stimuli and flight instrument manipulation, is presented in our earlier paper [34].

In our previous studies [1,19,58], the simulator-induced stimuli (described above) were combined with additional visual, motion, and auditory task-induced cognitive load in four experiments. **Experiment 1** (Exp. 1) consisted of the set stimuli included in the above-defined 12 flight scenarios (more details about these flight scenarios have been given in our previous papers [1,33]). In **Experiment 2** (Exp. 2), simultaneously with the stimuli presented in Exp. 1, the pilots were exposed to an additional visual stimulus related to the size of the visual stimulus. This visual stimulus (CDFT) was presented on the computer monitor screen (Lenovo IdeaPad Yoga 13) and was fixed in the simulator cabin below OTW. The CDFT was based on a sustained attention, change detection activity that measures the correctness with which participants respond to a visual stimulus. Detailed descriptions of stimuli and participant's reaction procedure in this task are included in the papers [19,35]. **Experiment 3** (Exp. 3) comprised the stimuli presented in Exp. 1, and the sound stimuli (an NBT) was presented binaurally using headphones. These sound stimuli involved the sequential letter memory task, in which pilots had to decide whether each letter in a sequence matched the one that appeared N items ago. The stimuli were presented continuously in each flight profile, except for the moment when audio flight instructions were given. More details about the stimuli have been given in our previous papers [36,58]. **Experiment 4** (Exp. 4) included the stimuli presented in Exp. 1 and the sound stimuli (tones) presented binaurally using headphones. The pilots were asked to discriminate between short and long tones by pressing a button located on the control stick. The tones were presented continuously throughout each flight profile, except for the time when audio flight instructions were given. The characteristics of the acoustic stimuli and procedure of response to them were described in detail in the papers [37,58].

Measurement of the severity of simulator sickness

To examine whether simulator sickness during flights in the SD trainer could have affected results in our previous studies [1,19,58], participants completed a Polish version of the SSQ [4]. SSQ data collected during these studies were rated regarding severity and then were summed to yield three subscale scores: nausea score (SSQ-N), oculomotor disturbances score (SSQ-O), disorientation score (SSQ-D), and a total severity score (SSQ-TS). Mean SSQ scores that were obtained after completing all flight profiles were determined based on predefined factor weightings suggested by Kennedy et al. [27]. Next, the scoring criteria of SSQ that reflect the severity of simulator sickness symptoms was applied [55]. All SSQ data collected in our previous studies [1,19,58] were used for comparative analysis in the present study.

Procedure

The test procedure in each of the four experiments is described in detail in our previous studies [1,19,58]. A brief description is as follows: Each experiment included familiarization and a flight training session in a flight simulator, and the main exposition consisted of 12 flight profiles (six conflict flights and six non-conflict flights). The training session had 5–10 minutes of "free-flight" and was given to all pilots to get them acquainted with the operational characteristics of the simulator. The familiarization flight profile included the basic elements of pilotage with the approach-to-landing manoeuvre. If a pilot reached a given target altitude, heading, vertical speed, and bank (within the acceptable deviations [34]), he could participate in the study. The pilots were only briefed with all relevant flight-related requirements, but were not introduced to the flight scenario and the purpose of research.

The order of flight profiles (six conflict flights and six non-conflict flights) was fixed at random. Pilots did not know the order of profiles and which were conflict flights. The pilots who took part in Exp. 1 (12 flight profiles) performed manoeuvres with the maintenance of flight parameters according to the flying instructions given (recorded commands) [1]. In Exp. 2, the pilots from another group (Tab. 1) were asked to perform a dual-task involving control of the aircraft position (as in the Exp. 1) and detection of visual stimulus changes from behind the cockpit (CDFT) at the same time [19]. In Exp. 3, the next group of pilots (Tab. 1) performed the flying task (the same as in the Exp. 1) and the NBT [58] simultaneously. In Exp. 4, the pilots were asked to perform a flying task, as in the Exp. 1, and the DDT simultaneously [58]. To obtain simulator sickness ratings, the SSQ [4] was administered after the simulator main exposition (12 flight profiles). The duration of a single experiment did not exceed 60 minutes (not including training or familiarization flight). All participants completed the study at the same time of day (between 10:00 and 16:00).

Statistical Analysis

To compare the effect of the between-factors that are represented by the group type (control, CDFT, NBT, and DDT groups), a one-way repeated measures Analysis of Variance (ANOVA) and post-hoc pairwise t-tests with Bonferroni correction were used. The ANOVA was run on the recorded mean scores of SSQ and was performed for each subscale of SSQ symptoms (nausea SSQ-N, oculomotor SSQ-O, and disorientation SSQ-D) separately. A significance level of p = 0.05 was considered statistically significant and was set for all analyses. For all statistical analysis, IBM SPSS version 17.0 (IBM Corporation, US) was used.

RESULTS

Overall, summarising the results of our previous studies [1,19,58], we found that the incidence of simulator sickness symptoms (measured by SSQ) was reported by 68% of participants; however, it remained a minor severity and was not a discomfort in pilots [55]. The mean scores of SSQ symptoms for each analysed subscales of SSQ symptoms and study groups are shown in Table 2.

