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SIMULATOR SICKNESS: A REACTION TO A TRANSFORMED
PERCEPTUAL WORLD: I. SCOPE OF THE PROBLEM

by

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SIMULATOR SICKNESS:
A REACTION TO A TRANSFORMED PERCEPTUAL WORLD
I. SCOPE OF THE PROBLEM

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ABSTRACT

If sickness occurs in the simulator, but not in the real world, there is evidence of a bad simulation. We reviewed the available data on simulator sickness in terms of their incidence, etiology, and contributing factors. It was found that psychophysiological disturbances can occur during simulator flight, continue several hours post-flight, or be delayed. Effects were found in both motion-base and fixed base simulators, to pilots, other aircrew, and instructors. Simulator sickness may lead to decreased trainer use, distrust of the training received, and post-effects which may place the individual at risk in real-life situations such as driving a car. Adaptation, while it is known to occur, is not the answer. Adaptation to the simulator can lead to acquisition of responses which may produce negative transfer to the aircraft. Data on the relative incidence of simulator sickness in various trainers, its symptomatology, possible etiology, possible solutions and suggestions for research are discussed.

PERSPECTIVE

Humans, along with other species, adapt biologically to obstacles placed in their paths; otherwise, they do not survive. Ordinarily, this adaptation involves long-term evolutionary modifications of structure and function. However, less permanent modifications occur in humans which capitalize on the plasticity of the central nervous system (CNS). These short-term changes may be considered under the general rubric of adaptation to the environment. It is these short-term changes which lead us to consider that simulator sickness is an important problem.

It is axiomatic that motion occasions motion sickness; and the constellation of symptoms which occur under some force environment conditions illustrates that this is one obstacle to which humans have not yet adapted.

Opinions or conclusions contained in this report are those of the authors and do not necessarily reflect the view or endorsement of the Navy Department.

It is our view that motion sickness is an ordinary consequence of exposure to certain moving environments. The incidence, time course, symptom mix, etc., follow certain rules, some of which are known. Frequently, if the stimulus parameters of the force environment are sufficiently specified, our technology can predict what the ordinary expectation of the outcome will be (cf. e.g., McCauley & Kennedy, 1976). From this view, it follows that, to the extent that the real system produces motion sickness, a simulator which replicates the real environment is liable to induce the same responses. However, when a simulator produces effects which are dissimilar than those which occur, for example, in the aircraft, then these outcomes are logically implicative of the inadequacy of the simulation. Thus, we propose that the term "simulator sickness" be reserved for those circumstances where the sickness occurs only (or to a far greater extent) in the simulator. In other cases, car, air, sea, camel, or motion sickness should continue to be employed.

Moreover, and more importantly, although our plastic nervous systems can be expected to enable us to adapt to an untoward simulator environment, it is this latter that is potentially a most insidious problem of simulators. We do not believe that adaptation is the answer to this problem, although the adaptation can be expected to occur and will reduce the unpleasant side effects of simulator exposure. However, this "learning" may involve acquisition of responses (or inhibition thereof) which may place us at risk when in similar but different situations in the real environment.

There have been numerous recent reports of aircrews experiencing psychophysiological disturbances, visual illusions and sickness following the use of flight simulators. Symptoms of simulator sickness have occurred not only during the simulator flight, but in some cases, have lasted up to several hours post-exposure. Furthermore, simulator aftereffects may be delayed; some aircrews have reported symptom onset as late as eight to ten hours post utilization (Kellogg, Castore & Coward, 1980). Incidents of simulator sickness have been reported in fighter (McGuinness, Bouwman & Forbes, 1981), patrol (Crosby & Kennedy, 1982) and helicopter simulators (Frank & Crosby, 1982). Interestingly, these occurrences have been reported in both motion-base and fixed-base simulators, to pilots, other aircrewmen, and to instructors.

Symptoms of simulator sickness include: disorientation, dizziness, nausea, emesis, spinning sensations, motor dyskinesia, flashbacks, visual dysfunction, burping, confusion, and drowsiness, among others.

