The Sensitivity to Motion Sickness Induced by Aircraft and Flight Training Devices and the Role of Experience During Flight Training

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THE SENSITIVITY TO MOTION SICKNESS INDUCED BY AIRCRAFT AND FLIGHT TRAINING DEVICES AND THE ROLE OF EXPERIENCE DURING FLIGHT TRAINING

by

Angela M. Baskin

A Thesis Submitted to the
Department of Human Factors and Systems
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Human Factors & Systems

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This thesis was prepared under the direction of the candidate's thesis committee chair, Jon French, PhD, Department of Human Factors & Systems, and has been approved by the members of this thesis committee. It was submitted to the Department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

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The incidence and severity of motion sickness, which can be incapacitating and can prevent training, is ill-established in career paths where motion or simulated motion is commonplace. To assess different aspects of this problem, each of 175 Embry-Riddle student pilots early in their training and 43 Embry-Riddle student non-pilots participated in one of four parts of this study. The Motion History Questionnaire was utilized to compare pilot and non-pilot groups on reported motion sickness sensitivity: non-pilots reported significantly more sensitivity than did pilots for 3 out of 7 items included in the composite score, suggesting possible career self-selection (though composite scores themselves were not significantly different). Among pilots, the Simulator Sickness Questionnaire (SSQ) Total Score showed that (using non-parametric 2-way comparisons): a) experience significantly eased symptoms in the aircraft, but in not the flight training device (FTD), b) “extremity” of lesson content did not affect motion sensitivity in either device, and c) training device did not make a difference in symptom elicitation. Using 20 as an SSQ threshold, 4.2% of pilots in the aircraft and 4.9% of pilots in the FTD suffered from motion/simulator sickness. Though these incidence rates are low, they warrant further research in terms of replication, the role of experience, prevention, and treatment strategies.
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INTRODUCTION

Motion sickness is considered to be a normal physiological response to conflict between the sensory inputs from the visual, vestibular, and proprioceptive systems, or between the pattern of motion information inputs and their expected values based on past experience (Crampton, 1990). Its symptoms range from the discomfort, pallor, dizziness, nausea and vomiting, familiar to all as motion sickness, to the less familiar symptoms of the “sopite syndrome” which consists of fatigue, drowsiness, even mental depression and can sometimes be the sole manifestation of motion sickness (Greybiel & Knepton, 1976).

The compelling graphics of today’s high fidelity simulators convincingly give the perception of motion to the visual system, yet the accompanying vestibular input does not support that perception. This disequilibrium, among other contributing factors, can result in simulator sickness which is one of the more recently identified forms or subsets of motion sickness. The Department of Defense and amusement park companies, among others, spend billions of dollars per year to increase simulator fidelity for training and enjoyment purposes. However, in many cases the more “realistic” a simulation is created, the more it is capable of provoking symptoms of profound motion sickness which blunt training and enjoyment.

The incidence and severity of motion sickness is not well known in the general population, nor is it well established in career paths where sensitivity to motion could prevent advancement such as in aviation or naval cadets. This is compounded by the fact that fatigue can be an unrecognized symptom of motion sickness and also can reduce performance.

It is commonly recognized that repeated exposure to motion stimuli from simulators or flight reduces the sensitivity to future simulator or motion sickness. McCauley (1984) identifies both the incidence of the simulator sickness problem and the time course of adaptation (and
readaptation) as recommendations for future research into simulator sickness. The current study proposed to examine the incidence of motion sickness in the student pilot and non-pilot populations, and test the severity of airsickness and simulator sickness in the student pilot population. Further, the impacts of repeated exposure to motion and simulated motion stimuli, as well as lesson content, on motion sickness symptoms were addressed.

Statement of the Problem

The literature on motion sickness is not definitive with regard to the incidence of motion sickness in the general population. The incidence and severity of motion/simulator sickness is neither well-established in career paths where motion or simulated motion is commonplace, such as in aerospace, nautical environments, and amusement parks. This study sampled the sensitivity to motion sickness in both the pilot and non-pilot college student populations. In the pilot college student population, it assessed the severity of motion sickness symptoms induced by flight and flight simulation in early vs. the late portions of the introductory flight course. Symptom severity as experienced in the flight training device (FTD) was compared with the severity as experienced in the aircraft. Finally, the severity of motion sickness symptoms experienced during especially acrobatic lessons involving spins and stalls in both the aircraft and the FTDs were compared with the severity experienced during “normal” lessons. These issues were considered to be important since they could have an impact on the career paths of students avoiding situations that induced motion sickness and on strategies to dilute the impact of motion sickness in aerospace students.
Motion sickness is not actually a true sickness, but a normal physiological response to conflicting sensory inputs. McCauley (1984) described motion sickness as a general term for a constellation of symptoms and signs, generally adverse, due to exposure to abrupt, periodic, or unnatural accelerations. It is a very generic “diagnosis” that is widely used to refer to a set of autonomic nervous system (ANS) symptoms that may be experienced during and following real or illusory motion (Money, Lackner, & Cheung, 1996), and individuals may react to real or apparent motion with much variation (Crampton, 1990).

Symptoms of Motion Sickness

The most common or “cardinal” signs and symptoms of motion sickness include pallor, cold sweating, nausea, and vomiting; salivation, headache, drowsiness, dizziness, sensation of increased body temperature, general malaise, apathy, depression, and decreased motor coordination are additional signs and symptoms that tend to occur with more variation in incidence and duration (Reason & Brand, 1975; Benson, 1978; Money, 1970).

The general malaise, fatigue, sleepiness, apathy and depression also characterize motion sickness, and can be extremely debilitating. Graybiel and Knepton (1976) coined the term “sopite syndrome”, indicating that these manifestations are only part of a symptom-complex within motion sickness. They further described typical symptoms as yawning, drowsiness, disinclination for work (physical or mental), and lack of participation in group activities. They explain that these symptoms are generally interwoven with other motion sickness symptoms, but can also be the sole manifestation of motion sickness. Also, sopite symptoms can occur before
other motion sickness symptoms appear, or after they disappear through adaptation in a prolonged exposure to a stimulus. Lawson and Mead (1998) pointed out that sopite syndrome may be particularly hazardous in transportation settings where other performance challenges like sleep deprivation are already present. Thus, pilots of long-haul flights, among others, are especially at risk. This syndrome can be particularly dangerous because it can easily go unrecognized; fatigue may be attributable to many causes including the rigors of training.

**Causes of Motion Sickness**

Motion sickness is considered to be a set of physiological disturbances that can result from spatial disorientation (Kennedy & Frank, 1985). Typically, however, spatial disorientation refers to illusory phenomena only. Several theories have been postulated as to the cause of motion sickness. Seemingly, the most currently accepted theory is the neural mismatch theory, also known as perceptual conflict theory, cue conflict, and sensory rearrangement, among others (Kennedy & Frank, 1985). Normally, the visual, vestibular, and proprioceptive systems act together in agreement to give a person a perception of self-motion, spatial location, and the motion of surrounding things. The neural mismatch theory posits that the motion information input by these three systems may be in disagreement with their anticipated values based on a neural store from past experience or with the natural endowment of the system circuitry (Kennedy & Frank, 1985; McCauley, 1984). This mismatch of expectations and actual inputs is thought to be what produces motion sickness symptoms. The mismatch may also occur between the different sensory inputs themselves, so long as one of the inputs is vestibular (Crampton, 1990).

Guedry (1991b) pointed out that while “sensory conflict” is an appropriate term for some motion sickness-provoking stimuli, others involve the abnormal absence of a system’s motion
information input when another is calling for a reaction. In the latter case, sensory messages are not in conflict with one another per se, but exist in combinations that are not immediately interpretable by certain brain networks. Thus, the term “neural mismatch” may describe the phenomenon better than the term “sensory conflict”.

The overstimulation theory posits that intense stimulation of the vestibular system is the cause of motion sickness (Kennedy & Frank, 1985). This theory is specific to the vestibular system and predicts that higher levels of stimulation result in higher likelihood or severity of sickness. The vestibular apparatus has been shown to be necessary for motion sickness, as animals or people who lack a functional vestibular apparatus (either naturally or as a result of surgical removal) are completely nonsusceptible to motion sickness (Crampton, 1990). The overstimulation theory may have some validity, but visual stimuli alone can induce sickness, which contradicts part of the theory (Kennedy & Frank, 1985).