The ANOVA was performed separately for each subscale of SSQ symptoms (nausea SSQ-N, oculomotor SSQ-O, and disorientation SSQ-D) and for total score of SSQ symptoms showed no significant differences between the symptoms reported by the study groups (control, CDFT, NBT, and DDT). The results of the ANOVA are shown in Table 2. The differences between the mean scores of SSQ symptoms for each subscale and the study groups are given in Figs. 2–5.

DISCUSSION

The standard flight scenario

As we noted in our previous study [1], according to the SSQ scoring criteria [55], the symptoms of simulator sickness reported by pilots after exposure to the standard flight scenario were neg-

Tab. 2. The mean scores of SSQ symptoms and the one-way ANOVA results for each SSQ subscales.

The subscale of SSQ symptoms	**Group type**				**Statistical results**		
	Control	CDFT	NBT	DDT	F	p	η2
Nausea (SSQ-N)	1.46 (1.31)	1.53 (1.22)	1.38 (1.41)	1.88 (1.72)	0.451	0.717	0.018
Oculomotor (SSQ-O)	3.41 (2.12)	3.12 (2.61)	2.88 (2.31)	3.63 (2.42)	0.355	0.786	0.014
Disorientation (SSQ-D)	1.90 (1.63)	2.05 (1.71)	1.81 (1.72)	1.81 (1.52)	0.090	0.965	0.004
Total (SSQ-TS)	2.25 (1.52)	2.23 (1.85)	2.02 (1.59)	2.44 (1.55)	0.196	0.899	0.008

Note: Values represent mean and standard deviation; CDFT – change detection flicker task; NBT – auditory N-back task; DDT – duration discrimination task.

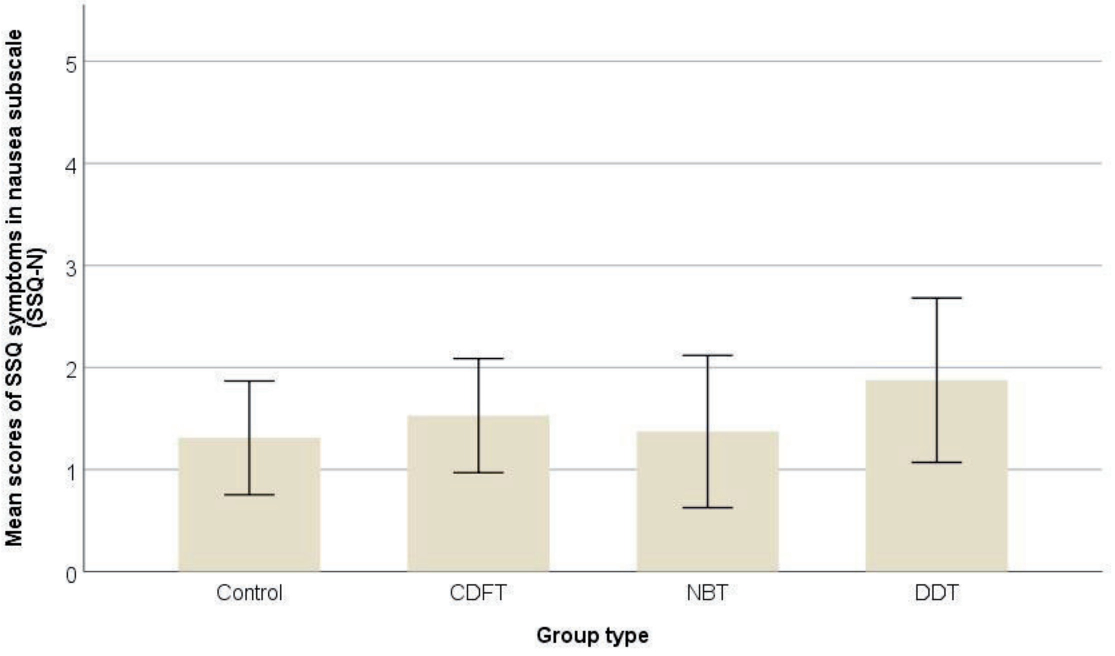

Fig. 2. The mean scores of SSQ symptoms in nausea subscale (SSQ-N) by study group type.

Error bars represent the standard error of the mean; CDFT – change detection flicker task; NBT – auditory N-back task; DDT – duration discrimination task.