The phenomenon of simulator sickness was first mentioned by that name in reports by Havron and Butler (1957) and Miller and Goodson (1958). Since that time, the evidence which has accumulated suggests that simulator sickness symptomatology resembles motion sickness and other forms of distress which occur

following exposure to altered and rearranged sensory information, and perceptions. Hence, we feel that simulator sickness is a subclass of these phenomena.

Figure 1 is a schematic depiction of where we believe simulator sickness fits, compared to other classes of subject matter. We feel that the largest category is PERCEPTION. Another realm, which overlaps with that, but is not exactly homologous with it, is MOTION SICKNESS. SIMULATOR AFTEREFFECTS exist within both worlds, but are not perfectly encompassed by either. Motion sickness, indeed, has some perceptual components and some which are purely physiologic. Moreover, the world of perception can be used to understand, somewhat, problems of motion sickness. While simulator sickness exists within both worlds, it is possible that some aspects of simulator aftereffects are outside of both the motion sickness and the perceptual worlds.

Reported Cases of Simulator Sickness

As previously noted, the studies by Havron and Butler (1957) and Miller and Goodson (1958) were the first published reports of simulator sickness. They found a substantial incidence of symptoms among users of the Navy's 2-FH-2 helicopter simulator. (Instructor pilots were found to be more susceptible than students.)

In recent years, there has been an increase in the reports of simulator sickness, although the extent of the problem is still not clearly defined.

One of the first attempts to document the problem in the Air Force was reported recently by Kellogg, Castore and Coward (1980 and in press). They surveyed 48 pilots using the Air Force Simulator for Air-to-Air Combat (SAAC) and found that a majority (88%) had experienced some symptoms of simulator sickness (primarily nausea) during SAAC training. Of particular interest were the F-4 pilots, who reported delayed perceptual aftereffects occurring eight to ten hours following simulator flight. These included sensations of climbing and turning while watching TV, or experiencing an 180-degree inversion of the visual field while lying down. The authors cogently suggested that "the users of such (wide field-of-view) simulators should be aware that some adjustment may be required by pilots when stepping back into the real world from the computer-generated world."

In a study of flight simulator motion sickness conducted for the Canadian Department of National Defence, Money (1980) reported that nearly half of the pilots using the Aurora simulator experienced sickness ranging from slight discomfort to mild nausea.

An investigation of simulator sickness in the Navy's 2E6 Air Combat Maneuvering Simulator (ACMS) found that 27% of the aircrews using the ACMS reported varying degrees of symptoms

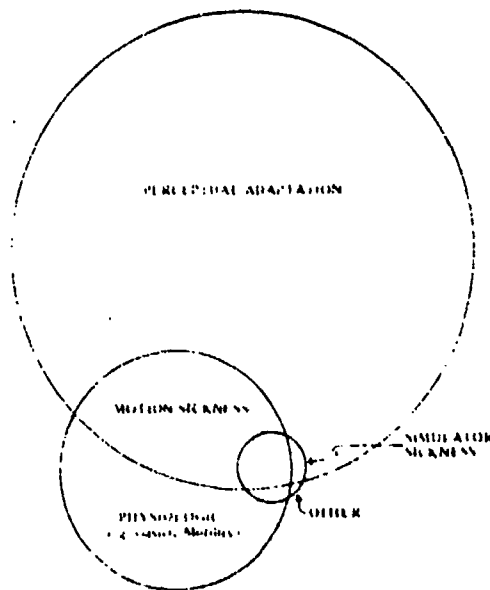


Figure 1. Schematic representation of the relationship among Perceptual Adaptation (sensory rearrangement), Motion Sickness and Simulator Sickness.