Another postulated cause of motion sickness is the shift of fluid within the body, aptly called the fluid shift theory. Steele (1968) observed that a decrease in circulating blood volume, or cardiovascular inadequacy, seems to cause the most severe motion sickness symptoms. An opposing thought is that motion sickness is caused by an overabundance of cerebral circulation, which seems to be more geared toward space sickness than to any other form of motion sickness. Kennedy and Frank (1985) suggested that the main problem with the fluid shift theory is that blood flow changes could be a result of motion sickness, and not the other way around. They judged the fluid shift theory as weak, although “fluid shifts could perform some modulating influence on vestibular threshold functions”.

According to the toxic reaction theory (Treisman, 1977), there must be some evolutionary significance of the emetic response to motion sickness (Kennedy & Frank, 1985). Treisman
reasoned that vomiting is the body’s response to the ingestion of poison. Normally, the visual, vestibular, and proprioceptive systems function harmoniously, and there exists a continuous need for neural activity to coordinate these sensory inputs to appropriately control limb and eye movements (Treisman, 1977; Kennedy & Frank, 1985). Treisman (1977) theorized that disruption in this activity could serve as a warning system for the detection of early central effects of neurotoxins, and if this disruption occurs because of certain motions, and is interpreted as an early physiological disturbance produced by absorbed toxins, it triggers emesis. Treisman’s toxic reaction theory is supported by the sensory mismatch theory, although the mismatch theory does not address the evolutionary development of the mechanisms of motion sickness, nor does it address how or why vomiting may result (Crampton 1990).

The fear/anxiety theory presents another possible factor in the cause of motion sickness. Some pilots may be anxious for their first few flights or simulated flights, check-rides, solos, etc. Benson (1978) observed that nausea and vomiting are symptoms associated with fear and anxiety, and that when coupled with provocative motion stimuli, could increase one’s susceptibility to motion sickness. No definite correlation between this susceptibility and psychometric measures of anxiety or neuroticism has been established, and findings within this general area are limited to an ill-defined association between motion sickness susceptibility and introversion. It is difficult to discern the contributory roles that anxiety and motion stimuli take in the event of sickness while flying. Kennedy & Frank (1985) observed that although anxiety’s role in motion sickness is “nebulous”, efforts to study this relationship should continue.

This research used the most currently accepted neural mismatch theory as the basis for the hypotheses below.
Simulator Sickness

One of the more recently identified “subsets” of motion sickness is known as simulator sickness. Kennedy, Frank, and McCauley (1985) speculated that a simulator is liable to induce motion sickness responses to the same extent as the real environment. They proposed reserving the term “simulator sickness” for cases in which symptoms occur only in the simulator and not in the real environment, or to a far greater extent in the simulator than in the real environment. Thus, if an aircraft simulator produces sickness similar to that of the real aircraft, then sickness incurred in the simulator should be termed “airsickness”, not “simulator sickness”. Adherence to this concept is not overly evident in other simulator sickness literature. One goal of the current research is to attempt to distinguish between airsickness (that induced by actual flight) with motion sickness induced by simulators or flight training devices, called simulator sickness.

Reported symptoms of simulator sickness are usually very similar to those of motion sickness. Frank, Kennedy, McCauley, and Kellogg (1983) described simulator sickness as “polygenic and polysymptomatic; symptoms include nausea, dizziness, spinning sensations, visual flashbacks, motor dyskinesia, confusion, and drowsiness”.

However, simulator sickness generally involves more visual disturbances, dizziness, and after-effects than other types of motion sickness, and less gastrointestinal problems such as nausea and vomiting (Money, 1991). The Simulator Sickness Questionnaire (SSQ) developed by Kennedy, Lane, Berbaum, and Lilienthal (1993; please see Appendix A) is a popular measure of simulator sickness that uses three global groups to classify symptoms which they determined through factor analysis of the myriad papers of motion sickness symptoms: nausea, oculomotor discomfort, and disorientation. It is postulated that in addition to the motion sickness that is probably caused by sensory conflict, simulator sickness “includes other, separate, visual and
vestibular phenomena” (Money, 1991). It would support Treisman’s theory if motion of the visual field acting indirectly on the vestibular system through the visual system also could provoke a poison response, emesis.

McCauley (1984) described simulator sickness as a “special case” of motion sickness that may be due to those abrupt, periodic, or unnatural accelerative forces that cause motion sickness or may be caused by visual motion cues without actual movement of the subject. Thus, simulator sickness can be experienced in both motion-base and fixed-base simulators and flight training devices (FTDs). It has been well documented that visual stimuli alone can cause symptoms (Crampton, 1990:). The perceptual illusion of self-motion induced in stationary individuals who are viewing optic flow images that the person would normally see when he or she is actually moving is termed “vection”. A moving visual field coupled with a lack of confirmation of motion by semicircular canal and otolith cues of the vestibular system or by the contact cues of the proprioceptive system can result in the experience of vection (Kennedy, Hettinger, Harm, Ordy, and Dunlap, 1996). Vection is commonly experienced, for example, when one is stopped at a traffic light and a side-adjacent car backs up a few feet suddenly. The driver of the stopped car might slam on the brakes thinking (s)he is lurching forward when in fact the car is still.

Crampton (1990) made the distinction that vection is the experience of illusory self-motion, as opposed to the perception of a motion display that depicts self-motion with no accompanying experience of displacement by the user. Visual displays that produce strong vestibular effects may be the most bothersome in terms of producing simulator sickness.

Vection does not necessarily cause simulator sickness, but may involve significant vestibular elements, while the mere perception of a representation of self-motion with no
experience of displacement may not (Crampton, 1990). Vection is likely to be an indication of strong immersion of the user into the simulation.

The perceptual conflict theory tells us that visually specified motion without the accompanying vestibular input will result in illness. However, a mismatch alone between these two inputs must be insufficient to cause illness—otherwise, fixed-base simulators would result in sickness much more frequently due to their conflicting visual-vestibular information (Crampton, 1990). Crampton suggested that a causal factor may be a visual input powerful enough to elicit vestibular signals that conflict with the known body position. Thus the conflict would arise between the expectancy or cognitive awareness of one’s self as stationary and the incongruent perceptual information. Needless to say, simulator sickness is a complex problem; a motion pattern that sickens one individual may not sicken another, and individuals may show day-to-day changes in their susceptibility levels and symptoms (Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1988).

**Simulator Sickness Questionnaire**

The tool used for data collection was the Simulator Sickness Questionnaire (SSQ), a well-established procedure in the literature used to quantify the subjective symptoms of simulator sickness. Developed by Kennedy, Lane, Berbaum, and Lilienthal (1993), the SSQ is a checklist of 16 symptoms whose degree of severity is rated by the participant on a 4-point Likert-type scale, including the options “none”, “slight”, “moderate”, and “severe”. Please see Appendix A. The SSQ takes about one to two minutes to complete. Four scores can be computed from the SSQ: an overall Total Severity score, and three subscale scores representing three distinct symptom clusters: Nausea, Oculomotor Discomfort, and Disorientation. Each subscale considers seven of the sixteen symptoms on the SSQ. The nausea cluster contains the
symptoms: general discomfort, increased salivation, sweating, nausea, difficulty concentrating, stomach awareness, and burping. The oculomotor cluster involves the symptoms: general discomfort, fatigue, headache, eyestrain, difficulty focusing, difficulty concentrating, and blurred vision. The disorientation cluster includes the symptoms: difficulty focusing, nausea, fullness of head, blurred vision, dizzy (with eyes open), dizzy (with eyes closed), and vertigo.

Subscale scores are calculated by multiplying symptom variable scores from each cluster (0, 1, 2, and 3 for none, slight, moderate, and severe, respectively) by their appropriate conversion formula (N=9.54, O=7.58, and D=13.92). The Total Severity score sums each cluster score (before the conversions) and applies its own conversion formula to this sum (x 3.74).

To provide a reference, a Total Severity score of 20 indicates noticeable discomfort, and a Total Severity score of 100 or more indicates that a person is actively ill or nearly so (Kennedy, Drexler, Stanney, & Harm, 1997). It should be noticed that this subjective scale produces ordinal data, heavily skewed towards the absence of symptoms. Thus, the scores are likely to be nearer to the no to low symptoms than the extreme or compromised by motion sickness side of the scores. Equal intervals between symptom scores cannot be assumed nor can it be assumed that there is a meaningful population mean due to the individual and day to day variability of the sensitivity to motion sickness scores. This leads to the conclusion that the data from the SSQ are best considered distribution-free or nonparametric in nature.