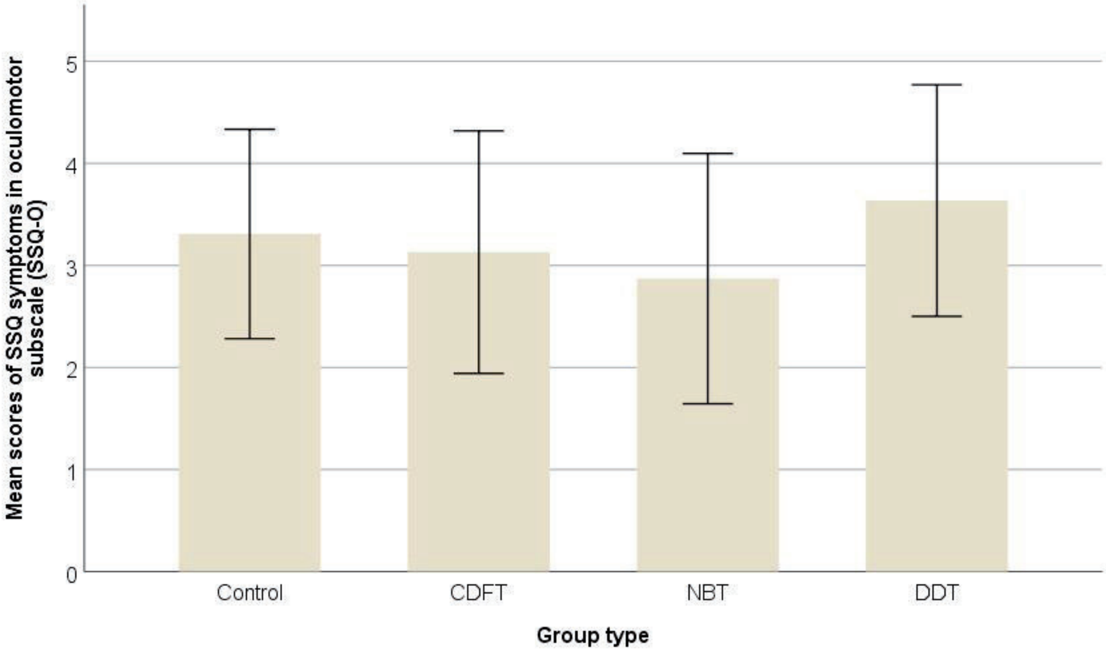

Fig. 3. The mean scores of SSQ symptoms in oculomotor subscale (SSQ-O) by study group type.

Error bars represent the standard error of the mean; CDFT – change detection flicker task; NBT – auditory N-back task; DDT – duration discrimination task.

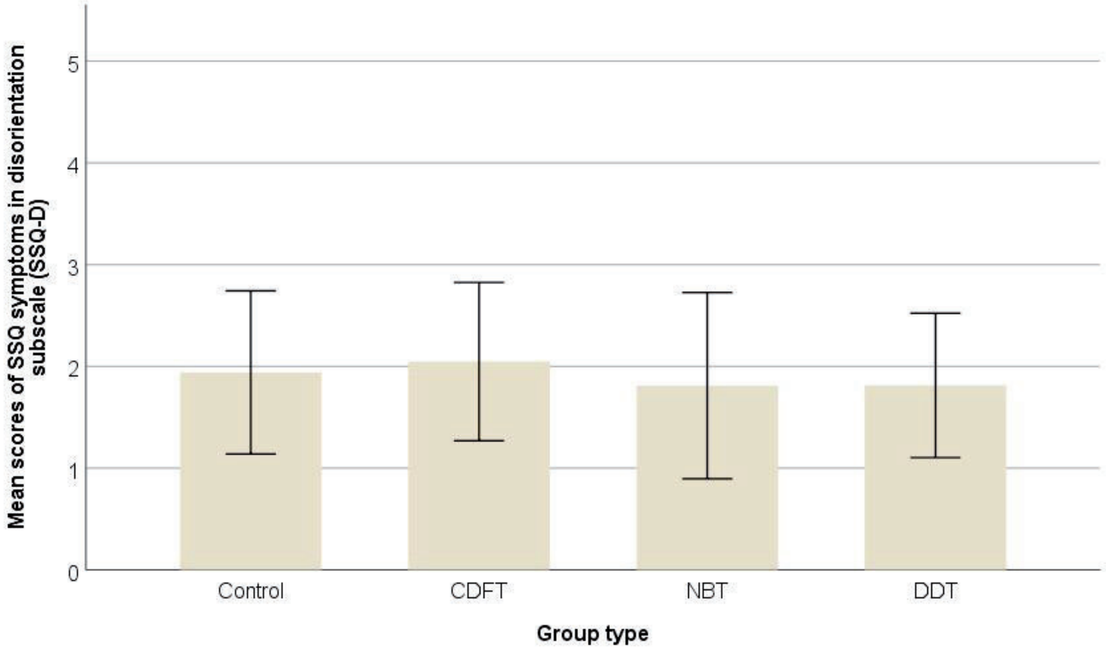

Fig. 4. The mean scores of SSQ symptoms in disorientation subscale (SSQ-D) by study group type.

Error bars represent the standard error of the mean; CDFT – change detection flicker task; NBT – auditory N-back task; DDT – duration discrimination task.

ligible (MSSQ-N = 1.46; MSSQ-O = 3.41; MSSQ-D = 1.90; MSSQ-TS = 2.25). As we noted earlier, it means that this SD simulator did not induce symptoms of simulator sickness, which would raise concerns for post-exposure activities.

The flight scenario with additional cognitive task

The results of comparing the findings of our previous studies [1,19,58] were presented in Figs. 2–5 and Table 2, and are separately discussed below in detail for each type of cognitive task.