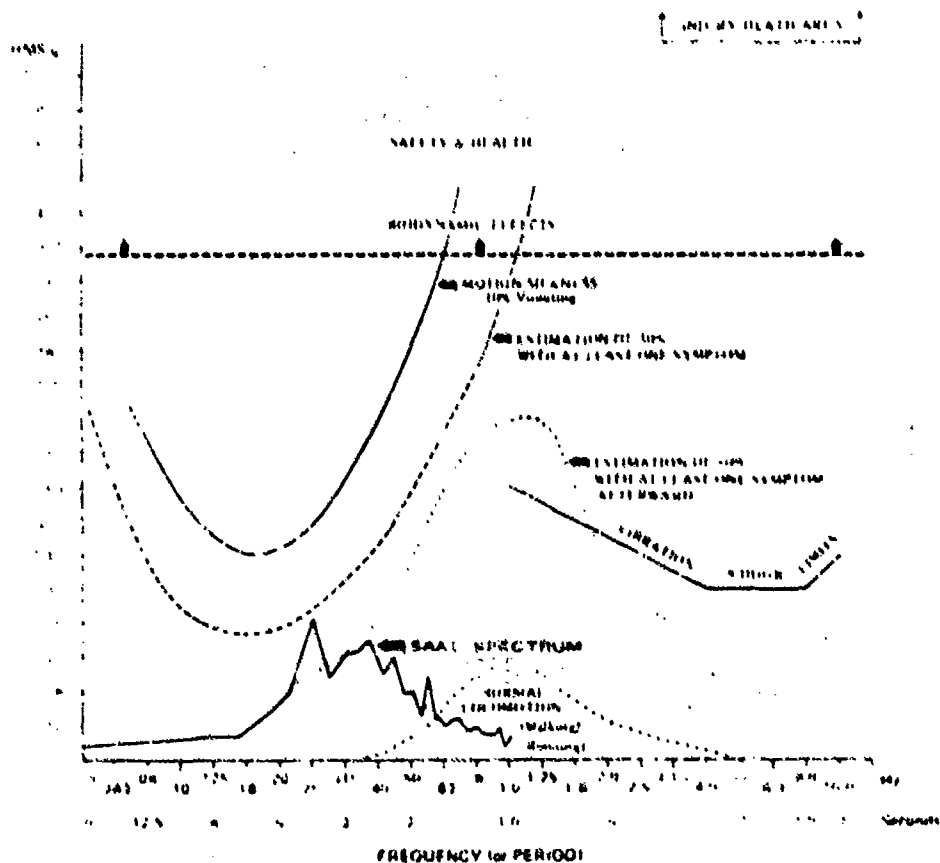


Figure 2. A comparison between MILSTD 1472C vomiting criteria and a projected envelope for lesser symptomatology. (Derived from Kennedy & McCauley, 1982.)

(McGuinness, Bouwman & Forbes, 1981). The more experienced aircrews (over 1500 flight hours) had a higher incidence of symptoms than the less experienced flight crew. Dizziness was the most frequent symptom, followed by vertigo, disorientation, "leans," and nausea. The incidence of symptomatology was greater in pilots than in radar intercept officers (RIOs). The authors suggested that one reason for the reduced levels of simulator sickness found in the 2E6, relative to the Air Force SAAC, may have been the less intensive schedule of simulator time. Exposure duration and frequency appear to be potentially important variables, as has been found in other environments that produce motion sickness (McCauley & Kennedy, 1976).

Frank (1981) has reported that almost one out of every ten individuals using the F-14, 2F112 experienced symptoms of simulator sickness, and that close to 48% of the 21 aircrew sampled using the E-2C, 2F110 reported symptoms. Crosby and Kennedy (1982) have documented cases of simulator sickness in the P-3C, 2F87, particularly at the flight engineer's position. There have also been reported occurrences in the CH-46E, 2F117A (Frank & Crosby, 1982).

Implications of Simulator Sickness

The possible negative implications of simulator sickness can be grouped into three broad categories:

1. Compromised Training. First, symptomatology may interfere with and retard learning in the simulator through distraction. Secondly, since humans are flexible, trainees may adapt to unpleasant perceptual experiences. If new learned processes are not similar to responses required in flight, then the new responses comprise negative transfer to in-flight conditions.