Design Characteristics of Simulators

Some characteristics of simulator design are thought to be contributors to simulator sickness. One such characteristic is the field of view (FOV) of the visual display. Depending on the purpose of the simulation, horizontal fields of view in flight simulators may range from 40° to 360° (McCauley, 1984). The research of Leibowitz, Post, Brandt, and Dichdans (1982)
suggested that peripheral visual information is important in processing dynamics and orientation, though subtended angle may be confounding; objects in the periphery usually appear larger because one is moving forward. A wider FOV provides more stimulation for the ambient visual system which may contribute to more conflict with vestibular inputs (McCauley, 1984).

Scene detail, flicker frequency, lags in the temporal presentation of the visual display, and optical distortion are other design characteristics of the simulator which may contribute to simulator sickness (McCauley, 1984). Image scale may be another factor to consider, as one study found significantly higher reports of simulator sickness in the minification (0.5) and magnification (2.0) image scale factor conditions than in the neutral condition (1.0) in a head-coupled virtual environment (Draper, Viirre, Furness, & Gawron, 2001).

Levels of Fidelity

Aviation simulation devices are often categorized into three groups: airplane simulators, airplane flight training devices (FTDs), and computer-based simulators, although the word “simulator” is often used to refer to any of these groups in common usage. However, to be considered an “airplane simulator”, a device must meet certain requirements specified by the Federal Aviation Regulations Part 61.2:

(i) is a full-size aircraft cockpit replica of a specific type of aircraft, or make, model, and series of aircraft; (ii) includes the hardware and software necessary to represent the aircraft in ground operations and flight operations; (iii) uses a force cueing system that provides cues at least equivalent to those cues provided by a 3 degree freedom of motion system; (iv) uses a visual system that provides at least a 45 degree horizontal field of view and a 30 degree vertical field of view simultaneously for each pilot; and (v) has been evaluated, qualified, and approved by the Administrator.
Airplane simulators are described in levels of fidelity, from Level A with the lowest fidelity including a 3 degree-of-freedom motion system, up to Level D with the highest fidelity including a 6 degree-of-freedom motion system, a daylight, dusk, and night visual system, etc. For detailed requirements, see Rehmann, 1995.

An airplane flight training device, according to Federal Aviation Regulations Part 61.2, (i) is a full-size replica of the instruments equipment, panels, and controls of an aircraft, or set of aircraft, in an open flight deck area or in an enclosed cockpit, including the hardware and software for the systems installed, that is necessary to simulate the aircraft in ground and flight operations; (ii) need not have a force (motion) cueing or visual system; and (iii) has been evaluated, qualified, and approved by the Administrator. FTDs are grouped into seven levels: Level 1 is currently reserved, Levels 2 and 3 are generic (they do not represent a specific airplane), and Levels 4 though 7 represent a specific cockpit for the airplane represented. Each higher level of FTD within a specific category is progressively more complex.

A computer-based simulation device is a microcomputer (e.g. a desktop) that utilizes a standard desktop computer monitor and joysticks to simulate the operational aspects of the flight deck environment, and ideally permits systematic interaction between the user and the device, provides appropriate feedback, and records user performance (Rehmann, 1995). Computer-based simulation devices vary so widely in sophistication that they have not been classified in the same manner as have airplane simulators and airplane FTDs.

Rehmann (1995) describes the somewhat vague concept of fidelity as relating to “the degree to which the characteristics of a flight simulator match those of the real airplane” Ideal levels of fidelity depend on the task and require trade-offs among cost, equipment, and transfer
of training, among other requirements and considerations. Further, several types of fidelity itself may necessitate consideration, such as objective, perceptual, equipment cue, environmental cue, etc.

Slick, Tran, and Cady (2005) studied perceptions of realism in motion-base and fixed-base driving simulators, and found that although realism was rated higher in the motion-base driving simulator, negative physical health ratings were also higher in the motion-base simulator. They suggested that training programs consider this tradeoff. In a study by Kennedy, Lilienthal, Berbaum, Baltzley, and McCauley (1989) detailed later in this review, a survey of ten different flight simulators revealed that motion-base simulators provoked more simulator sickness symptoms than did fixed-wing, fixed-base simulators/FTDs, though it is established that movement is not necessary to elicit simulator sickness (Crampton, 1990).

**Susceptibility to Motion Sickness**

Some people may seem to be much more susceptible to motion sickness than others. Several factors are thought to contribute to susceptibility, though few characteristics are consistently found to be significant predictors, according to Kolasinski (1996), who put forward three global categories of factors which may be associated with simulator sickness in virtual environments: simulator-related, task-related, and individual-related. She pointed out that “although various factors associated with both the system [simulator] and task are likely important in the prediction of sickness, for results which generalize over systems and tasks, prediction of sickness will likely have to be based primarily on characteristics of the individual.”

Women tend to experience a higher incidence of motion sickness than do men (Flanagan, May, & Dobie, 2005; Reason & Brand, 1975; Kennedy & Frank, 1985; Money 1970; Guedry
The reason for this is unknown, but hormones have been considered, as the incidence of motion sickness in women appears to be highest near menstruation and during pregnancy (Reason & Brand, 1975). Other potential contributors to the sex difference are a larger field of view exhibited by women in terms of functional peripheral fields (Burg, 1968), and a tendency for women to be more field-dependent and men to be more field-independent (Guedry, 1991a).

Kolasinski (1996) developed a model that indicated a complex relationship between predicted sickness and gender, age, mental rotation ability, and pre-exposure postural stability; she revealed that sickness is not predicted to differ for gender directly, but points at a gender interaction with mental rotation ability in its effect on sickness.

Kennedy and Frank (1985) observed that the distribution for susceptibility to motion sickness as a function of age is negatively skewed; individuals between about two years old and puberty are the most susceptible. Benson (1978) added that between puberty and about 21 years of age, susceptibility decreases rapidly, and continues to gradually decrease beyond that, trailing off to almost nothing after age 50. However, people older than 50 are not exempt from motion sickness, but the age group’s reduced susceptibility may relate to “declining vestibular afferent information with advancing age” (Guedry, 1991a).

Though people may associate motion sickness with being too warm, ambient temperature has not been shown to be a contributing factor in the onset of motion sickness (Guedry, 1991a; Money, 1970).

Other factors may have an impact on motion sickness susceptibility, such as pre-existing fatigue or sickness, unpleasant odors (Money, 1970), the task of the individual (Reason & Brand, 1975), and exposure duration (Stanney, Hale, Nahmens, & Kennedy, 2003). The hypothesis that people reporting that they are prone to motion sickness are less likely to volunteer for motion
sickness provocative experiments than those who are motion sickness resistant was examined by Flanagan, May, and Dobie (2005), and was not supported. The idea that men may be more reticent to report motion sickness in order to uphold a “macho” image has been suggested, but Dobie, McBride, Dobie, and May (2001) did not find supporting evidence of this in a questionnaire study into the effects of sex, age, and physical activities on susceptibility to motion sickness.

*Motion History Questionnaire*

The ability to identify individuals’ susceptibility to motion sickness has great application. For a current example, virtual reality (VR) simulations are gaining popularity as training instruments, and “at least some significant piece of the potential training population (perhaps 25% to 50% depending on the application) may not be able to tolerate the VR training” (Kennedy, Lane, Stanney, Lanham, & Kingdon, 2001). Attempts to identify extremely susceptible individuals began as early as World War II (Alexander, Cotzin, Hill, Ricciuti, and Wendt, 1945), and Kennedy and Graybiel (1965) later came out with a Motion History Questionnaire (MHQ). The now well-established MHQ asks participants about their history in relation to motion sickness, such as if and how frequently they get motion sick in a variety of potentially provocative environments (Kennedy, et al., 2001) such as in the car, on amusement park rides, while flying, etc. Please see Appendix B for a copy of a MHQ. Although the MHQ usually provides “useful but modest predictive validity” (Kennedy, et al., 2001), Kennedy, et al. (2001) found a .408 and .448 correlation between four combined composite scores they developed in two large samples in a virtual reality based study of motion sickness.
Incidence of Motion Sickness

The incidence of simulator sickness is usually higher among pilots with little or no experience in the simulator (Money, 1991). Interestingly, many studies have often found comparable or even higher simulator sickness incidence rates in pilots with extensive aircraft experience but little simulator experience (Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1988; Money, 1991; Crowley, 1987). This latter finding supports the sensory conflict theory: the seasoned pilot’s past experiences are so ingrained that a small incongruity in the simulator that does not meet the pilot’s expectations may cause a strong conflict.