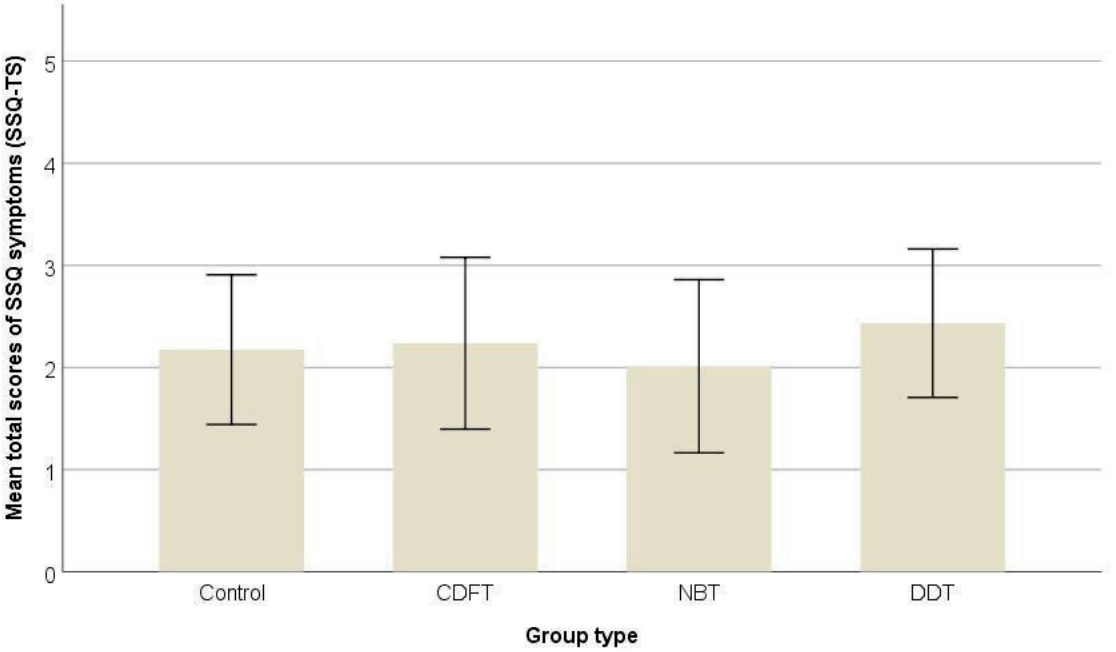

Fig. 5. The mean total scores of SSQ symptoms (SSQ-TS) by study group type.
Error bars represent the standard error of the mean; CDFT – change detection flicker task; NBT – auditory N-back task; DDT – duration discrimination task.

Each of these tasks involved the engagement of a higher level of processing (reaction with a choice) and their possible impact on simulator (motion) sickness was considered in terms of the source of mental distraction - shifting attention (induced by a visual or auditory stimulus).

Change detection flicker task (CDFT)

An increase in the mean scores of SSQ symptoms was observed for the nausea and disorientation subscales; however, these differences were not statistically significant (Tab. 2, Figs. 2–5). The lower value of the mean scores of SSQ symptoms occurred on the oculomotor (SSQ-O) subscale (MSSQ-O = 3.12 vs. 3.41) and for the total score (MSSQ-TS = 2.23 vs. 2.25). Lower values in the SSQ-O subscale can be explained by the fact that the CDFT was a visual task. In addition to scanning flight instruments (primary piloting task), the pilots performed detection of visual stimulus, to which they had to respond in a pre-determined manner (motor response). Therefore, they mostly focused their gaze on the task performance (scanning instruments and detecting changes) without recognising possible impairments in oculomotor activity. This observation is in the line with previous studies [18,61], which have shown that an object on which it is possible to focus the gaze (suppressing saccadic eye movements) may provide less severity of simulator sickness.

The lack of significant differences in the severity of simulator sickness symptoms between the control group and the CDFT group indicates that this additional perceptual task did not result in a significant increase or decrease in these symptoms. Thus, detecting and responding to an additional visual stimulus (CDFT) appears to have not been a factor which increased the risk of simulator sickness. This finding is supported by other studies [14], which indicate that reducing the number of visual stimuli (fixated objects) is an effective strategy for mitigating motion sickness. Moreover, Webb and Griffin [62] demonstrated that both foveally- and peripherally-presented visual stimuli can induce motion sickness, but the latter are more provocative stimuli than the former, which includes CDFT.

Auditory N-back task (NBT)

The total severity score of SSQ symptoms (SSQ-TS) revealed that the pilots who performed NBT experienced simulator sickness symptoms with less severity (MSSQ-TS = 2.02) than pilots from the control group (MSSQ-TS = 2.25). The same direction of change in the mean scores of SSQ symptoms was also observed in each SSQ subscales (Figs. 2–5); however, the incidence of simulator sickness between pilots from the NBT and control groups does not differ significantly at all of the analysed subscales of SSQ symptoms (Tab. 2). Nevertheless, these findings confirm the results of earlier studies [6], in which a reduction of 19% in symptoms was observed in subjects who were performing an audio letter-memorising task. It appears that the additional auditory stimuli may shift attention away from the provocative stimulus, and adding noise to the neural processing of afferent sensory inputs (Fig. 1, summing block A) may down-weight the visual-vestibular conflict input (Fig. 1, K gain block).