2. Decreased Simulator Use. Because of the unpleasant side-effects, simulators may not be used, or persons may lack confidence in the training that they receive in such simulators.

3. Simulator Aftereffects. Exposure to the simulator may result in aftereffects, or post-effects. These are not unlike the post-effects of other motion devices; but their relevance to safety (e.g., driving home) is not known.

The consequences and practical significance of varying degrees of simulator sickness have been alluded to in the past. Crosby and Kennedy (1982) in a Navy study of the P-3C, 2F87 stated:

The cause(s) of these symptoms should be eliminated for the following reasons. The flight engineers are at risk when walking on the ladders at the exit of the simulator following training because of extreme unsteadiness induced by the simulator. The students become reluctant to take more

training after this experience. Additionally, the symptoms of simulator sickness reduce the effectiveness of the flight engineers and hence jeopardize the flight crew in real flights that follow the training on the same day. Training is probably less effective because the flight engineers attend to their malaise rather than to the flight being simulated. Scheduling problems due to illness result in lost crew time on the simulator following aborts.

Perhaps the most insidious symptom of simulator sickness is drowsiness. Drowsiness has been reported in connection with nearly all simulators which have reported simulator aftereffects. Drowsiness, of course, is a well known symptom of motion sickness; and the so-called sopite syndrome is likely to be the most debilitating problem of motion sickness, and may be of simulator sickness, also. Ryan, Scott and Browning (1978) report this after simulator exposures. It is acknowledged that the vestibular nuclei in the brain stem exert some control over the pontine reticular formation (Yules, Krebs & Gault, 1966). Reports from squadrons -- particularly in Air Combat Maneuvering (ACM) -- are that even brief exposures (i.e., less than one hour) result in long-term fatigue effects. Woodward and Nelson (1976) described the types of performance impairment most likely from sleep loss, including slower reaction time, short-term memory decrement, impairment in reasoning and complex decision-making, errors of omission, and lapses of attention. It is possible that the drowsiness that often accompanies vestibular and simulator sickness may have similar effects on human performance. Sleep loss has been shown to have a deleterious effect on vestibular processes. Dowd (1975) reported increased vestibular sensitivity, decreased recovery rate, and abnormal vestibular habituation to be associated with sleep deprivation. He warned of the implications of sleep loss for increasing the hazards of flying, due to degraded vestibular function.

Etiology of Simulator Sickness

It is extremely doubtful that there is a single causal factor for simulator sickness, any more than there is for motion sickness in general. Most of the distress and upset present in true motion sickness are also present in simulator sickness. Occasionally the symptomatology reported in connection with simulators use does not involve nausea and vomiting, but include headache, visual streaming and other more migraine-like symptoms. Careful perusal of the motion sickness literature reveals that these symptoms are also present occasionally in motion sickness experiences.

It is for these reasons that the cue conflict theory (also recognized as the sensory rearrangement theory) of motion sickness (Guedry, 1970; Reason, 1978; Steele, 1968) has been generally accepted as a working model for simulator sickness. In brief, the model postulates a referencing function in which motion information signaled by the retina, vestibular apparatus

or proprioception may be in conflict with these inputs' "expected" values based on a neural store which reflects past experience, or with how the system's circuitry is wired.

The problem with the model as presently pronounced, is that: 1) there is no good method within the model to determine the magnitude of the conflict for specific combinations of "conflicts." 2) researchers have tended to address only conflict between sensory modalities. Guedry (1970) has suggested as an explanatory principle for space sickness that it is also possible to have a vestibular/vestibular conflict. We would argue that there can be further conflict between either one of the two visual systems (focal/ambient, Leibowitz & Post, 1982) and the vestibular information from either the canals or the otoliths although conflict between ambient and the vestibular are expected to be the more motion sickness provocative. Additionally, it is logically possible that there could be cue conflict between the two visual systems. Miller & Goodson (1959) implicitly argue this position in their seminal paper. Whether conflict between the latter (e.g., forward motion [ambient perception] with receding depth [focal perception]) can produce emesis is problematic, although it is believed that the transformed perceptual events which would attend such a circumstance would challenge the plasticity capabilities of the CNS and might be the genesis of some of the more bizarre visual experiences which are occasionally reported.