Most of the literature concerning the incidence of motion sickness and/or simulator sickness refers to military studies. Havron and Butler were the first to report simulator sickness in 1957, terming it only “motion sickness” with the footnote: “This term is used here to refer to the sickness encountered, in the 2-FH-2 [FTD]” While studying the effectiveness of a fixed-base, curved projection screen 2-FH-2 helicopter flight trainer research tool, the sickness problem became so acute that personnel decided to investigate the “sickness induced by the 2-FH-2 and factors related to it”. They developed a sickness questionnaire and 77% of the 2-FH-2 helicopter and autorotation trainer pilots reported having symptoms like nausea, dizziness, vertigo, headaches, blurred vision, sweating, and “double vision.” The sickness was observed as “quite persistent”, and lasted overnight in some cases. Some respondents reported “getting over their sickness after a few hops [sessions]”, and some did not, and some reported delayed symptoms.

Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley (1989) surveyed 1,186 U.S. Navy simulator flights, spanning ten different flight simulators in six locations. Participants were Naval and Marine Corps aviators and student aviators in normal flight status and thus judged to
be in good health. Prior simulator exposure ranged from one to thirty hops; some participants had possibly already adapted or habituated to the simulation. Using the Motion Sickness Symptom Checklist (MSSC), which is quite similar to the Simulator Sickness Questionnaire (SSQ) utilized by the current study, incidence of at least one simulator sickness symptom (vomiting, retching, increased salivation, nausea, pallor, drowsiness, or sweating) ranged from 10% to 60%, depending on the simulator. Almost no vomiting/retching resulted (0.2%). Motion-base simulators with multiple, wide field-of-view cathode ray tube displays seemed to be the most provocative in terms of eye-strain symptoms, and motion-base helicopter simulators with multiple, wide field-of-view cathode ray tube displays seemed to be the most provocative simulators in terms of nausea-related symptoms. Fixed-wing, fixed-base, dome display simulators provoked the least incidence of symptoms.

In a U.S. Army study, Dr. John Crowley (1987) surveyed 112 helicopter pilots on the AH-1 Cobra Flight Weapons Simulator, which is a motion-base simulator with a laser-enhanced photomultiplier tube receptor bank visual system. One screen was located in the front seat, and two were in the rear pilot’s station separated by 11 degrees, and each screen had a 48 by 36 degree field of view. This simulator elicited reports of “some sensation of motion sickness” by 40% of the participants using the Diagnostic Criteria for Simulator Sickness (modified SSQ). Interestingly, pilots who reported having symptoms of simulator sickness had significantly more total flight time than those who did not report experiencing symptoms, and pilots with more than 1,000 hours in the Cobra helicopter were significantly more likely to develop simulator sickness than those with less than 1,000 hours. Conversely, the incidence of simulator sickness symptoms was negatively correlated with experience in this simulator, suggesting some form of adaptation. A policy of mandatory grounding after a Flight Weapons Simulator session was instituted as a
result of this study, which medically restricts aviators from flying duties until the beginning of the next duty day. This may be a policy that others who use high fidelity FTDs should consider seriously.

Based on this small sample of studies alone, the incidence of “some sensation of” simulator sickness ranges from 10% to 77% depending on the simulator.

Adaptation

Many motion and simulator sickness studies have suggested or noted some form of adaptation or habituation (Crowley, 1987; Lackner & Lobovits, 1978, Harm & Parker, 1994; Stroud, Harm, & Klaus, 2005; Crampton, 1990). Individuals who repeatedly experience provocative environments like simulators, aircraft, roller-coasters, etc. may build a tolerance to sickness-inducing stimuli and learn adaptive behaviors that minimize adverse effects (Kolasinski, 1995). In fact, preexposure to provocative stimuli before space flight shows promise as an effective countermeasure to space motion sickness (Harm & Parker, 1994; Stroud, Harm, & Klaus, 2005). Crampton (1990) observed that one of the strongest, most potent “fixes” for simulator sickness is adaptation, and he gave the guideline to optimize adaptation: “there should be a minimum of 1 day and a maximum of 7 days between simulator training sessions”

Usually this modification of sensory processes that enables users to function more successfully with increasing adaptation levels in an environment is looked upon as a positive development. However, Kennedy and Frank (1985) pointed out that when the “adapted” individual returns to the “normal” environment, the modified sensory processes most probably will not be optimal, and the “readaptation” must occur in the opposite direction for the individual to function optimally in the “normal” environment. Virtual environments (VEs) often provoke adaptation that aids the user while in the VE, but creates its own problems when users must
return and readapt to the real world (Stanney and Kennedy, 1997). Kennedy and Frank (1985) observed that to rely on the reduction or elimination of symptoms through adaptation “misses the point of the requirement for minimum human factors engineering design criteria, and may also impact on safety of subsequent flying and other activities”. Benson (1988) pointed out that some individuals continue to suffer from motion sickness even after very repetitive exposure to provocative motion in automobiles, thus the “question of experience remains open”.

*Special Problems Associated with Adaptation to Simulator Sickness*

Aside from the obvious problems simulator sickness invokes, like reduced performance while piloting the simulator, simulator sickness may be the root of some other problems, delineated by McCauley (1984). First, training may be compromised because of distraction and decreased motivation. Behaviors that the trainee may develop in the simulator to avoid symptoms (e.g. not looking out the window, reducing head movements, avoiding aggressive maneuvers) may not be appropriate for flight.

Secondly, because symptoms and aftereffects are generally adverse, the trainee may become reluctant to return for subsequent training sessions, and also have less confidence in the simulator training (McCauley, 1984).

Thirdly, ground safety could be compromised. Some people experience aftereffects such as disequilibrium, which is potentially hazardous for trainees when exiting the simulator or driving home (McCauley, 1984). Although suggestion may be capable of “inducing” motion sickness (if a pilot sees another pilot who is sick, it can be contagious. Crampton, 1990), pilots should be warned about the aftereffects of simulator sickness so that they do not attempt things like roof repair following a simulated flight (Money, 1991).
Lastly, flight safety could be compromised in much the same way. McCauley (1984) points out that although no direct evidence exists showing a relationship between aftereffects of simulator sickness and accident probability, “one could predict that adaptation to a simulator’s rearranged perceptual dynamics would be counterproductive in flight. Indeed, anecdotal reports from the Royal Air Force in the early 1970s indicate that flight instructors claimed increased susceptibility to disorientation in flight hours after a simulator session.”

Statement of Hypotheses
The following hypotheses were generated to guide the research efforts contained in this report.

1. It is expected that non-pilots will report greater sensitivity to motion sickness than will pilots as assessed by a composite score of the MHQ.

   The literature reports a very wide range of general motion sickness incidence, and does not well-establish incidence of motion sickness in career fields where motion or simulated motion is commonplace, thereby giving little information to compare these two groups. This hypothesis seeks to explore whether people might “self-select” into or out of career paths that necessarily involve motion or simulated motion based on their susceptibility to motion sickness.

2. It is expected that time in training (early vs. late) will impact motion sickness symptom severity as assessed by the SSQ Total Severity score, specifically:

   2a. In the FTD, pilots tested earlier in the AS132 curriculum at ERAU will report greater severity of motion sickness symptoms as assessed by SSQ Total Severity scores
than those tested later in the curriculum.

2b. In the **aircraft**, pilots tested earlier in the AS132 curriculum will report greater incidence and severity of motion sickness symptoms as assessed by the SSQ Total Severity Score than those tested later in the curriculum.

The evidence cited above for adaptation and the role of experience in reducing the symptoms of motion sickness would argue that “late” in training, the student pilots will have more experience and hence more adaptation than those tested “early” in training.

3. It is expected that *lesson content (extreme vs. non-extreme)* will impact motion sickness symptom severity as assessed by the SSQ Total Severity score, specifically:

3a. “Extreme” lessons will elicit more severity of symptoms as assessed by the SSQ Total Severity score than will “non-extreme” lessons in the **FTD**.

3b. “Extreme” lessons will elicit more severity of symptoms as assessed by the SSQ Total Severity score than will “non-extreme” lessons in the **aircraft**.

The extreme lessons are those that involve a high degree of vestibular disruption. Hence, the extreme lessons should be associated with a higher SSQ score than the non-extreme lessons.
4. It is expected that type of *practice device* will impact motion sickness symptom severity as assessed by the SSQ Total Severity score, such that scores will be different for pilots tested in actual flight compared to pilots tested in simulated flight.