Duration discrimination task (DDT)

Performing the DDT, in which the pilots had to respond to the sound stimuli (tones), revealed an increased severity of SSQ symptoms in the nausea (SSQ-N) subscale (MSSQ-N = 1.88 vs. 1.46 in the control group), the oculomotor (SSQ-O) subscale (MSSQ-O = 3.63 vs. 3.41 in the control group), and the total score (MSSQ-TS = 2.44 vs. 2.25 in the control group) (Tab. 2). These differences were not statistically significant. Therefore, this task-related cognitive stimulus (tones) was not related to the motion at issue in any way, nor the source of mental distraction - shifting attention, thus being unable to mitigate the sickness symptoms. This is in accordance with data presented by Dahlman et al. [14], where subliminally-presented special sound stimuli were not an effective strategy for mitigating the sickness symptoms. A possible mechanism for how DDT acts may be represented in the weighting of the mismatch signal in the psychophysiological model (Fig. 1, K gain block).

General comment

From previous studies [1,19,58], we have learned that despite the use of distraction (CDFT, NBT, or DDT) incorporated into a flight scenario in the Gyro-IPT simulator (to improve the effectiveness of SD training), no severe symptoms of simulator (motion) sickness were observed. In the presented research, we compared the results of those studies and considered the possible impact of these additional tasks on motion sickness in terms of the source of mental distraction - shifting attention (induced by a visual or auditory stimulus). We found that the performing CDFT and DDT tended to increase severity of simulator sickness symptoms, whereas the mental distraction task induced by NBT was found to be effective in reducing these symptoms. Although performing a task during sickening conditions can lead to a reduction in symptom severity (however, not every type of task can mitigate the sickness symptoms [11,56]), it should be noted that "the motion sickness is less probable when attention is directed toward external events" [48]. Thus, even though distraction by mental activity, as was applied in our previous studies [1,19,58], occurs when ones attention is removed from the processing of certain information [57,68], performing additional tasks (CDFT, NBT, or DDT) did not significantly reduce severity of sickness.

Since the symptoms of simulator sickness appeared to be minor in the previous studies [1,19,58], it is important to mention that their gradual development may not have been noticed by a pilot. This means that the responses given in the SSQ may only include those symptoms of which the pilot was aware. It is also worth emphasizing that the effectiveness of distraction can only make a difference when the symptoms of simulator sickness are noticeable. This means that when the pilot was not experiencing severe simulator sickness symptoms, the distraction (shift attention/mental distraction) may not activate the mechanisms responsible for reducing this sickness. Although the study did not investigate how applied distractors are a potential countermeasure to simulator sickness, we assume that perhaps with stronger SD-inducing stimuli, additional tasks (CDFT, NBT, and DDT) would have shown a greater effect on the pilots' perceived simulator sickness symptoms. It could also be that differences in the severity of sickness symptoms would show a different direction to those found in the presented study.

Study limitation

In addition to the limitations of our previous studies [1,19,58] and their possible impact on the results, another major limitation that made it difficult to analyse these data in the present study should be mentioned. Due to the small effect size (η2, Tab. 2) and sample size (Tab. 1), the above-discussed results of the study may not be representative. This observation is also supported by the low statistical power (not exceeding 0.14). This indicates that it is possible to draw the erroneous conclusion that there is no effect (no statistically-significant difference between groups), when in fact there may be. To enhance the power of the study, a larger sample size and/or interventions to increase the effect size (e.g. the use of stimuli that induce more severity symptoms of simulator sickness) should be considered. This would enable more valid conclusions to be drawn about the differences detected between groups.

CONCLUSION

To explore whether including an additional task to improve the effectiveness of SD training may change the severity of simulator sickness symptoms, we compared the severity of sickness in pilots during training in the Gyro-IPT simulator under different multisensory conditions (CDFT, NBT, and DDT) [19,58] with the severity in pilots who did not perform the additional task in the simulator [1]. We found that in pilots who performed additional cognitive tasks, the severity of simulator sickness symptoms did not change significantly. Nevertheless, our findings suggest that under certain conditions (NBT), performing an additional task may delay the onset of simulator sickness or weaken the severity of its symptoms. It may also indicate that the applied cognitive task could serve as such a non-sickness distractor. We conclude from our findings that the additional tasks (CDFT, NBT, or DDT) applied to improve the effectiveness of SD training that give desirable illusions in the Gyro-IPT simulator do not significantly change unwanted effects such as simulator sickness.

AUTHORS' DECLARATION:

Study Design: Rafał Lewkowicz, Bibianna Bałaj, Agnieszka Fudali-Czyż, Paweł Stróżak, Paweł Augustynowicz, Piotr Francuz. **Data Collection:** Rafał Lewkowicz, Bibianna Bałaj, Agnieszka Fudali-Czyż, Paweł Stróżak, Paweł Augustynowicz. **Manuscript Preparation:** Rafał Lewkowicz, Bibianna Bałaj, Agnieszka Fudali-Czyż, Paweł Stróżak, Paweł Augustynowicz. The Authors declare that there is no conflict of interest.