It is apparent from our attempts to systematically evaluate the studies of simulator sickness -- in terms of the etiological significance of design, personnel and scenario factors, etc. -- that these pieces of critical information are not yet available. Hence, the U.S. Navy is about to conduct a major survey of multiple flight simulators to identify those predisposing factors that contribute towards simulator sickness.

RECOMMENDATIONS

Although sparse information is available, there is a growing list of items that appear to work in alleviating the problem of distress in simulators. Each of these, listed below, has a consequent theoretical underpinning, which it is expected will stimulate research in order to determine the mechanism. The following advice is offered to simulator users to ameliorate the adverse symptoms of simulator sickness:

1. Eliminate unnecessary use of situational freeze. (The situational freeze button permits the simulator visual and inertial systems to be "frozen" in time by the instructor.) Although situational freeze provides a valuable tool for the instructor, freezing the aircrew in an off-horizon position can be very disorienting. Some aircrewmembers have reported extreme difficulty in attempting to climb out of the cockpit at the end of a training session, if the visual (dome) display was frozen in a wings-down position (Frank, 1981).

2. Avoid indiscriminate use of the reset function. (The reset function permits the simulator instructor to reposition the aircraft to an earlier phase of flight after a situational freeze.) For example, an aircrew may be practicing landings. Upon touchdown, the simulator can be frozen and "reset" to, say, 15 miles out. Unfortunately, when this occurs, 15 miles of visual information -- in reverse -- is also reset, and streams by the aircrew in a matter of a few milliseconds. This can be extremely disorienting.

3. Avoid prolonged and/or intense exposure to the simulator. The most bizarre and wide-spread occurrences of simulator sickness were reported in the SAAC (Kellogg, Castore & Coward, 1980), where 550 ACM engagements were flown over a five-day period.

4. Do not use simulators any more than necessary when suffering from the adverse effects of flu (flu shot?), hangover, radiation, etc., because in the literature on motion sickness and vomiting, the symptoms have been shown to summate (deWit, 1957; Cordts, 1982).

5. Remove scene content from the visual screen at the termination of the flight. This is an added safety precaution which may minimize any problems that might ensue when leaving the simulator.

6. Ascertain the visual and inertial lags inherent in current simulator and "tune" as necessary.

7. Ascertain simulator resonance and "tune" as necessary. It has long been known that maximum symptomatology of motion sickness occurs as a resonant frequency of .2 Hz (Money, 1970). Figure 2 shows that the "energy" from a SAAC flight tends to be in this region.

SUMMARY

If sickness occurs in the simulator, but not in the real world, there is evidence of a bad simulation.

Simulator sickness can lead to: a) decreased use of the simulator due to motivational problems; b) distrust of training received in the simulator; and c) post-effects which can place the user at risk in real-life situations, such as driving home.

Adaptation is not the only answer, since adaptation can create its own problems -- namely, adverse training. Due to the plasticity of the human nervous system, the user learns "bad habits" in the simulator which do not relate to later real-world requirements in the aircraft, and therefore constitute negative transfer.

From a review of literature relevant to simulator sickness (Kennedy, Frank, McCauley & Berbaum, 1983) the authors suggest as chief candidates for research, variables which appear to exacerbate the problem of simulator sickness: a) optical distortion; b) poor resolution; c) wide field-of-view; d) flicker; e) visual and inertial lags; f) viewing distance; g) head movements; h) subject's physical state; i) off-axis viewing; j) frequency and duration of exposures; k) scene content; l) motion frequency/acceleration spectrum; m) shudder; and n) visual-vestibular conflict.

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