Since more somatosensory stimulation is associated with actual flight as opposed to virtual flight in an FTD, the additive contribution of factors in motion symptoms of the actual flight might be greater than in virtual flight. However, the possible clash between motion sensory expectancy and actual motion sensory experience in the fixed-base FTD might elicit more symptoms than in the actual flight. Thus this hypothesis is non-directional.

**METHOD**

Students were selected as participants from classes at Embry Riddle Aeronautical University at the Daytona Beach campus over 3 semesters in 2005 and 2006 as specified below. This study was funded in part by a grant from the Link Foundation to assess simulator sickness.

**Participants**

For Hypothesis 1, participants included 43 students from the pilot population (only new aviation students enrolled in Aeronautical Science (AS) 132: Basic Aeronautics I at Embry-Riddle Aeronautical University’s Daytona Beach campus), and 50 students from the non-pilot population (students from undergraduate Psychobiology and Human Factors in Air Traffic Control classes and undergraduate/graduate Work Physiology classes). All student pilots were required to have at least a Class III medical certificate.
Experiments for Hypotheses 2, 3, and 4 used only new aviation students enrolled in AS (Aeronautical Science) 132: Basic Aeronautics I at Embry-Riddle Aeronautical University’s Daytona Beach campus. As part of their pilot-training curriculum, the students are subjected to fourteen one-hour activities of flight training in Embry-Riddle’s Frasca Cessna 172 fixed-base flight training devices, located in Embry-Riddle’s Center for Advanced Simulation, as well as fourteen one-hour activities of flight training in Cessna-172 aircraft. The twenty-eight lessons are listed broken down into their respective topic summaries in Table 1, and will be referenced by Topic Summary throughout this paper.

Table 1. FTD and Flight Activities Broken Down into Topic Summaries

<table>
<thead>
<tr>
<th>Topic Summary</th>
<th>FTD Lesson(s)</th>
<th>Flight Lesson(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Normal Maneuvers and Procedures</td>
<td>1,2</td>
<td>1</td>
</tr>
<tr>
<td>2 Slow Flight and Stalls</td>
<td>3,4</td>
<td>2</td>
</tr>
<tr>
<td>3 Takeoffs, Ground Reference, Emergency Procedures</td>
<td>5,6</td>
<td>3</td>
</tr>
<tr>
<td>4 Landings, Traffic Pattern, Airport Environment</td>
<td>7,8</td>
<td>4,5</td>
</tr>
<tr>
<td>5 Advanced Stalls, Forward Slips, Spins, and Go-Around</td>
<td>9,10</td>
<td>6,7</td>
</tr>
<tr>
<td>6 Flight by Reference to Instruments, Unusual Attitudes</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>7 Short/Soft-Field Takeoff and Landing, LAHSO</td>
<td>12</td>
<td>9,10</td>
</tr>
<tr>
<td>8 Pre-Solo Checkride</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>9 Solo Operations</td>
<td></td>
<td>12,13</td>
</tr>
<tr>
<td>10 Cross-Country Operations, NAS, Wx Information</td>
<td>13,14</td>
<td>14</td>
</tr>
</tbody>
</table>
Each Topic Summary will be considered either “Extreme” in terms of expected motion-sickness-evoking maneuvers, or “Non-extreme” in these terms. The “Extreme” category will include Topic Summaries 2 (Slow Flight and Stalls), 3 (Takeoffs, Ground Reference, and Emergency Procedures), 5 (Advanced Stalls, Forward Slips, Spins, and Go-Around), and 6 (Flight by Reference to Instruments, Unusual Attitudes). The “Non-extreme” category will include the remaining Topic Summaries: numbers 1, 4, 7, 8, 9, and 10.

Because AS 132 contains 14 FTD activities and 14 flight activities, data were collected from each of 130 students at a varying point of course completion ranging from the student’s very first flight or FTD activity, to the 14th flight or FTD activity. Pilots tested within the first seven FTD or flight activities were considered “early” in training and considered as a group, and those tested in FTD or flight activities 8-14 were considered “late” in the training and considered as a second group. Students may have been surveyed one time in the FTD, and one time in the aircraft. Participants included AS132 students that completed both the pre- and post-SSQs for a simulated flight experience in a Frasca Cessna 172 flight training device (FTD) and/or an actual flight experience in a Cessna 172.

Materials

For Hypothesis 1, materials included the paper-and-pencil MHQ (See Appendix B).

Experiments for Hypotheses 2, 3, and 4 utilized two laptop computers provided by the Human Factors and Systems Department, each outfitted with an electronic version of the SSQ (See Appendix A) in MicroSoft Access format. Also, Embry-Riddle Aeronautical University’s six fixed-base Frasca Cessna-172 Level 6 Flight Training Devices were utilized by the participants on their normally scheduled basis. The visual images in the FTDs are projected onto
220° curved screens. A side view of a representative FTD is pictured Figure 1, and a rear view in Figure 2.

Figure 1. Side View of FTD

Figure 2. Rear view of FTD
Also, Embry-Riddle Aeronautical University’s Cessna-172 aircraft were utilized by participants on their normally scheduled basis. A view of a representative aircraft is pictured in Figure 3.

![Figure 3. One of Embry-Riddle's Cessna 172 Aircraft](image)

**Design**

Because MHQ and SSQ data are not normally distributed, and MHQ and SSQ responses are ordinal data, nonparametric statistical analyses were employed. This study consists of several two-group comparisons, assessed with the Mann-Whitney U test (nonparametric equivalent to the parametric independent samples t-test). Any reports of significance are based on an alpha level less than 0.05.

Hypothesis 1 was tested using two-group comparisons. Pilot or non-pilot status and Motion History Questionnaire (MHQ) responses were the independent variables. MHQ composite score was the dependent variable.

Hypothesis 2 was tested with two, two-group comparisons. Time in training was the independent variable, and SSQ Total Severity score was the dependent variable. SSQ scores of pilots tested early in the training (Activities 1-7) in the FTD were compared with those tested late in the training (Activities 8-14) in the FTD. Likewise, SSQ scores of pilots tested early in the
training (Activities 1-7) in the aircraft were compared with those tested late in the training (Activities 8-14) in the aircraft.

Hypothesis 3 was tested with two two-group comparisons. Lesson content was the independent variable, and SSQ Total Severity score was the dependent variable. SSQ scores from pilots tested in “extreme” lessons were compared with those tested in a “non-extreme” lesson in the FTD. Likewise, SSQ scores from pilots tested in “extreme” lessons were compared with those tested in a “non-extreme” lesson in the aircraft.

Hypothesis 4 was tested via a two-group comparison. Training device was the independent variable (FTD vs. aircraft). SSQ Total Severity score was the dependent variable.

Procedure

For Hypothesis 1, pilot students were asked to complete the MHQ, which takes about 6 minutes, after an AS 132 class. Non-pilots were asked to complete the MHQ during biopsychology, work physiology, or human factors in air traffic control classes.

For Hypotheses 2, 3, and 4, pilot students eligible for the survey (meaning AS 132 students) were tagged with “Take Survey” written in the comment box in ETA (Education Training Administration). ETA is a computerized system used for check-in at the dispatch desks at the Advanced Flight Simulation Center and the Gill Robb Wilson Flight Center/Tine W. Davis Building on Embry-Riddle’s Daytona Beach campus, for FTDs and aircraft, respectively. Minutes before a qualifying student’s scheduled FTD or flight activity, they were asked by the dispatcher if they would like to complete the SSQ, which takes about one minute. This was used as a screening tool to exclude pilots with pre-existing sickness from the current study. As a precedent established by Stanney, Hale, Nahmens, & Kennedy (2003), participants’ preexposure SSQ score must have fallen at or below 7.48 to qualify them to be in good health prior to the
experiment. Thus, data from participants whose preexposure SSQ score fell above 7.48 were not included in the analyses. The survey was completed electronically via a designated laptop computer located at the check-in desk in the Advanced Flight Simulation Center, and a designated laptop computer located at the paystation at the Flight Center. An electronic briefing of the study preceded the questionnaire, and emphasized that by completing the questionnaire, the participant would indicate his or her approval to participate in the study, establishing informed consent. Anonymity within the Aeronautical Science Department was ensured. Please refer to Appendix C.

Within minutes of completing the FTD lesson or flight, the student completed the same SSQ again on their way out. The SSQ asked participants to report the most severe descriptor of each symptom they had experienced in the last hour.