REFERENCES

1. Bałaj B, Lewkowicz R, Francuz P, Augustynowicz P, Fudali-Czyż A, Stróżak P, et al. Spatial disorientation cue effects on gaze behaviour in pilots and non-pilots. Cogn Technol Work. Springer London; 2019; 21(3):473–486.
2. Benson AJ, Scott JRR. Motion sickness. In: Rainford DJ, Gradwell DP, editors. Ernsting's Aviation Medicine. 4th ed. Cornwall, UK: Edward Arnold (Publishers) Ltd; 2006. p. 459–75.
3. Biernacki MP, Dziuda Ł. Choroba symulatorowa jako realny problem badań na symulatorach. Med Pr. 2012; 63(3):377–88.
4. Biernacki MP, Kennedy RS, Dziuda Ł. Simulator sickness and its measurement with Simulator Sickness Questionnaire (SSQ). Med Pr. 2016; 67(4):545–55.
5. Bles W. Spatial disorientation training – demonstration and avoidance. RTO-TR-HFM-118 AC/323 TP/206. Bles W, editor. Soesterberg, Netherlands: The Research and Technology Organisation of NATO; 2008. 132 p.
6. Bos JE. Less sickness with more motion and/or mental distraction. J Vestib Res Equilib Orientat. 2015; 25(1):23–33.
7. Cevette MJ, Stepanek J, Cocco D, Galea AM, Pradhan GN, Wagner LS, et al. Oculo-Vestibular Recoupling Using Galvanic Vestibular Stimulation to Mitigate Simulator Sickness. Aviat Sp Environ Med. 2012; 83(6):549–55.
8. Cheung B. Airsickness desensitisation for the Canadian Forces - a recommendation. Technical report DCIEM TR 2001-110. 2001.
9. Cheung B, Wong WT. Recommendation to implement Gyro-IPT for disorientation training at CFSAT. Report number: DCIEM-98-TM-59. Toronto; 1998.
10. Cobb SVG, Nichols S, Ramsey A, Wilson JR. Virtual reality-induced symptoms and effects. Presence Teleoperators Virtual Environ. MIT Press Journals; 1999; 8(2):169–86.
11. Correia MJ, Guedry FE. Modification of vestibular responses as a function of rate of rotation about an Earth-horizontal axis. Acta Otolaryngol. Acta Otolaryngol; 1966; 62(4):297–308.
12. Curthoys IS, Macdougall HG. What galvanic vestibular stimulation actually activates. Front Neurol. Switzerland; 2012; 3:117.
13. D'Amour S, Bos JE, Keshavarz B. The efficacy of airflow and seat vibration on reducing visually induced motion sickness. Exp Brain Res. Springer Berlin Heidelberg; 2017; 235(9):2811–20.

14. Dahlman J, Sjörs A, Ledin T, Falkmer T. Could sound be used as a strategy for reducing symptoms of perceived motion sickness? J Neuroeng Rehabil. BioMed Central; 2008; 5(1):1–9.

15. Dilda V, MacDougall HG, Moore ST. Tolerance to extended galvanic vestibular stimulation: optimal exposure for astronaut training. Aviat Space Environ Med. United States; 2011; 82(8):770–4.

16. Domeyer JE, Cassavaugh ND, Backs RW. The use of adaptation to reduce simulator sickness in driving assessment and research. Accid Anal Prev. Elsevier Ltd; 2013; 53:127–32.

17. Flanagan MB, May JG, Dobie TG. Sex differences in tolerance to visually-induced motion sickness. Aviat Sp Environ Med. 2005; 76(7 I):642–6.

18. Flanagan MB, May JG, Dobie TG. The role of vection, eye movements and postural instability in the etiology of motion sickness. J Vestib Res Equilib Orientat. Netherlands; 2004; 14(4):335–46.

19. Fudali-Czyż A, Lewkowicz R, Francuz P, Stróżak P, Augustynowicz P, Truszczyński O, et al. An Attentive Blank Stare Under Simulator-induced Spatial Disorientation Events. Hum Factors J Hum Factors Ergon Soc. 2022; .

20. Gutkovich YE, Lagami D, Jamison A, Fonar Y, Tal D. Galvanic vestibular stimulation as a novel treatment for seasickness. Exp brain Res. Germany; 2022; 240(2):429–37.

21. Headquarters Department of the Army. Temporary Flying Restrictions Due to Exogenous Factors Affecting Aircrew Efficiency (Army Regulation 40–8). Medical Services. Washington, DC: Headquarters Department of the Army; 2007. p. 9.

22. Hettinger LJ, Berbaum KS, Kennedy RS, Dunlap WP, Nolan MD. Vection and simulator sickness. Mil Psychol. American Psychological Association; 1990; 2(3):171–81.

23. Johnson DM. Simulator Sickness Research Summary. RTO-TR-HFM-121-Part-II. 2005.

24. Jones JGR. Prediction and Prevention of Simulator Sickness: An Examination of Individual Differences, Participant Behaviours, and Controlled Interventions. The University of Guelph, Ontario, Canada; 2011.