In a latter portion of the study, paper-and-pencil SSQ surveys were utilized rather than the identical electronic version to facilitate data collection. As pilot students were staggered in their training activities at any given time, the administration of different survey forms was not experienced by any one group of pilots more than any other (e.g. those participating during early or late lessons, etc.). Paper-and-pencil participants were made aware verbally during class that participation was completely voluntary, anonymous within the Aeronautical Science Department, and that filling out pre and post SSQs implied informed consent.

RESULTS

As noted in the Design section, nonparametric statistical analyses were utilized in this study due to the non-normal distribution of MHQ and SSQ data (these distributions typically have a positive skew because most people do not experience many motion sickness symptoms), as well as the ordinal nature of MHQ and SSQ data. This study consists of several two-group
comparisons, assessed with the Mann-Whitney U test (nonparametric equivalent to the parametric independent samples t-test). Any reports of significance are based on an alpha level less than 0.05.

Hypothesis 1

It was expected that non-pilots would report greater sensitivity to motion sickness than would pilots as assessed by the MHQ. A logistic regression was attempted so as to be able to predict group membership (pilot or non-pilot) from the set of 16 variables (all MHQ questions). However, the lack of a strong relationship prevented a valid model from being constructed.

Thus, an MHQ composite score was created (see Kennedy et al., 2001 for theoretical foundation and precedent). Seven of the sixteen MHQ questions were included in this composite score, illustrated in Table 2.

Table 2. MHQ Questions Included in Composite Score

<table>
<thead>
<tr>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>How often would you say you get airsick?</td>
</tr>
<tr>
<td>From your experience at sea, how often would you say you get seasick?</td>
</tr>
<tr>
<td>How often do you get carsick?</td>
</tr>
<tr>
<td>How often do you get motion sick while reading in the car?</td>
</tr>
<tr>
<td>Do amusement park rides make you motion sick?</td>
</tr>
<tr>
<td>In general, how susceptible to motion sickness are you?</td>
</tr>
<tr>
<td>How often have you been dizzy in the past year?</td>
</tr>
</tbody>
</table>

A Mann-Whitney U test determined that no population differences existed between MHQ composite scores of the pilot group (N=43) and non-pilot group (general population) (N=50), (U(92)=872, p=.058). Figures 4 and 5 illustrate the frequency distributions of the pilot and non-pilot groups’ composite MHQ scores.
In order to explore the possibility that one or more of the composite scores were diluting any differences that might exist, the seven questions were analyzed individually. Three of the
seven questions differed significantly, namely those inquiring about seasickness, carsickness while reading, and motion sickness from amusement park rides as shown with asterisks in Table 3. In each of the three, non-pilots reported significantly more motion sickness symptoms, or more severe ones, than did pilots.

Table 3. MHQ Composite Questions and Calculations

<table>
<thead>
<tr>
<th>Question</th>
<th>U</th>
<th>p</th>
<th>% Never</th>
<th>% Rarely</th>
<th>% Sometimes</th>
<th>% Frequently</th>
<th>% Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>How often would you say you get airsick?</td>
<td>1144</td>
<td>0.256</td>
<td>83.3</td>
<td>16.7</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>From your experience at sea, how often would you say you get seasick?</td>
<td>974.5</td>
<td>0.0495*</td>
<td>66.7</td>
<td>20.8</td>
<td>8.3</td>
<td>2.1</td>
<td>0</td>
</tr>
<tr>
<td>How often do you get carsick?</td>
<td>1080</td>
<td>0.13</td>
<td>79.2</td>
<td>20.8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>How often do you get motion sick while reading in the car?</td>
<td>982</td>
<td>0.0445*</td>
<td>62.5</td>
<td>20.8</td>
<td>12.5</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>Do amusement park rides make you motion sick?</td>
<td>963.5</td>
<td>0.0195*</td>
<td>83.3</td>
<td>14.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>In general, how susceptible to motion sickness are you?</td>
<td>1094</td>
<td>0.322</td>
<td>39.6</td>
<td>45.8</td>
<td>6.3</td>
<td>4.2</td>
<td>0</td>
</tr>
<tr>
<td>How often have you been dizzy in the past year?</td>
<td>1016</td>
<td>0.193</td>
<td>29.2</td>
<td>33.3</td>
<td>27.1</td>
<td>4.2</td>
<td></td>
</tr>
</tbody>
</table>
Non-pilots were not operationally assessed for motion and simulator sickness via survey as the pilots were, so a rate of incidence could not be calculated. In the pilot population, 4.5% of the pilots experienced “noticeable discomfort” based on Kennedy, Drexler, Stanney, and Harm’s (1997) SSQ Total Score threshold of 20.

Hypothesis 2

It was predicted that students in the last half of the course would present lower SSQ Total Severity scores than would students in the first half of the course. This would correspond to a training effect, that exposure to motion sickness inducing situations or sensory conflict might reduce the sensitivity to motion. Differences between the SSQ Total Scores of the “early” distributions and the SSQ Total Scores of the “late” distributions were found in the aircraft condition, but not in the FTD condition.

In the FTD, no differences (U(60)=384, p=.08) were found between the early group (N=31) and the late group (N=30). Figures 6 and 7 illustrate the frequency distributions of the FTD early and late groups.
Figure 6. Frequency Distribution: FTD Early

Figure 7. Frequency Distribution: FTD Late
In the aircraft, however, differences between the early group (N=32) and the late group (N=39) were found (U(70)=484, p=.03), with the late group reporting less motion sickness symptoms or less severe ones than did the early group. Figures 8 and 9 illustrate the frequency distributions of the aircraft early and late groups.

Figure 8. Frequency Distribution: Flight Early
Because of the heavy skew of the SSQ distribution as shown in Figs. 8 and 9, and because pilots reported even fewer motion sickness symptoms than the general population as shown in Figs 4 and 5 above, further exploration of this early vs. late effect compared only those pilots who actually did experience motion sickness symptoms. To better estimate a definition of those who ‘actually did experience motion sickness symptoms’, a standard deviation was calculated for the early and late groups in both the FTD and the aircraft, and only those SSQ scores above the first positive standard deviation for each group were included in this examination. This attempted to identify the motion sensitive individuals within the pilot population under study. In the FTD, this revealed that the late group (N=4) had significantly higher SSQ scores than did the early group (N=7) with (U(10)=1, p=.012), which is in the opposite direction of what was predicted.
In the aircraft, this procedure of omitting those within the first standard deviation of scores, similarly showed no differences ($U(17)=32, p=.596$) between the early group ($N=11$) and the late group ($N=7$).

Hypothesis 3

It was predicted that students tested in the “non-extreme” modules would present lower SSQ Total Severity scores than would students in the “extreme” modules due to the increased sensory conflict of the “extreme” modules. The differences between the SSQ Total Scores of the “extreme lesson content” and the SSQ Total Scores of the “non-extreme lesson content” were not different for both the FTD condition and the aircraft condition.

In the FTD, no differences were found ($U(60)=414, p=.46$) between the extreme group ($N=21$) and the non-extreme group ($N=40$). Figures 10 and 11 illustrate the frequency distributions of the FTD non-extreme and extreme subgroups.

FTD Non-extreme ($N=40$)

Figure 10. Frequency Distribution: FTD Non-Extreme
Similarly, in the aircraft no differences were found ($U(70)=485, p=.18$) between the extreme group ($N=23$) and the non-extreme group ($N=48$), illustrated in Figures 12 and 13.

Figure 11. Frequency Distribution: FTD Extreme

Figure 12. Frequency Distribution: Flight Non-Extreme
Hypothesis 4

It was predicted that SSQ Total Severity scores would be different for pilots tested in actual flight compared to pilots tested in simulated flight. No differences were found between the SSQ Total Scores from the FTD group and those from the aircraft group ($U(131)=2089$, $p=.687$). Flight and FTD frequency distributions of SSQ Total Scores are shown in Figures 14 and 15.
In the event that an interaction effect might exist between training device (FTD vs. aircraft conditions) and experience (early vs. late), each device was compared on the basis of
early and late groups. Thus, the early FTD group was compared to the early aircraft group, as well as the two late groups. The early groups (FTD N=31, aircraft N=32) were not different from each other. The early FTD group seemed to have a higher SSQ scores than the early aircraft group but this was not confirmed by statistical comparison (U(62)=374, p=.057). Similarly, the late groups (FTD N=30, aircraft N=39) were not different from each (U(68)=495, p=.199).

As in Hypothesis 2, these results were evaluated in those pilots who actually did experience motion sickness symptoms. Again, the standard deviation was calculated for the early and late groups in both the FTD and the aircraft. Only those pilots whose SSQ scores were above the first positive standard deviation for each group were included in this examination. When both early groups (FTD N=7, aircraft N=11) were assessed, no differences were found (U(17)=36.5, p=.860). However, this procedure did reveal a difference between the late FTD group (N=4) and the late aircraft group (N=7), with the late FTD group scored higher on the SSQ than the late aircraft group (U(10)=3.5, p=.042). Frequency distributions of the significantly different late groups are shown in Figures 16 and 17.
To calculate overall incidence rates of motion sickness and simulator sickness, Kennedy, Drexler, Stanney, and Harm’s (1997) SSQ Total Score threshold of 20 was utilized to indicate
"noticeable discomfort". In the aircraft, 3 out of 71, or 4.2% of pilots experienced "noticeable discomfort". In the FTD, 3 out of 61, or 4.9% of pilots experienced "noticeable discomfort".

**SSQ Subscale Evaluation**

SSQ subscale scores (Nausea (N), Disorientation (D), and Oculomotor Disturbance (O)) from the overall FTD and aircraft conditions were examined individually to see if symptom profiles differed between the FTD and aircraft conditions. In the FTD condition, cluster scores took on an O>N>D profile, while cluster scores in the aircraft condition took on a N>O>D profile. That is, in the FTD, oculomotor disturbance cluster symptoms were scored the highest, followed by nausea, followed by disorientation, while in the aircraft, nausea symptoms were scored the highest, followed by oculomotor disturbances, followed by disorientation. Although these differences were not statistically substantiated, according to Stanney and Kennedy (1997), the FTD profile matches typical simulator sickness profiles, but airsickness usually has a N>D>O profile (Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992) rather than the clear N>O>D profile found here with the aircraft group. There were no differences between the aircraft and FTDs in any of the matched cluster scores (Aircraft N vs. FTD N, Aircraft O vs. FTD O, and Aircraft D vs. FTD D) (see Table 4).

**Table 4. Subscale Calculations for Aircraft and FTD**

<table>
<thead>
<tr>
<th></th>
<th>% of Total</th>
<th>U</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>N Aircraft (N=71)</td>
<td>48.82</td>
<td>1967.5</td>
<td>0.257</td>
</tr>
<tr>
<td>N FTD (N=61)</td>
<td>29.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O Aircraft (N=71)</td>
<td>42.35</td>
<td>2113.5</td>
<td>0.762</td>
</tr>
<tr>
<td>O FTD (N=61)</td>
<td>49.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Aircraft (N=71)</td>
<td>9.41</td>
<td>2049.0</td>
<td>0.348</td>
</tr>
<tr>
<td>D FTD (N=61)</td>
<td>20.69</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Further Examination**

**Individual FTDs**

Seven Frasca Cessna 172 FTDs were utilized by participants in this study (called C1, C2, C4, C5, C6, C7, and C8). SSQ Total Scores per FTD were examined with a Kruskal-Wallace test to examine the possibility of FTD variation. No significant differences were found.

Subscale scores (N, O, D) were also examined among the seven devices, which did not differ either. Though no differences were found, FTDs C1, C4, and C6 showed slightly higher scores on the SSQ Total Severity Score and all three subscales.

**DISCUSSION**

**Two populations?**

The extant literature implies that there is a wide range of general motion sickness generating conditions, and yet does not establish incidence of motion sickness in career fields where motion or simulated motion is commonplace. This study sought to answer the question “In general, are pilots less prone to motion sickness than the general population?” In other words, might people “self-select” into or out of careers that necessarily involve motion or simulated motion based on their ability to handle it? If the answer to this question is that yes, self-selection is involved in motion-oriented careers, a greater motivation to research motion sickness triggers, countermeasures, etc. might be argued as necessary.

Using non-pilot and pilot students as representative samples of the aforementioned groups, this study found a tendency in the MHQ composite scores that the two populations were
different (U(92)=872, p=.058), with the former reporting higher scores than the latter. This suggests a possible career self-selection on the part of the pilots over non-pilots although these results are far from conclusive. It is interesting to note that the three composite questions that did significantly differ inquired about seasickness, carsickness, and motion sickness on amusement park rides, yet the questions pertaining to airsickness and general motion sickness susceptibility were not significantly different. There may be some dimensions of motion sickness that can distinguish pilots from non-pilots and that also argue for self selection.

A limitation of this study is that a level of health was established in the pilot population (Class III medical certificate requirement), but such a standard was not imposed on the non-pilot population. Given the generality of the MHQ, the confounding capability of this uncontrolled variable appears minor, but the implications are uncertain.

Experience

It was predicted that training experience would affect motion sickness symptoms such that by the time pilots got to the “late” section of the class (the last half), they would have adapted to the motion or simulated motion and would experience fewer symptoms than pilots still in the “early” section of the class (the first half). In the aircraft this appears to be true, as the late group scored significantly lower on the SSQ than did the early group (U(70)=484, p=.03). Interestingly, however, in the FTD, the opposite trend appeared to occur, with higher SSQ scores in the late group. When data were examined more closely by excluding data within the first standard deviation*, late group pilots actually scored significantly higher than the early group on the SSQ (U(10)=1, p=.012).

Though sample size was small, unequal, and the data within the first standard deviation of data were omitted*, this phenomenon may be the most interesting finding of this study and
warrants further research. As noted earlier, many studies, when comparing to pilots with little or no experience in the simulator, have found comparable or higher simulator sickness incidence rates in pilots with extensive aircraft experience but little simulator experience (Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1988; Money, 1991; Crowley, 1987). However, “late group” pilots in this study hardly match that profile—though they have had at least seven previous exposures to simulators and roughly as many aircraft flights, this is not considered “extensive” aircraft experience, nor is it considered “little to no” simulator experience.

Perhaps this phenomenon can be partially explained by the sensory conflict theory, in that by alternating between FTD and aircraft throughout their initial training, pilots “notice” the incongruencies more after a bit of experience. Why then, did pilots’ symptoms significantly improve over time in the aircraft, yet show the effects of these incongruencies over time only in the FTD? Perhaps the answer lies in the difference between simulator sickness and airsickness and their respective profiles. Further research here could include assessment of pilots in the class that follows AS132: does the worsening trend continue throughout training for these susceptible individuals (if they exist, based on their position outside the first standard deviation)?

Does it plateau or begin to improve, and where? Answering these questions could be important to the simulation industries in terms of design, to training industries in terms of curricula, to medical and behavioral research in terms of countermeasures, and to individuals in terms of expectations and consideration of countermeasures.

The finding that pilots differed from non-pilots in some of their MHQ results suggests that there may be a subpopulation of motion sensitive pilots within a majority of pilots who are less sensitive. This possibility was evidenced again by the comparison of flight vs. FTD in terms of the SSQ scores. It would seem useful for future research to select pilots from their
MHQ results who are sensitive and those who are less sensitive to motion and to repeat the study on those populations. If pilots are more resistant on the whole, if some sort of self selection for pilot training is going on, then the results on the motion sensitive pilots may be diluted by these less sensitive pilots. The motion sickness that results in the sensitive population could have dramatic consequences for the training even though they may be a small percent of the population of pilots at large. The effects of motion countermeasures should be evaluated in both populations but should similarly focus on the motion sensitive pilot, identified by the three questions from the MHQ.

* It was discerned that due to the nonparametric nature of the data, use of tertiles or quartiles would be more appropriate as sectioning agents than the “first standard deviation” method utilized in this study, as it is a parametric function.

Lesson Content

It was predicted that more “extreme” lessons (i.e. spinning, stalling, unusual attitudes, etc.) would elicit greater motion sickness symptoms in both training devices than “non-extreme” lessons. This was analyzed mainly to assess whether lesson content could be a confound in the early/late comparisons. Surprisingly, no differences were found, and thus this factor is ignored in the other comparisons.

The reason for this “robustness” of symptoms to type of lesson is unclear. Perhaps “non-extreme” lessons are sufficient to elude symptoms from a susceptible individual, and any motion or simulated motion more extreme than that does not further impact the symptoms.