25. Kaufeld M, De Coninck K, Schmidt J, Hecht H. Chewing gum reduces visually induced motion sickness. Exp Brain Res. Springer Berlin Heidelberg; 2022; 240(2):651–63.

26. Kennedy RS, Lilienthal MG, Berbaum KS, Baltzley DR, McCauley ME. Simulator sickness in U.S. Navy flight simulators. Aviat Space Environ Med. United States; 1989; 60(1):10–6.

27. Kennedy RS, Lane NE, Berbaum KS, Lilienthal MG. Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness. Int J Aviat Psychol. Lawrence Erlbaum Associates, Inc.; 1993; 3(3):203–20.

28. Keshavarz B, Ramkhalawansingh R, Haycock B, Shahab S, Campos JL. Comparing simulator sickness in younger and older adults during simulated driving under different multisensory conditions. Transp Res Part F Traffic Psychol Behav. Elsevier Ltd; 2018; 54:47–62.

29. Keshavarz B, Riecke BE, Hettinger LJ, Campos JL. Vection and visually induced motion sickness: How are they related? Front Psychol. 2015; 6(APR):1–11.

30. Keshavarz B, Hecht H. Pleasant music as a countermeasure against visually induced motion sickness. Appl Ergon. England; 2014; 45(3):521–7.

31. Kluch W. Badania fizjologiczne przebiegu restytucji narządu przedsionkowego u osób poddawanych przyspieszeniom w symulatorze Gyro IPT. Rozprawa doktorska. Wojskowy Instytut Medycyny Lotniczej; 2003.

32. Lerman Y, Sadovsky G, Goldberg E, Kedem R, Peritz E, Pines A. Correlates of military tank simulator sickness. Aviat Space Environ Med. United States; 1993 Jul; 64(7):619–22.

33. Lewkowicz R, Bałaj B, Francuz P. Susceptibility to flight simulator-induced spatial disorientation in pilots and non-pilots. Int J Aerosp Psychol. Routledge Taylor & Francis Group; 2020; 30(1–2):25–37.

34. Lewkowicz R, Francuz P, Bałaj B, Augustynowicz P. Flights with the risk of spatial disorientation in the measurements of oculomotor activity of pilots. Polish J Aviat Med Psychol. 2015; 21(3):22–8.

35. Lewkowicz R, Fudali-Czyż A, Bałaj B, Francuz P. Change detection flicker task effects on simulator-induced spatial disorientation events. Aerosp Med Hum Perform. 2018; 89(10):863–72.

36. Lewkowicz R, Stróżak P, Bałaj B, Francuz P. Auditory verbal working memory load effects on a simulator-induced spatial disorientation event. Aerosp Med Hum Perform. 2019; 90(6):531–9.

37. Lewkowicz R, Stróżak P, Bałaj B, Francuz P, Augustynowicz P. Selective Auditory Attention and Spatial Disorientation Cues Effect on Flight Performance. Aerosp Med Hum Perform. 2018; 89(11):976–84.

38. Lilienthal MG, Merkle JR. PJ. Simulator sickness in flight simulators: a case study. In: Vehicular simulation and user behavioral studies. Washington, DC United States: Transportation Research Board; 1986. p. 81–6.

39. Lorente JM, Esteban B, Vallejo P, Rios F, García-alcón JL. Pilot disorientation, sensorial response measured by dynamic posturography in SPAF pilots. In: RTO HFM Symposium on "Spatial Disorientation in Military Vehicles: Causes, Consequences and Cures." La Coruña, Spain; 2002. p. 8.

40. Maffert A, Aupy B. Optokinetic stimulation efficiency for sea sickness treatment. Int Marit Health. Int Marit Health; 2020; 71(4):249–52.
41. Mccauley ME. Research Issues in Simulator Sickness: Proceedings of a Workshop. 2nd ed. Washington D.C.: National Academies Press; 1984. 82 p.
42. Oman CM. A heuristic mathematical model for the dynamics of sensory conflict and motion sickness. Acta Otolaryngol Suppl. 1982; 392:1–44.
43. Oman CM. Motion sickness: a synthesis and evaluation of the sensory conflict theory. Can J Physiol Pharmacol. NRC Research Press; 1990; 68(2):294–303.
44. Pausch R, Crea T, Conway M. A Literature Survey for Virtual Environments: Military Flight Simulator Visual Systems and Simulator Sickness. Presence Teleoperators Virtual Environ. MIT Press - Journals; 1992; 1(3):344–63.
45. Peck K, Russo F, Campos JL, Keshavarz B. Examining potential effects of arousal, valence, and likability of music on visually induced motion sickness. Exp Brain Res. Springer; 2020; 238(10):2347–58.
46. Ranasinghe N, Jain P, Tolley D, Karwita Tailan S, Yen CC, Do EYL. Exploring the Use of Olfactory Stimuli towards Reducing Visually Induced Motion Sickness in Virtual Reality. In: Proceedings - SUI 2020: ACM Symposium on Spatial User Interaction. Toronto, Canada: Association for Computing Machinery, Inc; 2020. p. 1–9.
47. Reason JT. Motion sickness adaptation: a neural mismatch model. J R Soc Med. 1978; 71(11):819–29.
48. Reason JT, Brand JJ. Motion sickness. London, UK: Academic press; 1975.
49. Rizzo-Sierra C V, Gonzalez-Castaño A, Leon-Sarmiento FE. Galvanic vestibular stimulation: a novel modulatory countermeasure for vestibular-associated movement disorders. Arq Neuropsiquiatr. Germany; 2014; 72(1):72–7.
50. Sharma K, Aparna. Prevalence and correlates of susceptibility to motion sickness. Acta Genet Med Gemellol (Roma). The Mendel Institute; 1997; 46(2):105–21.
51. Sherman CR. Motion sickness: review of causes and preventive strategies. J Travel Med. England; 2002; 9(5):251–6.
52. Signorella ML, Jamison W, Krupa MH. Predicting Spatial Performance From Gender Stereotyping in Activity Preferences and in Self-Concept. Dev Psychol. 1989; 25(1):89–95.
53. Smither JAA, Mouloua M, Kennedy R. Reducing symptoms of visually induced motion sickness through perceptual training. Int J Aviat Psychol. Taylor & Francis Group; 2008; 18(4):326–39.
54. Smyth J, Jennings P, Bennett P, Birrell S. A novel method for reducing motion sickness susceptibility through training visuospatial ability – A two-part study. Appl Ergon. Elsevier Ltd; 2021; 90:103264.
55. Stanney KM, Kennedy RS, Drexler JM. Cybersickness is not simulator sickness. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Los Angeles, CA: SAGE Publications Inc; 1997. p. 1138–42.
56. Stein M, Robinski M. Simulator Sickness in Flight Simulators of the German Armed Forces. Aviat Psychol Appl Hum Factors. Hogrefe Publishing Group; 2012; 2(1):11–9.
57. Strayer DL, Watson JM, Drews FA. Chapter two - Cognitive Distraction While Multitasking in the Automobile. In: Ross BHBT-P of L and M, editor. Advances in Research and Theory. Academic Press; 2011. p. 29–58.
58. Stróżak P, Francuz P, Lewkowicz R, Augustynowicz P, Fudali-Czyż A, Bałaj B, et al. Selective attention and working memory under spatial disorientation in a flight simulator. Int J Aerosp Psychol. Routledge; 2018; 28(1–2):31–45.
59. Trendel D, Haus-Cheymol R, Erauso T, Bertin G, Florentin JL, Vaillant PY, et al. Optokinetic stimulation rehabilitation in preventing seasickness. Eur Ann Otorhinolaryngol Head Neck Dis. Elsevier Masson; 2010 Sep 1; 127(4):125–9.
60. Webb CM, Bass JM, Johnson DM, Kelley AM, Martin CR, Wildzunas RM. Simulator sickness in a helicopter flight training school. Aviat Sp Environ Med. Aviat Space Environ Med; 2009 Jun; 80(6):541–5.
61. Webb NA, Griffin MJ. Optokinetic stimuli: motion sickness, visual acuity, and eye movements. Aviat Space Environ Med. United States; 2002; 73(4):351–8.
62. Webb NA, Griffin MJ. Eye movement, vection, and motion sickness with foveal and peripheral vision. Aviat Space Environ Med. United States; 2003; 74(6 Pt 1):622–5.
63. Weech S, Moon J, Troje NF. Influence of bone-conducted vibration on simulator sickness in virtual reality. PLoS One. United States; 2018; 13(3):e0194137.
64. Weech S, Wall T, Barnett-Cowan M. Reduction of cybersickness during and immediately following noisy galvanic vestibular stimulation. Exp Brain Res. 2020; 238(2):427–37.
65. Wojciechowski P, Błaszczyk J. Simulator sickness in the aircraft training of military and civil pilots of various types of aircraft. Med Pr. Nofer Institute of Occupational Medicine; 2019; 70(3):317–25.
66. Yen Pik Sang FD, Golding JF, Gresty MA. Suppression of sickness by controlled breathing during mildly nauseogenic motion. Aviat Space Environ Med. United States; 2003; 74(9):998–1002.

67. Zhang LL, Wang JQ, Qi RR, Pan LL, Li M, Cai YL. Motion sickness: current knowledge and recent advance. CNS Neurosci Ther. 2016; 22(1):15–24.

68. Zhou C, Bryan CL, Wang E, Artan NS, Dong Z. Cognitive Distraction to Improve Cybersickness in Virtual Reality Environment. Proc - 2019 IEEE 16th Int Conf Mob Ad Hoc Smart Syst Work MASSW 2019. Institute of Electrical and Electronics Engineers Inc.; 2019; :72–6.

Cite this article as: Lewkowicz R, Bałaj B, Fudali-Czyż A, Stróżak P, Augustynowicz P, Francuz P. How Does Mental Distraction Induced by an Additional Task Affect the Severity of Simulator Sickness Symptoms in Pilots: A Spatial Disorientation Simulator Study. Pol J Aviat Med Bioeng Psychol 2021; 27(2): 5-18. DOI: 10.13174/pjambp.22.04.2024.01