Training Device

It was predicted that SSQ data collected from pilots after an FTD and that from pilots after flight would differ. The FTDs utilized were fixed-base, which usually bring about fewer
symptoms than motion-based simulators, yet their visual systems also have a wide field of view (220°), which usually contributes to symptom onset. Thus directional prediction of FTD and aircraft differences was difficult, and the hypothesis was written without directional specification. In addition, pilots alternate between FTD and aircraft almost every lesson during their training curriculum, which is a possible confound when comparing training device, but though a pilot may have two lessons a day, they do not switch training devices in the same day. Thus a pilot tested in the aircraft group has had at least a day away from the FTD, and vice versa.

Overall FTD and aircraft scores were not significantly different. These scores were then separated into early and late groups, and the two early groups were compared, as well as the two late groups. These comparisons found no significant experience-related difference between the FTD and the aircraft. These same scores were then compared after omitting any scores falling below the first positive standard deviation* in order to focus on the small portion of the pilots who actually did experience symptoms. Interestingly, while the two early groups were not significantly different, this analysis showed that the late FTD group scored significantly higher than the late aircraft group. This stands to reason given that using the same procedure in Hypothesis 2, the FTD late group scored significantly higher than the FTD early group itself.

The fact that little evidence was found for motion symptoms in the FTD should be useful information for the use of FTD and training. Link foundation scientists have found that FTD training can be effective and data are presented here that it is also less stressful, in terms of motion sickness, than actual flight. Students should be able to focus on the module and practice the maneuvers rather than quelling their nausea.
Cluster profiling

It was expected that FTD and aircraft symptom cluster profiles would differ, as a fixed-base FTD is quite different from an aircraft. In the FTD, cluster profiling showed an O>N>D

* Again, it was discerned that due to the nonparametric nature of the data, use of tertiles or quartiles would be more appropriate as sectioning agents than the “first standard deviation” method utilized in this study, as it is a parametric function.

The contributor for the difference is that these pilots are alternating between fixed-base FTD and aircraft almost every lesson, which could affect their oculomotor symptoms (general discomfort, fatigue, headache, eyestrain, difficulty focusing, difficulty concentrating, and blurred vision) more than their disorientation symptoms (difficulty focusing, nausea, fullness of head, blurred vision, dizzy (with eyes open), dizzy (with eyes closed), and vertigo).

This phenomenon may warrant further research, as the way the curriculum is set up may be too demanding on the oculomotor system, and may be easily adjusted (e.g., wait an extra day after an FTD lesson to fly aircraft, tweak a component of the FTD visual system, etc.) Perhaps the FTD has no interaction with this aircraft profile difference, and the difference is due to oculomotor conditions in the aircraft such as glare. Or, perhaps the difference is not from an upward deviation in oculomotor disturbances from the typical airsickness profile, but from lesser experience of disorientation symptoms.

Individual FTDs

Seven FTDs were utilized in this study, and though they were all identical models, analyses on each FTD’s respective SSQ scores were done to assess possible differences due to a component inherent in an individual FTD. For example, a significantly larger number of
oculomotor symptoms elicited by one certain FTD may be diagnostic of a problem in the visual system of that FTD, such as a dim bulb or a low flicker rate. Also, as shown in the Advanced Flight Simulation Center (AFSC) Bay Layout map in Appendix D, two FTDs (C5 and C6) are in view of a mezzanine walkway on which people often walk during lessons, which was considered a possible contributor to taking one out of vection, possibly affecting SSQ scores from those two FTDs.

No significant differences were found among any of the FTDs in SSQ Total Score or in any of the cluster scores. FTDs C1, C4, and C6 showed slightly higher scores than the others. The walkway didn’t seem to affect SSQ scores, as C6 was among the highest score provokers while C5 was among the lowest score provokers.

This analysis may warrant further research due to small and unequal sample size in each FTD. Also, this type of analysis may be good practice to continue in the AFSC Bay for regular and diagnostic maintenance.

RECOMMENDATIONS

Further research is highly recommended in the area of motion and simulator sickness among student pilots, particularly that as affected by experience. A within-subjects, repeated measures, longitudinal study would be ideal for this exploration. Though sample sizes in this study were at least 30 for the main comparisons, the between-subjects design is a limitation in terms of power when considering the effects of experience. It may be useful based on these findings to pre-select the pilot populations into motion sensitive and motion insensitive based on MHQ scores.
Though it is difficult to obtain data from pilots trained only in FTDs and pilots trained only in aircraft, as their normal curriculum involves the alternation of both training devices, the accomplishment of this feat may be useful because of the elimination of an interaction confound. Cluster profiling would also be of interest here to see if the airsickness profile matched the one found in the current study (N>O>D), or the “normal” airsickness profile reported in the literature (N>D>O), which, in the case of the latter, might point at an interaction of devices.

Ongoing regular assessment of individual FTDs in terms of SSQ scores is also recommended as a means of regular and diagnostic maintenance.
REFERENCES


visually-induced motion sickness. *Aviation, Space and Environmental Medicine, 76(7), 642-646.


### APPENDIX A

#### Simulator Sickness Questionnaire

<table>
<thead>
<tr>
<th>Symptom</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>INDICATE A or B or C or D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. General discomfort</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>2. Fatigue</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>3. Headache</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>4. Eye Strain</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>5. Difficulty focusing</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>6. Salivation increased</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>7. Sweating</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>8. Nausea</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>9. Difficulty concentrating</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>10. “Fullness of the head”</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>11. Blurred Vision</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>12. Dizziness with eyes open</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>13. Dizziness with eyes closed</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>14. Vertigo (general dizziness)</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>15. Stomach awareness</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>16. Burping</td>
<td>None</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
</tbody>
</table>
MOTION HISTORY QUESTIONNAIRE

Reducing Symptoms of Space Adaptation Syndrome through Perceptual Training

Developed by Robert S. Kennedy & colleagues under various projects. For additional information contact:

Robert S. Kennedy, RSK Assessments, Inc., 1040 Woodcock Road, Suite 227, Orlando, FL 32803
(407) 894-5090

1. Approximately how many total flight hours do you have? ____ hours

2. How often would you say you get airsick?
   Always____ Frequently____ Sometimes____ Rarely____ Never____

3. a) How many total flight simulator hours? ____ Hours
   b) How often have you been in a virtual reality device? ____ Times ____ Hours

4. How much experience have you had at sea aboard ships or boats?
   Much ____ Some ____ Very Little ____ None ____

5. From your experience at sea, how often would you say you get seasick?
   Always ____ Frequently____ Sometimes____ Rarely____ Never____

6. Have you ever been motion sick under any conditions other than the ones listed so far?
   No____ Yes____ If so, under what conditions?

7. In general, how susceptible to motion sickness are you?
8. Have you been nauseated FOR ANY REASON during the past eight weeks?

No ___ Yes ___ If yes, explain

9. When you were nauseated for any reason (including flu, alcohol, etc.), did you vomit?

Easily ___ difficulty ___ Retch and finally vomited with great difficulty ________

10. If you vomited while experiencing motion sickness, did you:

a) Feel better and remain so?

b) Feel better temporarily, then vomit again?

c) Feel no better, but not vomit again?

d) Other - specify

11. If you were in an experiment where 50% of the subjects get sick, what do you think your chances of getting sick would be?

Almost certainly ___ Probably ___ Almost would ___

Probably ___ Certainly ___ would not ___

12. Would you volunteer for an experiment where you knew that: (Please answer all three)

a) 50% of the subjects did get motion sick? Yes ___ No ___

b) 75% of the subjects did get motion sick? Yes ___ No ___

c) 85% of the subjects did get motion sick? Yes ___ No ___

13. Most people experience slight dizziness (not a result of motion) three to five times a year.

The past year you have been dizzy:

More than this ___ The same as ___ Less than ___ Never dizzy ___

14. Have you ever had an ear illness or injury, which was accompanied by dizziness and/or nausea? Yes ___ No ___
The Department of Human Factors and Systems is conducting a study which includes a 16 item survey. Participation is completely voluntary and will require approximately 2 minutes prior to, and at the completion of, your FTD activity. You are under no obligation to participate but if you do, results will be completely confidential. Furthermore, results will not be kept, evaluated, nor considered by anyone from the College of Aviation. By completing the survey you are indicating your approval to participate in the study.

PLEASE CLICK HERE TO PROCEED WITH INITIAL SURVEY

PLEASE CLICK HERE TO PROCEED WITH FINAL SURVEY
APPENDIX D: Advanced Flight Simulation Center Layout.

AFSC BAY LAYOUT

As of 07/02/04

BAY EXIT DOORS ARE FOR EMERGENCY USE ONLY

YOU WILL RISK PERSONAL INJURY AND/OR DEATH

REV. D. 2004-07-07